Appendices

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Appendix 1

Summary of Methods for the Green Growth Index[1]

A. Index Development Process

A.1 Iterative Approach

GGGI adopted a thorough process in designing the Green Growth Index through iterative activities including expert consultations, assessment of expert feedback, and quality improvements. GGGI pursued two complementary strategies to enhance the relevance and practicality of the Index in policy making:

- A stepwise scientific approach through rigorous research to understand the complexity and multi-dimensionality of green growth; and
- A consultative process involving experts and other stakeholders to determine the policy relevance of the indicators at the national and regional contexts.

A.2 Participatory Approach

The stakeholder engagement process was initiated in 2016 and completed in early 2019. The three main phases included:

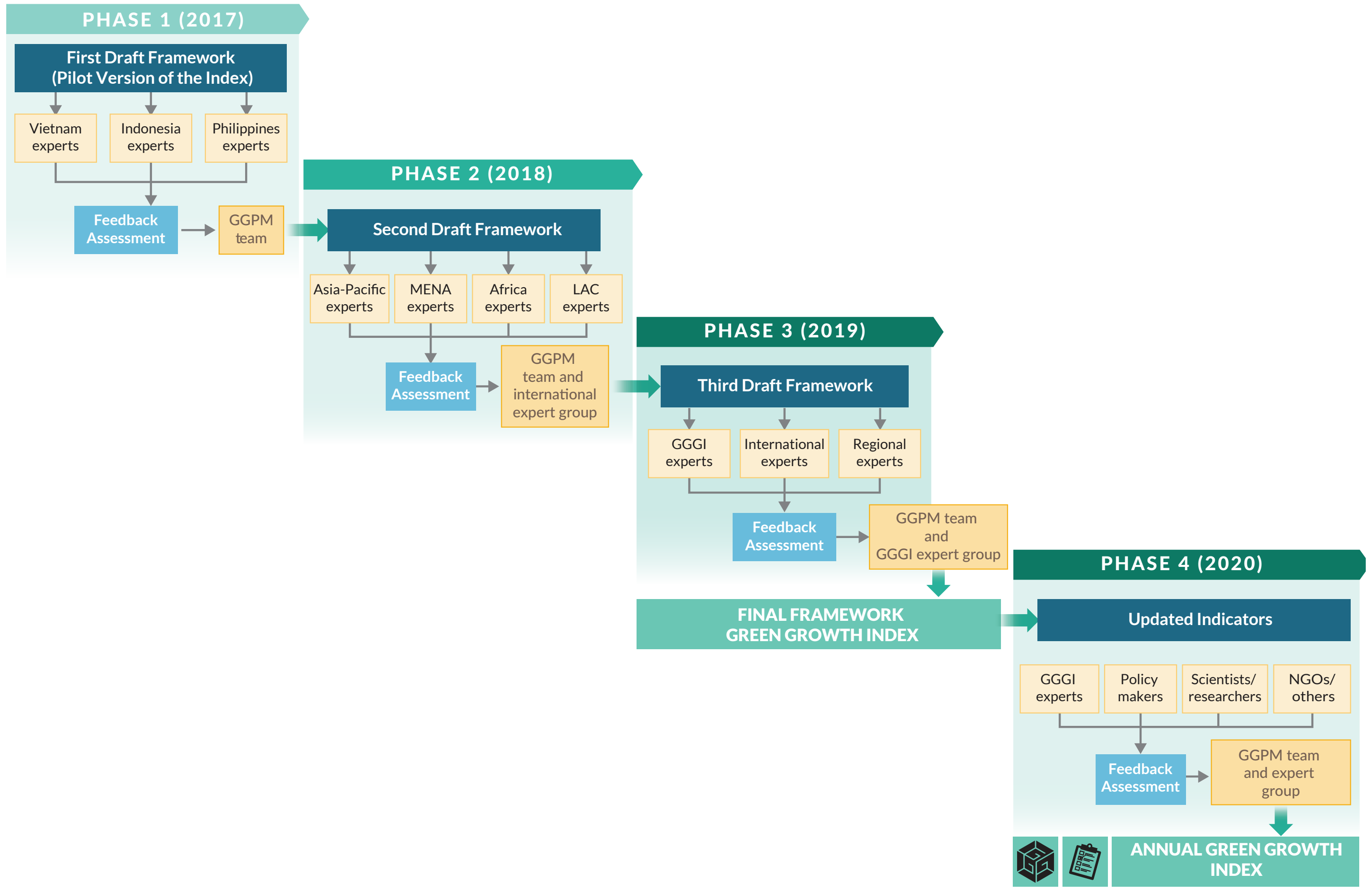
1. Phase 1 – Pilot: GGGI developed a pilot version of the Index covering 34 GGGI member and partner countries[2]. The Index was presented in an international expert workshop at GGGI headquarters in Seoul, South Korea, three in-country stakeholder workshops (in Vietnam, Indonesia, and the Philippines), and an international stakeholder consultation during Global Green Growth Week 2017 in Addis Ababa, Ethiopia. These consultative activities aimed to inform GGGI member countries about the ongoing process of developing the Index and collect initial feedback.
2. Phase 2 – Regional Consultations: GGGI presented the revised framework incorporating the preliminary feedback in 2018 in four regional consultation workshops for the Asia-Pacific Region (Bangkok), Middle East (Dubai), Africa (Addis Ababa), and Latin America and the Caribbean (Mexico City), as well as an international expert meeting in Geneva. These workshops served as a platform for dialogue and interaction among the stakeholders to ensure a transparent process for improving the Index. Outcomes of the workshops were presented during an international expert meeting in Rome, Italy.
3. Phase 3 – Expert Consultations: The last phase of the Index development process involved the circulation of the draft technical report on the concept, methods, and applications of the Index to the internal and external experts for their review and feedback. GGGI collected expert feedback through an online survey. GGGI also conducted two additional expert consultations—the first with GGGI thematic experts to align the Index to the priority areas of the Institute and the second with selected research institutions and international organizations[3] to validate the sustainability targets. These expert inputs from the online survey and consultations were used to finalize the Index.
4. Phase 4 – Annual Expert Consultations: The fourth phase of the Index development process is the expert consultations which are conducted every year to continuously improve the indicators of the Green Growth Index. As discussed in chapter 5.3 Next steps forward and as indicated in Table 4, missing green growth indicators will need to be included and proxy variables will still need to be replaced with more relevant indicators when data become available in the next years. Detailed description of this year's consultations is discussed in chapter 5 Expert consultations and Appendix 2.

[1]Information in this Appendix was adapted from Acosta, L.A., C.O. Balmes, R.J. Mamiit, P. Maharjan, K. Hartman, O. Anastasia, and N.M. Puyo. (2019). Assessment and Main findings on the Green Growth Index, GGGI Insight Brief No. 3, Green Growth Performance Measurement, Global Green Growth Institute, Seoul, South Korea. http://greengrowthindex.gggi.org/wp-content/uploads/2020/04/GGGI-Insight-Brief-No.-3_Final.pdf

[2]"Members" refer to countries that have submitted their instrument of accession to GGGI and formal membership has commenced while "partner countries" include countries where GGGI has operations and those that have formally communicated their intent to become a Member.

[3]IASS, PIK, FAO, SDSN and OECD.

Figure A Process for developing the framework of the Green Growth Index



B. Analytical and Empirical Methods

B.1 Stepwise Analytical Approach

In building the Green Growth Index, GGGI applied a stepwise approach that conforms to "good practices" in developing composite indices[4] (Figure B). A composite index combines a number of indicators into a single score, which facilitates the comparison, ranking, benchmarking, and monitoring of progress for multifaceted, complex phenomena.

The development of the Green Growth Index followed four key steps:

- Concept building entails defining the objectives of the Index, conceptualizing green growth, and identifying its dimensions and indicators;
- Empirical application requires addressing methodological issues such as indicator selection, data preparation (i.e., scaling, imputation, outliers, correlation), normalization, weights, and aggregation of indicators;
- Robustness check involves assessing the explanatory power of the Index through correlation analysis and changes in model inputs and its impacts on aggregation through sensitivity and uncertainty analyses; and
- Presentation focuses on communicating the results at the global, regional, and country scale using various diagrams and tables.

[4]Nardo, M., Saisana, M., Saltelli, A., & Tarantola, S. (2005). *Tools for Composite Indicators Building.* Ispra, Italy: European Commission Joint Research Centre: Institute for the Protection and Security of the Citizen Econometrics and Statistical Support to Antifraud Unit; OECD & JRC 2008, op. cit.

Figure B Stepwise approach for developing the Green Growth Index

B.2 Empirical Steps

The Green Growth Index was constructed through aggregation of the normalized indicators (metrics), indicator categories (pillars), and dimensions (goals) (Figure C). Prior to the aggregation, several steps were necessary to select, prepare, and validate the indicators included in constructing the Index:

1. Indicator selection: Several criteria were applied in the selection of indicators, including the relevance of the data to the green growth dimensions based on conceptual and empirical evidence, coverage of more than 140 countries (including most GGGI member and partner countries); availability of time-series data to allow updates of the Index on a regular interval; accessibility of the data to ensure replication of methods and credibility of their sources; and acceptable level of association with other indicators in the same dimension. In a few cases, however, the criteria for country coverage and time-series data were waived due to a significant lack of data. All data were collected from online sources, mainly published in the UNSTATS SDG database and databases from other international organizations (e.g. FAO, World Bank, WIPO, UN COMTRADE, etc.).
2. Data preparation: Scaling and imputation are the most important methods to prepare the data and improve the comparability of the indicators. Scaling the data with an appropriate denominator (e.g., GDP, land area, etc.) allows an objective comparison across small and large countries. Available data for all the indicators were scaled except for the GHG emissions, export of environmental goods, and patents of environmental technology. Imputing data based on the available time-series data helps improve the country coverage of the indicators. To minimize the effects of imputation on data uncertainty, the simple method of imputing data from the closest years was applied.
3. Data validation: The most important method to validate the statistical appropriateness of the indicator data is to check for outliers and correlation. Since outliers can distort statistical properties and normalized values of the indicators,[5] their values were capped using lower or upper fences based on the interquartile range from 75th and 25th percentiles. The aims of the correlation analysis are to identify redundant indicators with very strong correlation to improve the explanatory power of the indicators and verify whether indicators have acceptable levels of association in their respective dimensions. Indicators with very strong correlation were excluded from the framework and replaced with ones having acceptable levels of association.
4. Indicator weights: The indicators have implicitly equal weights (i.e., no weights are attached to them). The explicit weights of the indicators are not equal because the number of indicators in each indicator category (or pillar) is not equal. The results from Principal Component Analysis validated the level of inequality in the explicit weights of the indicators. The results from Analytic Hierarchy Process revealed that there is low consensus among experts on the weights to be assigned to the indicators.
5. Indicator normalization: To translate the indicators with different units into a common scale, it is necessary to apply a normalization method. Through normalization, the indicator values measured in different units can be adjusted to a single scale to make the data comparable across the indicators. The re-scaling method (min-max transformation) for normalization was applied for the following reasons: it is the simplest and most widely used method that will facilitate ease of comprehensibility and replication; the use of upper and lower bounds will reduce issues related to outliers; and the integration of the targets will allow benchmarking against sustainability targets.

The normalized indicators were used as inputs to the aggregation model (i.e., level 1) as presented. The two most common and simple methods of aggregation include linear aggregation using arithmetic mean and geometric aggregation using geometric mean. These two methods have different underlying assumptions. Linear aggregation allows full and constant compensability, i.e. low values in one indicator can be traded off (substituted) by high values in another. On the other hand, geometric aggregation allows only partial compensability, limiting the ability of the indicators with very low scores to be fully compensated by indicators with high scores. The two methods were applied in the different aggregation models so that, as the level of aggregation increases, the level of substitutability decreases:

1. Level 1: Arithmetic mean was applied to linearly aggregate the normalized indicators, allowing compensability of the individual indicators in each indicator category. Moreover, at Level 1 of aggregation, countries with more than 25% missing values were dropped.
2. Level 2: Geometric aggregation was applied to the indicator categories to allow only partial compensability between indicators in each dimension. Like in Level 1, the 25% rule on

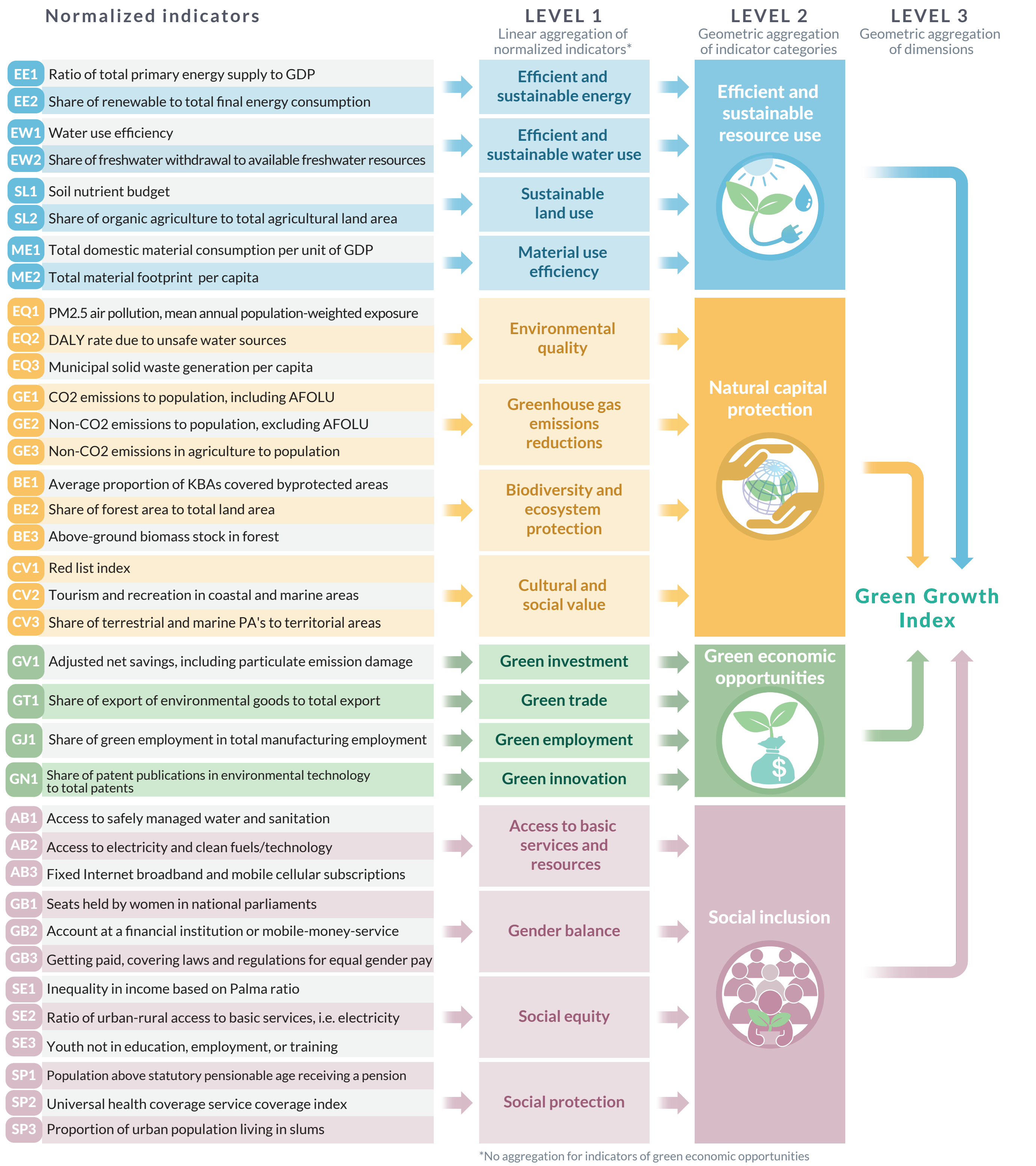
[5]Mishra, S. K. (2008). Construction of Composite Indices in Presence of Outliers. *SSRN Electronic Journal*, 1–5. https://doi.org/10.2139/ssrn.1137644; OECD & JRC 2008, op. cit.; Ibid.

missing values was applied to the dimensions with more than four indicator categories, i.e., resource efficiency and green economic opportunities.

3. Level 3: Geometric aggregation was applied on the dimensions and the 25% rule on missing values was not applied. At this level of aggregation, no dimension was allowed to easily substitute the other dimensions to improve the Green Growth Index.

Python software was used to conduct all the analysis described above, except for the correlation analysis which was done in Prism (GraphPad Software). Detailed discussion on the steps involved in constructing the Green Growth Index is provided in chapter 5 of GGGI Technical Report Number 5, Green Growth Index: Concepts, Methods, Applications (Acosta et al. 2019).

Figure C Methods of aggregation at the indicator, indicator category, and dimension levels



C. Validating and Improving the Index

Composite indices often face criticism because they can be misleading if badly constructed and interpreted.[6] Thus, the final important step in developing a composite index is the evaluation of the confidence in the model and its underlying assumptions (i.e. robustness check).

Three different types of analyses were conducted to validate the robustness of the Green Growth Index:

- Explanatory power: Using regression models, the ability of the indicators and their aggregated values (i.e., indicator categories, dimensions) to explain the structure of the Index was analyzed.
- Sensitivity analysis: The sensitivity of the Green Growth Index to changes in the input variables of the aggregation model at Level 1 was analyzed.
- Uncertainty analysis: The uncertainty analysis evaluates the impact of the assumptions made and methods used to build the model on the Index.

The results from the regression models suggested that sufficient variation in the Green Growth Index is explained by the dimensions, indicator categories, and indicators, while those from sensitivity and uncertainty analyses showed that the Green Growth Index is robust with respect to changes in model inputs and assumptions. Details of the results for the 2019 Green Growth Index are provided in chapter 5 of GGGI Technical Report Number 5, Green Growth Index: Concepts, Methods, Applications (2019) and GGGI Technical Report Number 9, Green Growth Index: Robustness Check (2019). Those for 2020 Green Growth Index will be published in a technical report that will be dedicated to the validation of the Index and its updated list of green growth indicators.

[6] *Saisana, M., & Tarantola, S. (2002). State-of-the-art report on current methodologies and practices for composite indicator development. European Commission, pp. 1–72. https://doi.org/10.13140/RG.2.1.1505.1762*