How to Operationalize the IPCC AR 4 (2007) Definition of Vulnerability

- **Exposure** refers to changes in climate parameters that might affect socio-ecological systems.
- **Sensitivity** tells us about the status quo of the physical and natural environment of the affected systems that makes them particularly susceptible to climate change.
- Exposure and sensitivity determine the potential impacts of climate change: focused on the result if climate change took place unrestrictedly, impacting on socio-ecological systems without further preparation.
- **Adaptive capacity** is “the ability or potential of a system to respond successfully to climate variability and change, and includes adjustments in both behaviour and in resources and technologies”.

- **Vulnerability** is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.
How to Operationalize the IPCC AR 4 (2007)

Definition of Vulnerability

- **Vulnerability is** “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (McCarthy et al., 2001; IPCC AR3, 2001)

Recommended Steps for Constructing a Composite Indicator

- **Definition**: A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multi-dimensional concept that is being measured. (OECD Glossary of statistics)

- **Step 1.** Defining the phenomenon/Developing a theoretical framework/Conceptualizing the Composition and Structure
- **Step 2.** Selecting indicators
- **Step 3.** Data pre-processing
- **Step 4.** Normalisation of data
- **Step 5.** Multivariate analysis/Statistical Coherence
- **Step 6.** Weighting and aggregation
- **Step 7.** Robustness/sensitivity/Uncertainty analysis
- **Step 8.** Back to the details (indicators)
- **Step 9.** Presentation and dissemination

**Theoretical**

Index construction flowchart

**Methodological/Statistical**
## Composite Indicators: Pros and Cons

<table>
<thead>
<tr>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can summarise complex, multi-dimensional realities with a view to supporting decision makers.</td>
<td>May send misleading policy messages if poorly constructed or misinterpreted.</td>
</tr>
<tr>
<td>Are easier to interpret than a battery of many separate indicators.</td>
<td>May invite simplistic policy conclusions.</td>
</tr>
<tr>
<td>Can assess progress of countries over time.</td>
<td>May be misused, e.g., to support a desired policy, if the construction process is not transparent and/or lacks sound statistical or conceptual principles.</td>
</tr>
<tr>
<td>Reduce the visible size of a set of indicators without dropping the underlying information base.</td>
<td>The selection of indicators and weights could be the subject of political dispute.</td>
</tr>
<tr>
<td>Thus make it possible to include more information within the existing size limit.</td>
<td>May disguise serious failings in some dimensions and increase the difficulty of identifying proper remedial action, if the construction process is not transparent.</td>
</tr>
<tr>
<td>Place issues of country performance and progress at the centre of the policy arena.</td>
<td>May lead to inappropriate policies if dimensions of performance that are difficult to measure are ignored.</td>
</tr>
<tr>
<td>Facilitate communication with general public (i.e., citizens, media, etc.) and promote accountability.</td>
<td>Help to construct/underpin narratives for lay and literate audiences.</td>
</tr>
<tr>
<td>Enable users to compare complex dimensions effectively.</td>
<td>Facilitate communication with general public (i.e., citizens, media, etc.) and promote accountability.</td>
</tr>
</tbody>
</table>

### RICCAR Vulnerability Assessment Nested Structure – Sector/ Sub-sector/ Climate Change Impact

- **Thematic Clustering/ Theoretically derived categorization of indicators into components, dimensions, pillars**
Identifying Indicators from Impact Chains

- Developed to identify indicators in order to operationalise the vulnerability assessment for each climate change impact
- outlines for each of the three components the key factors contributing to the vulnerability
- allows a better understanding of the cause-effect relationship between climate change and its implications for a selected system

Impact chain for “Change in water availability”

Normalisation and Evaluation of Data

- We deal with data of different scales of measurement (metric, ordinal, nominal), different value ranges and different units
  - For metric data:
    - Different nature of indicators (positive vs. negative orientation towards the index)
    - Asymmetric distribution, different variances, ranges of variation, and outliers
- data first need to be transformed into a unit-less score on a common scale, before aggregation
- For the integrated assessment of vulnerability in the Arab region:
  - For the Exposure and Sensitivity components: a scale with a value range of 1 to 10 is applied, with the value 1 representing a low vulnerability and the value 10 representing a high vulnerability
  - For the Adaptive Capacity Indicators: the value 1 represents a low adaptive capacity (high vulnerability) and the value 10 represents a high adaptive capacity (low vulnerability)
- Depending on the type of data, different techniques can be applied:
  - Min-Max Normalisation
  - Evaluation of Indicators Using a Reference
  - Evaluating Indicators Based on Expert Opinion
Normalisation and Evaluation of Metric Data: Min-Max Normalisation

\[ X_{i,0-1} = \frac{X_i - X_{\text{min}}}{X_{\text{max}} - X_{\text{min}}} \]

- **Indicator: Road density**
- **log-transformation**
- **In the Arab Countries, the original values range from 0.5 km of road per 100 km² of land area, to 545.7 km of road per 100 km² of land area.**

<table>
<thead>
<tr>
<th>Country</th>
<th>Road density, R</th>
<th>Data log-transformed</th>
<th>Normalised values (Log(R)-(0.7))/(9.3-(0.7))</th>
<th>Classes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algeria</td>
<td>4.8</td>
<td>1.6</td>
<td>0.33</td>
<td>4</td>
</tr>
<tr>
<td>Bahrain</td>
<td>540.7</td>
<td>6.3</td>
<td>1.00</td>
<td>10</td>
</tr>
<tr>
<td>Djibouti</td>
<td>47.3</td>
<td>3.9</td>
<td>0.65</td>
<td>7</td>
</tr>
<tr>
<td>Egypt</td>
<td>13.2</td>
<td>2.6</td>
<td>0.67</td>
<td>5</td>
</tr>
<tr>
<td>Iraq</td>
<td>13.7</td>
<td>2.6</td>
<td>0.48</td>
<td>5</td>
</tr>
<tr>
<td>Jordan</td>
<td>9.6</td>
<td>2.3</td>
<td>0.43</td>
<td>5</td>
</tr>
<tr>
<td>Kuwait</td>
<td>8.1</td>
<td>2.1</td>
<td>0.40</td>
<td>5</td>
</tr>
<tr>
<td>Lebanon</td>
<td>39.3</td>
<td>4.7</td>
<td>0.63</td>
<td>7</td>
</tr>
<tr>
<td>Libya</td>
<td>66.7</td>
<td>4.2</td>
<td>0.70</td>
<td>8</td>
</tr>
<tr>
<td>Mauritania</td>
<td>4.7</td>
<td>1.6</td>
<td>0.33</td>
<td>4</td>
</tr>
<tr>
<td>Morocco</td>
<td>11.1</td>
<td>0.1</td>
<td>0.12</td>
<td>2</td>
</tr>
<tr>
<td>Palestine</td>
<td>13.1</td>
<td>2.6</td>
<td>0.47</td>
<td>5</td>
</tr>
<tr>
<td>Oman</td>
<td>77.8</td>
<td>4.4</td>
<td>0.72</td>
<td>8</td>
</tr>
<tr>
<td>Qatar</td>
<td>77.8</td>
<td>4.4</td>
<td>0.72</td>
<td>8</td>
</tr>
<tr>
<td>Saudi Arabia</td>
<td>76.8</td>
<td>4.4</td>
<td>0.73</td>
<td>8</td>
</tr>
<tr>
<td>Iraq Khwârân</td>
<td>10.5</td>
<td>2.3</td>
<td>0.44</td>
<td>5</td>
</tr>
<tr>
<td>Sudan (excluding South Sudan)</td>
<td>3.5</td>
<td>1.2</td>
<td>0.28</td>
<td>3</td>
</tr>
<tr>
<td>Syrian Arab Republic</td>
<td>0.5</td>
<td>-0.7</td>
<td>0.00</td>
<td>1</td>
</tr>
<tr>
<td>Tunisia</td>
<td>37.7</td>
<td>3.6</td>
<td>0.66</td>
<td>7</td>
</tr>
<tr>
<td>United Arab Emirates</td>
<td>11.9</td>
<td>2.5</td>
<td>0.46</td>
<td>5</td>
</tr>
<tr>
<td>Yemen</td>
<td>4.9</td>
<td>1.6</td>
<td>0.33</td>
<td>4</td>
</tr>
</tbody>
</table>

Normalisation Methods:
- Linear scales
- Ordinal scales
- Ratio scales

Normalisation of data: overview of some methods for metric data

<table>
<thead>
<tr>
<th>Method</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Ranking</td>
<td>( I_w = \text{Rank} \left( x_w^* \right) )</td>
</tr>
<tr>
<td>2. Standardization (or z-scores)</td>
<td>( I_w = \frac{x_w^* - \mu_{\text{w},\mu}}{\sigma_{\text{w},\mu}} )</td>
</tr>
<tr>
<td>3. Re-scaling</td>
<td>( I_w = \frac{x_w^* - \min\left( x_w^* \right)}{\max\left( x_w^* \right) - \min\left( x_w^* \right)} )</td>
</tr>
<tr>
<td>4. Distance to reference country</td>
<td>( I_w = \frac{x_w^<em>}{X_{\text{ref}}^</em>} ) or ( I_w = \frac{x_w^* - \bar{x}<em>w^*}{x</em>{\text{ref}}^* - \bar{x}_{\text{ref}}^*} )</td>
</tr>
<tr>
<td>5. Logarithmic transformation</td>
<td>( I_w = \ln(x_w^*) )</td>
</tr>
<tr>
<td>6. Categorical scales</td>
<td>( \text{if } x_w^* \text{ in the upper } 5 \text{-th percentile then } y_w^* = 100 )</td>
</tr>
<tr>
<td></td>
<td>( \text{if } x_w^* \text{ in the upper } 15 \text{-th percentile then } y_w^* = 80 )</td>
</tr>
<tr>
<td></td>
<td>( \text{if } x_w^* \text{ in the upper } 35 \text{-th percentile then } y_w^* = 60 )</td>
</tr>
</tbody>
</table>

OECD/JRC 2008
Normalisation of data: overview of some methods

7. Indicators above or below the mean

- If \( \frac{x_{i}}{x_{i}^{mean}} > (1 + p) \) then \( I_{i} = 1 \)
- If \( \frac{x_{i}}{x_{i}^{mean}} < (1 - p) \) then \( I_{i} = -1 \)
- If \( (1 - p) < \frac{x_{i}}{x_{i}^{mean}} < (1 + p) \) then \( I_{i} = 0 \)

8. Cyclical indicators (OECD)

\[ I_{i}^{cyc} = \frac{x_{i}^{t} - E[x_{i}^{t}]}{E[x_{i}^{t}] - E[x_{i}^{t-1}]} \]

- Pro: minimize cycles
- Cons: penalize irregular indicators

9. Balance of opinions (EC)

\[ I_{i}^{pol} = 100 \frac{\sum x_{i}^{t}}{N} \text{sgn}(x_{i}^{t} - x_{i}^{t-1}) \]

- Pro: based on opinions
- Cons: no absolute levels

10. Percentage of annual differences over consecutive years

\[ I_{i}^{d} = \frac{x_{i}^{t} - x_{i}^{t-1}}{x_{i}^{t-1}} \]

- Pro: no levels but changes
- Cons: low levels are equal to high levels

OECD/URC (2008)

---

Normalisation and Evaluation of Data: Evaluation of Indicators Using a Reference

- Some data sets cannot be normalised in such a standardised way as this would not adequately represent the meaning of an indicator value in regard to the relevant vulnerability component.
- This meaning – again on a scale from 1 to 10 – needs to be assigned to each indicator value: evaluation. For that purpose, a reference such as an existing and widely accepted index can be used to allocate the indicator values into classes.
- **Practical example:**

For the indicator Total Available Renewable Water Resources (TARWR) per capita the classes to indicate the level of sensitivity could be based on the Falkenmark Indicator. The Falkenmark Indicator proposes a threshold of 1,700m³ of available water resources per capita per year for water stressed and 1000m³ per capita per year for water scarce-countries.

<table>
<thead>
<tr>
<th>Available TARWR per capita (m³ per capita)</th>
<th>Sensitivity Level</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1,700 - Not stressed</td>
<td>n.a.</td>
<td>1 – low sensitivity</td>
</tr>
<tr>
<td>&gt;1,700 - 1,700 - Stress</td>
<td>n.a.</td>
<td>2</td>
</tr>
<tr>
<td>&gt;1,700 - 1,700 - Stress</td>
<td>n.a.</td>
<td>3</td>
</tr>
<tr>
<td>&gt;1,700 - 1,700 - Stress</td>
<td>1500 – 1750</td>
<td>5</td>
</tr>
<tr>
<td>&gt;1,700 - 1,700 - Stress</td>
<td>1250 – 1500</td>
<td>6</td>
</tr>
<tr>
<td>&gt;1,700 - 1,700 - Stress</td>
<td>&gt;1000 – 1250</td>
<td>7</td>
</tr>
<tr>
<td>&lt;1,000 - 1,000 scarcity</td>
<td>750 – 1000</td>
<td>8</td>
</tr>
<tr>
<td>&lt;1,000 - 1,000 scarcity</td>
<td>500 – 750</td>
<td>9</td>
</tr>
<tr>
<td>&lt; 500 – Absolute scarcity</td>
<td>0 – &lt;500</td>
<td>10 – high sensitivity</td>
</tr>
</tbody>
</table>
Normalisation and Evaluation of Data: Evaluating Indicators Based on Expert Opinion

- **when references or thresholds are not available**
- Example in the context of the integrated vulnerability assessment of the Arab region: land use land cover “evaluation”, with the experts of the VA-WG. The experts evaluated the different classes of the Global Land Cover-SHARE data set, assigning the different classes provided in the data to the scale of ten.

<table>
<thead>
<tr>
<th>Sensitivity Value / class</th>
<th>Global Land Cover-SHARE Identification Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 ArtificialSurfaces</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2 Cropland</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3 Grassland</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>4 Tree Covered Areas</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>5 Shrub-Covered Areas</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>6 Herbaceous vegetation aquatic or regularly flooded</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>7 Mangroves</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>8 Sparse vegetation</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>9 Barrenol</td>
<td></td>
</tr>
<tr>
<td>n.a.</td>
<td>10 Snow and glaciers*</td>
<td></td>
</tr>
</tbody>
</table>

* The description for “snow and glaciers” in Global Land Cover-SHARE refers to permanent snow cover and glaciers. It was thus determined to be not applicable (n.a.) for the Arab region.

Metric Data Normalisation and Evaluation: Some Practical Guidelines

1) **Data representation/ Transformation into non-dimensional scales:** percentages, per capita, density functions

- percentage of elderly or the elderly count? Unemployment rates or the number of unemployed? Population counts or population densities?

Two main representational methods are available:

- ‘absolute representations,’ which use the variable counts; and
- ‘relative composition’ methods, where relative numbers are computed so as to consider relative proportions of vulnerable populations:
  - using absolute size greatly influenced by the ranks of total population
  - absolute composition might be used if the purpose of the index is to identify the number of vulnerable people, such as for evacuation planning
  - combining both absolute and relative representations of variables, through averaging the absolute and relative normalised values, is possible

- **don’t only relate to demographic-related indicators, but also most socio-economic and in some instances environmental indicators:**
  - should we use the total amount of official development aid, the official development aid per capita, or official development aid as percentage of government revenues?
  - should we use the number of scientific and technical journal articles or express this number per million population?
  - Should we use the number of hospital beds or express this number per thousand population?
Metric Data Normalisation and Evaluation: Some Practical Guidelines

2) A **statistical analysis** of the original raw data is essential as it enables:
   - **the identification of outliers**
     - Indicative of heavy tailed distribution, a mixture of two distributions, or errors
     - Distort the correlation structure and
     - Become unintended benchmarks during normalization
       - Particularly problematic in the case of min-max linear transformation
   - Techniques to identify outliers:
     - Percentile rank
     - Skewness and kurtosis rule of thumb
     - Boxplot analyses
     - Leverage and influence analyses

- **Need for scale transformation?**
- **Imputation of missing values**

---

Metric Data Normalisation and Evaluation: Some Practical Guidelines

- **Missing values**: Imputation necessary to obtain a complete dataset
  - Case deletion/ Indicator deletion?

- **Approaches**:
  - Introduce more than one indicator per pillar/ dimension/ component to complement each other
  - Data from the most recent year available: threshold?
  - Hot-deck imputation/ Cold-deck imputation
  - Unconditional sample mean/median/mode
  - Regression imputation
  - Imputation with MAR and MCAR assumptions
    - Expectation maximization
    - Markov Chain Monte Carlo (MCMC) multiple imputation

- **Measure the reliability of imputed values: sensitivity analysis**
Metric Data Normalisation and Evaluation: Some Practical Guidelines

3) Minimum and Maximum values choices

- Main considerations:
  - Closely linked to/ dependent on the outliers treatment step
  - Using regional or global minima and maxima?
    - Is there a potential for the countries of the region with the highest scores to continue their progress on some indicators?
    - Might well be the case for some indicators of the adaptive capacity dimension: technology indicators? governance indicators? educational attainment indicators?
  - From a time series perspective
    - Panel normalisation/ annual normalisation
    - Fixed min and max values recommended: preserve the rescaling factor and make the transformation stable through time

Metric Data Normalisation and Evaluation: Some Practical Guidelines

4) Classification decisions for metric data:

- choice depends on data distribution:
  - equal intervals classification;
  - quantile classification;
  - natural breaks (Jenks) classification;
  - user defined classification;
  - geometrical intervals classification;
  - mean-standard deviation method;
  - nested means method;
  - maximum breaks classification

- most used: equal intervals classification, the quantiles classification, and the user defined
Metric Data Normalisation and Evaluation: Some Practical Guidelines

5) Directionality change/ data inversion: several approaches/ several levels:
- At the indicator level: different indicators have different directions of functional relationship with the construct being measured, compare:
  - a temperature increase and an increase in precipitation (Sensitivity component)
  - Literacy rates, GDP/capita and refugees in percent of population, disability prevalence data (Adaptive capacity component)
- Data inversion during the normalisation phase necessary for the indicators class numbers to indicate similar vulnerability states
  - Can be handled within the normalisation procedure for single indicators: example of a (0-1) min-max rescaling,
    \[
    x_i^j = \frac{X_i^j - \min \{X_i^j\}}{\max \{X_i^j\} - \min \{X_i^j\}} \quad \text{vs} \quad y_i^j = \frac{\max \{X_i^j\} - X_i^j}{\max \{X_i^j\} - \min \{X_i^j\}}
    \]
  - Inversion after the normalization and classification step: apply the \((1-x)\) transformation

Metric Data Normalisation and Evaluation: Some Practical Guidelines

- data inversion: necessary at (almost) every aggregation level to take advantage of the partial compensability property of the geometric aggregation,
  - Low (high) values should indicate high (low) vulnerability states
  - This is in contrast to the classification convention of exposure and sensitivity indicators
- The following equivalences/ correspondences should be kept in mind:
  - Low adaptive capacity - High Exposure/ Sensitivity - High Vulnerability
  - High adaptive capacity - Low Exposure/ Sensitivity - Low Vulnerability
- Similarly inversion is necessary
  - When combining Sub-sectors vulnerability indices into Sectoral indices
  - When combining Sectoral vulnerability indices into an Overall vulnerability index
Aggregation Methods: The Linear Additive Aggregation and the Arithmetic Aggregation

- There is a large variety of different aggregation techniques: compensatory and non-compensatory.
- Additive aggregation is a weighted (or unweighted) linear combination of the normalized indicators.
- A special case is an arithmetic aggregation.

Index value \( \sum w_i X_i = (w_1 \cdot X_1 + w_2 \cdot X_2 + w_3 \cdot X_3 + \cdots + w_n \cdot X_n) \)

- \( n \): number of indicators
- \( w_i \): weight for indicator \( i \), with \( 0 \leq w_i \leq 1 \) and \( \sum w_i = 1 \)
- \( X_i \): normalised value of indicator \( i \)

Main drawbacks in the context of socio-economic vulnerability assessments:
- The preference independence condition, or the mutually preferential independence of the different indicators, dimensions, or components: property of "no interaction" can be problematic.
- The property of full compensability violates preferred invariance property to plausible transformations.

Aggregation Methods: Geometric Aggregation

- The geometric aggregation, a nonlinear aggregation technique, avoids these issues with interaction and compensability. It is the product of normalized weighted (or unweighted) indicators and can be calculated using the following formula:

\[ \prod w_i (X_i) = (X_1)^w_1 \cdot (X_2)^w_2 \cdot (X_3)^w_3 \cdots (X_n)^w_n \]

Where,

- \( n \): number of indicators
- \( w_i \): weight for indicator \( i \), with \( 0 \leq w_i \leq 1 \) and \( \sum w_i = 1 \)
- \( X_i \): normalised value of indicator \( i \)

- It has the property of partial compensability, meaning that a poor performance in some indicators cannot be easily compensated for by high values in other indicators.
- Countries with divergent normalized indicators are penalised.

Intuition behind Partial/Full compensability:
Arithmetic average of 1 and 9 = (1+9)/2 = 5
Geometric average of 1 and 9 = (1*9)^1/2 = 3
Aggregation method in the Integrated Vulnerability Assessment of the Arab Region

- For the integrated vulnerability assessment of the Arab region, a geometric aggregation approach was chosen. As previously noted, depending on the knowledge available, it can be used with or without assigned weights.

- There are several levels on which aggregation will be done in order to implement the integrated vulnerability assessment methodology.

- The aggregation methodology consists of a multi-level (nested) structure which incorporates three main architectural elements: components, dimensions, and indicators:
  - The three components are exposure, sensitivity, and adaptive capacity.
  - Exposure and sensitivity are aggregated to obtain an index for potential impact, which is then combined with adaptive capacity to obtain a vulnerability index.
  - The sensitivity and adaptive capacity components are further composed of several dimensions.
  - Each dimension is in turn represented by several indicators.

- This general structure can be simplified or elaborated upon according to the theoretical and conceptual framework, and the specificities of the index design structure.

RICCAR Vulnerability Assessment Nested Structure – Sector/ Sub-sector/ Climate Change Impact
Aggregation approach for the Adaptive Capacity component

* Individual indicators are aggregated to obtain sub-indices.
** Individual indicators and sub-indices are aggregated to obtain an index for every dimension.
*** The six dimensions are aggregated to calculate an index for the Adaptive capacity component.

Aggregation approach to the Infrastructure dimension

The Infrastructure dimension aggregates eleven indicators that relate to five pillars: energy, transport, health, water and sanitation supply, and environment.
Weighting Methods

- Weighting schemes can have a significant effect on countries' vulnerability scores.
- Can be assigned to 1) the indicators of each dimension; 2) the dimensions of each component; and 3) the three components of vulnerability.
- Statistical methods:
  - Advantages
  - Drawbacks
- Participatory methods, examples:
  - budget allocation process (BAP)
  - analytic hierarchy process (AHP): produces coherent and robust weights based on a set of stated preferences of experts from rotating pair-wise comparison of priorities, and controls for internal consistency for priority assessment.
- When the relative importance of indicators is judged to be roughly the same, or when to the trade-offs between indicators or dimensions are poorly understood so that the assignment of differential weights cannot be justified, equal weightings might be applied.
- Remarks regarding the use of equal weightings:
  - distinction between the "targeted" or "ex ante", and the "ex-post" importance.

Introduction of weights

\[
CI_{Dimension\ i} = (SE_1 \times SE_2 \times ... \times SE_n)^{1/n}
\]

\[
CI_{Weighted\ Dimension\ i} = (SE_1^{w1} \times SE_2^{w2} \times SE_3^{w3} \times ... \times SE_n^{wn})
\]

\[
CI_{Dimension\ 1} = (AC_1 \times Sub-Ind\ AC_2 \times AC_3 \times ... \times AC_n)^{1/n}
\]

\[
CI_{weighted\ Dimension\ 1} = AC_1^{w1} \times (Sub-IndAC_2^{wSub-IndAC2} \times AC_3^{w3} \times ... \times AC_n^{wn})
\]

\[
CI_{Adaptive\ Capacity} = (CI_{Dim1} \times CI_{Dim2} \times CI_{Dim3} \times CI_{Dim4} \times CI_{Dim5} \times CI_{Dim6})^{1/6}
\]

\[
CI_{weighted\ Adaptive\ Capacity} = (CI_{Dim1}^{wDim1} \times CI_{Dim2}^{wDim2} \times CI_{Dim3}^{wDim3} \times CI_{Dim4}^{wDim4} \times CI_{Dim5}^{wDim5} \times CI_{Dim6}^{wDim6})
\]
### Aggregating the Components of Vulnerability

\[
\begin{align*}
\text{PI}_x &= (\text{EX}_x \cdot \text{SE}_x)^{1/2} \\
\text{PI}_{\text{Weighted}} &= (\text{EX}_x)^{wEX} \cdot (\text{SE}_x)^{wSE} \\
V_x &= (\text{PI}_x \cdot \text{AC}_x)^{1/2} \\
&\text{or} \\
V_x &= (\text{PI}_x)^{wPI} \cdot (\text{AC}_x)^{wAC}
\end{align*}
\]

### Impacts of choices of operationalisation of the IPCC AR4 (2007)

**Definition 1:** Sensitivity, exposure, and adaptive capacity are assumed to have an equal influence on vulnerability, 

\[
V_x = (\text{EX}_x \cdot \text{SE}_x \cdot \text{AC}_x)^{1/3}
\]

Since the potential impact is calculated by:

\[
(\text{EX}_x \cdot \text{SE}_x)^{1/2} = \text{PI}_x
\]

Vulnerability can also be calculated using the following formula:

\[
V_x = (\text{PI}_x^2 \cdot \text{AC}_x)^{1/3} = \text{PI}_x^{2/3} \cdot \text{AC}_x^{1/3}
\]

**Definition 2:** Potential impact and adaptive capacity have an equal influence on vulnerability, where Potential Impact is itself equally influenced by exposure and sensitivity.

In this case,

\[
V_x = (\text{PI}_x \cdot \text{AC}_x)^{1/2} = \text{PI}_x^{1/2} \cdot \text{AC}_x^{1/2}
\]

Hence, in this case \(wPI = wAC = \frac{1}{2}\).
Overview of inversion and aggregation steps towards the overall vulnerability

<table>
<thead>
<tr>
<th>Component (C)</th>
<th>Original Indicator Values: EX + SE: high values = high V</th>
<th>Inverse Indicator values</th>
<th>Aggregation to vulnerability component</th>
<th>Aggregation to PI</th>
<th>Output PI + AC</th>
<th>Aggregation to V single</th>
<th>Output V single</th>
<th>Aggregation to V total</th>
<th>Output V total</th>
</tr>
</thead>
<tbody>
<tr>
<td>EX Inv EX-1</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>EX-2 Inv EX-2</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>EX-3 Inv EX-3</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>EX-x</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>SE Inv SE-1</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
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<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
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<td>Inv V total</td>
<td>V total</td>
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<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>SE-x</td>
<td>Geometric aggregation InvEX</td>
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<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>AC Inv AC-1</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
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<td>V total</td>
<td>V single</td>
<td>V single</td>
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<tr>
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<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
<td>PI Inv</td>
<td>Inv V total</td>
<td>Inv V total</td>
<td>V total</td>
<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
<tr>
<td>AC-3 Inv AC-3</td>
<td>Geometric aggregation InvEX</td>
<td>InvEX x InvSE x PiInv</td>
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<td>Inv V total</td>
<td>Inv V total</td>
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<td>V total</td>
<td>V single</td>
<td>V single</td>
</tr>
</tbody>
</table>

Notes:
1. The inversion will only be necessary for those adaptive capacity indicators where high values represent high vulnerability, e.g., refugees or people with disability figures.
2. "Inv" refers to the inversion of the direction of some indicators or components through the 11-x transformation, see Part I: Chapter 7.3.

Aggregating Vulnerability within Sectors

Sub-sector vulnerabilities can be aggregated to a sectoral vulnerability using the geometric approach by applying the following formula:

\[ V_{\text{Sector}} = (V_1 \times V_2 \times \ldots \times V_n)^{1/n} \]

For example, in the sector Ecosystems and Biodiversity, the vulnerability towards the climate change impacts 'change in water availability on wetlands' and 'change in water availability on forests' is assessed.
Aggregating Sectoral Vulnerabilities to Overall Vulnerability

- The overall vulnerability of the Arab region comprises several sectors.
- An aggregation of sectoral vulnerabilities is problematic when the vulnerability of one sector is in a direct cause-effect relationship with another sector.
- We recommend aggregating only the sectoral vulnerabilities highlighted in the figure using the following formula:

\[ V_{\text{overall}} = (V_1 \cdot V_2 \cdot V_3)^{1/3} \]

THANK YOU

Dony El Costa
Water Resources Section, Sustainable Development Policies Division, ESCWA
elcostad@un.org; donyelcosta@hotmail.fr