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Categorization of Science, Technology and Innovation (STI) Indicators' Frameworks: Focus and areas covered

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Abstract

In today's world, where knowledge-based economy is playing a major role in promotion of welfare and sustainable economic development of nations, the demand for evaluation of science, technology and innovation (STI) has been escalating. The problem is that when designing a national STI framework as a role of government, policy-makers would encounter a lot of diverse frameworks in connection with STI area being developed by international organizations and countries. Dealing with this plethora of frameworks requires skills to compare, categorize, benchmark and utilize them in order to best leverage previous fragmented efforts. This paper extends the recently published research, in which four criteria were suggested for categorization and comparison of STI indicator frameworks, including Coverage of STI (comprehensiveness), Implementation, logical Simplicity and Comparability of a framework, its components and indicators (CISC model). The present extension suggests areas covered and focus by frameworks as two complementary criteria to yield extended CISCAF model. By the focus criterion, STI frameworks could be classified as focused on development of 1) R&D, 2) technology, 3) holistically STI and R&D, 4) economic and industrial development, 5) innovation and 6) human resources. By areas covered, one may seek if a framework covers 1) human resources, labour and education areas, 2) firms and private sector, entrepreneurship and industry, 3) institutions, 4) ICT and physical infrastructures, 5) educational, trade, legal, intellectual property, business and labour environments, 6) scientific, market, export and trade outputs, 7) R&D activities and resources, and 8) STI expenditure and finance. Governments and policy-makers could benefit from the categorization in setting up STI indicator frameworks, while comparing and leveraging diverse international and national frameworks available.

Keywords: Criteria for Design and Comparison of S&T Indicators, S&T Policy, STI Indicators' Framework; National STI Systems.

1. Introduction

In today's world where knowledge-based economy is playing a major and trending role in prosperity and welfare of nations, science, technology and innovation (STI) policy is of prominent importance (Furman et al., 2002; Litan et al., 2014). When a country attempts to design its science, technology and innovation (STI) framework to meaningfully accommodate relevant STI indicators, it would encounter a lot of frameworks, models or platforms developed by international organizations and countries, upon which science and technology (S&T) indicators are fitted.

While title, goal, mission and positioning of the studied frameworks may seem diverge and sometimes their comparison peculiar, it is the logical framework behind and their connection with STI areas in various ways which has made them nominated for the comparison and analysis. As pointed out by Litan et al. (2014), every S&T framework is based on an issue, question, policy or objective. For S&T framework examples studied and categorized here, one could see (Dutta & Lanvin, 2013, 2014; Es-Sadki & Hollanders, 2014; In et al., 2014; National Science Board (NSB), 2012; OECD, 2002; OECD/Eurostat, 1995, 2005; UIS, 2012; World Bank, 2016). Litan et al. (2014) have named such S&T frameworks as "policy-driven frameworks" to best indicate their uniqueness, situationalness, and dependency to the policies underlying them. In selecting, designing and comparing S&T indicators, having some criteria for comparison and categorization would be of value, especially when taking the variety of frameworks available into the account.

Based on panel discussions and literature review as part of a government project over the last year, four criteria were identified for categorization and comparison of STI frameworks, including Coverage of STI (comprehensiveness), Implementation, logical Simplicity and Comparability of components and indicators (CISC model). The CISC model was applied into 22 STI frameworks in a Cartesian diagram, which yielded four major quadrants and sixteen sub-quadrants (categories), each of distinct features and utilities for decision making and comparison purposes.

The present paper tries to complement the initial CISC model based on the comments received at Eu-SPRI Early Career Conference 2016 by two categorization criteria of focus of and areas covered by STI indicator frameworks. In the following, first the base CISC model is introduced in brief, and then the extension is discussed in details.

2. Diversity of STI Indicator Frameworks

While title, goal and positioning of the 22 studied STI indicator frameworks may seem diverge and sometimes their comparison peculiar, it is the logical framework behind and their connection with STI areas in various ways which has made them nominated for the analysis. Table 1 lists these 22 well-known frameworks. As it could be seen from Table 1, the frameworks are developed under different themes of economy, innovation, STI, S&T, human development, education, industry, etc. Even, they are under different general names of model, framework, capacity index, capability index, manual, scoreboard, schematic overview, etc.

Table 1. STI indicator frameworks studied

1. Global Innovation Index (GII) (2016)	2. STI Indicators for Developing Countries (UNCTAD, 2010)
3. Knowledge Economy Framework (WorldBank, 2016)	4. US National Science Board's (NSB) model (2012)
5. South Korean STI Framework (In et al., 2014)	6. Competitive Industrial Performance of UNIDO (2001)

7. The US (Litan et al., 2014)	8. Global Competitiveness Report of World Economic Forum (WEF)
9. National Innovative Capacity (Furman et al., 2002)	10. Framework of Canberra Manual of OECD (1995)
11. EU Innovation Union Scoreboard (Ed-Sadki and Hollanders, 2014)	12. Schematic Diagram of National System of Innovation (NSI) of UNCTAD (2011)
13. Dutch STI2 Framework (Hertog et al., 2012)	14. Technology Life Cycle Framework of Tassey (2011)
15. OECD Oslo Manual (OECD/ Eurostat, 2005)	16. UNESCO STI Statistics (UIS, 2012)
17. ArCo Model of Technological Capability (Archibugi and Coco, 2004)	18. Schematic Overview of STI System (Hall and Jaffe, 2012)
19. Links Between Technology and Human Development (UNDP, 2001)	20. Links between Technology and Human Development (UNDP, 2001)
21. Schematic Overview of Innovation System (Jaffe, 2011)	22. Logic Model of Publicly Funded R&D in Health (Sampat, 2011)

3. Base Framework to be extended (CISC Model)

In this section, the four categorization criteria building up the base CISC model are first defined and elaborated and then presented in a four-quadrant cartesian visual presentation. This would provide a necessary background for the extension of the model into CISCAF model in the next section.

3.1. Coverage (Comprehensiveness)

Although there are multiple goals attributable to a S&T framework, we could do a binary categorization based on STI area coverage, i.e. issue-driven S&T frameworks aimed at solving a special problem and of niche coverage, such as Sampat (2011) in health area or ArCo model of Archibugi and Coco (2004), versus frameworks of the widest scope of STI possible covering all science, technology and innovation areas, such as the review model of Litan et al. (2014) for The US or Global Innovation Index (GII) (Dutta and Lanvin, 2013). Achieving a wide STI coverage is not costless and there is always some trade-offs between coverage, cost and accuracy (UNESCO Institute for Statistics, 2010). A wide STI coverage would be beneficial to a country when developing a general-purpose and reference STI framework rather than a problem-oriented or niche one

To achieve the aim of comprehensiveness, Barré et al. (2004) suggest that input indicators such as spending and human resources are essential elements in a comprehensive system. They also point that macro-economic indicators provide a prompt and comprehensive picture on the S&T output at a national level. As a partial practical solution to the objective of comprehensiveness, Barré et al. (2004) suggest that the establishing an up to date, comprehensive computerized database of scientific journals and the maintenance of that database would be valuable. Chinaprayoon (2007) says that in the longer term, UNESCO Institute of Statistics (UIS) intends to collect comprehensive output indicators, including scientific and technology outputs and even impact indicators, including social impact indicators, public perception towards S&T, and indicators for STI impacts by sectors.

Additionally, a wide scoped STI indicator framework facilitates maximum accommodation of S&T indicators, of course as far as needed and permitted by practical concerns such as costs, measurability and time limits. In fact, a general S&T framework is like a meaningful puzzle of necessary and affordable indicators to be used in isolation or in further policy-driven S&T frameworks which in turn implies a maximum coverage of science, technology, research and innovation indicators (Barré et al., 2004).

3.2. Implementation

Implementation criterion covers development of indicators, data collection and periodical publication. This means that a S&T framework containing immeasurable S&T components, indicators not being developed so far, or data of indicators not being published regularly makes the framework less utilizable and desirable (Barré, 1997; Reale et al., 2012). Implementation criterion not just stands for all impracticalities, but also if data collection is possible but times-consuming, not economical, of low reliability and replicability, or volatile. Theoretical frameworks that have not developed indicators yet are examples of less desired frameworks regarding implementation criterion, such as Schematic Diagram of NSI (UNCTAD, 2011) and Schematic Overview of Innovation System (Jaffe, 2011), while well-known ones such as Knowledge Economy Index (World Bank, 2016) and OECD Oslo Manual (OECD/Eurostat, 2005) are fully implemented. Whatever the goal and mission, it seems that satisfaction of implementation criterion is always desired for a STI framework, unless the theory and rigor behind a framework be of such value which compensates for.

3.3. Simplicity

Simplicity as one of the underlying principles of modelling indicates that a model should be as simple as possible while maintaining essential elements. This equals the exclusion of whatever components/indicators possible to be excluded without losing too much information. An advantage of this selection criterion is more understandability to the widest audience. Concerning simplicity, linkages and spillover indicators are of special attention. Although simplicity criterion is more familiar for indicators (e.x., Bornmann, 2013), here the simplicity of an overall framework is meant.

A logically straightforward (simple) STI framework avoids inclusion of causal/ correlation linkages, i.e. unknown unknowns as referred by Litan et al. (2014), between components or indicators, uses less number of components and indicators, and a straightforward design. Global Innovation Index (GII) (Dutta and Lanvin, 2013), Knowledge Economy Framework (World Bank, 2016), EU Innovation Union Scoreboard (Es-Sadki and Hollanders, 2014) and Dutch STI2 Framework (Hertog et al., 2012) could be considered as logically straightforward. On the contrary, National Innovative Capacity (Furman et al., 2002), Schematic Overview of STI System (Hall and Jaffe, 2012) and Schematic Overview of Innovation System (Jaffe, 2011) could be classified as complicated.

An important element contributing to the simplicity of an STI indicator framework is overlapping of components. As every social category, S&T indicators and components are interrelated to each other which indicate a degree of overlapping. It is argued that this overlapping should be kept at minimum. This eases the dedication of indicators to the components of an S&T framework without the need to develop lengthy guidelines and exclusions, and also promotes the logic of the framework. In this regard, two approaches could be imagined: unique attribution of indicators, or tagging. While unique attribution seems more common and neat, tagging would impose greater efforts at the first step but will pay back gradually when developing various issue-driven frameworks out of a single general-purpose S&T framework.

3.4. Comparability

This is one of the rationales utilized by National Research Council of the National Academies of US (NCSES) to improve its current S&T indicators' program (refer to Litan et al., 2014). It has also been stressed by other researchers as an issue for development of S&T indicators (e.x., Barré, 2009, 2001; Lepori et al., 2008; Reale et al., 2012). A STI framework is defined as more comparable when the main components, sub-components and also the indicators are more comparable with a considerable number of well-known frameworks out there. For example, South Korean STI Framework (In et al., 2014) could be considered as a comparable framework, since it is composed of cultural environment and infrastructure, R&D and entrepreneurial activities, human and organizational resources, and performance (output) at the component-level while having number of researchers, patents, papers, BERD, GERD, high-tech exports etc. as indicators, all of which share a lot with well-known STI frameworks such as Global Innovation Index (GII) (Dutta and Lanvin, 2013) and Knowledge Economy Framework (World Bank, 2016). On the other side, a framework such as Logic Model of Publicly Funded R&D in Health (Sampat, 2011) or Schematic Overview of STI System (Hall and Jaffe, 2012) share considerably less, which makes them to be labelled as less comparable. In addition, benchmarking productivity associated with the usage of S&T indicators is another associated concern, which has been pointed out by Barré (2001).

Contrarily, having considerable number of native, customized and synthetic indicators and components makes a STI framework less comparable. Consideration of native factors has also been discussed under the titles of “relevance” and “pertinence” (Argenti et al., 1990; Barré, 2001; UNESCO Institute for Statistics, 2010).In this regard, Argenti et al. (1990) have stressed the differences between STI environment of developing and developed countries and thus the need for differentiated S&T components and indicators. Based on goals and missions, an international organization developing a worldwide STI framework for comparison of countries may move toward the highest comparability, while a developing country possibly incorporates its special strategic orientations and issues by developing native components and indicators beside maintaining core comparability.

Although each rationale could be scaled as three, five or more discrete points, a binary (extreme) categorization would be useful for the purposes of visual presentation of all rationales in a single plain diagram (Figure 1). As it could be seen from Figure 1, the major x-axis indicates whether a S&T framework is of wide or niche STI coverage, while the major y-axis shows if a framework has indicators developed or not. It should be noted that all rationales (axes) have deployed a binary (extreme) categorization of frameworks, i.e. for example, a framework as either logically straightforward or complicated. In addition, each major quadrant is further divided into four sub-quadrants by the two remaining rationales of simplicity and comparability (16 sub-quadrants in total).

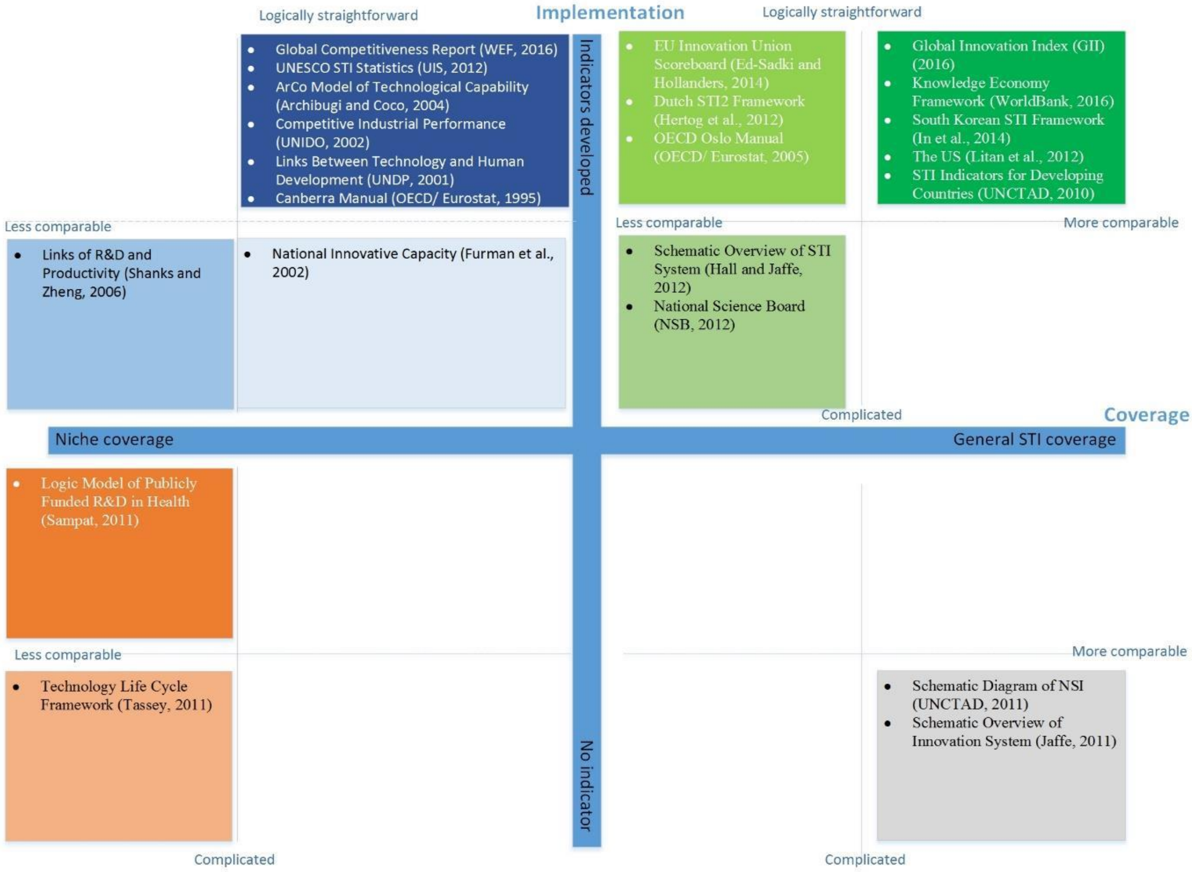

Figure 1. Visual presentation of base CISC (Coverage, Implementation, Simplicity and Comparability) model as applied onto the 22 frameworks

Each quadrant and sub-quadrant of Figure 1 implies a specific message. Due to the space limit, the discussion has been limited to selective major quadrants and sub-quadrants. The first major quadrant (top-right corner) illustrates those frameworks which are of wide STI coverage and that their S&T indicators have been developed. Its first sub-quadrant, which includes Global Innovation Index (GII) (Dutta and Lanvin, 2013) for example, shows such frameworks that also are logically straightforward and more comparable. These could be of interest for a country developing a wide STI coverage framework, which also wants to leverage based on internationally comparable indicators and periodical STI statistical data ready to use, while logically as straightforward as possible to a wider and less professional audience.

4. Extension of Model: Focus and areas covered

According to the comments received from senior discussants at EU-SPRI Early Career Conference 2016 on the initial CISC model, two complementary criteria of focus and areas covered have been under development. In contrast to the previous four categorization criteria which were approached as binary[i] ones to make them visually and simultaneously presentable in a Cartesian diagram, the two complementary new criteria are developed as multi-scale due to their nature. Therefore, we are faced with tables categorizing STI indicator frameworks separately for each of the criteria of focus and areas covered.

4.1. Categorization based on focus area

While focus area may seem similar and redundant to the other complementary categorization criterion, i.e. areas covered, the difference is about the scope vs. focus. In relation to the first initial criterion, i.e. widely scoped vs niche models (coverage criterion), focus area in fact expands coverage criterion by attributing comprehensive (widely covered) STI indicator frameworks to the single case of holistic focus on STI and R&D, while specifically pinpointing niche coverages of development of science, technology, innovation, economy and industry, and human resources, which are just simply being indicated as niche coverage in the coverage criterion.

Table 2 categorizes STI indicator frameworks by focus area. Notably, just the econometric modelling of R&D productivity of Shanks and Zheng (2006) was assigned twice in Table

[i] Categorizing just the two extremes of a case, as either simple or complex, for example, and nothing in between

1 (sharing the two focuses of R&D development, and industrial and economic development simultaneously. All other frameworks were exclusively assigned to a single focus area.

Table 2. Categorization of STI indicator frameworks by focus area

Focus Area	**STI indicator frameworks**
R&D development	• Logic Model of Publicly Funded R&D in Health (Sampat, 2011) • Econometric modelling of R&D productivity (Shanks and Zheng, 2006)
Technology development	• ArCo Model of Technological Capability (Archibugi and Coco, 2004) • Technology Life Cycle Framework of (Tassey, 2011)
Holistic: STI and R&D development	• South Korean STI Framework (In et al., 2014) • The US (Litan et al., 2014) • STI Indicators for Developing Countries (UNCTAD, 2010) • Dutch STI2 Framework (Hertog et al., 2012) • Schematic Overview of STI System (Hall and Jaffe, 2012) • US National Science Board's model (NSB, 2012)
Economic and industrial development	• Knowledge Economy Framework (WorldBank, 2016) • Global Competitiveness Report of World Economic Forum (WEF, 2016) • Competitive Industrial Performance (UNIDO, 2013) • Econometric modelling of R&D productivity (Shanks and Zheng, 2006)
Innovation development	• Global Innovation Index (GII) (2016) • EU Innovation Union Scoreboard (Ed-Sadki and Hollanders, 2014) • OECD Oslo Manual (OECD/ Eurostat, 2005) • National Innovative Capacity (Furman et al., 2002) • Schematic Diagram of National System of Innovation (NSI) (UNCTAD, 2011) • Schematic Overview of Innovation System (Jaffe, 2011)
Human resource development	• UNESCO STI Statistics (UIS, 2012) • Links between Technology and Human Development (UNDP, 2001) • Framework of Canberra Manual (OECD, 1995)

4.2. Categorization based on areas covered

By areas covered, it is meant a specificity on areas addressed, e.x. if a framework addresses and monitors financing of STI, the environment, infrastructure, if science, technology, innovation, R&D or multiple of them are covered, etc. Linking it to innovation system functions or activities seems interesting, but it is still a naive idea. Table 3 lists the eight areas that were found to be covered by the 22 well-known STI indicator frameworks.

Table 3. Eight functional areas distinguished for STI indicator frameworks

1)	Human resources, labour and education areas
2)	Firms and private sector, entrepreneurship and industry
3)	Institutions
4)	Infrastructures: ICT and physical
5)	Environments: Educational, labour, trade, legal, intellectual property and business
6)	Outputs: Scientific, market, export and trade
7)	R&D activities and resources
8)	STI expenditures and finance

Table 4 shows which frameworks cover each area. It should be noted that green cells in Table 4 indicates that the STI indicator framework minimally covers that area, while grey cells show lack of coverage of an area. In relation to the first categorization criteria (coverage), it is expected that widely general scoped (comprehensive) frameworks cover most of the areas of Table 4.

Table ٤ . Comaprison of STI indicator frameworks based on areas covered

STI indicator framework	**HR**	**Firms**	**Institution**	**Infrastructure**	**Environment**	**Output**	**R&D**	**Finance**
EU Innovation Union Scoreboard (Ed-Sadki and Hollanders, 2014)	✓	✓			✓	✓	✓	✓
UNESCO STI Statistics (UIS, 2012)	✓	✓	✓	✓	✓	✓	✓	✓
Econometric modelling of R&D productivity (Shanks and Zheng, 2006)	✓	✓				✓	✓	✓
Knowledge Economy Framework (WorldBank, 2016)	✓			✓	✓	✓		
Technology Life Cycle Framework of (Tassey, 2011)		✓		✓	✓			✓
South Korean STI Framework (In et al., 2014)	✓	✓	✓	✓	✓	✓	✓	✓

STI indicator framework	HR	Firms	Institution	Infrastructure	Environment	Output	R&D	Finance
Schematic Overview of STI System (Hall and Jaffe, 2012)	✓	✓	✓			✓		
Schematic Overview of Innovation System (Jaffe, 2011)	✓	✓	✓			✓		
Schematic Diagram of National System of Innovation (NSI) (UNCTAD, 2011)	✓	✓	✓	✓	✓	✓	✓	✓
OECD Oslo Manual (OECD/ Eurostat, 2005)	✓	✓	✓	✓	✓		✓	
Framework of Canberra Manual (OECD, 1995)	✓							
Global Innovation Index (GII, 2016)	✓	✓	✓	✓	✓	✓	✓	✓
STI Indicators for Developing Countries (UNCTAD, 2010)	✓	✓	✓			✓	✓	✓
Dutch STI2 Framework (Hertog et al., 2012)	✓	✓	✓	✓	✓	✓	✓	✓
National Innovative Capacity (Furman et al., 2002)	✓				✓	✓	✓	✓
Competitive Industrial Performance (UNIDO, 2013)						✓		
US National Science Board's model (NSB, 2012)	✓	✓	✓		✓	✓	✓	
Links between Technology and Human Development (UNDP, 2001)	✓			✓		✓	✓	✓
Global Competitiveness Report of World Economic Forum (WEF, 2016)	✓	✓	✓	✓	✓	✓		
The US (Litan et al., 2014)	✓	✓	✓		✓	✓	✓	✓
ArCo Model of Technological Capability (Archibugi and Coco, 2004)	✓			✓		✓		
Logic Model of Publicly Funded R&D in Health (Sampat, 2011)						✓	✓	✓

5. Conclusion on CISCAF model

The literature shows a diversity of STI indicator frameworks being developed fragmentedly from each other. This paper attempts to put first steps toward categorization and comparison of highly diverse STI indicator frameworks to make policy makers and governments able to build upon previous efforts of international organizations and countries. Although these frameworks are oriented toward economic, sustainable development, employment, industrial development, or higher or elementary education, to name some, it their interconnectedness with STI field which makes them nominee for our analysis and interest. In this regard, an initial categorization model was developed by introducing four criteria of coverage (comprehensiveness), implementation, simplicity and comparability (CISC). That yielded a visual presentation of 22 well-known STI indicator frameworks on a Cartesian diagram. The present study tries to complement the initial CISC model by two new complementary criteria of focus area and areas covered, to have the extended CISCAF model. In fact, it helps building upon previous efforts regarding development of STI indicator frameworks and restricts search agenda, when a country or organization is seeking development, design or revise a framework.

As some remarks, it should be reminded that categorization criteria could be defined at different levels of overall framework, components or indicators (but it should be specified). Here the criteria were defined at different levels but specified. As matter of fact, we had two omitted criteria because of the difficulties encountered to practically and robustly apply them onto the STI indicator frameworks. These two were overlapping of components and inclusion of native factors. The latter was merged with comparability criterion. In addition, the three criteria of coverage (comprehensiveness), areas covered and focus area considerably overlap, but they were found still useful as three separate criteria due to providing extreme comparison of wide vs niche frameworks, setting the focus of all areas covered and specifying all the areas coverable in details. The model is of course open to other probably useful criteria such as robustness of methodology and framework, transparency of methodology and data, replicability, logically overlapping components, availability of data and use of synthetic indicators.

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