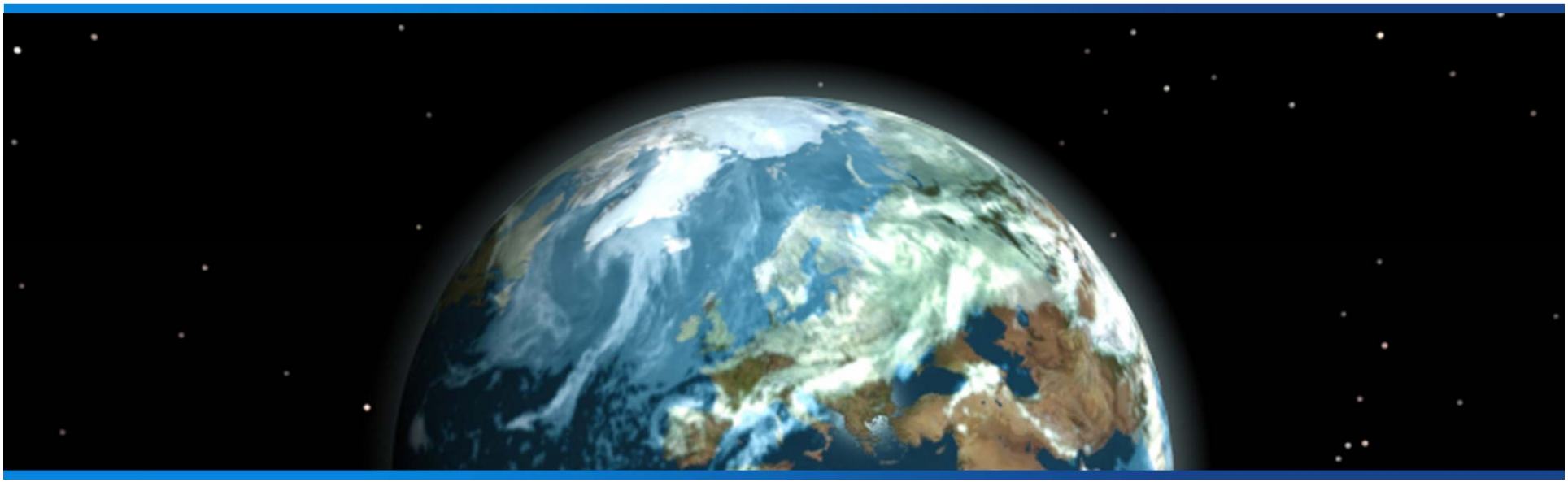
Science-Metrix

The Relationship Between Environmental and Scientific Performance of Nations:

Lessons Learned From a Macro-Level Evaluation Using Scientometric Indicators and an Environmental Performance Index



Evaluation 2011: Values and Valuing in Evaluation | AEA Conference
Multipaper Session 484: Multiple Methods for Assessing Societal and Environmental Impacts of Research
Thursday, Nov 3, 4:30 PM to 6:00 PM | Room: Malibu | Sponsored by the RTD TIG

Outline

- **Background**
  - Need for a composite index of scientific performance
  - Use of composite indexes for macro-evaluation of national outcomes
  - Environmental Performance Index (EPI)
- **Objectives**
  - Develop a composite scientometric index
  - Apply to macro-evaluation
  - Drive research
- **Methods**
  - Six steps: Development of a Composite Index of Scientific Performance
- **Preliminary results**
  - Relationship between the CISP and the EPI
- **Next steps**

Background: The challenge

- **How can evaluators investigate the impact of scientific research on the environmental performance of countries?**
  - Macro-indicators are often used to investigate the influence of **economic and non-economic factors on the environmental performance of nations**.
  - The Environmental Performance Index (EPI) is commonly used for this.
  - Literature shows examples of the influence of **economic** and **non-economic** factors on the environmental performance of nations.
  - However, the role of **national research performance**, as a determinant of the national environmental performance, has not been fully investigated.
  - We need a **new composite index** that takes scientific research into account.
  - We also, and primarily, need an **approach** to investigate the relationship between scientific research and the environmental performance of nations.

Background: Need and opportunities

- **Need for a Composite Index of Scientific Performance**
  - **Multi-criteria analysis** is a synthesis tool often sought by policy makers to inform the decision-making process.
  - When several dimensions characterizing a phenomenon are being measured for comparative purposes, it is often **difficult to determine the position of the countries being compared relative to one another** (i.e., A performs better than B or vice-versa) without a well-structured ranking mechanism.
  - Various methods have been developed to **reduce numerous indicators to a single composite indicator or multi-rank**.
  - These methods are often **sensitive to the composition of the study sample**.
  - A "**similarity-based approach to ranking multi-criteria alternatives**" was adapted to provide a stable composite indicator (Composite Index of Scientific Performance [CISP]) for ranking [Deng, 2007] in a bibliometric context.

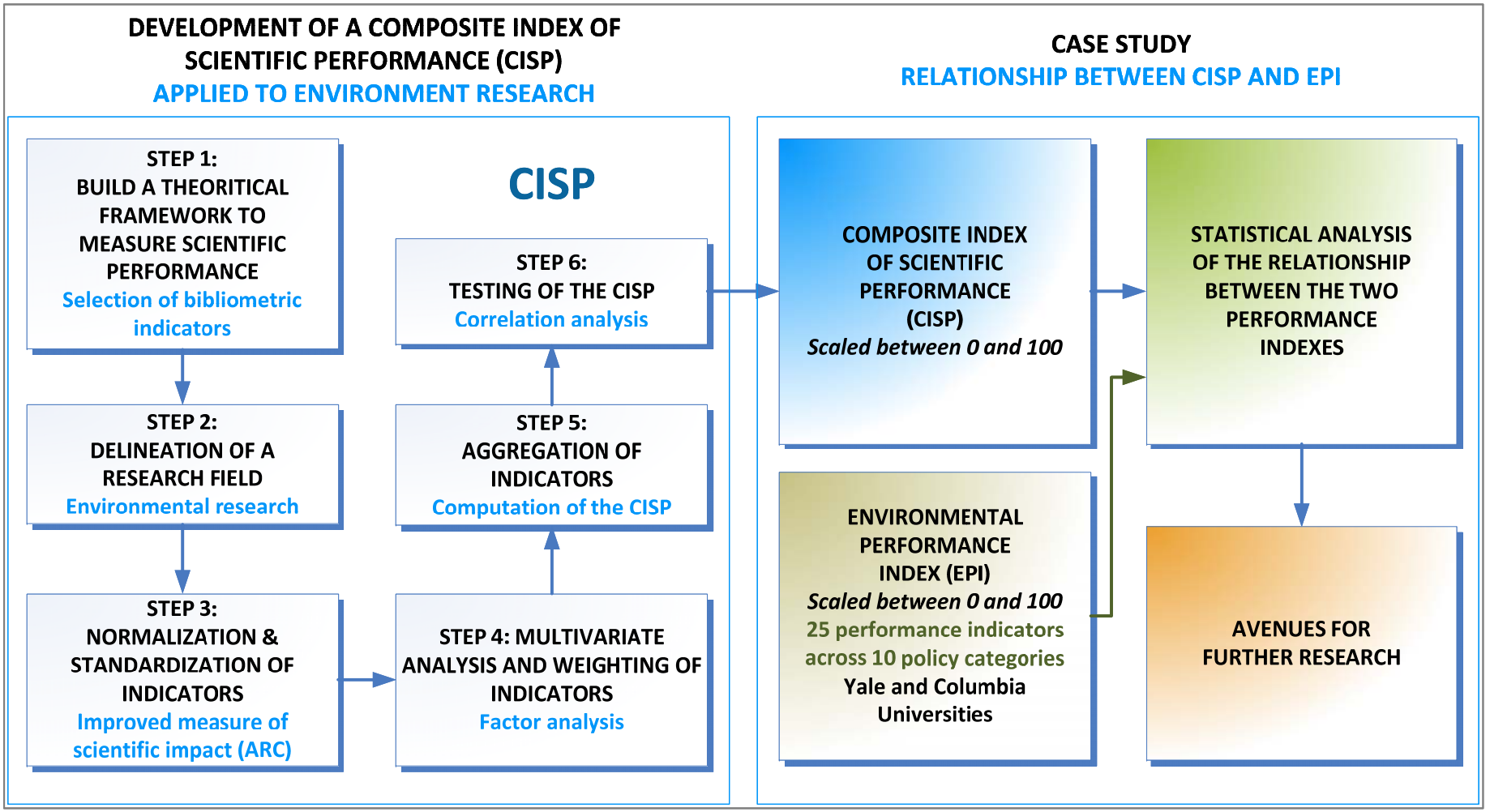
Background: Environmental Performance Index (EPI)

- **The Environmental Performance Index (EPI)**
  - Performance-oriented **composite index** developed by Yale and Columbia Universities. (See Annex 2 for EPI's advantages and limitations)
  - Formally released in Davos, at the annual meeting of the World Economic Forum in January 2006. Revised in 2008 and 2010.
  - Measures progress toward a set of targets of **desirable environmental outcomes**, taking into account a country's current policies.
  - Ranks 163 countries on **25 performance indicators tracked across 10 policy categories** for both environmental public health and ecosystem vitality objectives. (See Annex 1 for details on EPI's framework)
  - All variables are normalized on a scale from 0 to 100. The maximum value of 100 is attributed to the target, as the zero value is credited the worst player in the field.
  - Many examples of the use of the EPI to examine relations with other indices/indicators (See Annex 3 for examples)

Objectives

- **Develop a Composite Index of Scientific Performance (CISP):** Apply methods and scientometrics to improve the multi-criteria analysis of scientific performance of nations
- **Apply to macro-evaluation:** Investigate the relationship between the scientific and environmental performances of countries using the CISP and the EPI to support the macro-evaluation of research outcomes
- **Drive research**: Provide the basis for further exploration of the interpretative value of macro-level indicators by better understanding the links between the environmental research performance and environmental outcomes of nations

Methods: Approach Overview



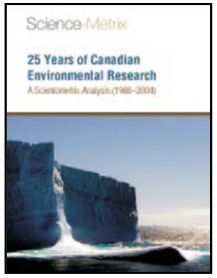
Methods (STEP 1): CISP Theoretical Framework

- **The CISP should capture, at a minimum, the three following dimensions relating to scientific performance:**
  - **Scientific Impact:** Direct versus indirect measures of a country's scientific impact.

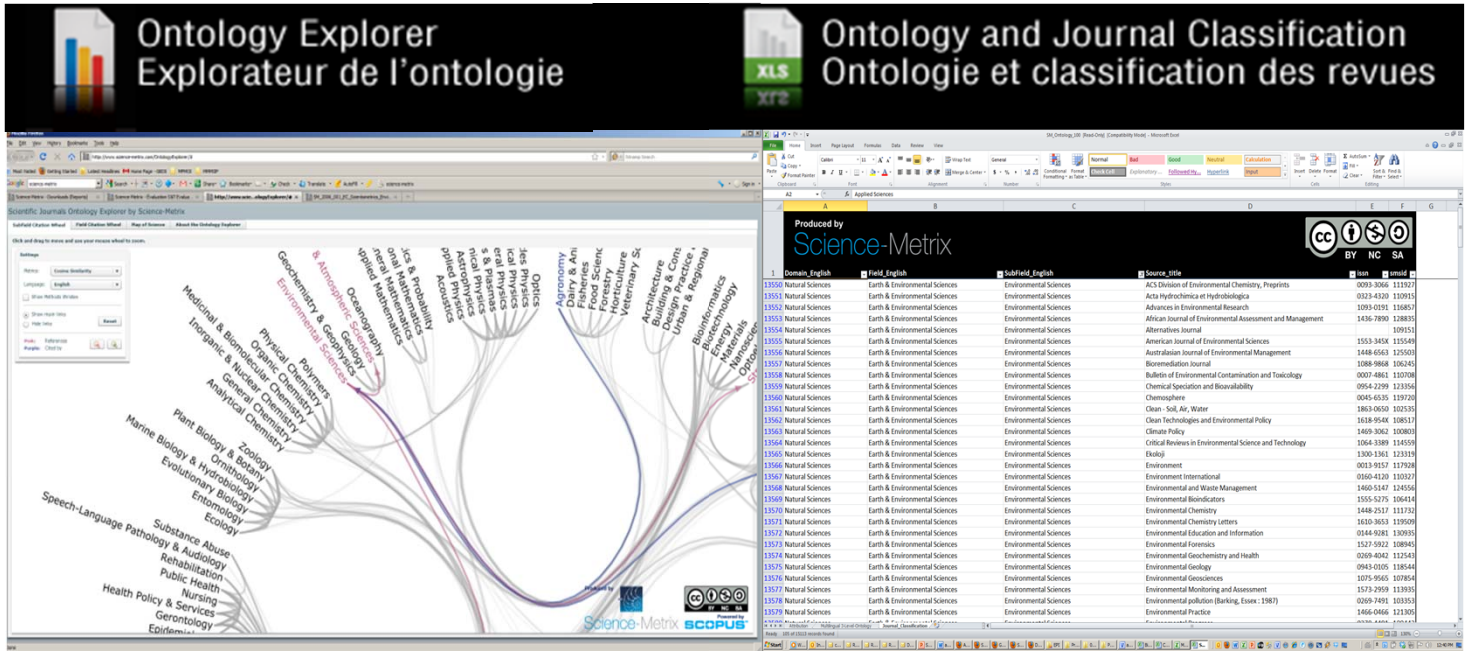
    Average of Relative Citations (ARC): Field normalized indicator of scientific impact which has been improved through transformation of the raw citation scores (*Normalized ARC*).
  - **Specialization Index (SI):** Proportion of a country's papers published in research area relative to the same proportion at world level (SI < 1 means not specialized; SI > 1 means specialized). Based on the fractional counting of papers.
  - **Scientific Productivity:** The number of papers published by a country (fractional counting) relative to the number expected given its gross expenditure in R&D (GERD).

Methods (STEP 2): Delineation of Scientific Research

- **Included the set of journals used in a previous scientometric study completed for Environment Canada** (Bertrand F. and Côté G. Science-Metrix 2006)



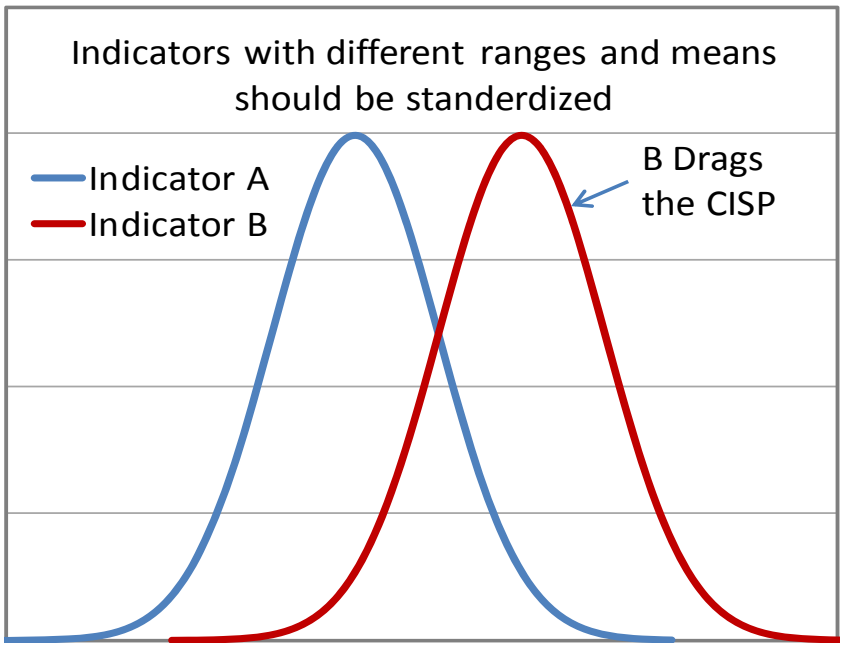
- **Identified additional environmental research journals using the Ontology Explorer Ontology and Journal Classification developed by Science-MEtrix**



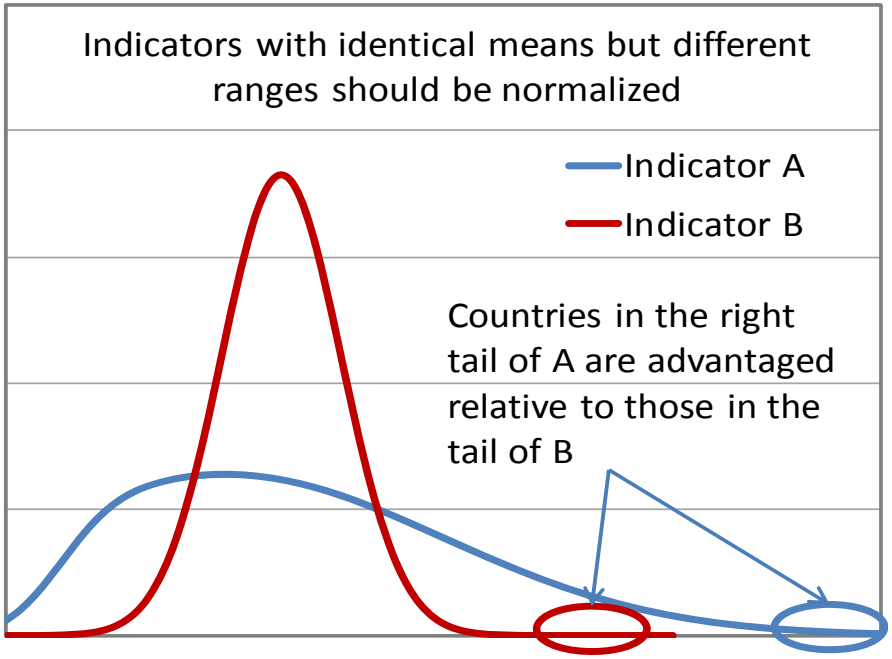
Methods (STEP 3): Normalization of Indicators

- **Normalization and standardization**
  - Crucial step to ensure that the indicators to be summarized are comparable

Standardization



Normalization

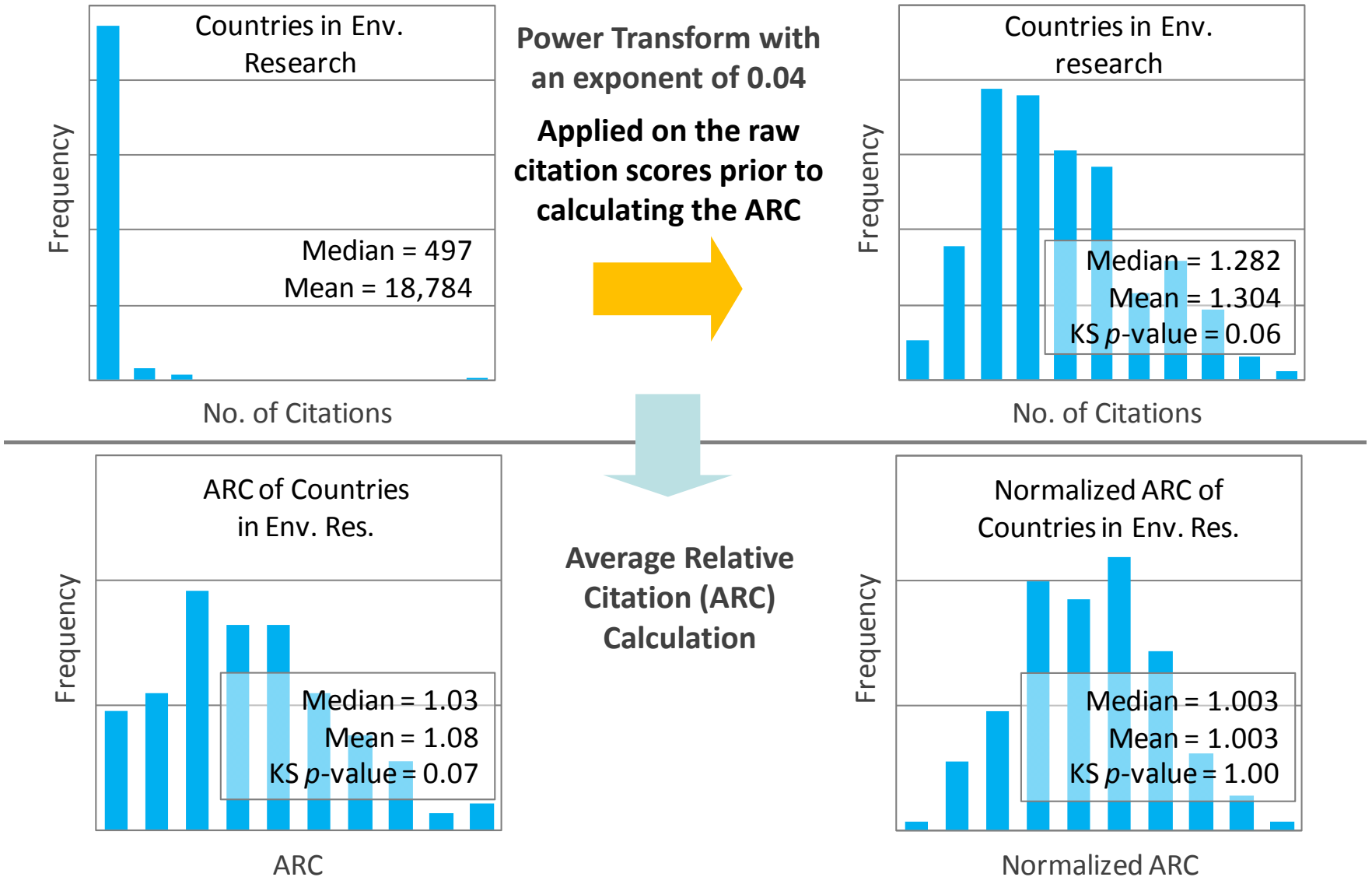


  - Country ranking based on rank normalization leads to unstable rankings and loss of information (See example at Annex 4)

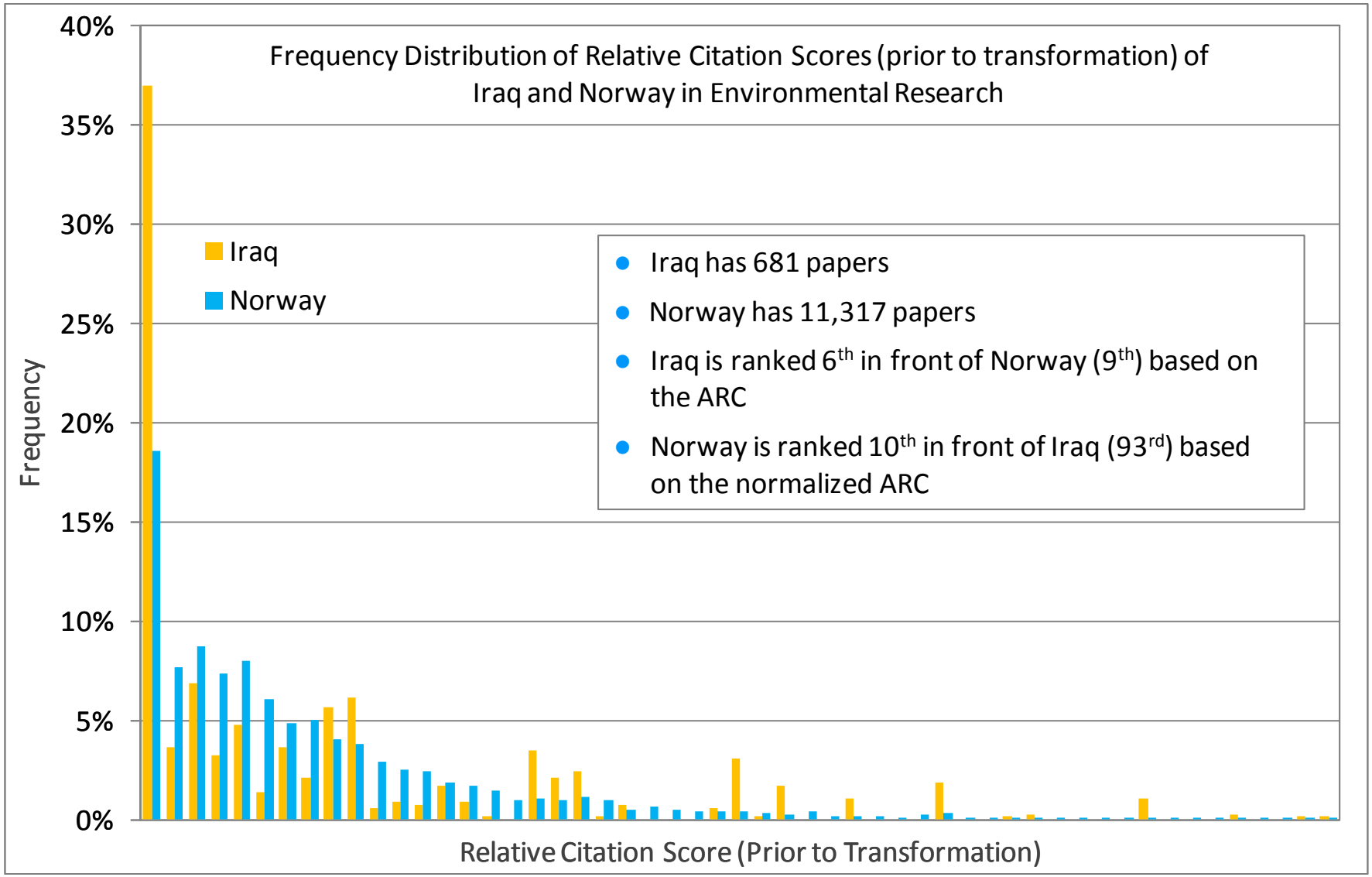
Methods (STEP 3): Normalization of Indicators

- **Normalization to fit a Gaussian (or normal) distribution followed by standardization to obtain a scale between 0 and 1:**
  - **Scientific Impact:**
    - *Normalization:* Detailed description follows.
    - *Standardization:* (Value – Min)/(Max – Min)
  - **Specialization Index (SI):**
    - *Normalization:* Box-Cox Power Transformation (KS *p*-value = 0.08)
    - *Standardization:* (Value – Min)/(Max – Min)
  - **Scientific Productivity:**
    - *Normalization:* Square root (KS *p*-value = 0.06)
    - *Standardization:* (Value – Min)/(Max – Min)

Methods (STEP 3): Normalization of Indicators



Methods(STEP 3): Normalization of Indicators



Methods (STEP 4): Multivariate Analysis (Weighting)

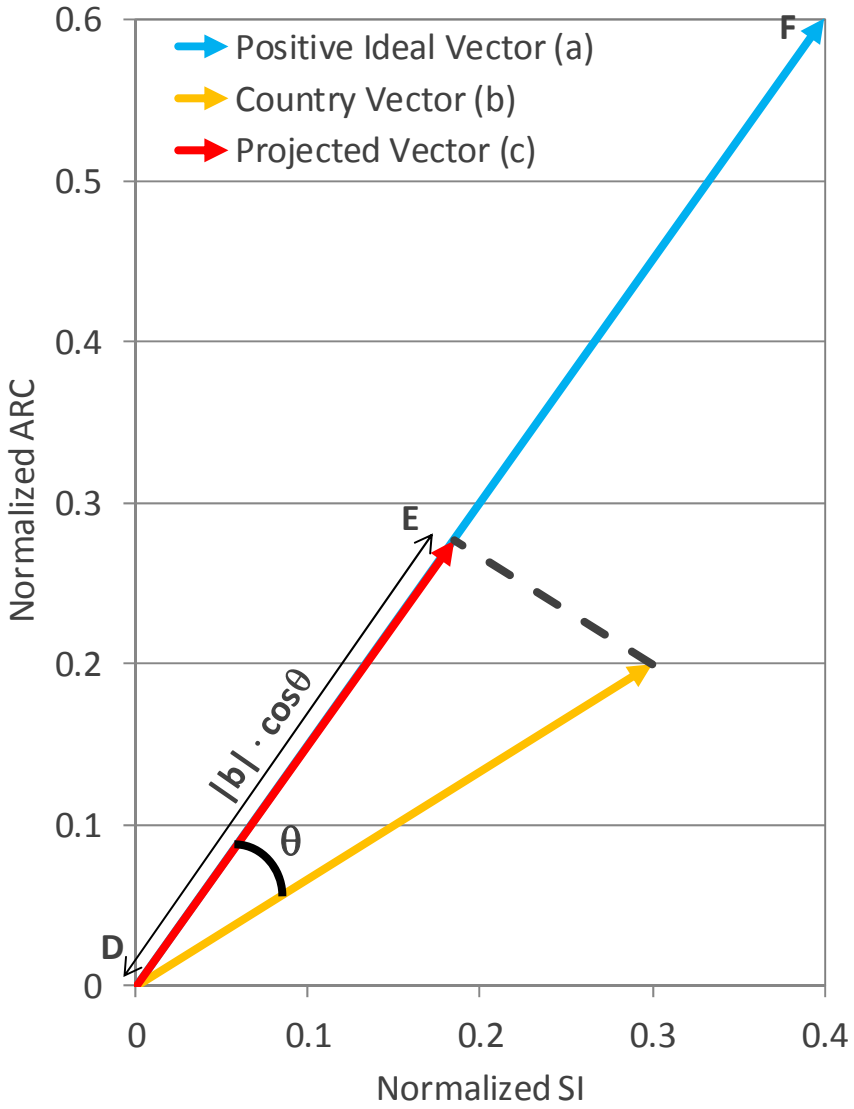
- **Statistical weighting of indicators included in the CISP to remove redundancy from correlated indicators:**

Pearson Correlation Matrix and Weighting from the Factor Analysis

	Normalized ARC	SI	Productivity	Weighting
Normalized ARC	1.00			**0.39**
SI	0.18	1.00		**0.29**
Productivity	0.03	**0.52**	1.00	**0.31**

- **Based on factor analysis**, for more details, see OECD and JRC joint Handbook on Constructing Composite Indicators: Methodology and User Guide.

Methods (Step 5): Aggregation of Indicators



- Fictive example for the explanation of the aggregation method in 2D
- The positive ideal vector = (1, 1) prior to weighting
- In this example, the SI has a weight of 0.4 and the ARC a weight of 0.6
- The weighted positive ideal vector = (0.4, 0.6)
- The weighted country vector is obtained in the same manner = (0.3, 0.2)
- CISP = |c|/|a| * 100 = DE/DF * 100 = 46.15
- CISP ranges from 0 to 100

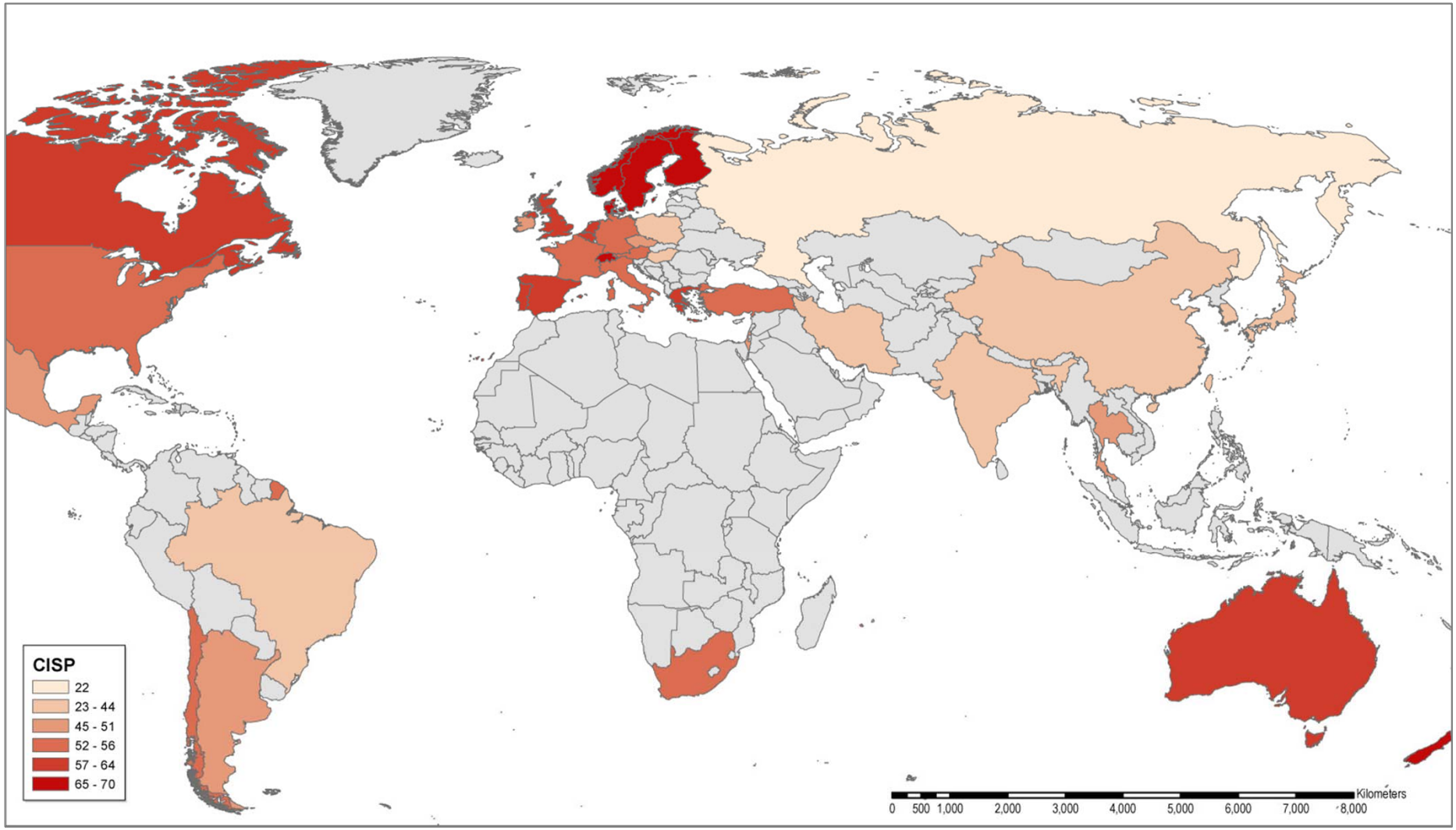
Methods (Step 6): Testing of the CISP

- **Validation of the CISP**
  - To validate the CISP, correlations between the individual indicators and the CISP were computed to ensure that the CISP reflects each indicator to the extent determined by the differential weighting

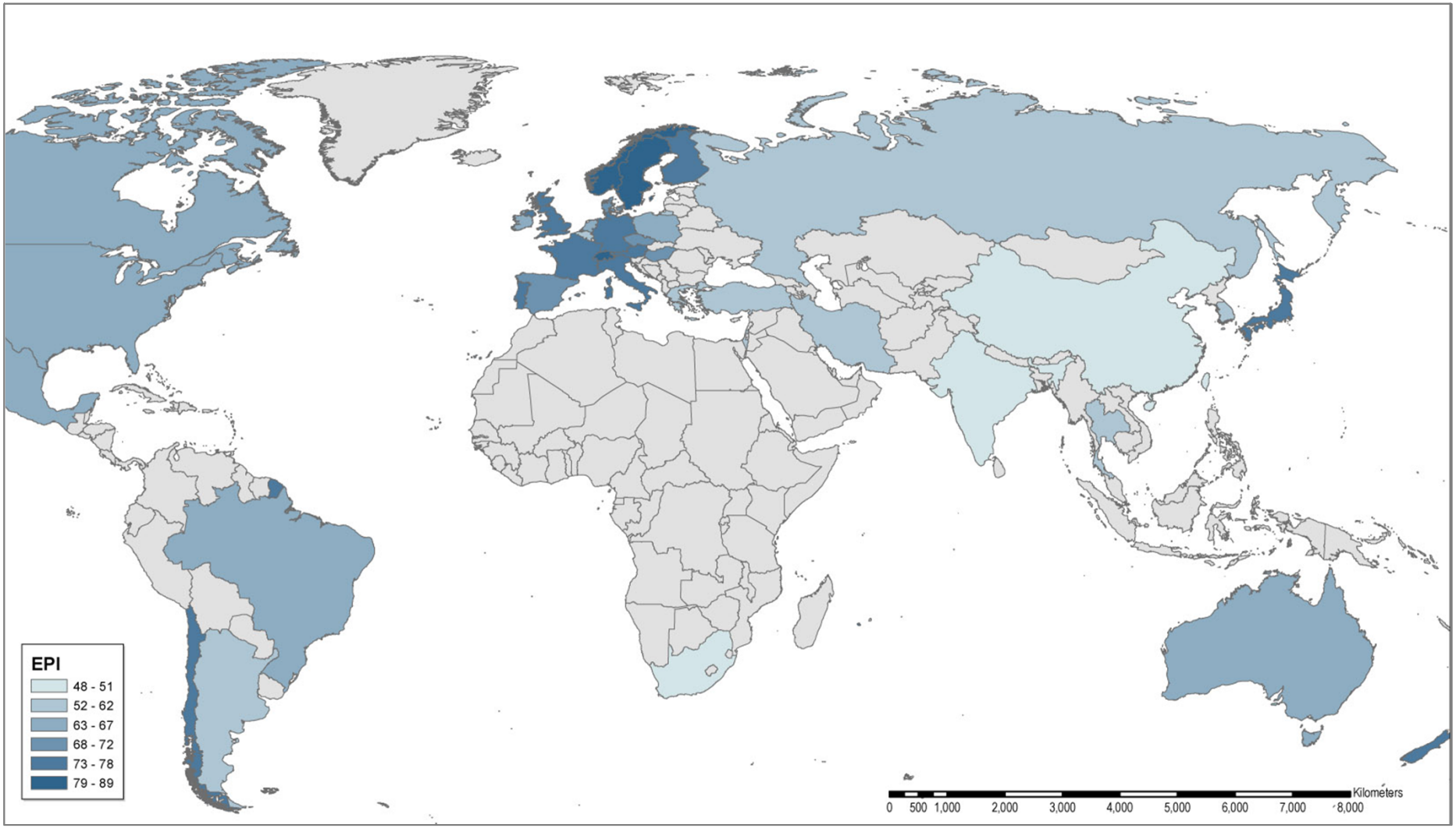
Pearson Correlation Coefficient of Individual Indicators with the CISP

	R	R^2	R^2 (sum scaled to one)	Weighting (sum scaled to one)
Normalized ARC	0.759	0.58	**0.41**	**0.39**
SI	0.703	0.49	**0.35**	**0.29**
Productivity	0.59	0.34	**0.24**	**0.31**

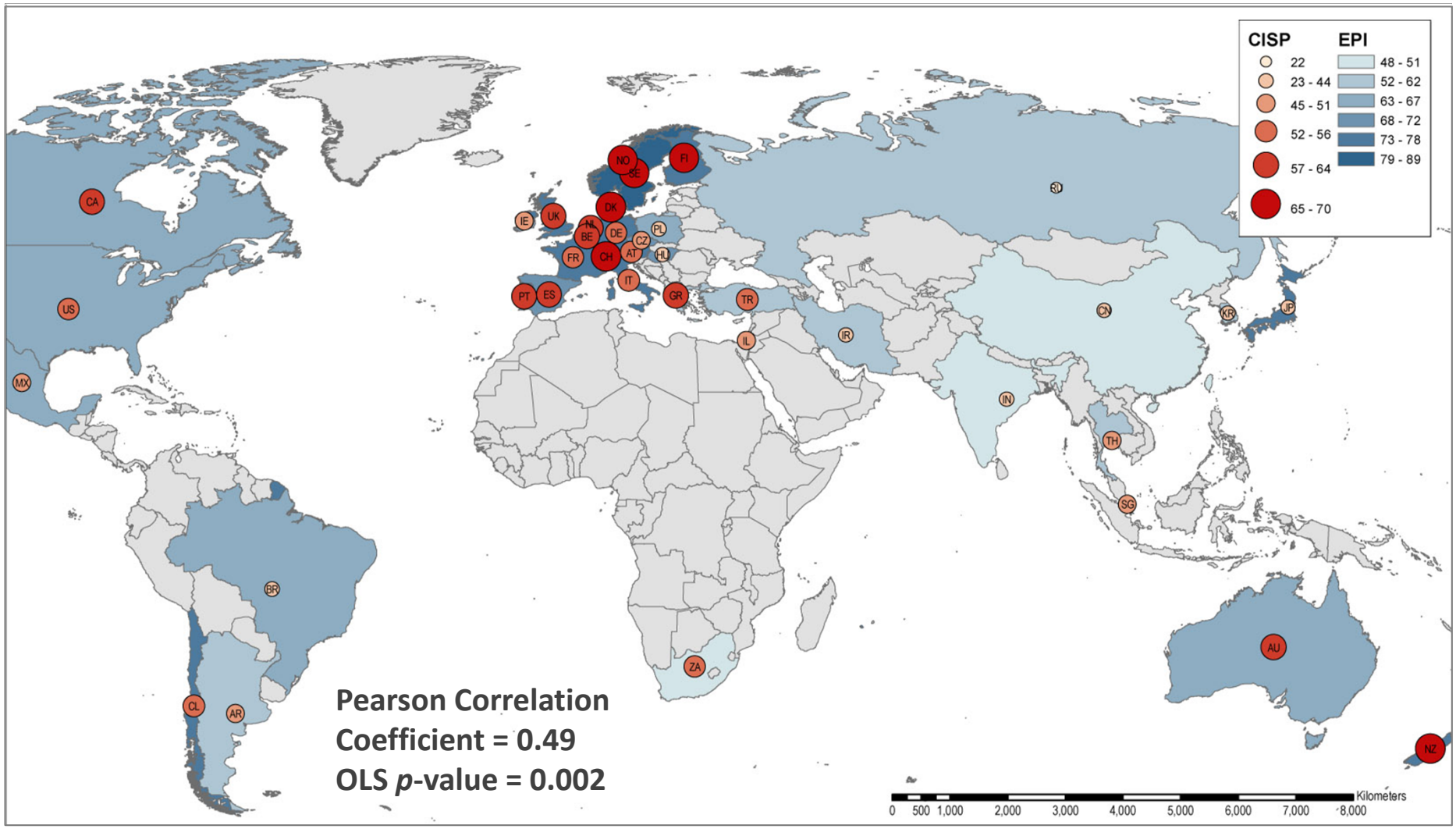
Results: Mapping of CISP scores



Results: Mapping of EPI scores



Results: Mapping of CISP and EPI scores



Next steps

- **Further validate and improve the CISP:**
  - Compute principal components and/or factor analysis to further validate the selection of scientometric indicators used in the composite index
  - Additional testing of the limits/errors of the approach (composite indicator and ranking in a bibliometric context)
- **Further explore the interpretative value of macro-level indicators:**
  - Delineate environmental research at the subfield level to align with EPI policy categories indicators (e.g., air pollution, fisheries, environmental health, etc.)
  - Further explore the value of macro-level indicators with multiple sources of evidence (other data on national policies and programs) to explain macro-evaluation results
  - Test the experimental design (including the limits/errors of the EPI)

Thank you for your time and feedback

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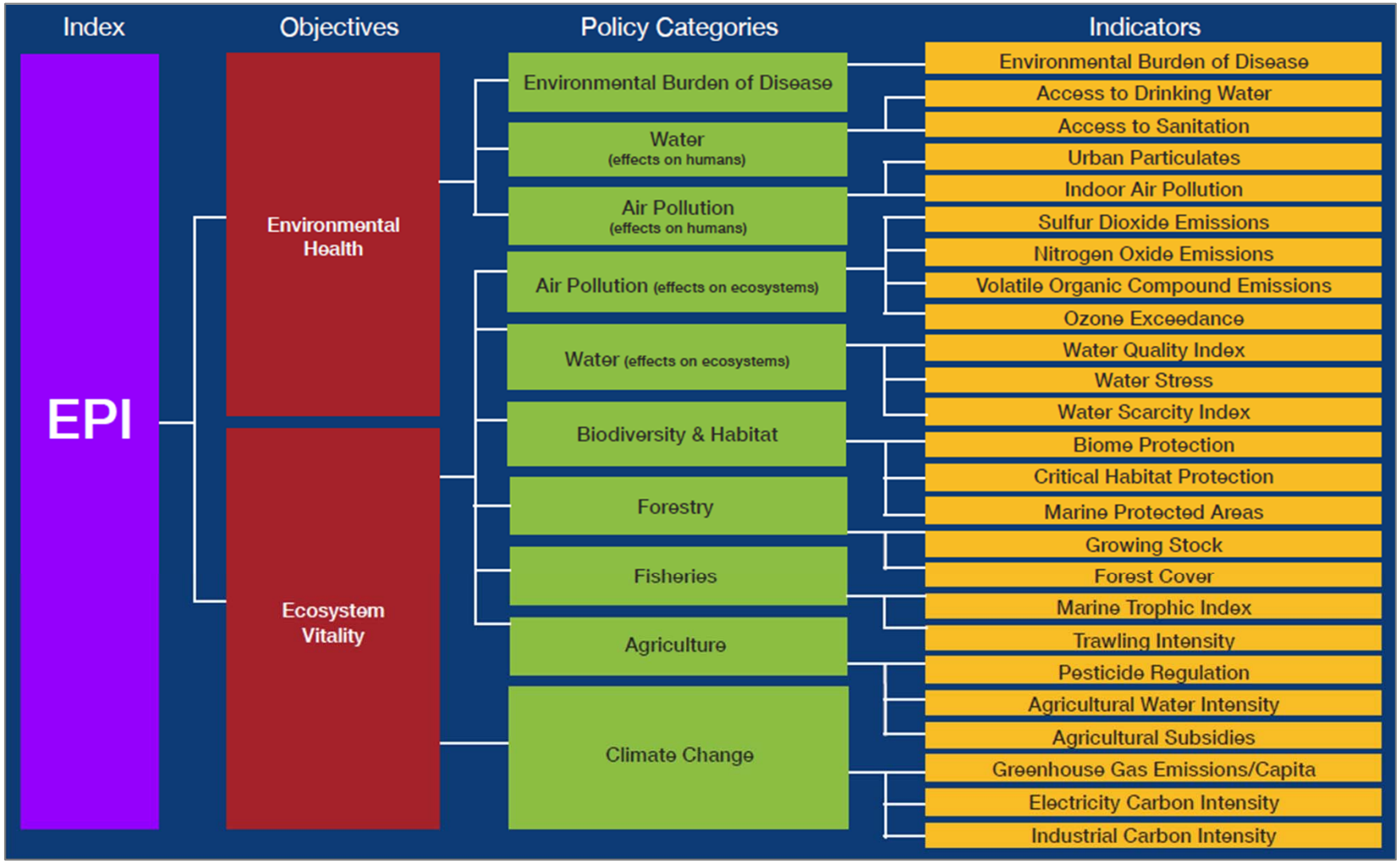
Annex 1: Background – EPI's Framework



Annex 2: EPI's Advantages and Limitations

Advantages	Limitations
One-dimensional metric to facilitate cross-country comparisons and analysis [Emerson *et al.*, 2010]	Absence of broadly-collected and methodologically-consistent data [Saisana & Saltelli, 2010]
Unambiguous yardstick against which a country's development can be measured and even a cross-country comparison can be performed [Böhringer & Jochem, 2008]	Fails to meet fundamental scientific requirements with respect to the three central steps of indices formation: normalization, weighting, and aggregation [Böhringer & Jochem, 2008]
Facilitates the identification of leaders and laggards, highlights best policy practices, and identifies priorities for action [Samimi *et al.*, 2010]	Utilizes the best available global datasets on environmental performance, but overall data quality and availability alarmingly poor [Emerson *et al.*, 2010]
Intuitive methodology, possibility to drill down into specific issues, global coverage, full data access and transparency [Srebotnjak, 2010]	Lack of time series, focus too narrow [Pillarosetti & van den Bergh, 2010]

Annex 3: Examples of the use of the EPI (Relation between two indices/indicators)

Question and data used	Main findings
Impact of improvements in environment quality as a determinant of economic growth in developing countries [Samimi, Erami, and Mehnatfar, 2010] **Data:** EPI and Economic Growth	• Impact of EPI on economic growth in the countries under consideration is positive and significant.
Trade or cross-border investment flows as a determinant of environmental degradation [Chakraborty & Mukherjeeo, 2010] **Data:** Relations between the EPI and the share of a country in the global export market and Foreign Direct Investment inflow	• No strong support to the Pollution Haven Hypothesis (i.e. migration of pollution-intensive industries to the developing world), but showed relationships between socio-economic and socio-political factors and national environmental performance.
Governance and social development as a determinant of environmental performance and capacity for climate change adaptation [Foa, 2009] **Data:** EPI and EM-DAT database, Worldwide Governance Indicators and Indices of Social Development	• Democracy in itself is not a sufficient precondition for good environmental policies • Strong evidence that engagement in local community can help improve environmental performance • Positive effect of gender equity upon environmental performance

Annex 4: Methods (Step 3): Normalization of Indicators

Country rankings based on rank normalization of indicators leads to unstable rankings and loss of information, 2003 - 2007

			Rank within top producers			Rank within all countries		
Country	**ARC**	**SI**	**ARC**	**SI**	**Average rank**	**ARC**	**SI**	**Average rank**
Norway	0.6270	0.6131	6	1	3.5 (2nd)	19	50	34.5 (1st)
Denmark	0.6766	0.5527	2	4	3.0 (1st)	7	79	43.0 (2nd)
Finland	0.6182	0.5735	9	2	5.5	22	71	46.5
Sweden	0.6455	0.5	4	5	4.5	13	89	51.0
Canada	0.6829	0.5	3	3	8.5	37	76	56.5
Australia	0.6001	0.5180	11	6	8.5	27	92	59.5
Switzerland	0.6850	0.4330	1	10	5.5	5	122	63.5
Netherlands	0.6592	0.4403	3	9	6.0	11	118	64.5
Spain	0.6132	0.4478	10	7	8.5	23	112	67.5
Belgium	0.6378	0.4321	5	11	8.0	15	123	69.0
United Kingdom	0.6217	0.4128	8	13	10.5	21	131	76.0
United States	0.5981	0.4207	13	12	12.5	30	128	79.0
France	0.5996	0.3732	12	16	14.0	28	143	85.5
Germany	0.6268	0.3368	7	19	13.0	20	154	87.0
Turkey	0.5406	0.4432	17	8	12.5	65	116	90.5
Italy	0.5753	0.3433	15	18	16.5	40	153	96.5
Brazil	0.5154	0.3879	19	15	17.0	78	137	107.5
Rep. of Korea	0.5520	0.2646	16	21	18.5	53	166	109.5
China	0.5145	0.2693	20	20	20.0	79	165	122.0
Japan	0.5227	0.2381	18	22	20.0	75	172	123.5
India	0.4636	0.3989	21	14	17.5	119	134	126.5
Poland	0.4562	0.3724	22	17	19.5	125	145	135.0

0.0496 in favour of Denmark

0.0604 in favour of Norway

Source: Computed by Science-Metrix using Scopus

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