Appendix I
Conceptual and measurement framework of the Global Innovation Index

Rationale and origins

The Global Innovation Index (GII) was launched in 2007 with the aim of identifying and determining metrics and methods that could capture a picture of innovation in society that is as complete as possible.

There were several motivations for setting this goal. First, innovation is important for driving economic progress and competitiveness – for both developed and developing economies. Many governments are putting innovation at the center of their growth strategies. Second, the definition of innovation has broadened – it is no longer restricted to research and development (R&D) laboratories and published scientific papers. The concept of innovation has become more general and horizontal in nature, and now includes social, business model and technical aspects. Last, but not least, recognizing and celebrating innovation in emerging markets is critical for inspiring people – especially the next generation of entrepreneurs and innovators.

Now in its 16th edition, the GII helps to create an environment in which these innovation factors are subject to continual evaluation. It provides a key tool for decision-makers and a rich database of detailed metrics, offering a convenient source of information for refining innovation policies.

Measuring innovation outputs and their impact remains a challenging task, hence great emphasis is placed on measuring the climate and infrastructure for innovation and assessing related outcomes.

Although the final results are presented as a ranking, the primary aim of the GII is to improve the "journey" to more accurate methods of measurement, understanding innovation and identifying targeted policies, good practices and other levers that foster innovation. The rich data metrics, at index, sub-index or indicator level, can be used to monitor performance over time and to benchmark developments against economies within the same region or income group classification.

Defining innovation in the GII

The GII adopts a broad definition of innovation, originally elaborated in the *Oslo Manual* developed by the Statistical Office of the European Communities and the Organisation for Economic Co-operation and Development (OECD). In its fourth edition, in 2018, the *Oslo Manual* introduced a more general definition of innovation:[1]

> "An innovation is a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)."

This update of the *Oslo Manual* also introduced a series of definitions associated with innovation in business activities and for different types of innovation firms. In this context, innovation translates as improvements made to outcomes in the form of either new goods or new services, or any combination of these. While the GII focuses on a more general definition of innovation, it is important to highlight how these specific definitions capture the evolution of the way in which innovation has been perceived and understood over the past two decades.

Economists and policymakers previously focused on R&D-based technological product innovation, largely produced in-house and mainly in manufacturing industries. Innovation of this nature was executed by a highly educated labor force in R&D-intensive companies. The process leading to such innovation was conceptualized as closed, internal and localized. Technological breakthroughs were necessarily "radical" and took place at the "global knowledge frontier." This characterization implied the existence of leading and lagging economies, with low- or middle- income economies only able to play "catch-up."

Today, innovation capability is increasingly seen as the ability to exploit new technological combinations; it embraces the concept of incremental innovation and "innovation without research." Non-R&D innovative expenditure is an important component of reaping the rewards of technological innovation. Interest in understanding how innovation evolves in low- and middle- income economies is increasing, along with an awareness that incremental forms of innovation can impact development.

Furthermore, the process of innovation itself has changed significantly. Investment in innovation-related activity and intangible assets has intensified consistently at the firm, economy and global levels, adding both new innovation actors from outside high-income economies and non-profit actors. The structure of knowledge production activity is more complex, collaborative and geographically dispersed than ever.[2]

A key challenge is to find metrics that capture innovation as it actually happens in the world today. Direct official measures that quantify innovation outputs remain extremely scarce. For example, there are no official statistics on the amount of innovative activity – defined as the number of new products, processes or other innovations – for any given innovation actor, let alone for any given country. Most measurements also struggle to appropriately capture the innovation outputs of a wider spectrum of innovation actors, such as users or the public and services sectors, or more informal means, which are often the drivers of innovation in developing countries.[3]

The GII aims to improve the measurement of innovation in order to provide a more complete picture of innovation ecosystems across the globe. It explores new metrics regularly to reflect the changing nature of innovation and the increasingly sprawling field of new (big data) innovation indicators.

Since its inception, the GII has also made a special effort to cover creativity and creative outputs, taking a fresh view of the previously siloed approach to innovation versus creativity. In the opinion of the GII Editors, innovation and creativity are simply two faces of the same coin.

Interest in applying the GII framework and indicators to develop complementary and mutually reinforcing sub-national innovation indices is also growing among WIPO member states.[4] WIPO has been supporting these exercises since 2022.

Finally, since 2021, when WIPO became the sole editor of the GII, the GII team at WIPO has developed a robust data infrastructure for the GII – led by GII co-editor Lorena Rivera León – increasing the data quality and data quality control, and the robustness and replicability of the GII model (Appendix Box 1).

Appendix Box 1   Building a robust data infrastructure for the Global Innovation Index

To facilitate and permit a comprehensive workflow of the GII model, from data storage to the GII calculations, a new data infrastructure was developed in 2021, after WIPO became solely responsible for the GII. The data infrastructure comprises three parts.

- Data storage – the GII database: All GII data are stored, maintained and managed in the GII database. The database stores all collected data in a structured manner for all WIPO member states (not only the ranked GII economies) and for all indicators (those already included in the GII model and the new ones). It also stores data on outlier analysis (generated by the data quality checks that the GII team carries out after data collection – see below), as well as all the data queries sent to the GII data providers following an outlier analysis.
- The GII repository of collaborative codes: The GII repository of collaborative codes is on GitHub, which is one of the largest code-hosting platforms for version control and collaboration. The GII repository contains eight repositories in the statistical programming language R (R-codes), which are linked to diverse elements of the GII workflow and the GII report, enabling data collection, data calculation and data quality control of all GII indicators.
- The GII R-package for the calculation of the GII model: The GII R-package is a custom-built package of tools, created using R, to calculate the GII model and analyze its results. The structure of the tailor-made GII R-package follows the general COINr R-package, which was

developed by the European Commission Joint Research Centre (JRC) and follows the steps in the OECD/JRC Handbook for constructing composite indicators.[5]

Assuring data quality control is at the center of the GII methodology and processes. Each collected indicator for the GII undergoes a data quality control and data audit process every year. Several data tests and analyses are performed on all collected indicators, including the analysis of means, identification of outliers based on mean and z-scores for both unscaled and scaled data, analysis of rank changes, analysis of missing data and analysis of outdated data. Following these analyses, the GII team goes back to the data providers for any necessary clarification and, when required, the data providers themselves correct the data at the source. These additional exhaustive checks ensure the reliability of all data used in the GII.

This new infrastructure enables a complete workflow that links data storage and data quality control with data analysis (GII rankings and the GII report) in a fully integrated way, increasing the overall robustness of the GII data and model.

The GII conceptual framework

The overall GII ranking is based on two sub-indices that are both equally important in presenting a complete picture of innovation: the Innovation Input Sub-Index and the Innovation Output Sub-Index. Hence, three indices are calculated:

– Innovation Input Sub-Index: Five input pillars capture elements of the economy that enable and facilitate innovative activities. The idea is that the innovation inputs of today – and corresponding efforts to develop the science, innovation and human capital base, and the associated innovation environment – prepare the ground for the innovation outputs of tomorrow.
– Innovation Output Sub-Index: Innovation outputs are the result of innovative activities within the economy. Although the Output Sub-Index includes only two pillars, it carries the same weight as the Input Sub-Index in calculating the overall GII scores. In other words, innovation output pillars and indicators have a disproportionally greater weight compared to innovation inputs.
– The overall GII score is the average of the Input and Output Sub-Indices, from which the GII economy rankings are produced.

Each of the five input and two output pillars is divided into three sub-pillars, each of which is composed of individual indicators – a total of 80 this year (see the Economy profiles section for the Framework of the Global Innovation Index 2023). Each sub-pillar is calculated by taking the weighted average of its individual indicators' scores, which are normalized to again produce *scores* between 0 and 100. Pillar scores are calculated using the weighted average of each pillar's sub-pillar scores.

Adjustments to the GII model in 2023

Appendix Table 1 summarizes the adjustments made to the GII 2023 framework. Three indicators have undergone methodology changes. In addition, there is one new indicator and two indicators have been dropped from the framework. Furthermore, one indicator has shifted its position in the indicator framework, changing sub-pillars. Due to the removal of two indicators, the numbering of two remaining indicators has been adjusted, but without altering their methodology. Lastly, the names of three indicators and one sub-pillar have been modified.

Appendix Table 1   Changes to the GII 2023 framework

	GII 2022	Adjustment		GII 2023
1.1	Political environment	Name changed	1.1	Institutional environment
1.1.1	Political and operational stability*	Name changed	1.1.1	Operational stability for businesses*
1.3.2	Entrepreneurship policies and culture*	Methodology changed	1.3.2	Entrepreneurship policies and culture†
4.1.1	Finance for startups and scaleups*	Methodology changed	4.1.1	Finance for startups and scaleups†
6.2.2	New businesses/th pop. 15–64	Removed		
		New indicator	6.2.2	Unicorn valuation, % GDP
6.2.5	High-tech manufacturing, %	New indicator numbering	6.2.4	High-tech manufacturing, %
6.2.4	ISO 9001 quality certificates/bn PPP$ GDP	Sub-pillar and name changed	6.3.5	ISO 9001 quality/bn PPP$ GDP
7.2.4	Printing and other media, % manufacturing	Removed		
7.2.5	Creative goods exports, % total trade	New indicator numbering	7.2.4	Creative goods exports, % total trade
7.3.3	GitHub commit pushes received/ mn pop. 15–69	Methodology and name changed	7.3.3	GitHub commits/mn pop. 15–69

Source: Global Innovation Index 2023, WIPO.

Notes: Refer to Appendix III: Sources and definitions for a detailed explanation of terminology and acronyms.

Data limitations and treatment

This year, the GII model includes 132 economies, which represent 92.5 percent of the world's population and 97.6 percent of the world's GDP in purchasing power parity current international dollars.

The timeliest possible indicators are used for the GII 2023: from the non-missing data, 3.8 percent are from 2023, 34.7 percent are from 2022, 34.2 percent are from 2021, 15.1 percent are from 2020, 5.1 percent are from 2019, 2.8 percent are from 2018 and the small remainder of 4.2 percent are from earlier years.[6]

The GII 2023 model includes 80 indicators, which fall into three categories:

– quantitative/objective/hard data (64 indicators);
– composite indicators/index data (11 indicators); and
– survey/qualitative/subjective/soft data (5 indicators).

This year, for an economy to feature in the GII 2023, the minimum symmetric data coverage requirement is at least 36 indicators in the Innovation Input Sub-Index (66 percent) and 17 indicators in the Innovation Output Sub-Index (66 percent), with scores for at least two sub-pillars per pillar. In the GII 2023, 132 economies had sufficient data available to be included in the Index. A total of 61 economies did not make it into the GII 2023 due to a lack of available data. For each economy, only the most recent yearly data were considered. As a rule, the GII indicators consider data from as far back as 2013.

Missing values

For the sake of transparency and replicability of results, missing values are not estimated; they are indicated with "n/a" and are not considered in the sub-pillar score. In other words, missing indicators do not translate into a zero for the country in question; the indicator is simply not taken into consideration in the aggregation process.

That said, the audit undertaken by the European Commission's Competence Centre on Composite Indicators and Scoreboards at the Joint Research Centre (JRC-COIN) (see Appendix II) assesses the robustness of the GII modeling choices (no imputation of missing data, fixed predefined weights and arithmetic averages) by imputing missing data, applying random sets of perturbed weights and using geometric averages. Since 2012, based on this assessment, a confidence interval has been provided for each ranking in the GII as well as for the Input and Output Sub-Indices (Appendix II).

Treatment of series with outliers

Potentially problematic indicators with outliers that could polarize results and unduly bias the rankings were treated according to the rules listed below, as per the recommendations of the JRC-COIN. Only hard data indicators were treated (34 out of 64).

First rule: selection
Indicators were classified as problematic if they had:

– an absolute value of skewness greater than 2.25; and
– kurtosis greater than 3.5.[7]

Second rule: treatment
Indicators with between one and five outliers (27 cases) were winsorized; the values distorting the indicator distribution were assigned the next highest value, up to the level where skewness and/or kurtosis had the values specified above.[8]

Indicators with five or more outliers, and for which skewness or kurtosis did not fall within the ranges specified above, were transformed using natural logarithms after multiplication by a given factor f.[9] Since only "goods" were affected (i.e., indicators for which higher values indicate better outcomes, as opposed to "bads"), the following formula was used:

$$\ln \left[\frac{(\max \times f - 1)\,(\textit{economy value} - \min)}{\max - \min} + 1 \right]$$

where "min" and "max" are the minimum and maximum indicator sample values, respectively.[10]

Normalization

The 80 indicators were then normalized into the [0, 100] range, with higher scores representing better outcomes. Normalization was undertaken according to the min–max method, where the "min" and "max" values were the minimum and maximum indicator sample values, respectively. Following the recommendation of the JRC-COIN, all indicators, including index and survey data, were normalized to a 0–100 range. This normalization ensures that all indicators share the same range, facilitating their individual contribution to the overall index score.

Weights

In 2012, the JRC-COIN and GII team made a joint decision that scaling coefficients of 0.5 or 1.0 should be used instead of importance coefficients. This decision aimed to achieve balanced sub-pillar and pillar scores by considering the underlying components. In other words, the goal was to ensure that indicators and sub-pillars contribute a similar amount of variance to their respective sub-pillars/pillars.

To prevent multicollinearity during the aggregation process, any indicators within a sub-index that exhibited a high correlation, exceeding an absolute correlation of 0.95, were assigned a weight of 0.5. In 2023, two indicators have a weight of 0.5 – 1.2.1 Regulatory quality and 1.2.2 Rule of law – both of which fall within the input sub-pillar 1.2 Regulatory environment. Additionally, two sub-pillars – 7.2 Creative goods and services and 7.3 Online creativity – were also assigned a weight of 0.5.

Strengths and weaknesses

Strengths and weaknesses are calculated for all economies covered in the GII and are presented in the individual economy profiles (see the explanatory section Economy profiles). In simple terms, strengths and weaknesses are the top- and bottom-ranked indicators for each country. In addition, income group strengths and weaknesses are also provided, which are the respective high- and low-performing indicators within income groups.

The methodology for the calculation of strengths and weaknesses is as follows:

– The scores of each indicator are converted to percentile ranks.
– Strengths are defined as the indicators of an economy that have a percentile rank greater than or equal to the 10th percentile rank (across the indicators of that economy). Note that this can result in more than 10 strengths in the event of tied results.
– Weaknesses are defined in an equivalent manner for the bottom 10 indicators.
– If a country has an indicator that ranks equal to or lower than three, it is automatically a strength, regardless of the percentile rank.
– Importantly, although the cut-off value used to define the strengths (i.e., the 10th highest percentile rank) is calculated using only indicator percentile ranks, it is also applied to sub-pillars and pillars.
– In addition, for pillars and sub-pillars that do not meet the Data Minimum Coverage (DMC) criteria, strengths and weaknesses are not signaled. Pillars and sub-pillars that do not meet the DMC show the pillars and sub-pillars in brackets in the economy profiles.
– Income group strengths and weaknesses are somewhat similar to overall strengths and weaknesses but are defined within income groups and use means and standard deviations. The methodology for the calculation of income group strengths and weaknesses is as follows:
  – For a given economy, income group strengths are those scores that are above the income group average plus the standard deviation within the group.
  – For that economy, weaknesses are those scores that are below the income group average minus the standard deviation within the group.
  – The only exceptions to the income group strengths and weaknesses are the top 25 high-income economies, where these strengths and weaknesses are computed within the top 25 group.
  – As the only non-high-income economy in the top 25, China's income group strengths and weaknesses are computed within the non-top 25 group.
– Since, occasionally, the low threshold for weaknesses is below zero, any score of zero is automatically marked as a weakness.
– Finally, as of 2023 and following the recommendation of the audit by the WIPO Internal Oversight Section,[11] strengths and weaknesses are reset, or not signaled, where the data year for a given indicator is older than the indicator mode minus five years. In practice, for the GII 2023, this means that for indicators with a data year mode of 2022, the data year of an economy must be 2017 or later to qualify as a strength or weakness.

Caveats on the year-to-year comparison of rankings

The GII compares the performance of national innovation systems across economies and presents the changes in economy rankings over time.

It is important to note that scores and rankings are not directly comparable between one year and another. Each ranking reflects the relative position of a particular economy based on the conceptual framework, the data coverage and the sample of economies of that specific GII edition, and also reflects changes in the underlying indicators at source and in data availability.

A number of factors influence the year-on-year rankings of an economy:

– the actual performance of the economy in question;
– adjustments made to the GII framework (changes in indicator composition and measurement revisions);
– data updates, the treatment of outliers and missing values; and
– the inclusion or exclusion of economies in the sample.

Additionally, the following characteristics complicate the time-series analysis based on simple GII rankings or scores:

– **Missing values**: The GII produces relative index scores, which means that a missing value for one economy affects the index score of other economies. Because the number of missing values decreases every year, this problem reduces overtime.
– **Reference year**: The data underlying the GII do not refer to a single year but to several years, depending on the latest available year for any given variable. In addition, the

reference years for different variables are not the same for each economy, due to measures to limit the number of missing data points.

- **Scaling factors**: Most GII variables are scaled using either GDP or population, with the intention of enabling cross-economy comparability. However, this implies that year-on-year changes in individual indicators may be driven either by the variable (numerator) or by its scaling factor (denominator).
- **Consistent data collection**: Measuring the change in year-on-year performance relies on the consistent collection of data over time. Changes in the definition of variables or in the data collection process could create movements in the rankings that are unrelated to performance.

A detailed economy study based on the GII database and the economy profile over time, coupled with analytical work on the ground, including that of innovation actors and decision-makers, yields the best results in terms of monitoring an economy's innovation performance, as well as identifying possible avenues for improvement.

Notes

1   OECD and Eurostat (2018).

2   See WIPO (2011–2023) for bi-annual elaborations on the changing nature and geographic dispersion of innovation. See Arundel *et al.* (2021) for an elaboration on the role and measurement of knowledge and technology transfer between innovation actors.

3   On innovation in the informal economy, see Kraemer-Mbula and Wunsch-Vincent (2016).

4   See Box 2 in the main results and WIPO (2023, forthcoming).

5   OECD and EC JRC (2008).

6   The GII is calculated based on 9,403 data points out of a possible 10,560 (132 economies multiplied by 80 indicators), implying that 10.9 percent of data points are missing. The GII 2023 database includes the data year used for each indicator and economy, downloadable at www.wipo.int/global_innovation_index/en/2023. If an indicator for an economy is missing, it is marked as "n/a" in the economy profiles.

7   Based on Groeneveld and Meeden (1984), which sets the criteria of absolute skewness above 1 and kurtosis above 3.5. The skewness criterion was relaxed to accommodate the small sample under consideration (132 economies).

8   The indicators treated using winsorization are: 4.2.1, 5.2.3, 5.2.4, 5.3.2, 6.1.5, 7.2.2 and 7.3.1 (one outlier); 2.2.3, 3.2.1, 5.3.3, 6.1.3, 7.2.1 and 7.3.3 (two outliers); 4.1.3, 4.2.4, 6.3.4, 7.1.2 and 7.3.2 (three outliers); 4.2.3, 5.3.1 and 6.2.2 (four outliers); and 4.3.3, 5.2.5, 6.1.2, 6.3.1 and 7.2.4 (five outliers). Finally, indicator 7.1.1 was winsorized from the bottom of the distribution, on three outlier observations.

9   Indicators 2.3.3, 4.2.2, 5.3.4, 6.1.1, 6.3.3, 7.1.4 and 7.3.4 were treated using log-transformation (factor f of 1).

10 This formula achieves two things: it converts all series into "goods" and scales the series within the range [1, max] so that natural logs are positive, starting at 0, where "min" and "max" are the minimum and maximum indicator sample values. The corresponding formula for "bads" is:

$$\ln\left[\frac{(\max \times f - 1)\,(\max - economy\ value)}{\max - \min} + 1 \right]$$

11 IOD Ref: IA 2022-03, April 14, 2023: www.wipo.int/export/sites/www/about-wipo/en/oversight/docs/iaod/audit/audit-gii.pdf.

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