中華經濟研究院 綠色經濟研究中心
THE CENTER FOR GREEN ECONOMY,CHUNG-HUA INSTITUTION FOR ECONOMIC RESEARCH

The Evaluation of Business Environmental Performance in Taiwan by Analytic Hierarchy Process (AHP)

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Improving the Energy-Water-Material Nexus toward sustainable future in East Asia: Korea Workshop

Introduction

■ Chung-Hua Institution for Economic Research (CIER)

A think tank on the research of economics, mainly serving for Taiwanese government for the policy making and analysis.

■ Center for Green Economy (CGE)

Based in CIER

Specialized in the fields of environmental economics, international trade and national green policy

Introduction

- This research report aims to assess the status of green business (GB) in several APO member countries.
- The study developed an evaluation framework comprising a set of criteria to assess the status of GB among the APO member countries.
- The framework uses environmental sustainability, productivity and social contribution as the top-level criteria.
- the analytic hierarchy process (AHP), Microsoft Excel and Expert Choice 2000 were used in simulation.
- A set of two surveys; with Survey 1 covering 367 respondents, and Survey 2 covering 89 companies;

- In the evaluation of GB, respondents in six APO member countries considered environmental sustainability and productivity as the most important first-tier criteria, with scores of 0.550 and 0.246, respectively. The social-contribution criterion, with a score of 0.204, was regarded as relatively less important.
- Among all the 14 second-tier criteria, the most highly regarded was air quality with a score of 0.133, followed by water quality (0.111) and the use of renewable energy (0.095). Green label and customer complaints were considered the least important.
- All values, by their relative importance, obtained from Survey 1, were added to the corresponding values by actual data, as obtained from Survey 2, in order to rank all the companies. The company CC5, from Republic of China (ROC), was ranked as the best company. The companies EC3 of Indonesia and CC15 of ROC were awarded the second and third ranks [1]. The study also shows the diver

簡報大綱
Outline

- **Introduction of the Analytic Hierarchy Process (AHP)**
- **An Advanced Version of AHP: ANP**
- **Case Study**
- **Conclusion**

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Introduction of the Analytic Hierarchy Process (AHP)

What is AHP?

- The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions.
- It was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then.
- It is a method to derive ratio scales from paired comparisons. The input can be obtained from actual measurement such as price, weight etc., or from subjective opinion such as satisfaction feelings and preference.
- Application:

  Single choice/multi-choice decision, Ranking decision, Prioritization, Resource allocation, Benchmarking, or Quality Management

What Is AHP?(Cont.)

- The basic principles of AHP are as follows:

  - ✓ **The decomposition principle** is applied to structure a complex problem into a hierarchy of clusters, subclusters, sub-sub clusters and so on.

  - ✓ **The principle of comparative judgments** is applied to construct pair-wise comparisons of all combinations of elements in a cluster with respect to the parent of the cluster. These pair-wise comparisons are used to derive 'local' priorities of the elements in a cluster with respect to their parent.

  - ✓ **The principle of hierarchic composition or synthesis** is applied to multiply the local priorities of the elements in a cluster by the "global" priority of the parent element, producing global priorities throughout the hierarchy and then adding the global priorities for the lowest level elements (usually the alternatives).

What Is AHP?(Cont.)

- **The axioms of the AHP are as follows:**

  - ✓ Axiom 1: (Reciprocal Comparison). The decision maker must be able to make comparisons and state the strength of his preferences. The intensity of these preferences must satisfy the reciprocal condition: If A is x times more preferred than B, then B is 1/x times more preferred than A.

  - ✓ Axiom 2: (Independence). When expressing preferences, criteria are assumed independent of the properties of the alternatives.

  - ✓ Axiom 3: (Expectations). For the purpose of making a decision, the hierarchic structure is assumed to be complete.

  - ✓ Axiom 4: (Homogeneity). The characteristic of people's ability for making comparisons among things that are not too dissimilar with respect to a common property and, hence, the need for arranging them within an order preserving hierarchy.

AHP Process

Step 1
- Defining the decision problem

Step 2
- Developing a conceptual framework

Step 3
- Setting up the decision hierarchy
  - Such as decision **goal**, the **alternatives** for reaching it, and the **criteria** for evaluating the alternatives.

Step 4
- Collecting data from experts

Step 5
- Employing the pair-wise comparison
  - Developing a pair-wise comparison matrix
  - Calculating Eigen Value and Eigen vector

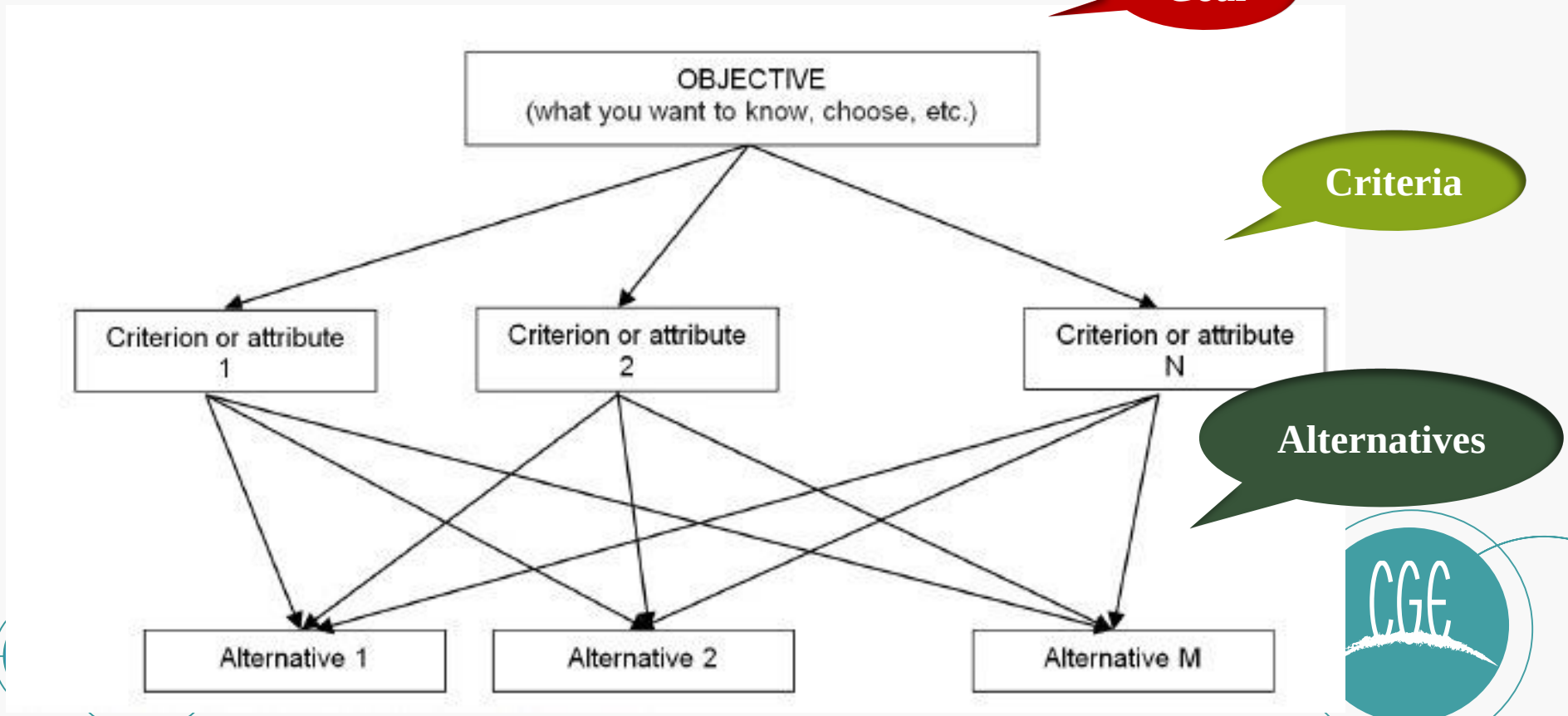
Step 6
- Estimating relative weights of elements

Step 7
- Calculating the degree of consistency

Step 8
- Come to a final decision based on the results of this process

Hierarchy Tree

- Divide the problem into its constituent parts
  - Goal at the topmost level
  - Criteria at the intermediate Level
  - Alternatives at the lowest Level



Collecting data from experts through survey questionnaire

- **Questionnaire example**
  - If you consider criterion A (e.g., environmental sustainability) is "very strongly important" than criterion B (e.g., productivity), you

A	A is more important than B						equal	B is more important than A						B
	very strongly,		strongly,		slightly			Slightly,		strongly,		very strongly		
Environmental sustainability	7	⑥	5	4	3	2	1	2	3	4	5	6	7	Productivity
Social Contribution	7	6	5	4	3	2	1	2	③	4	5	6	7	Productivity

A ⟵ **B**

Very strongly important — Equal important — Very strongly important

Employing the pair-wise comparison

- **Systematically evaluate its various elements by comparing them to each other two at a time, with respect to their impact on an element above them in the hierarchy.**
- **These pairwise comparisons are carried out for factors to be considered, usually not more than 7, and the matrix is completed.**

$$A = \begin{vmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ a_{} & a_{} & \cdots & a_{} \end{vmatrix} = \begin{vmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \cdots & \vdots \\ w_{} & w_{} & \cdots & w_{} \end{vmatrix}$$

A was that is

- $a_{ij}=w_i/w_j$, each entry a_{ij} of A represents the preference weight of criterion i obtained by comparison with criterion j.

Estimating relative weights of elements

$\overline{w}$

- Calculate Eigen v $\overline{w} = (w_1, w_2, \cdots, w_n)^t$ omparison matrix A for the

$$A\overline{w} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \vdots & \vdots & \cdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \cdot \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} \Rightarrow A\overline{w} = n \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix}$$

$$\Rightarrow A\overline{w} = n\overline{w}$$

- The normalized principal Eigen vector is also called priority vector.
- The priority vector shows relative weights among the things that we compare.

Calculating the degree of consistency

- **A comparison matrix A is said to be consistent if $a_{ij} \times a_{jk} = a_{ik}$ for all i, j and k. However, we shall not force the strong consistency because we are dealing with human judgment.**
- **Thus, $A\overline{w} = n\overline{w}$ can not be held completely. Prof. Saaty suggest that we can use λmax to approximate n.**

$$A\overline{w} = \lambda_{max}\overline{w} \quad \Longrightarrow \quad (A-\lambda_{max}I)\ \overline{w} = 0$$

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n}\frac{(AW)_i}{W_i}$$

- Prof. Saaty proved that for completely consistent reciprocal matrix, the largest Eigen value is equal to the size of comparison matrix, or λmax=n.

Calculating the degree of consistency (Cont.)

- **Then Prof. Saaty gave a measu… alled Consistency Index (C.I.) as deviation or degree of consis… owing formula:**

$$C.I. = \frac{\lambda_{max} - n}{n - 1}$$

- **Prof. Saaty also proposed that we use this index by comparing it with the appropriate one, called Random Consistency Index (R.I.). Then, he proposed what is called Consistency Ratio (C.R.) and only accepts a matrix as a consistent one iff C.R. < 0.1.**

$$C.R = \frac{C.I.}{R.I.}$$

  - The average random c… of sample size 500 matrices is shown in the table below:

n	1	2	3	4	5	6	7	8	9	10	11
R.I.	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Business Environmental Performance

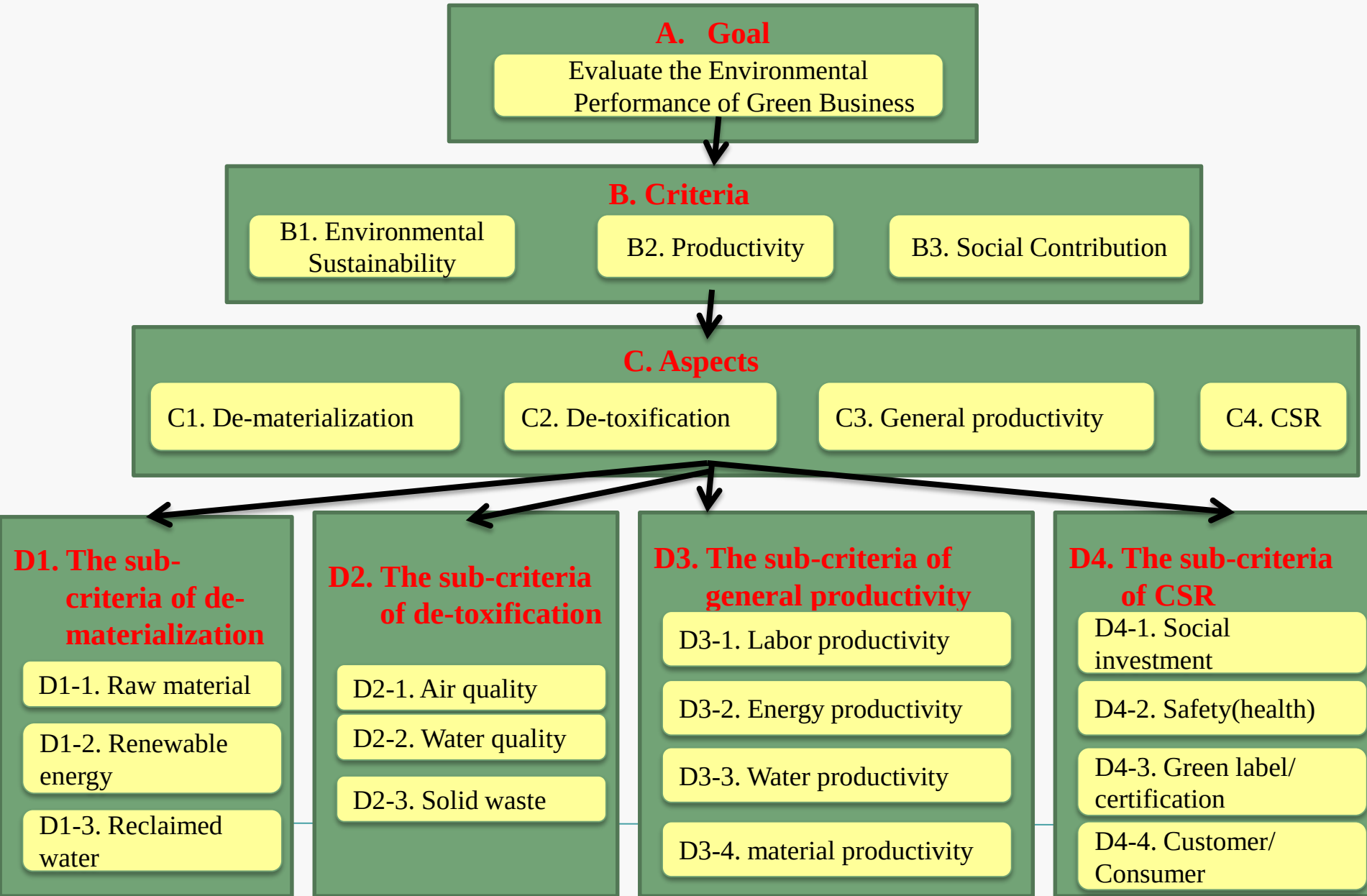
Evaluation Criteria and Definitions

1st trial evaluation criteria	Aspects	2nd evaluation criteria	Definition
Environmental Sustainability	De-materialization	Raw material	Percentage of natural material consumption to total usage
		Renewable energy	Percentage of renewable energy to total energy consumption
		Reclaimed water	Percentage of reclaimed water of total natural water used
	De-toxification	Air quality	Emissions of air pollutants, including SOx, NOx, VOC and other toxics
		Water quality	Total volume of water discharged by destination(BOD, COD and other toxics)
		Solid waste	Total amount of solid waste and hazardous waste materials

Evaluation Criteria and definitions (Cont.)

1st trial evaluation criteria	Aspects	2nd evaluation criteria	Definition
Productivity	General productivity	Labor productivity	Economic value created every year per person in the labor force
		Energy productivity	Economic value created every year per unit of energy consumed
		Water productivity	Economic value created every year per unit of water consumed
		material productivity	Economic value created every year per unit of material consume
Social Contribution	CSR (Corporate Social Responsibility)	Social investment	Amount of investment towards for contribution
		Safety(health)	Number of industrial incidence inside and outside
		Green label/ certification	Current number of label/certification
		Customer/ Consumer	Any channel for customer/consumer number of complaints

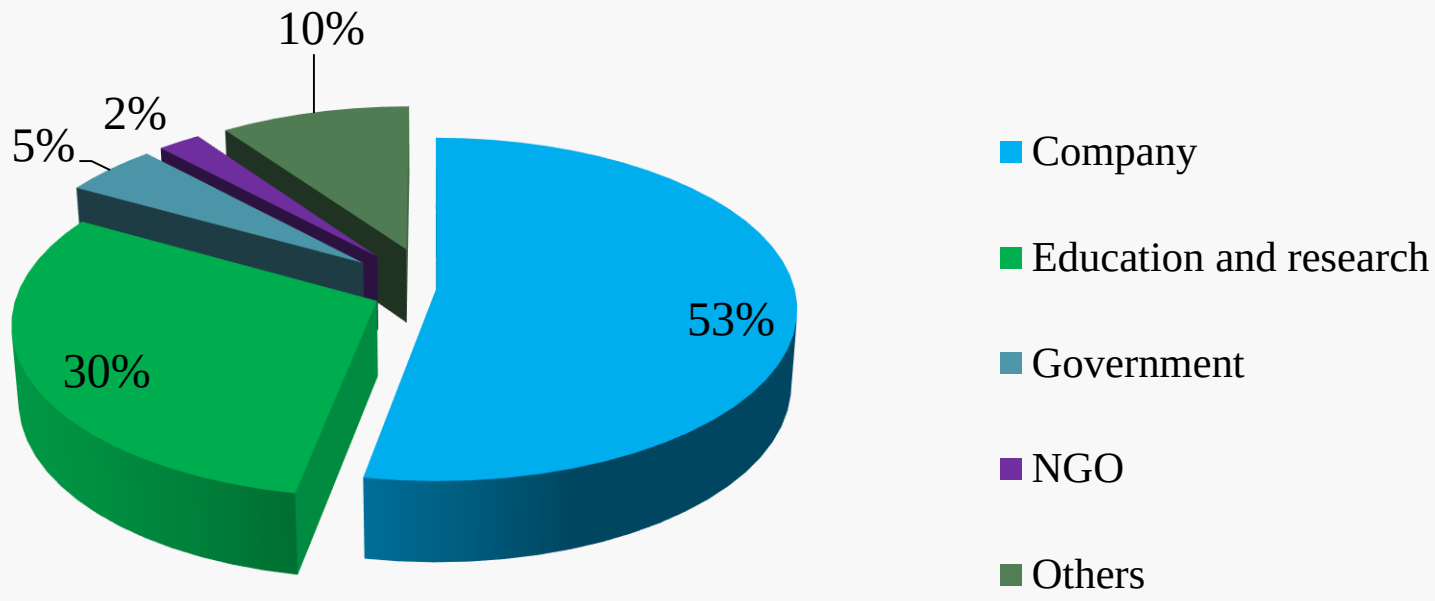
Questionnaire



The analysis of questionnaire

A sample of 225 experts was surveyed during the study conducted.

Distribution of Respondents Occupation



Note: the category called “others”, for instance, represents people who works in association, consultant services institution and so on.

Data analysis

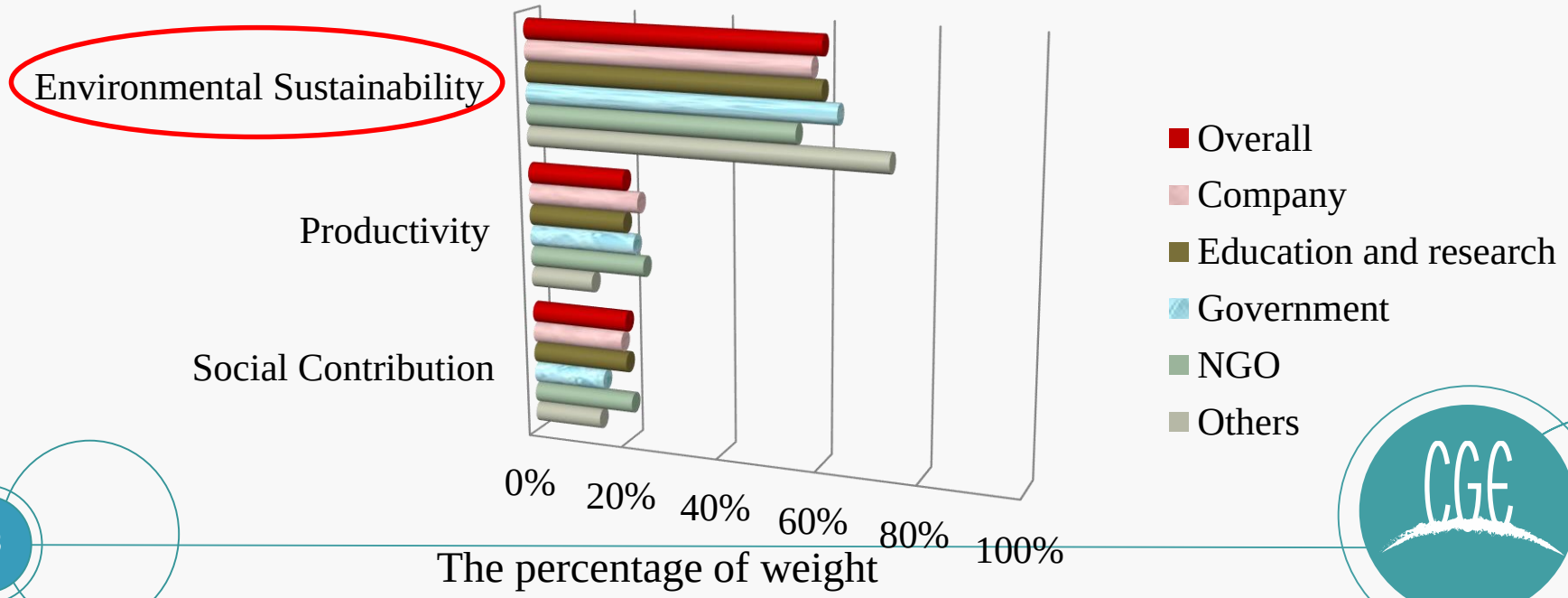
- **Consistency check:**
  - ✓ All calculations were made by Super Decisions software.
  - ✓ Only accepts a matrix as a consistent one iff(if and only if) C.R. < 0.1.
  - ✓ Overall Inconsistency(C.R.H)=0.056<0.1 indicates sufficient consistency for decision.

	Level 1	**Level 2**	**Level 3**			
	Environmental Sustainability **V.S.** Productivity **V.S.** Social Contribution	De-materialization **V.S.** De-toxification	Raw material **V.S.** Renewable energy **V.S.** Reclaimed water	Air quality **V.S.** Water quality **V.S.** Solid waste	Labor productivity **V.S.** Energy productivity **V.S.** Water productivity **V.S.** material productivity	Social investment **V.S.** Safety(health) **V.S.** Green label/ certification **V.S.** Customer/ Consumer
C.I.	0	0	0.052	0.009	0.045	0.044
C.R.	0	0	0.089	0.015	0.050	0.049
C.R.H	0.056					

The results

- **Ranking of 1st trial evaluation criteria:**

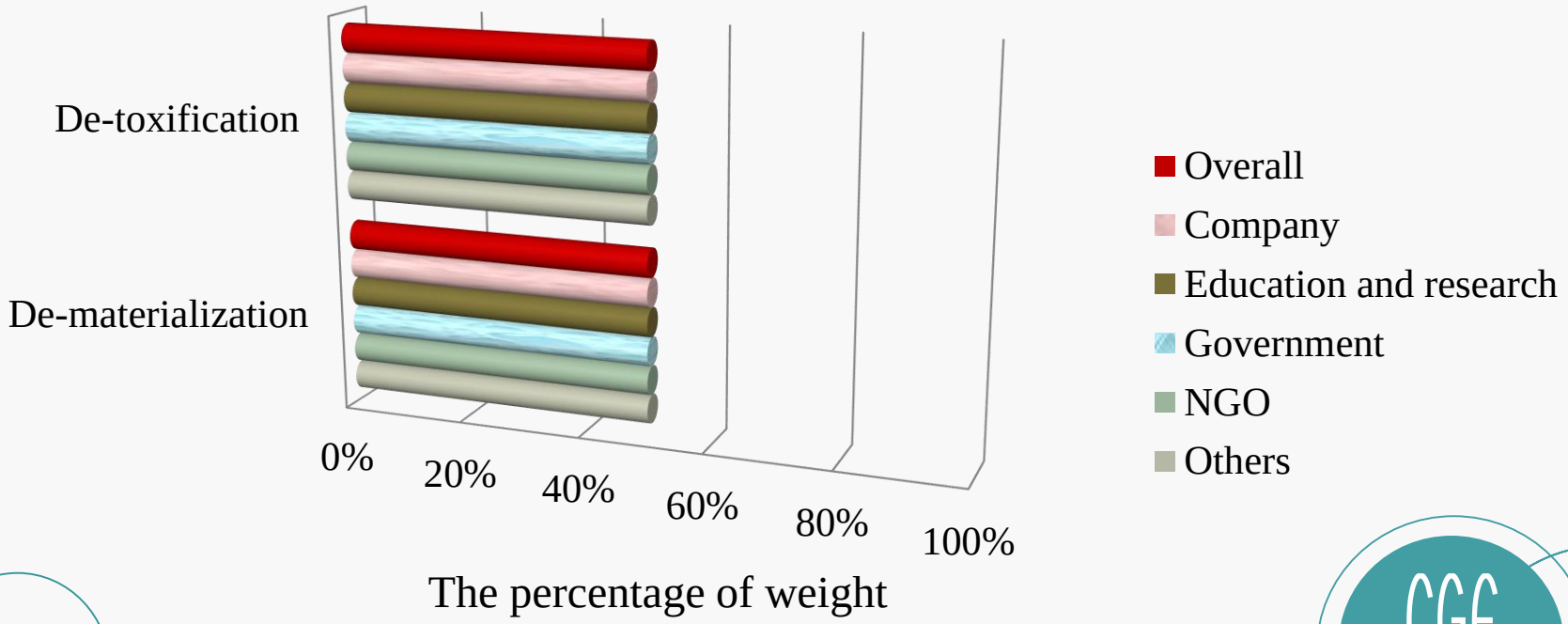
Weight distribution of each element						
	Overall	Company	Education and research	Government	NGO	Others
Environmental Sustainability	0.6	0.58	0.6	0.63	0.55	0.73
Productivity	0.2	0.23	0.2	0.22	0.24	0.13
Social Contribution	0.2	0.19	0.2	0.15	0.21	0.14



The Analysis of “Environmental Sustainability”

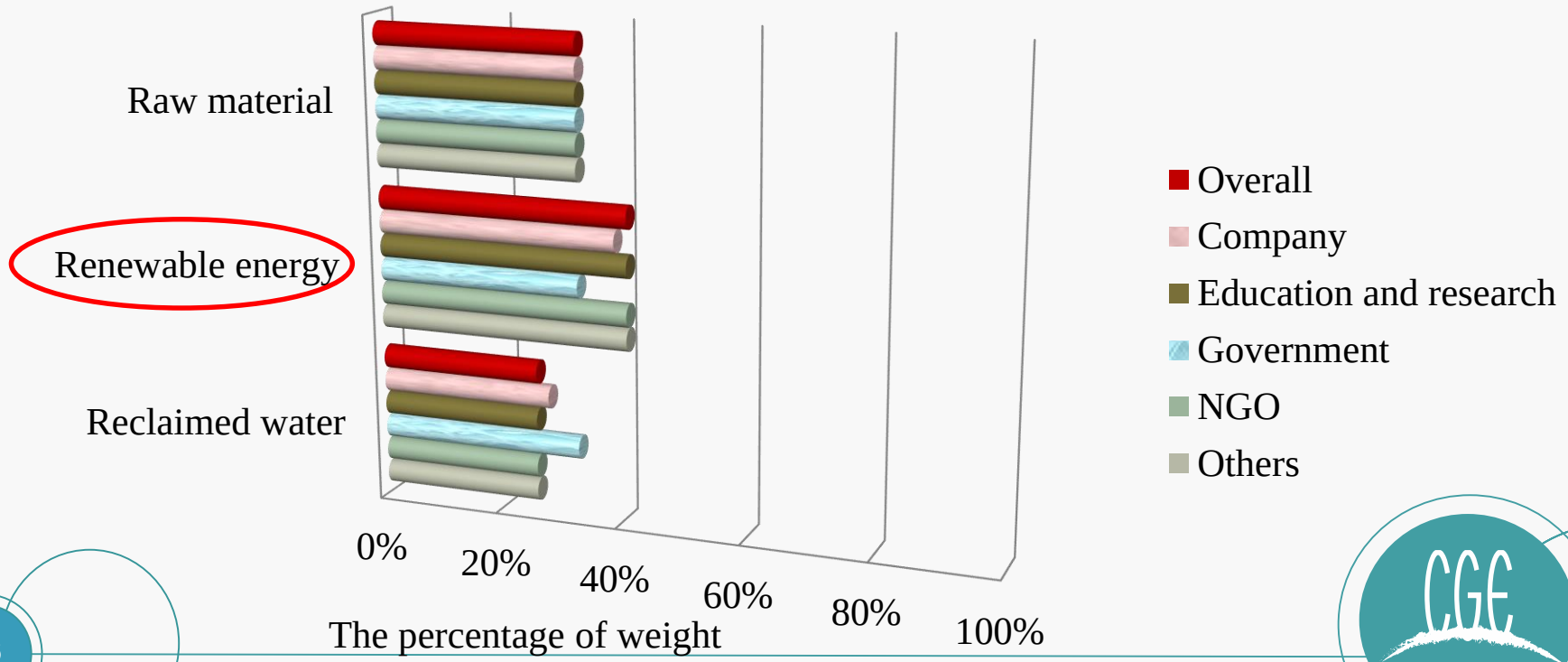
The results of Environmental Sustainability

Weight distribution of each element						
	Overall	Company	Education and research	Government	NGO	Others
De-materialization	0.5	0.5	0.5	0.5	0.5	0.5
De-toxification	0.5	0.5	0.5	0.5	0.5	0.5



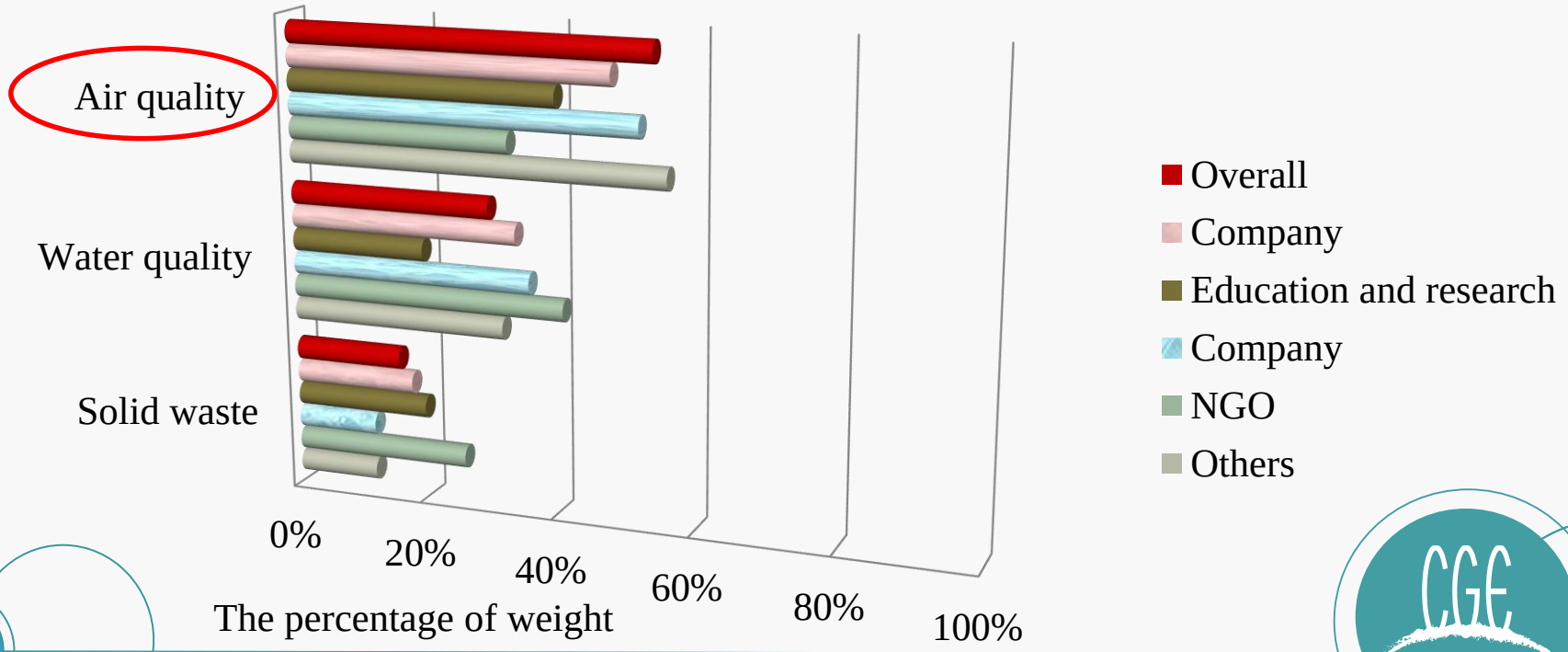
The results of “De-materialization”

Weight distribution of each element						
	Overall	Company	Education and research	Government	NGO	Others
Raw material	0.33	0.33	0.33	0.33	0.33	0.33
Renewable energy	0.41	0.39	0.41	0.33	0.41	0.41
Reclaimed water	0.26	0.28	0.26	0.33	0.26	0.26



The results of “De-toxification”

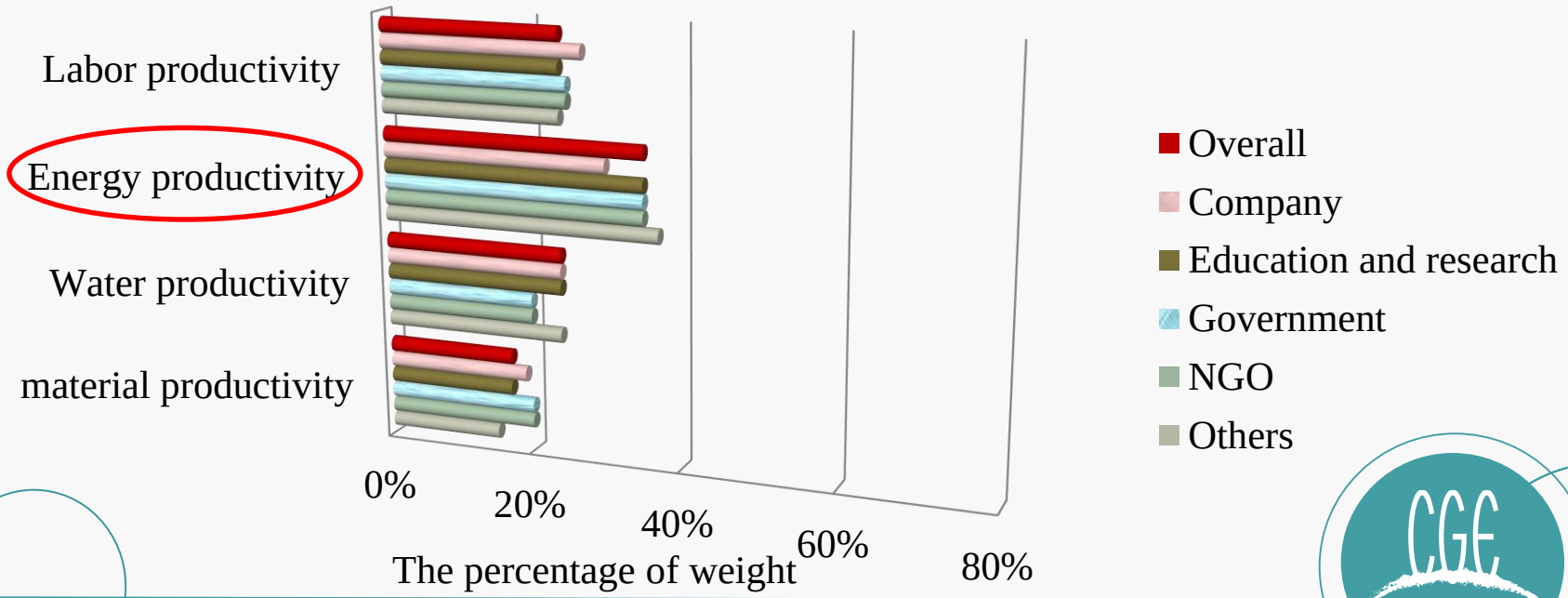
Weight distribution of each element						
	Overall	Company	Education and research	Government	NGO	Others
Air quality	0.54	0.48	0.4	0.52	0.33	0.56
Water quality	0.30	0.34	0.2	0.36	0.41	0.32
Solid waste	0.16	0.18	0.2	0.12	0.26	0.12



The Analysis of “Productivity”

General Productivity

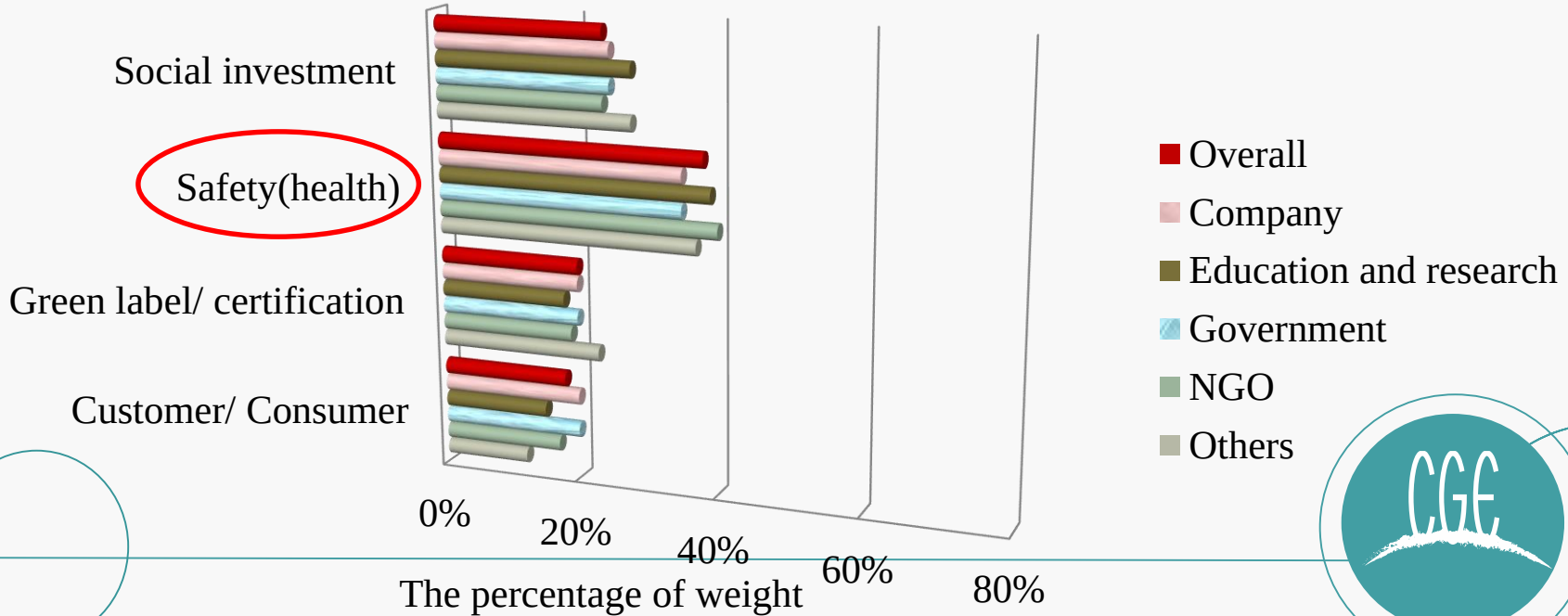
Weight distribution of each element						
	Overall	Company	Education and research	Government	NGO	Others
Labor productivity	0.24	0.27	0.24	0.25	0.25	0.24
Energy productivity	0.35	0.30	0.35	0.35	0.35	0.37
Water productivity	0.24	0.24	0.24	0.20	0.20	0.24
material productivity	0.17	0.19	0.17	0.20	0.20	0.15



The Analysis of “Social Contribution”

The results of “CSR”

Weight distribution of each element						
	Overall	Company	Education and research	Government	NGO	Others
Social investment	0.24	0.25	0.28	0.25	0.24	0.28
Safety(health)	0.38	0.35	0.39	0.35	0.40	0.37
Green label/ certification	0.20	0.20	0.18	0.20	0.19	0.23
Customer/ Consumer	0.18	0.20	0.15	0.20	0.17	0.12



Conclusion

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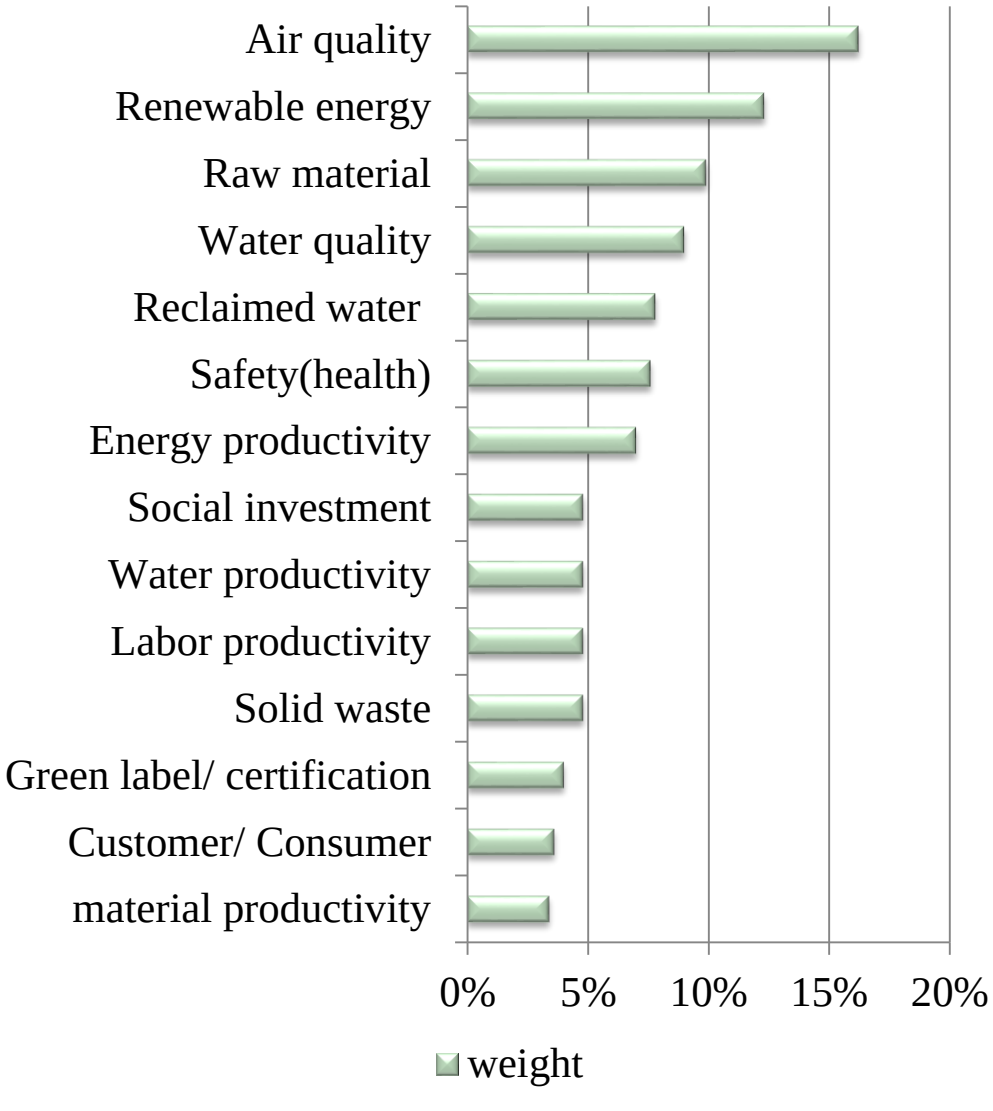
Relative Importance of Factors for Environmental Performance Evaluation of Green Business

ranking	Evaluation factors	weight
1	Air quality	0.162
2	Renewable energy	0.123
3	Raw material	0.099
4	Water quality	0.09
5	Reclaimed water	0.078
6	Safety(health)	0.076
7	Energy productivity	0.07
8	Solid waste	0.048
8	Labor productivity	0.048
8	Water productivity	0.048
8	Social investment	0.048
12	Green label/ certification	0.04
13	Customer/ Consumer	0.036
14	material productivity	0.034



Thank you for attention

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An Advanced Version of AHP: ANP (Analytical Network Process)

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What Is ANP?

- **The analytic network process (ANP) is a more general form of the analytic hierarchy process (AHP) used in multi-criteria decision analysis.**
- **AHP structures a decision problem into a hierarchy with a goal, decision criteria, and alternatives, while the ANP structures it as a network.**
- **The ANP would allow consideration of the dependence and feedback.**
  - Outer dependence: the parent node and the nodes to be compared are in different clusters. A directed link appears from the parent node cluster to the other cluster.
  - Inner dependence: the parent node and the nodes to be compared are in the same cluster. The cluster is linked to itself and a loop link appears.
  - Such feedback can capture the complex effects of interplay in human society, and this is especially important when risk and uncertainty are involved.

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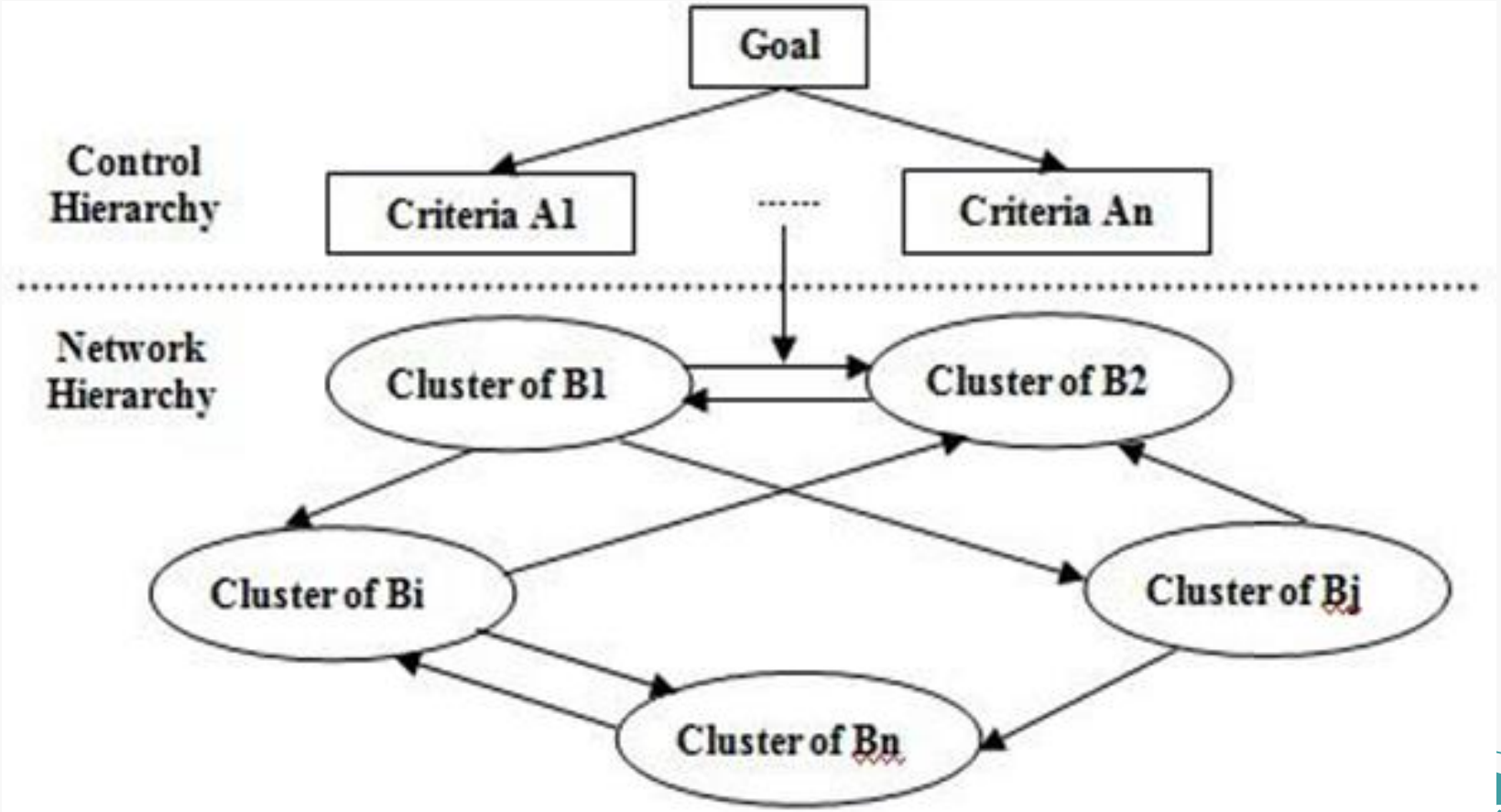
What Is ANP ?(Cont.)

- **The system of ANP can be divided into two parts, one is control hierarchy which consists of problem goal and decision criteria where decision criteria are considered to be independent of each other.**
  - Control hierarchy is a typical AHP structure and weight of each criteria can be gained by traditional calculation of AHP method.
- **The other part is network hierarchy, which consist of element groups that are subjected to control hierarchy. Network consists of elements that interact and multiinfluence each other.**
  - These influences are determined through paired comparisons that lead to priority vectors included as the columns of a matrix of interactions among the elements of two clusters (or the same cluster) in which the interactions take place. Then these matrices comprise the entries of a supermatrix to determine the overall priorities of all the elements in the network.

Control hierarchy and network hierarchy



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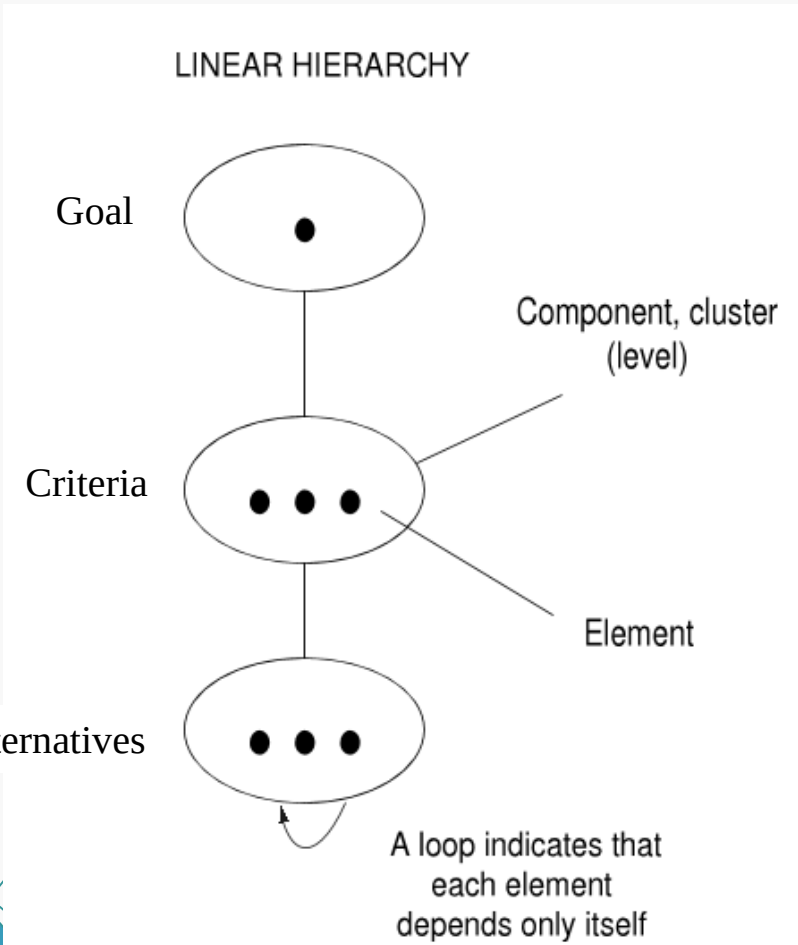
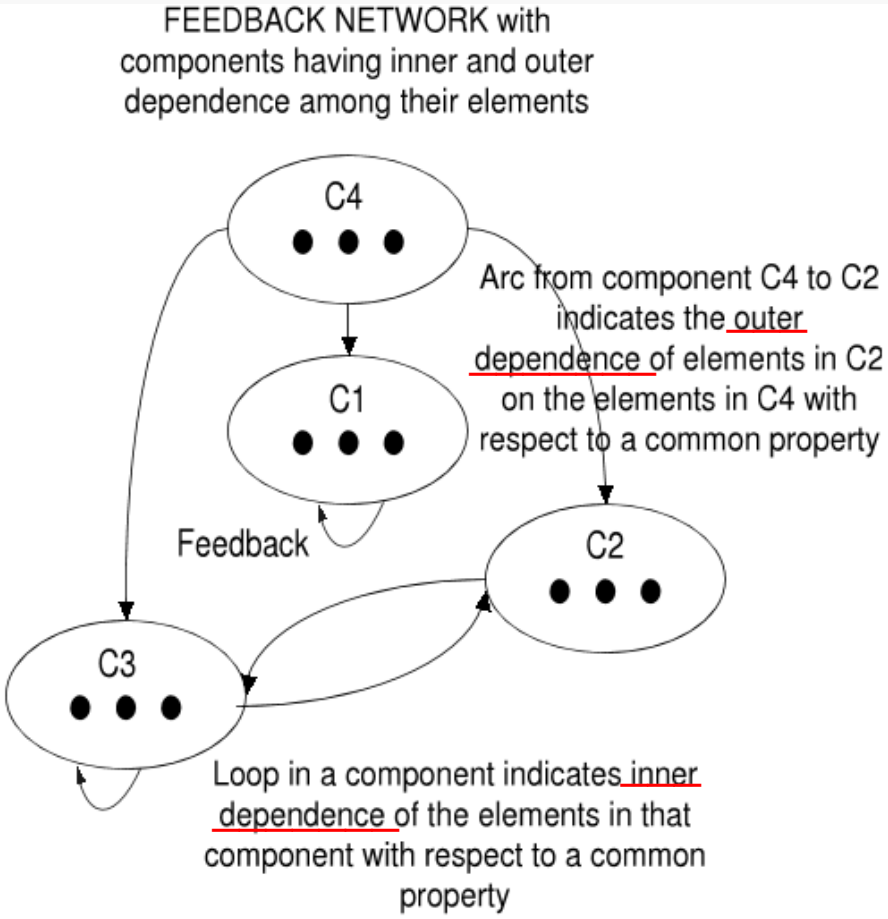
How a hierarchy compares to a network

AHP

ANP





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ANP Process

- Step 1
  - Constructing model and structuring problem
- Step 2
  - Developing a conceptual framework
- Step 3
  - Setting up the decision network
    - **Dependence and feedback** among elements and clusters will be taken into consideration
- Step 4
  - Collecting data from experts
- Step 5
  - Employing the pair-wise comparison
    - Developing a **supermatrix**
    - Calculating Eigen Value and Eigen vector
- Step 6
  - Estimating relative weights of elements
- Step 7
  - Calculating the degree of consistency
- Step 8
  - Come to a final decision based on the results of this process

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AHP VS. ANP

	AHP	ANP
Relationship of element	• Has a top-down influence relationship • Each elements/ criteria/ alternatives are assumed independent of all the others	• Allows both dependence and feedback within clusters of elements (inner dependence) and between clusters (outer dependence)
Feature of structure	• Linear hierarchy	• Non-linear network
Computation method	• Pair-wise comparison matrix	• Supermatrix
Advantages	• Simplify complex decisions • Both qualitative and quantitative information can be taken into consideration	• Allows both dependence and feedback mechanism • Can capture the complex effects of interplay in human society
Disadvantages	• Hard to find experts • Lack of representation	• Hard to find experts • Lack of representation • Calculation is getting much more complicated

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