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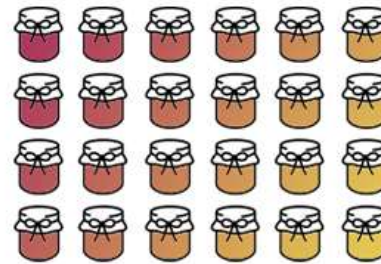
# **Analytic Hierarchy Process**

**AHP**

*Learning to choose is hard. Learning to choose well is harder. And learning to choose well in a world of unlimited possibilities is harder still, perhaps too hard. Barry Schwartz*

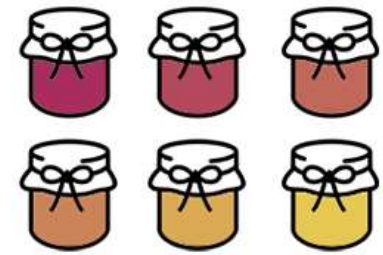
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## Too many choices?



### 24 choices of jam

attracted 60% of the shoppers  
**3%** of shoppers bought jam



### 6 choices of jam

attracted 40% of the shoppers  
**30%** of shoppers bought jam

## *Paradox of choice*

- Making decisions in complex environments: there is no unique solution
  - In making simple choices, an alternative is better than the others
  - When problems are complex, an alternative can be better than the others in some situations, but not in other situations
  - In complex problems different alternatives can be equally valid
-

### AHP

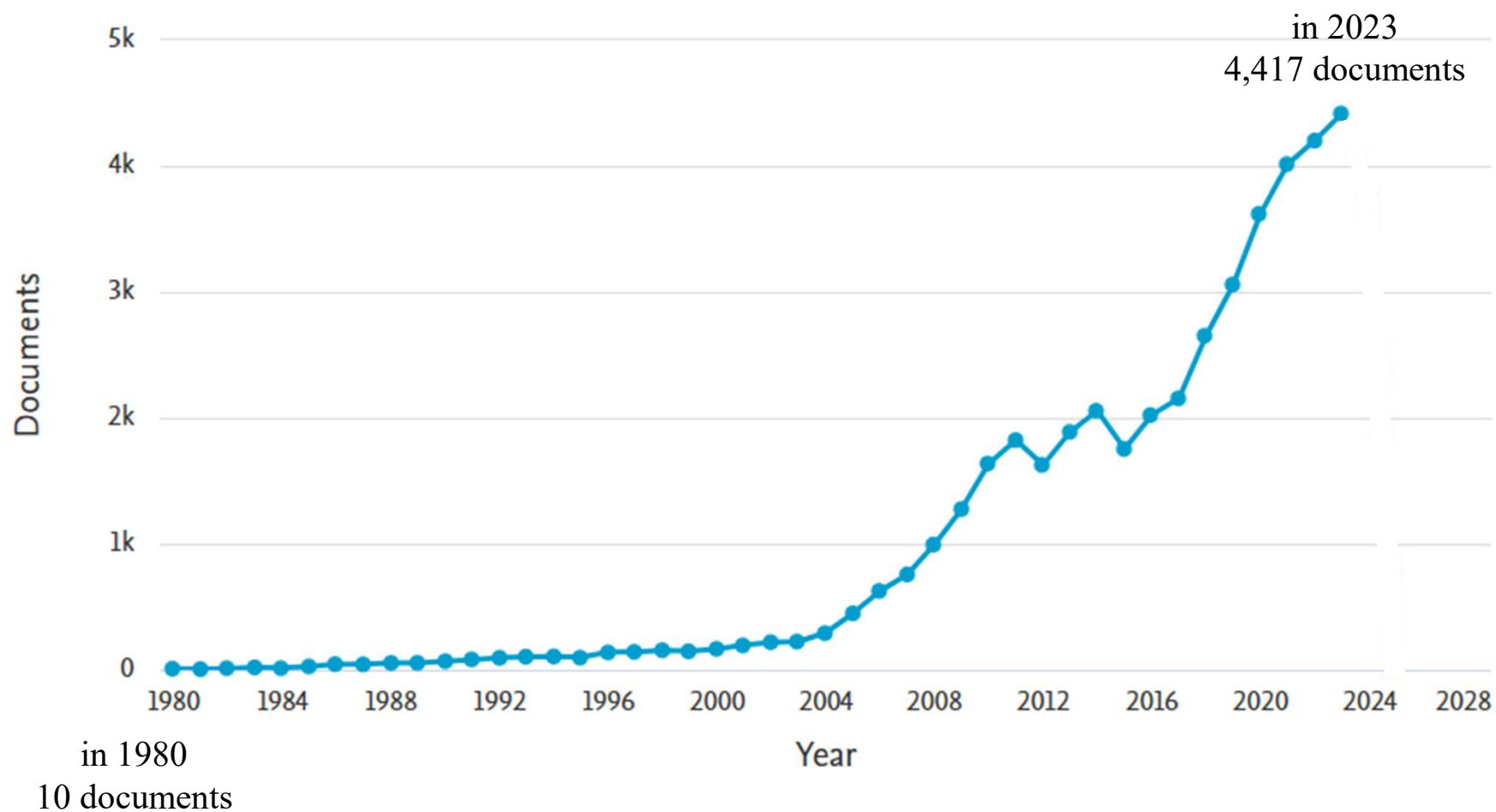
- AHP was developed in the **late 1970s**. Today it is the most widely used MCDA method.
  - AHP generates all criteria weighting and alternative preferences within each criteria by eliciting these values from the decision-maker through a series of pairwise comparisons, as opposed to utilizing numerical values directly.
  - Thus, **a complex decision is reduced to a series of simpler ones, between pairs of alternative values within criteria or between pairs of criteria**. The decision maker's preference is always explicit. However, the decision-maker may be asked to make very many small decisions. Hence, it becomes important to generate an optimized hierarchy of criteria and alternatives, to reduce the number of pairwise decisions.
-

# AHP

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**Search in Scopus: number of documents including «AHP» within abstract, title, keywords:**

Documents by year



### **SUBJECTIVITY $\neq$ ARBITRARINESS**

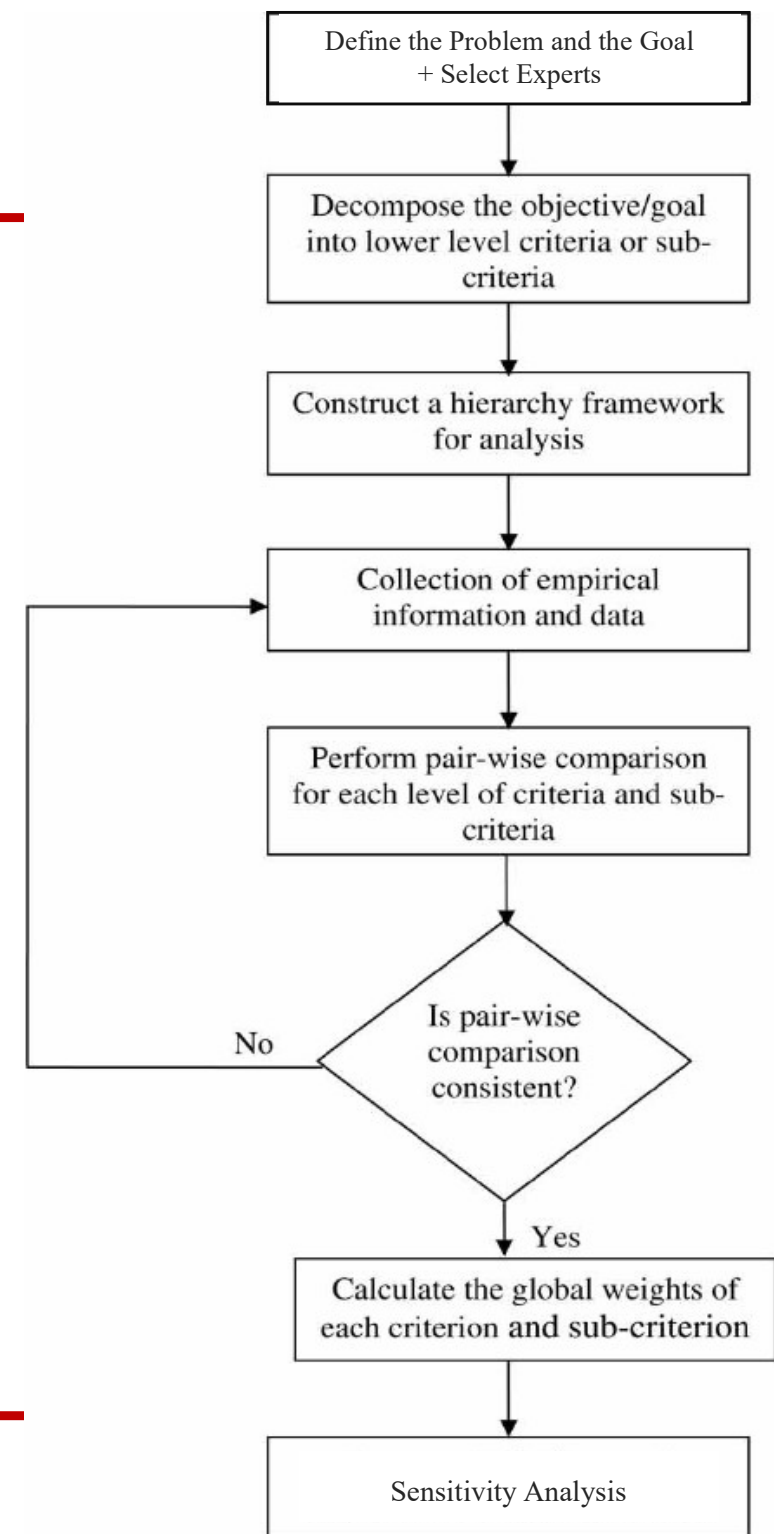
- The AHP permits the measurement of intangibles through expert judgments
- It permits to choose the ‘best’ alternative among a discrete set of alternatives, simplifying the choice
- Unlike common optimization methods, which assume the availability of ‘measures’, the AHP uses measures derived or interpreted subjectively, which are indicators of preference
- (Judgments are influenced by past experience)

## AHP

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### AHP – Flow Chart

- Analytic: breaks down the problem into its components
- Hierarchy: structures the problem components in a hierarchical way with respect to the main objective and sub-objectives
- Process: processes judgments and data in order to reach the final result



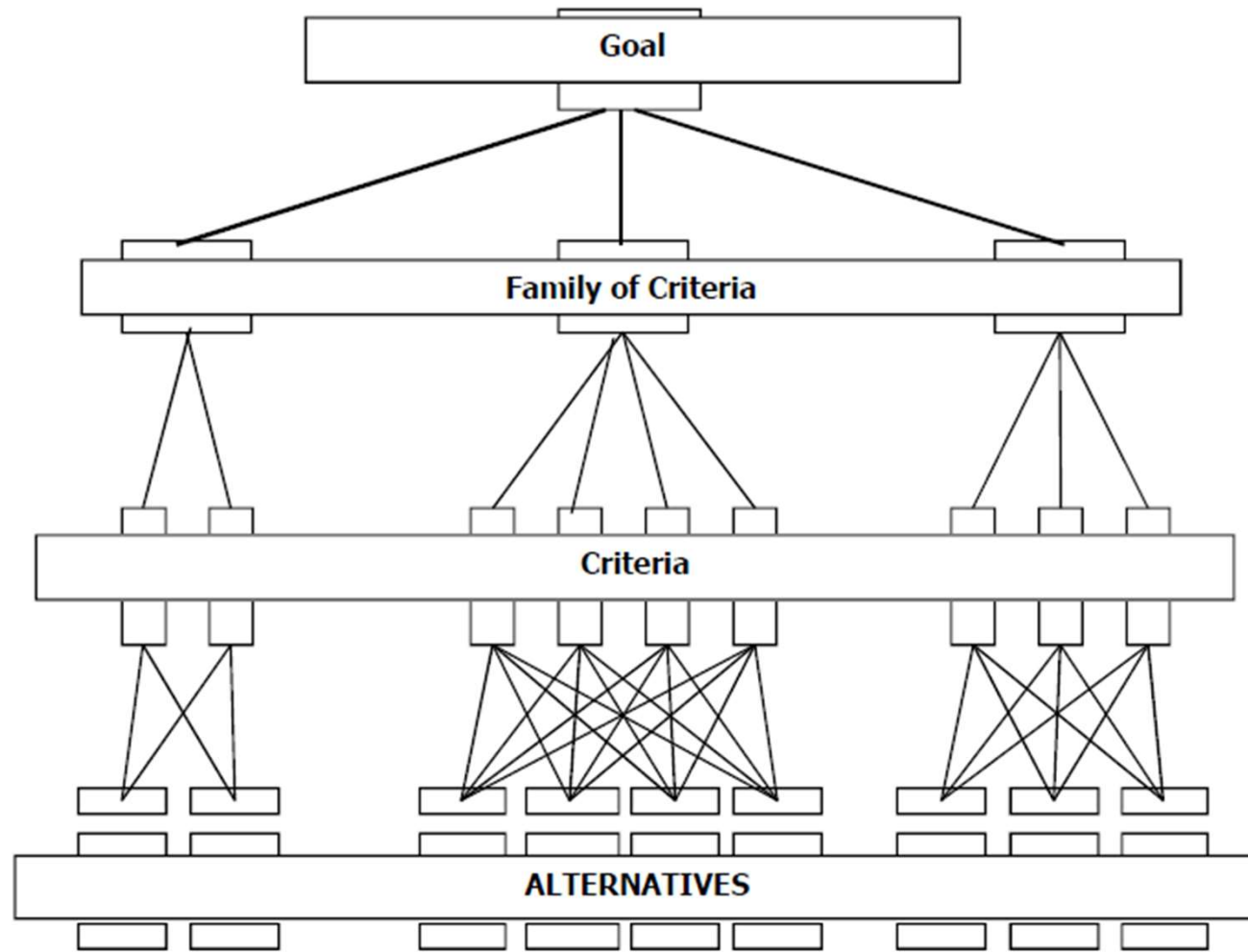
### AHP – Simplified Flow Chart

First phase: Construction of the Hierarchy

Second phase: Pairwise Comparisons

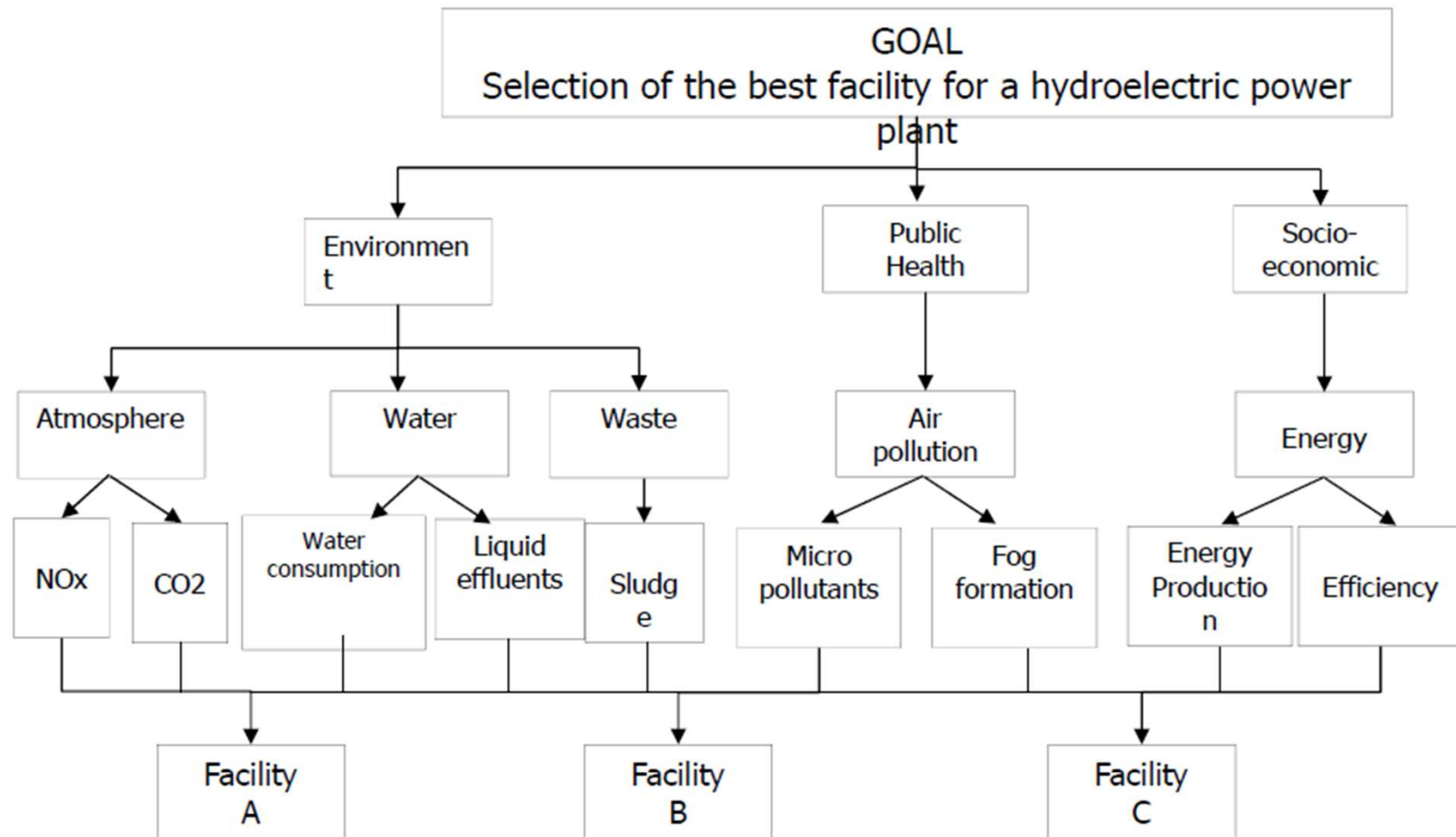
Third phase: Inconsistency Index Calculation

## GERARCHIA



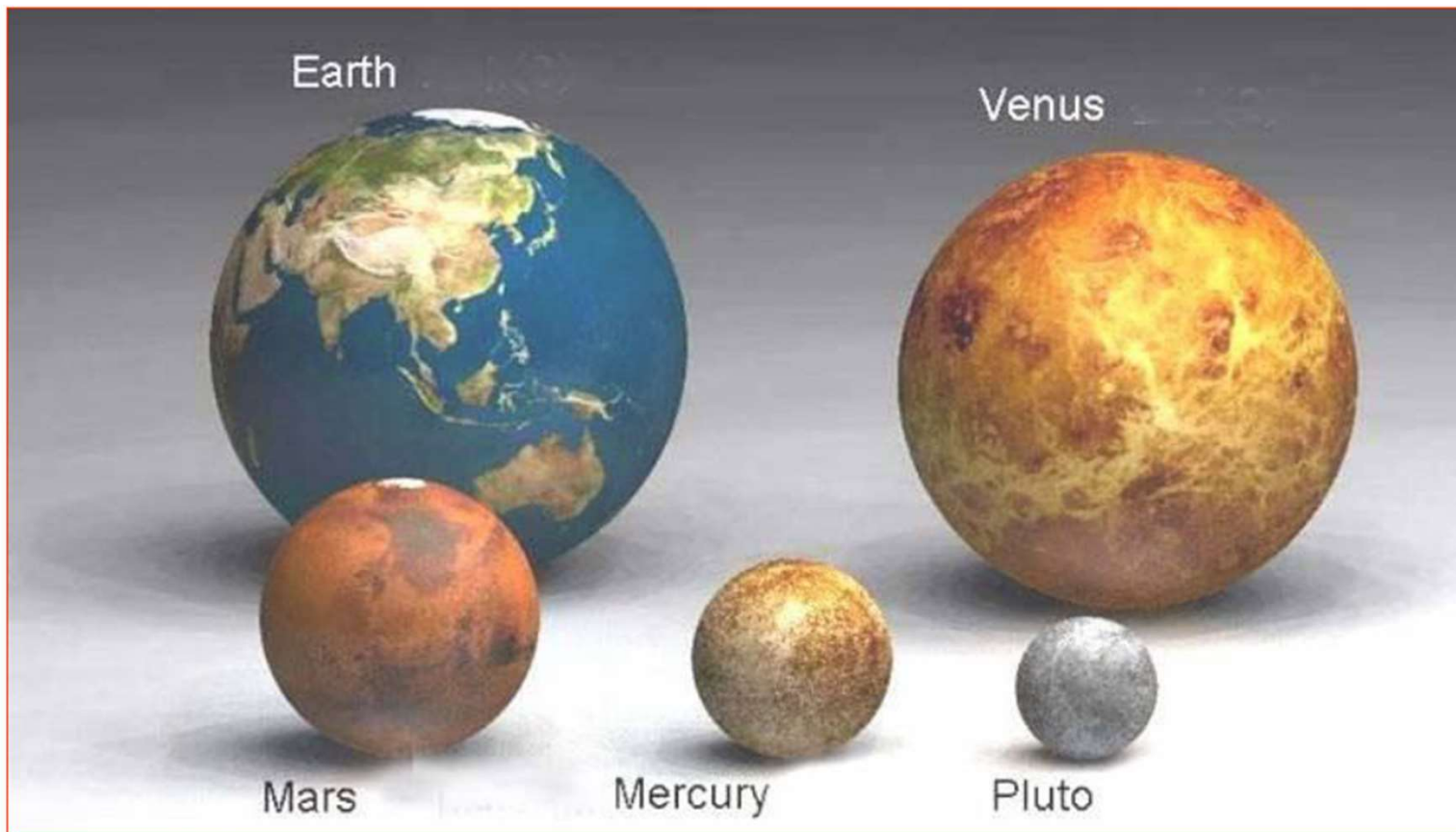


## GERARCHIA (Relative Model)

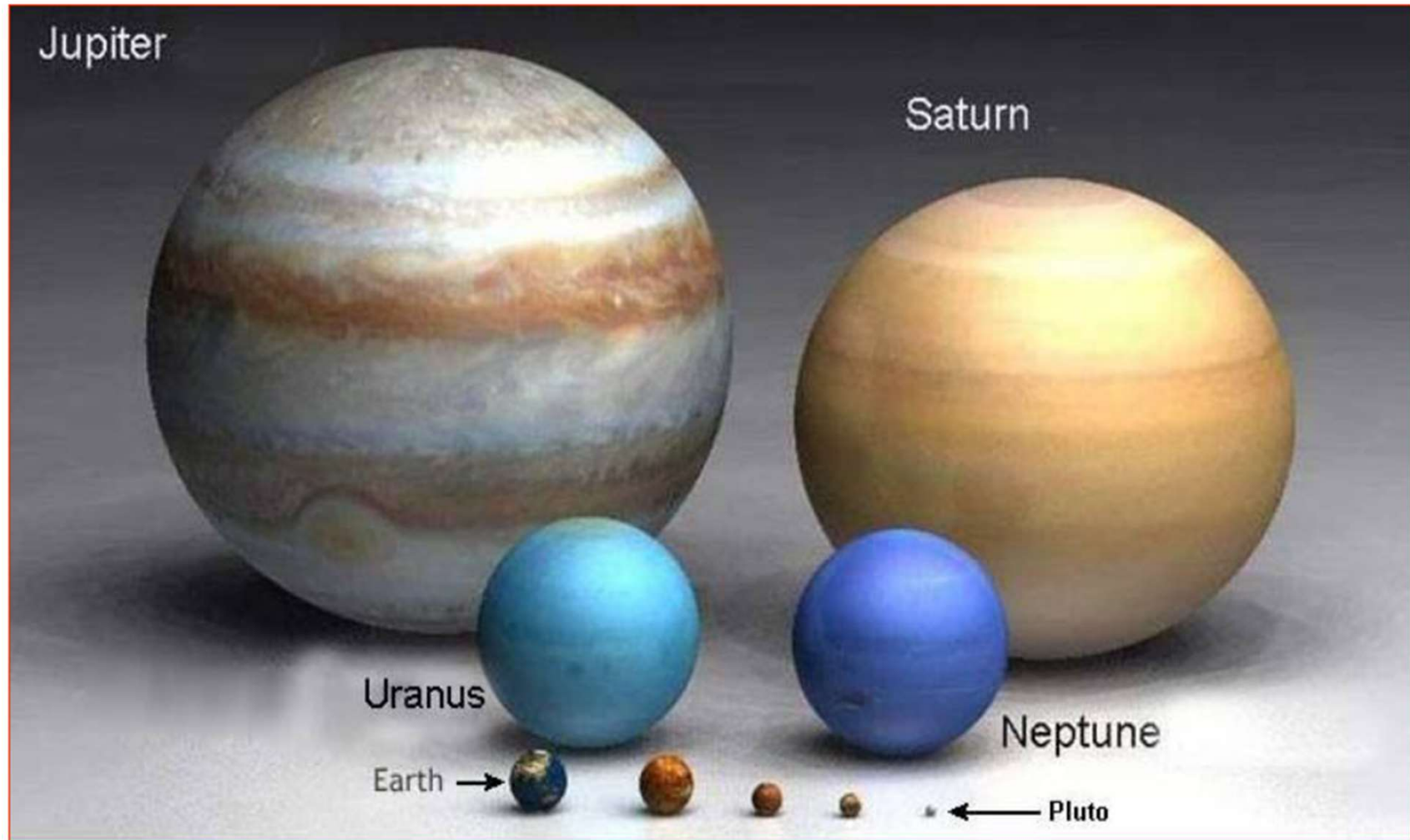


### Measurement Scales

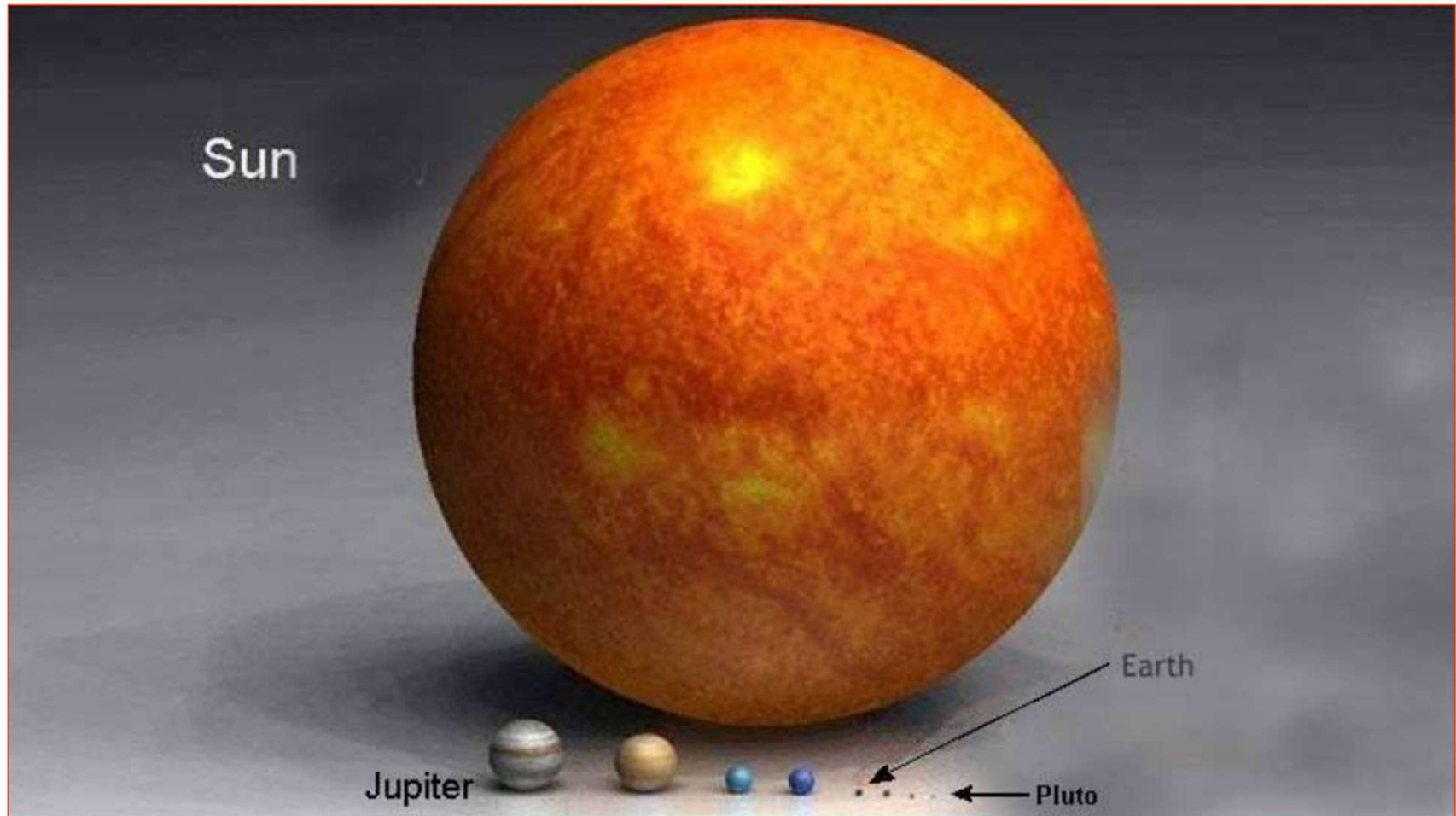
To take sound decisions, it is necessary to use appropriate scientific methods as well as appropriate measurement scales



## Measurement Scales



## Measurement Scales



### Measurement Scales: Saaty's scale:

#### Saaty's semantic/fundamental scale

Numerical value	Description
1	Equal importance
3	Slight importance of one over another
5	Moderate importance of one over another
7	Very strong importance
9	Extreme importance of one over another
2,4,6,8	Intermediate values between two adjacent values

Source: Saaty (1980)

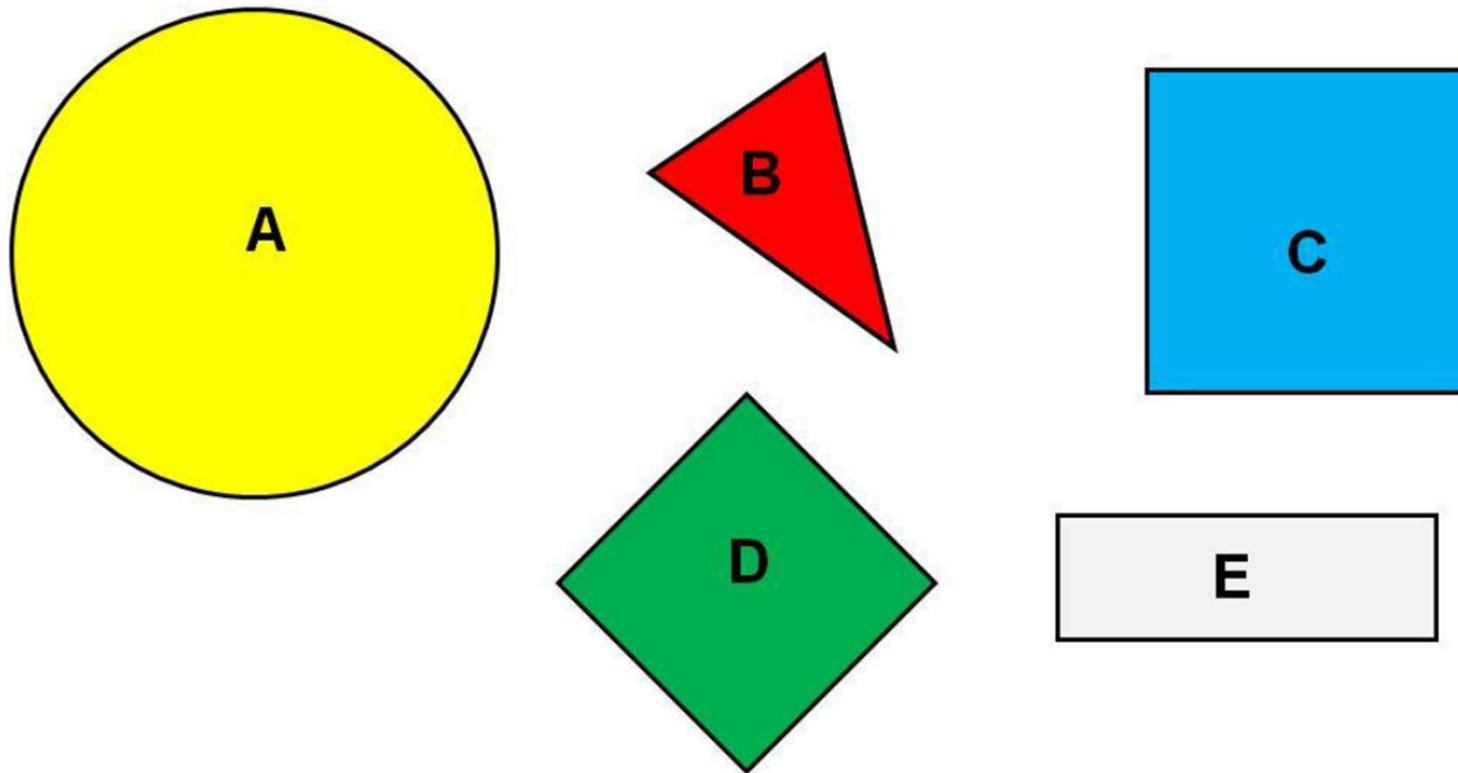


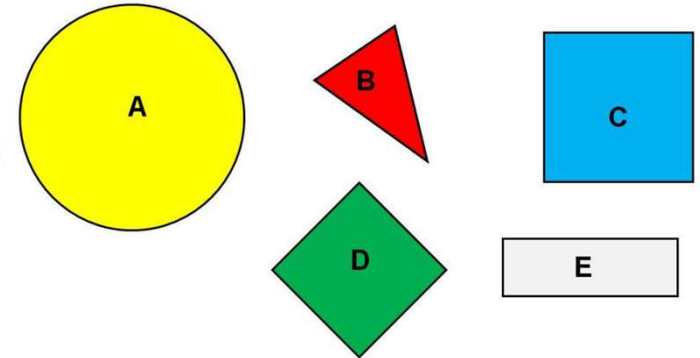
### Measurement Scales: Saaty's scale:

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one
5	Strong importance	Experience and judgment strongly one actively over another
7	Very Strong Importance	An activity is favored very strongly over another its dominance demonstrated in practice
9	Extreme Importance	The evidence of favoring over another is of the highest possible area of affirmation
Reciprocal	$1/2=0.500$ , $1/3=0.333$ , $1/4=0.250$ , $1/5=0.200$ , $1/6=0.1667$ , $1/7=0.1428$ , $1/8=0.125$ , $1/9=0.1111$	If activity has one of the above non zero numbers assigned to it when compared with activity j then j has the reciprocal value which compared with i.

Source: Saaty (1980)

**Measurement Scales: Saaty's scale:**





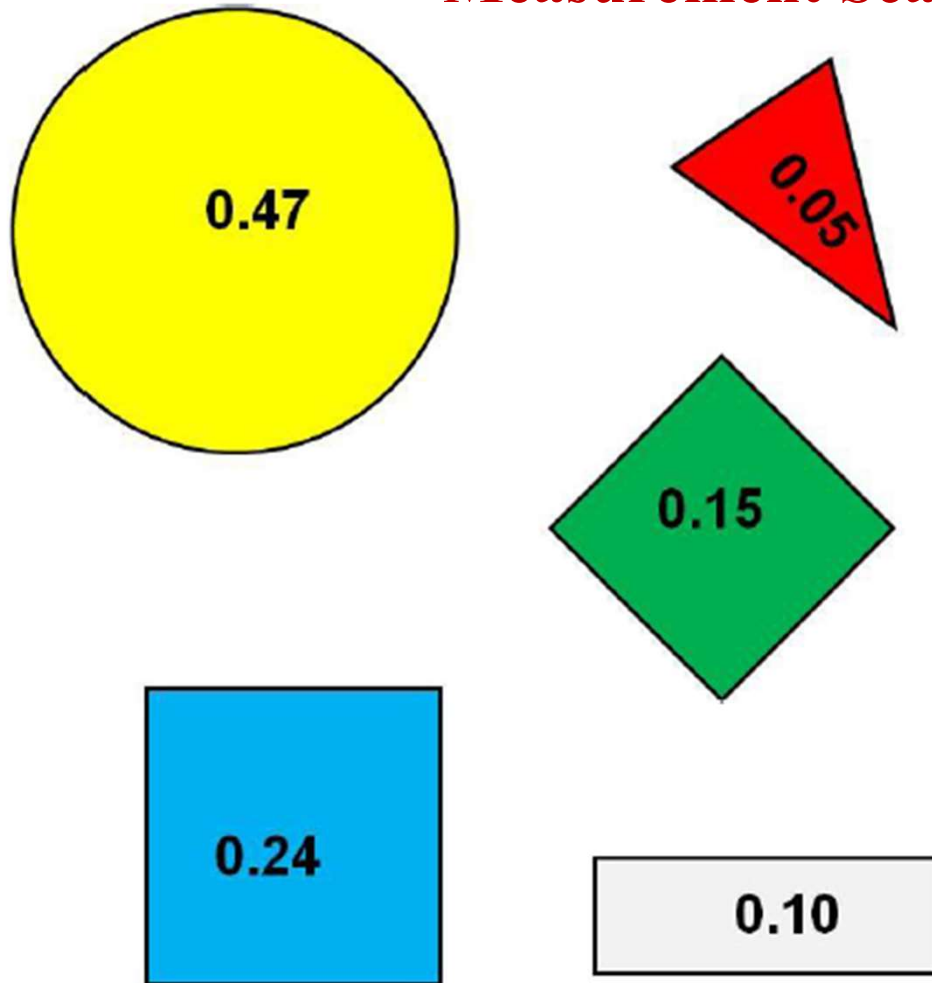
## Measurement Scales: Saaty's scale:

		Circle	Triangle	Square	Diamond	Rectangle	PRIORITY VECTOR
		A	B	C	D	E	
Circle	A	1	9	2	4	5	0,48
Triangle	B	1/9	1	1/5	1/3	1/2	0,049
Square	C	1/2	5	1	2	3	0,25
Diamond	D	1/4	3	1/2	1	2	0,138
Rectangle	E	1/5	2	1/3	1/2	1	0,085

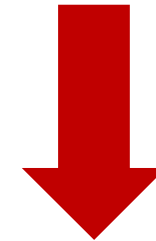
AREA ESTIMATION



### Measurement Scales: Saaty's scale:



If we calculated the areas via mathematical rules we obtain:  
0.47; 0.05; etc.



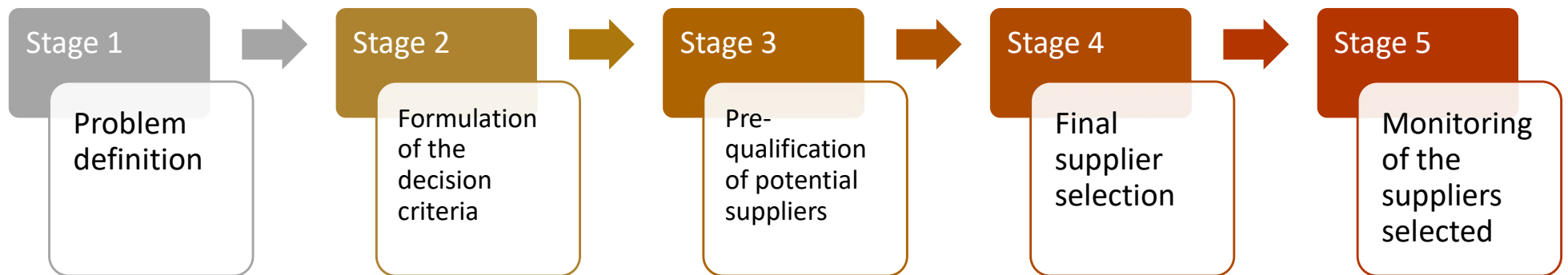
The aim of the example is to show that  
whenever judgments are sound and  
consistent results are reliable

The largest is the area of the circle, the  
smallest is the area of the triangle

### Example

New assembly line. Some components must be purchased from the factory

**PURPOSE:** Identify the best supplier

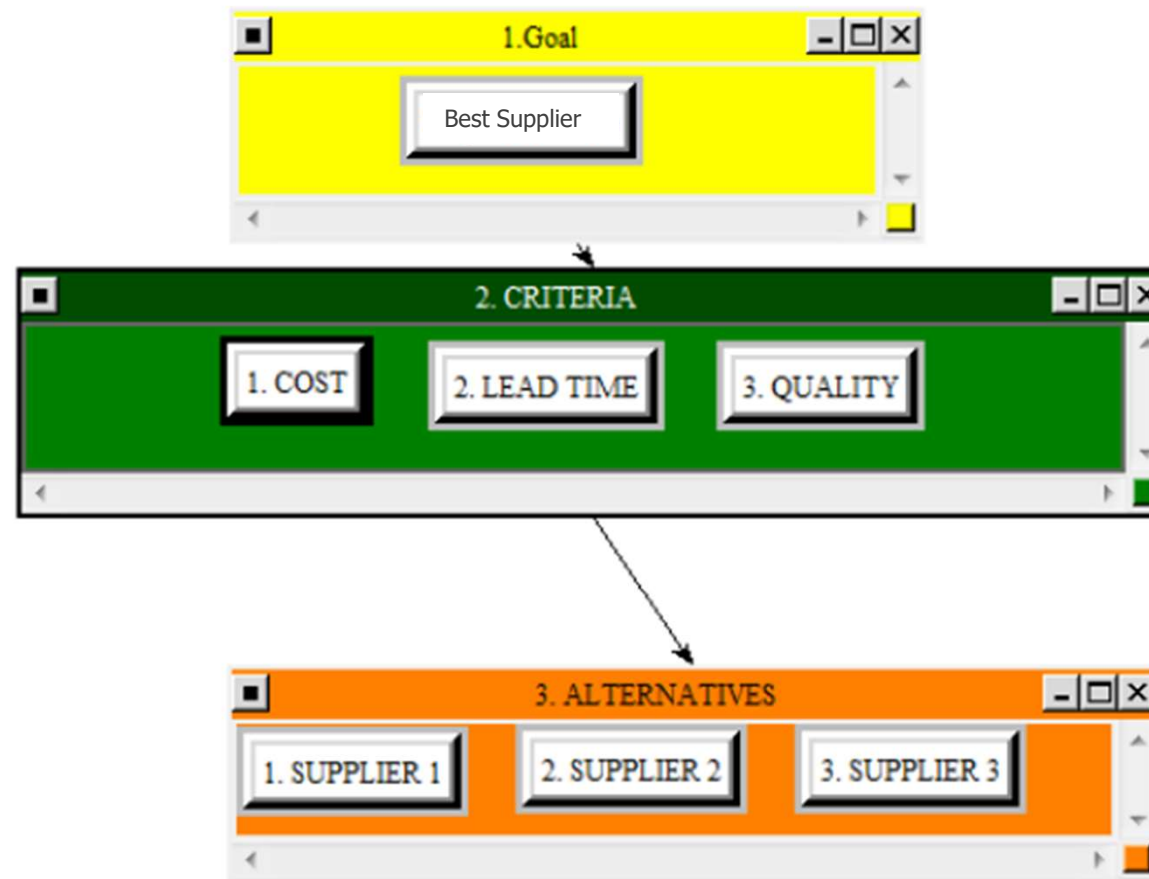


**CRITERIA:** Cost, Lead Time (LT), Quality, Efficiency, R&D initiatives

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## Example

### Hierarchy



### PAIRWISE COMPARISON

- Elements at the same hierarchical level are pairwise compared with respect to their parental node
- Elements are compared to elicit which element is (relatively) more important with respect to their parental node and how much
- Dominance coefficients  
 $a_{ij}$  represent the relative importance of a specific criterion, sub-criterion or action in comparison to another criterion, subcriterion or action

$$A = \begin{vmatrix} a_{11} & \dots & a_{1n} \\ \vdots & & \vdots \\ a_{n1} & \dots & a_{nn} \end{vmatrix}$$

### PAIRWISE COMPARISON

- Dominance coefficient  $a_{ij}$  identifies the relative importance of the component on row  $i$  over the component on column  $j$
- Elements' relative importance is determined through pairwise comparisons expressed in semantic judgments
- This scale was developed taking into account studies on the ability of the human brain to classify a finite number of elements
- The larger the number of variables, the more inconsistent the results (Saaty, 1980) as the probability to maintain the same hierarchy among variables decreases

### PAIRWISE COMPARISON

- The decision-maker can easily answer to questions that require a qualitative judgment such as: *'Are they equally important? Is it much more important?...'*
- Semantic judgments are converted into numerical values according to Saaty's fundamental scale
- It is therefore possible to compile the pairwise comparison matrix using the qualitative judgments of the decision maker

N.B.: the result of the comparison is **the dominance coefficient  $a_{ij}$**  which represents an estimate of the dominance of the first element (**i**) with respect to the second (**j**). The analysis involves the conversion of the dominance coefficients **into relative scores** ( $a_{ij} = w_i / w_j$ ).

## PAIRWISE COMPARISON

If judgments are perfectly coherent, the matrix of pairwise comparisons is symmetric, reciprocal and consistent, i.e. it satisfies the three following conditions:

$$\begin{aligned} a_{ij} &= a_{ji} = 1; \\ a_{ij} &= 1/a_{ji} \\ a_{ij}a_{jk} &= a_{ik} \quad i,j,k=1\dots n \end{aligned}$$

		j			
		A	B	C	D
i	A	1	4	3	7
	B	1/4	1	1	2
	C	1/3	1	1	2
	D	1/7	1/2	1/2	1

- **The diagonal = 1.** In fact, in the comparison with itself (A with A) there is parity, and, according to the Saaty scale, it is = to 1.
- By comparing A to B, A is preferred to B by 4; consequently, by comparing B to A, B gets  $\frac{1}{4}$
- $a_{ij} = 1/a_{ji}$  satisfies **the symmetry of value judgments**
- E.g. if A is worth twice as B ( $A=2B$ ), then necessarily B is worth half of A ( $B = \frac{1}{2} A$ )

## WEIGHT CALCULATION

The elements of the corresponding eigenvector, normalized with respect to their maximum value, represent the weights of the elements with respect to the parental node for which the pairwise comparison matrix is compiled

*For each row we calculate the 'weight', obtained by calculating the  $n$ -th root of the multiplication of the elements of each row*

		<i>j</i>				Matrix Rank	Weights (Xi)	Normalization	Coeff.	Enginvalue
		A	B	C	D					
<i>i</i>	A	1	4	3	7	4	3.027			
	B	1/4	1	1	2		0.841			
	C	1/3	1	1	2		0.904			
	D	1/7	1/2	1/2	1		0.435			
Total Yj		1.726	6.500	5.500	12.000		5.207			



## WEIGHT CALCULATION

Weights normalization:  $\sum i=5.207$  = this sum must be set to 1

(e.g.  $3.027/5.207 = 0.581$ )

		<i>j</i>				Matrix Rank	Weights (Xi)	Normalization	Coeff.	Enginvalue
		A	B	C	D					
<i>i</i>	A	1	4	3	7	4	3.027	0.581		
	B	1/4	1	1	2		0.841	0.162		
	C	1/3	1	1	2		0.904	0.174		
	D	1/7	1/2	1/2	1		0.435	0.083		
	Total Yj	<b>1.726</b>	<b>6.500</b>	<b>5.500</b>	<b>12.000</b>		<b>5.207</b>	<b>1.000</b>		

## WEIGHT CALCULATION

We then calculate the coefficients (ideal weights).

The highest weight is set to 1, the others are set equal to  $P_i/P_{max}$ .

In this example 0.581 is set to 1, then  $0.162/0.581=0.278$ , ....

		<i>j</i>				Matrix Rank	Weights (Xi)	Normalization	Coeff.	Enginvalue
		A	B	C	D					
<i>i</i>	A	1	4	3	7	4	3.027	0.581	<b>1.000</b>	
	B	1/4	1	1	2		0.841	0.162	0.278	
	C	1/3	1	1	2		0.904	0.174	0.298	
	D	1/7	1/2	1/2	1		0.435	0.083	0.144	
Total Yj		<b>1.726</b>	<b>6.500</b>	<b>5.500</b>	<b>12.000</b>		<b>5.207</b>	<b>1.000</b>		

## WEIGHT CALCULATION

To calculate the eigenvalue:  $X_i * (\text{total } Y_j) / (\text{total } X_i)$

A:  $(3.027) \times (1.726) / (5.207) = 1.004$

		<i>j</i>				Matrix Rank	Weights (Xi)	Normalization	Coeff.	Enginvalue
		A	B	C	D					
<i>i</i>	A	1	4	3	7	4	<b>3.027</b>	0.581	<b>1.000</b>	1.004
	B	1/4	1	1	2		0.841	0.162	0.278	1.050
	C	1/3	1	1	2		0.904	0.174	0.298	0.955
	D	1/7	1/2	1/2	1		0.435	0.083	0.144	1.002
Total Yj		<b>1.726</b>	<b>6.500</b>	<b>5.500</b>	<b>12.000</b>		<b>5.207</b>	<b>1.000</b>		

### PAIRWISE COMPARISON - Consistency Index

- Unlike other multi-criteria approaches, the AHP **tolerates** some **inconsistency in expert judgments**
- The consistency of pairwise comparison matrices is verified by determining the **consistency index CI**:

$$CI = (\lambda_{\max} - n) / (n-1)$$

- Then the consistency ratio is obtained:

$$CR = CI / RI$$

where *RI is a random consistency index*, which depends on n.



### PAIRWISE COMPARISON - Consistency Index

- **CR < 0.1 is considered acceptable**
- Whenever  $CR > 0.1$ , experts' judgments are inconsistent, and a revision of the pairwise comparison matrix is recommended
- If the pairwise comparison matrix A is perfectly consistent (judgments are perfectly coherent), then the maximum eigenvalue  $\lambda_{max}$  is equal to its rank n (Perron-frobenius theorem), therefore  $CI=0$
- When inconsistency increases, the CR increases (CI also)

Size of Matrix (n)	Random Consistency Index (RI)
1	0
2	0
3	0.52
4	0.89
5	1.11
6	1.25
7	1.35
8	1.40
9	1.45
10	1.49

## PAIRWISE COMPARISON - Consistency Index

- **CI:**  $CI = (\lambda_{\max} - n) / (n-1) = (4.010-4)/3 = \mathbf{0.003}$

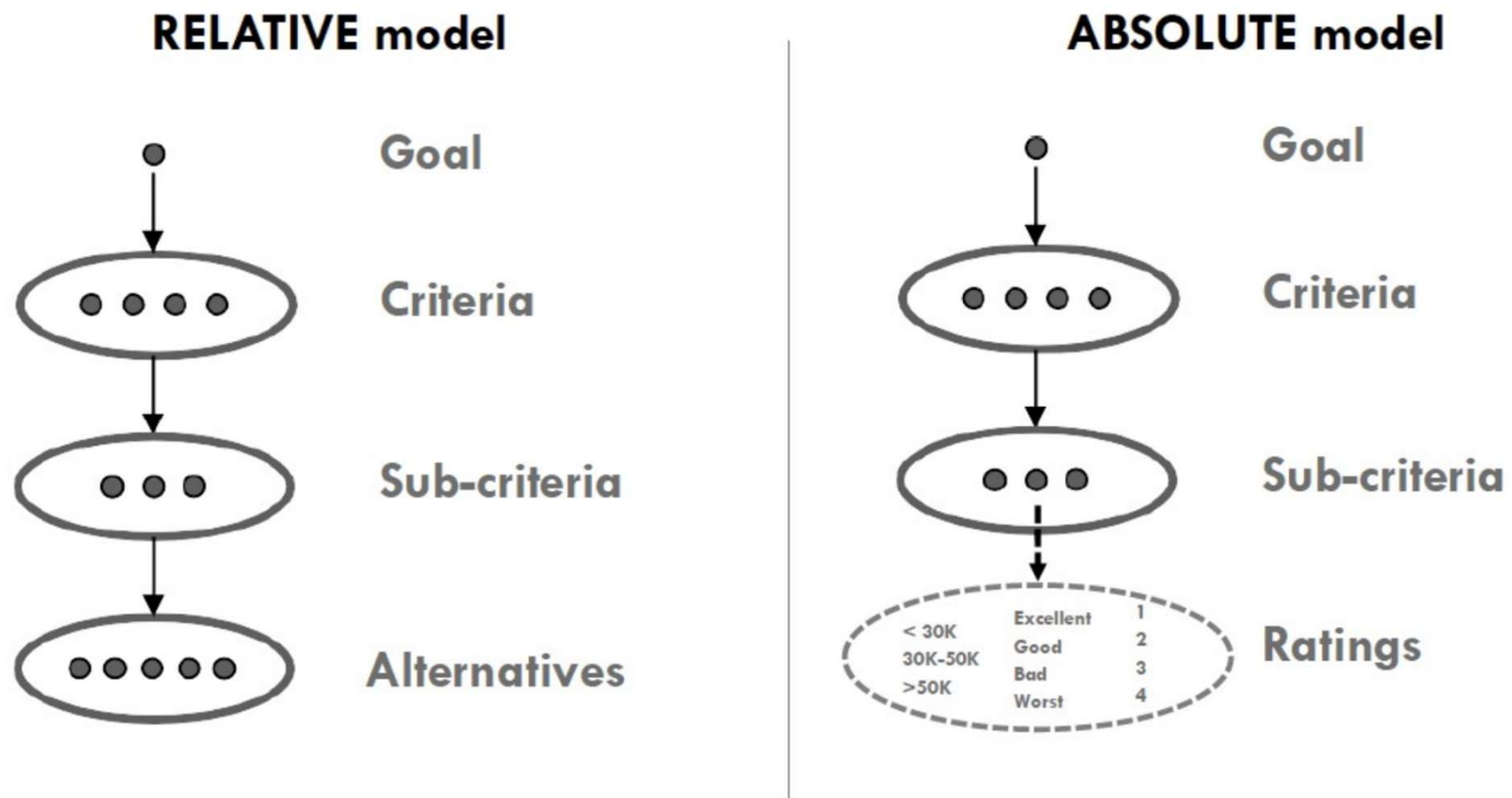
where:  $\lambda_{\max} = 4.010$ ;  $n = 4$ ;  $n-1 = 3$

- Then the consistency ratio is obtained **CR=CI/RI** where  $RI(n=4)=0.89$ ;

$$CR = \mathbf{0.003 / 0.89 = 0.04 < 0.1}$$

		<i>j</i>				Matrix Rank	Weights (Xi)	Normalization	Coeff.	Enginvalue
		A	B	C	D					
<i>i</i>	A	1	4	3	7	4	3.027	0.581	1.000	1.004
	B	1/4	1	1	2		0.841	0.162	0.278	1.050
	C	1/3	1	1	2		0.904	0.174	0.298	0.955
	D	1/7	1/2	1/2	1		0.435	0.083	0.144	1.002
Total Yj		1.726	6.500	5.500	12.000		5.207	1.000	<b>lmax</b>	<b>4.010</b>
									<b>CI</b>	<b>0.003</b>
									<b>RI</b>	<b>0.890</b>
									<b>CR</b>	<b>0.004</b>

## RELATIVE VS ABSOLUTE MODELS



# AHP – SUPER DECISION SOFTWARE

<https://www.superdecisions.com/>

Downloads: <https://www.superdecisions.com/downloads/>

The **Super Decisions** is decision support software **that implements the AHP and ANP**.

The **Analytic Hierarchical Process (AHP)** and the **Analytic Network Process (ANP)** make it possible to include **Intangibles** in decision making.

*AHP/ANP are the most powerful synthesis methodologies for combining judgment and data to effectively rank options and predict outcomes.*

**SuperDecisions V3.2 Overview**

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**Super Decisions**

SuperDecisions is decision making software based on the Analytic Hierarchy Process (AHP) and the Analytic Network Process (ANP). Decision making is all about setting priorities and the AHP and ANP, award-winning decision processes are the way to do that.

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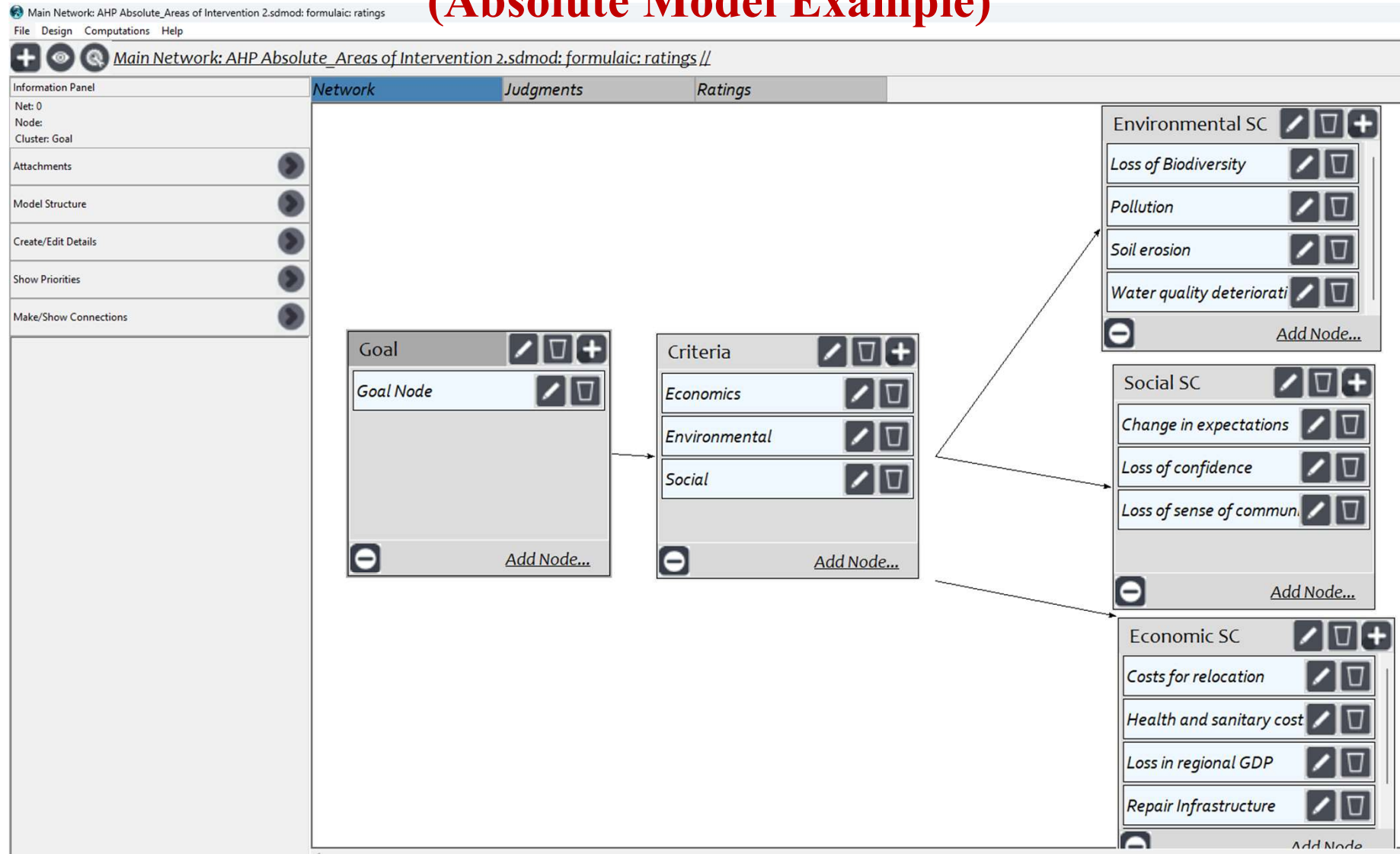
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# AHP – SUPER DECISION SOFTWARE

## (Absolute Model Example)



# AHP – SUPER DECISION SOFTWARE

## Questionnaire

Main Network: AHP Absolute\_Areas of Intervention 2.sdmod: formulaic: ratings

File Design Computations Help

Main Network: AHP Absolute\_Areas of Intervention 2.sdmod: formulaic: ratings //

Information Panel

Net: 0  
Node:  
Cluster:

Attachments

Model Structure

Create/Edit Details

Show Priorities

Make/Show Connections

Network

1. Choose

Node Cluster

Choose Node

Economics

Cluster: Criteria

Choose Cluster

Economic SC

Judgments

2. Node comparisons with respect to Economics

Graphical Verbal Matrix Questionnaire Direct

Comparisons wrt "Economics" node in "Economic SC" cluster

Health and sanitary costs is moderately to strongly more important than Costs for relocation

	1	2	3	4	5	6	7	8	9	10		
1. Costs for re~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
2. Costs for re~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
3. Costs for re~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
4. Costs for re~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
5. Health and s~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
6. Health and s~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
7. Health and s~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
8. Loss in regi~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
9. Loss in regi~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co
10. Repair Infra~	>=9.5	9	8	7	6	5	4	3	2	1	2 3 4 5 6 7 8 9 >=9.5	No co

3. Results

Normal Hybrid

Inconsistency: 0.07037

	Costs for~	Health an~	Loss in r~	Repair In~	Repair RE~
Costs for~	0.08644				
Health an~	0.34407				
Loss in r~	0.08264				
Repair In~	0.23565				
Repair RE~	0.25120				

2. Node comparisons with respect to Economics

Graphical Verbal Matrix Questionnaire Direct

Costs for relocation

Health and sanitary costs

Help for graphical mode.

1. Click and drag the circle to adjust the judgment.
2. Click the "No comparison" button to set the judgment to zero.
3. Use Tab/Enter to move between judgments or use the navigation buttons on the right.
4. Type a number to vote.
5. H8 - or / to invert.

No comparison

2. Node comparisons with respect to Economics

Graphical Verbal Matrix Questionnaire Direct

Comparisons wrt "Economics" node in "Economic SC" cluster

Health and sanitary costs is 4 times more important than Costs for relocation

Inconsistency

	Health and~	Loss in r~	Repair In~	Repair RE~
Costs for ~	4	2	4	4
Health and~		2	2	2
Loss in r~			3.0000	4
Repair In~				1

# AHP – SUPER DECISION SOFTWARE

Main Network: AHP Absolute\_Areas of Intervention 2.sdmod: formulaic: ratings

File Design Computations Help

Main Network: AHP Absolute\_Areas of Intervention 2.sdmod: formulaic: ratings //

Network Judgments Ratings

Step 1: Select criteria for rating alternatives

Step 2: Add alternatives

Step 3: Define rating scale for each criterion

Select a criterion and click "Add New" to create the scale intensity names. Examples are (Excellent, Above Average, Average, Poor); or (Very Dangerous, Dangerous, Safe). Click the Compare button to pairwise compare the intensities for preference. Click Computations->Idealized priorities to see results. Click the x at upper right to save these Ideal Priorities and close the comparisons window.

Costs for relocation  
Health and sanitary co...  
Loss in regional GDP  
Repair Infrastructure  
Repair RE  
Loss of Biodiversity

ScaleItem	Value	Graphic	Delete
Null_Very Low	1.0000		
Low	0.5756		
Moderate	0.2347		
High	0.1061		
Extreme	0.0667		

Add New Item Move Up Move Down  
Load from file.. Save to file.. Compare

Ratings Table

Display Options Show/Hide Calculations Manage Ratings

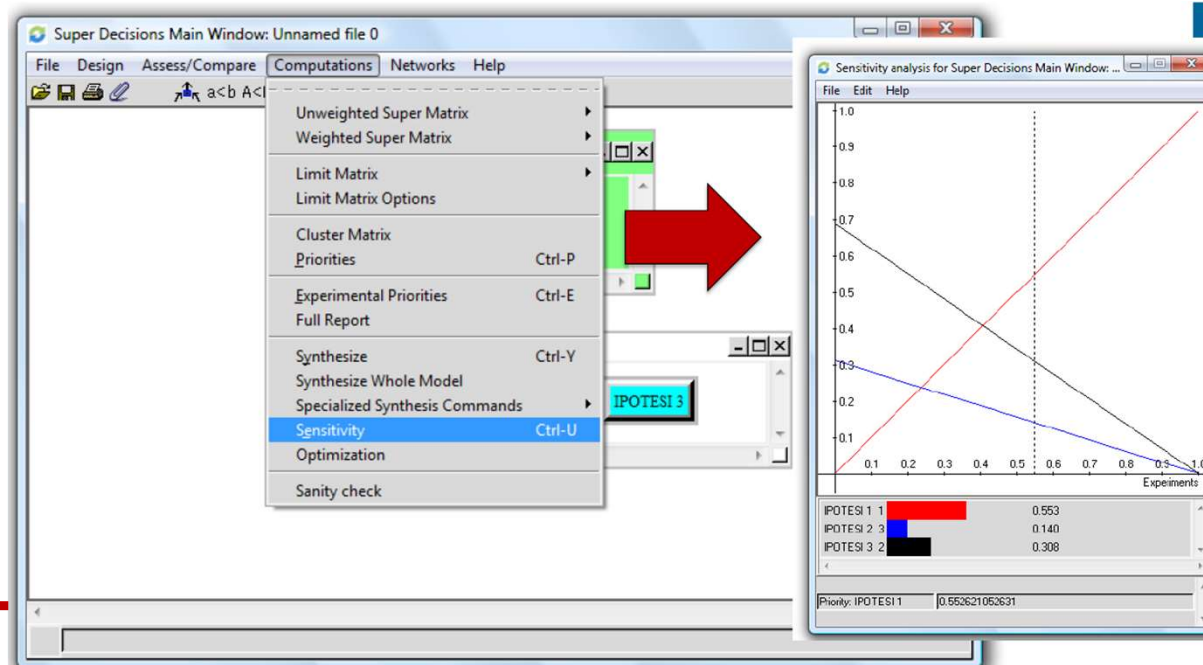
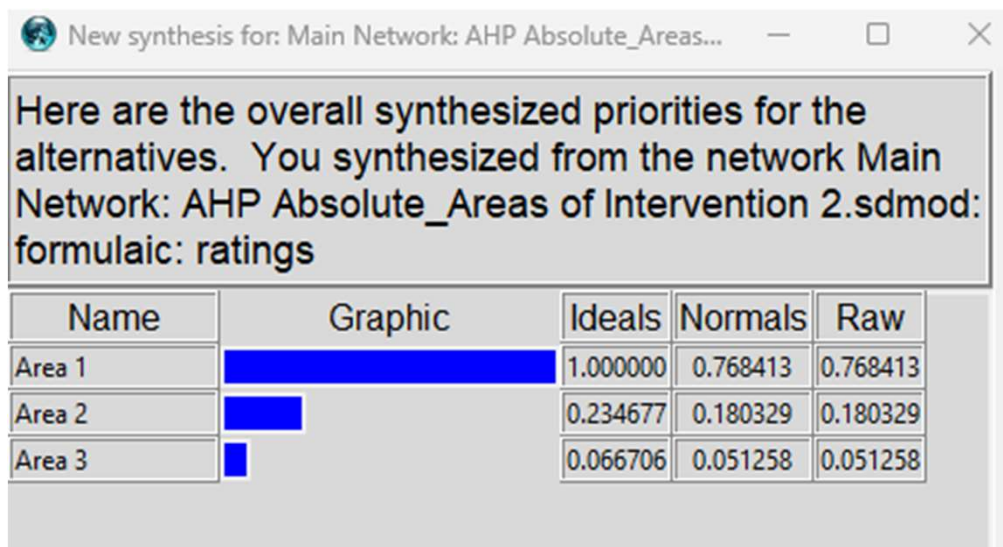
☒ Category Names ☒ Priorities Column  
☐ Category Priorities ☒ Totals Column  
☐ Both

Synthesize Synthesize whole model Column Priorities  
Copy Ratings Table to Clipboard Clear Ratings Judgments Revert to Relative Model

To rate an alternative with respect to a criterion, click on a cell then click the down arrow to display the Rating scale intensities for that criterion. Click to select the one you think applies. Move to the next cell by clicking with the mouse.

Alternatives	Priorities	Totals	Costs for reloc... (0.0864)	Health and san... (0.3441)	Loss in regiona... (0.0826)	Repair Infrastru... (0.2357)	Repair RE (0.2512)	Loss of Biodive... (0.1312)	Pollution (0.2303)	Soil erosion (0.0488)	Water quality d... (0.5897)	Change in exp... (0.1713)	Loss of confide... (0.7504)	Loss of sense o... (0.0782)
Area 1	0.7684	1.0000	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low	Null_Very Low
Area 2	0.1803	0.2347	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Area 3	0.0513	0.0667	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme	Extreme

# AHP – SUPER DECISION SOFTWARE



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DI PADOVA

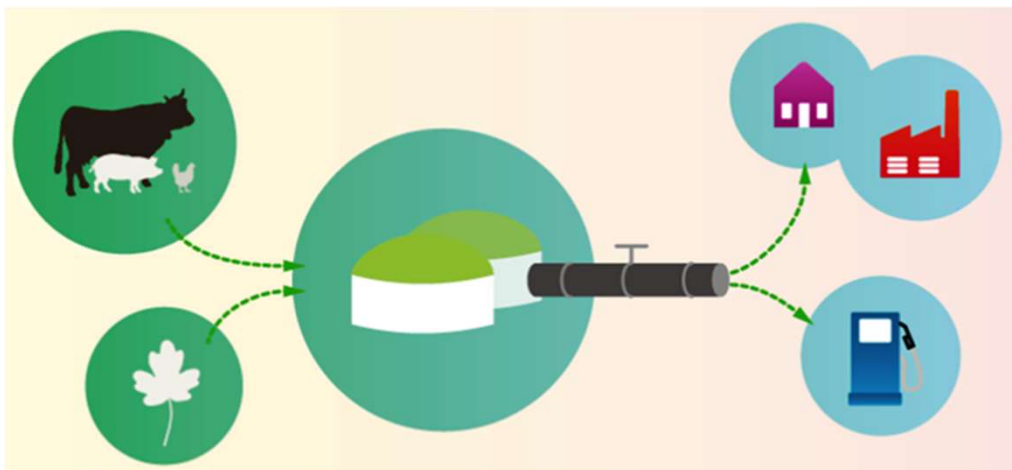
Department Of Civil, Environmental  
and Architectural Engineering



## **CASE STUDY:**

**BIOGAS AND BIOMETHANE TECHNOLOGIES**

**AHP MODEL TO SUPPORT THE POLICY MAKER IN INCENTIVE  
DESIGN**

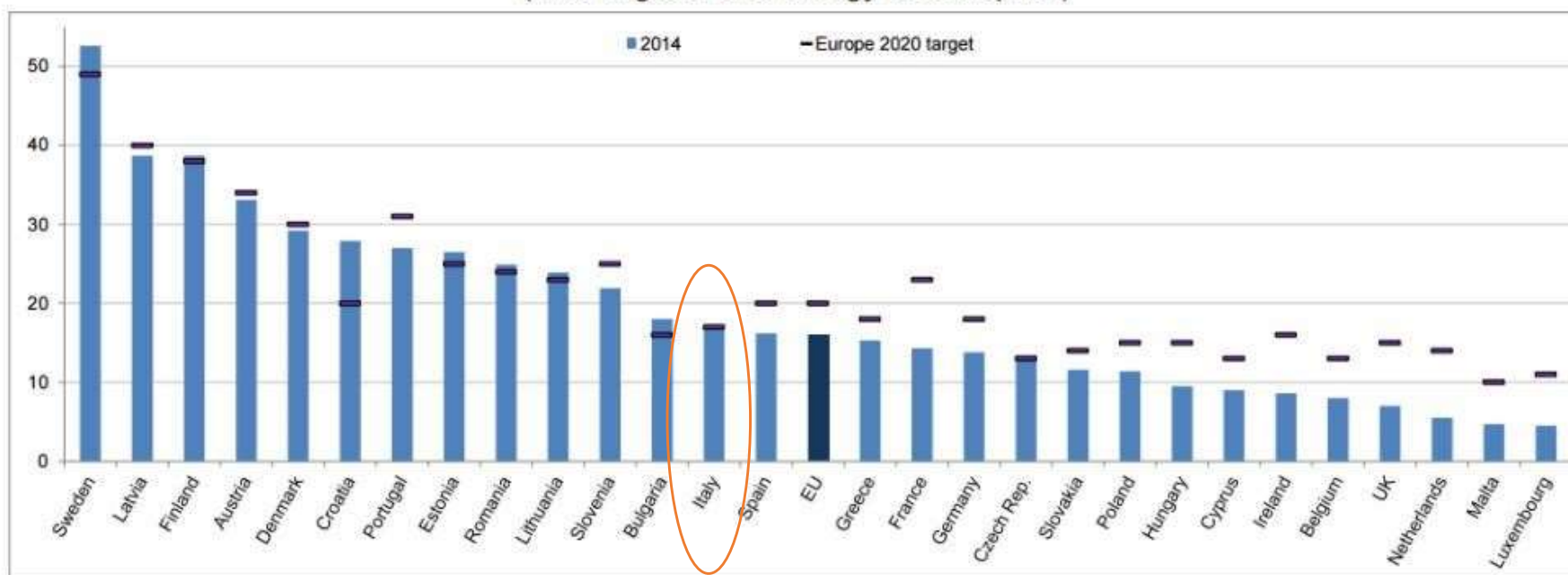




The 2030 climate and energy framework sets three key targets for the year 2030:

- At least 40% cuts in **greenhouse gas emissions** (from 1990 levels)
- At least 27% share for **renewable energy** consumption
- At least 27% improvement in **energy efficiency**

**Share of energy from renewable sources in the EU Member States, 2014**  
(in % of gross final energy consumption)



# Biogas and Biomethane (1)

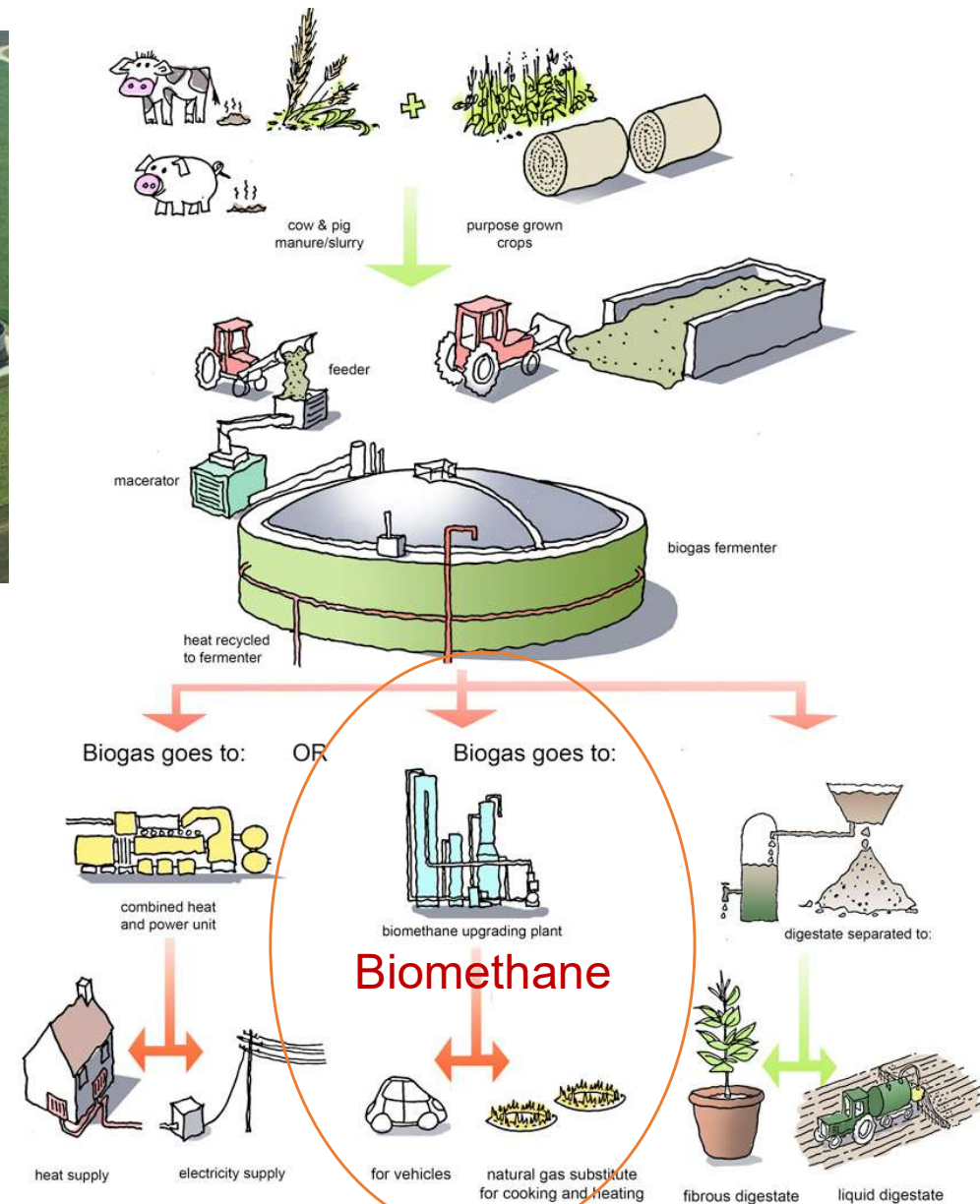
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Anaerobic Digestion 's contribution to key EU policy areas:

- **European climate targets** (cut greenhouse gas emission)
- **European energy security** (locally production of biomethane)
- **Food security and resource efficiency** (recycling waste)
- **Improved air quality** (carbon sequestration, reducing PM10 and NOx emissions)
- **Bioeconomy** (green job creation)
- **Bioenergy**
- **Prevention of contamination** (reducing pathogen fertilizer production)

(Source: EBA, 2015)



Biogas-Biomethane process (Source: Nethyenergy, 2016)



*EU National energy policies are evaluated by:*

- long-term RE targets,
- increased economic and export market opportunities,
- sustainable job creation,
- enhanced use of forestry,
- enhanced use of agricultural wastes,
- development of innovative RE technologies.

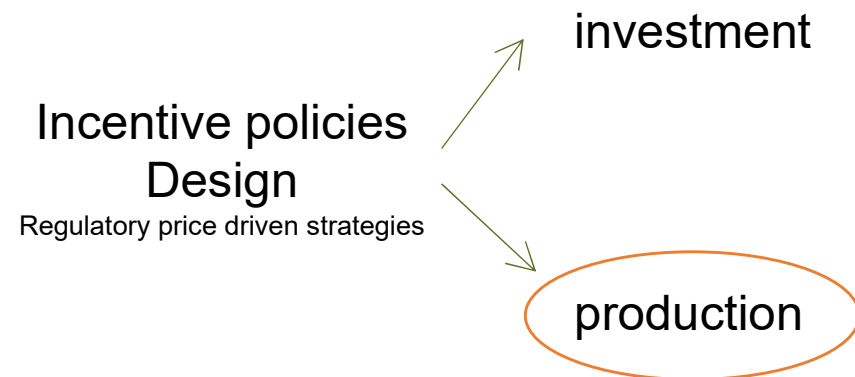
*(see European Commission, 2009/28/EC).*

to achieve Policy goals



FITs (feed-in tariffs) differentiated by:

- technology type,
- the project size
- outputs,
- inputs,
- resource quality
- location of the project
- etc....

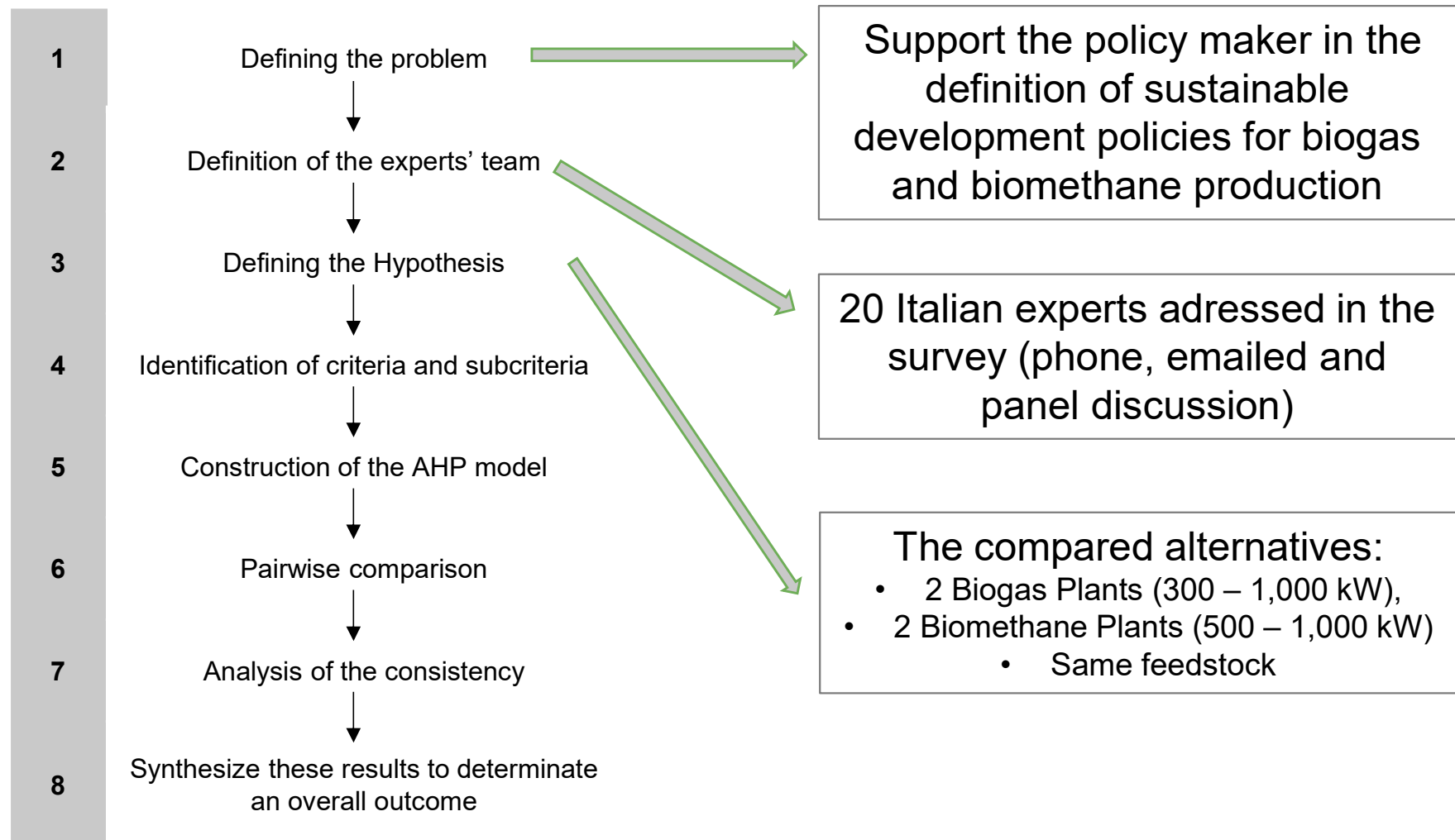


# The model

## Overall methodology

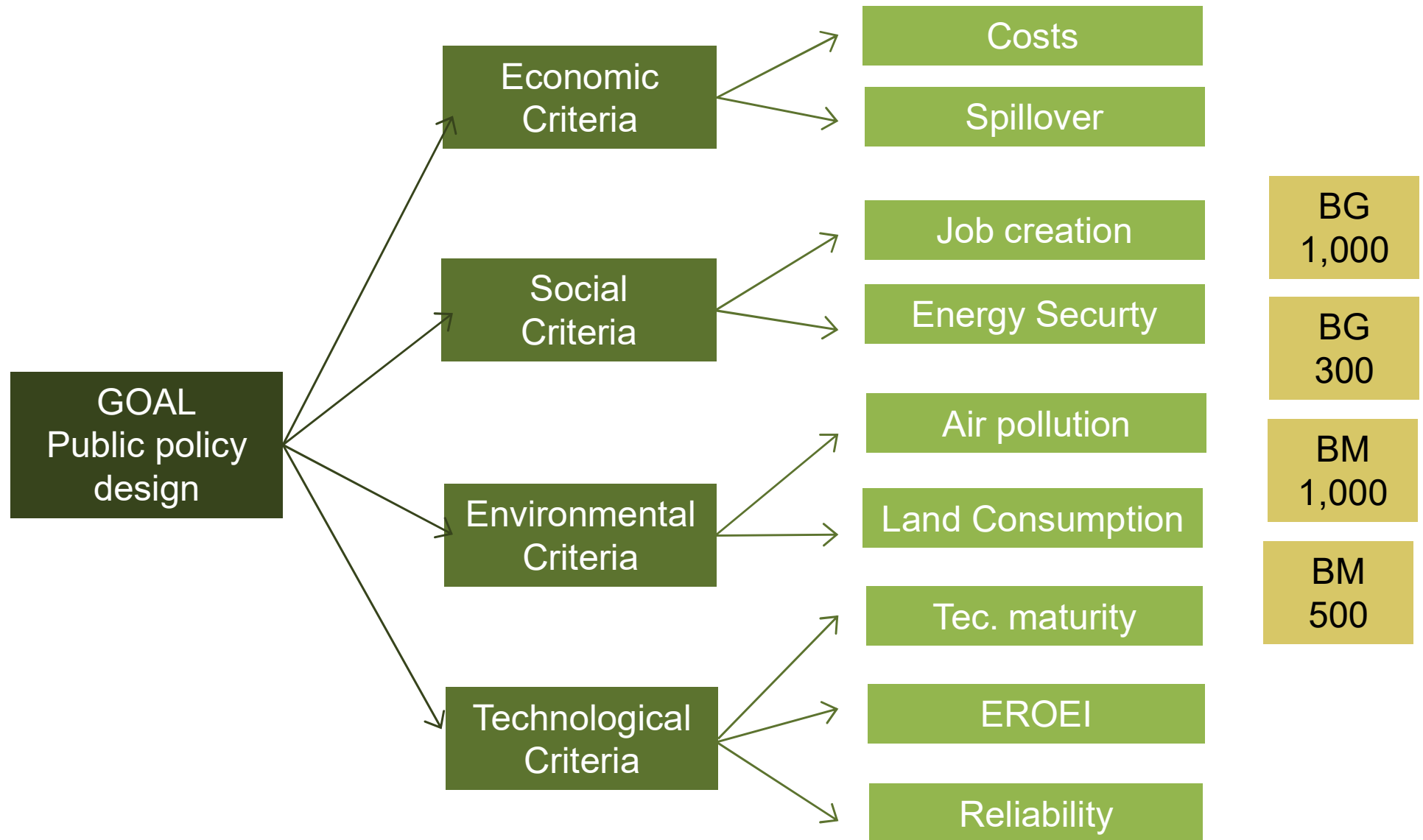
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AHP relative model, according to the following steps:



# The model The Hierachy

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# The model

## Criteria and Subcriteria

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Goal	Criteria	Subcriteria	Description
Public policy design	Economic	Costs	Global costs (investment cost, capex, opex) and feed-in costs
		Spillover	Generate externalities
	Social	Job creation	To estimate the employment effects resulting from the deployment of AD technologies both construction and operation phases have to be taken into account.
		Energy security	The reduction of dependence on imported energy
	Environmental	Air pollution	Amount of CH4 emissions
		Land Consumption	This criteria is related to the dimension of the plans and to the area involved in the transformation process
	Technological	Technical maturity	Refers to the specific involved technology, defying if it has successfully passed all research stages and has been commercialized for a number of years without severe problems in the operation
		EROEI	Energy Returned On Energy Invested
		Reliability	(start of uptime - start of downtime) / days of failure

# The model Results

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$$A = a_{ij} = \begin{matrix} & \begin{matrix} A_1 & A_2 & \dots & A_m \end{matrix} \\ \begin{matrix} A_1 \\ A_2 \\ \dots \\ A_m \end{matrix} & \begin{bmatrix} 1 & a_{12} & \dots & a_{1m} \\ 1/a_{12} & 1 & \dots & a_{2m} \\ \dots & \dots & \dots & \dots \\ 1/a_{1m} & 1/a_{2m} & \dots & 1 \end{bmatrix} \end{matrix}$$

Parewise  
comparisons

**Table 2** Criteria and subcriteria aggregation of experts' judgments (priority vectors)

Criteria	Priority vector	Subcriteria	Priority vector
Economic	0.198	Costs	0.25
		Spillover	0.75
Social	0.359	Job creation	0.66
		Energy security	0.33
Environmental	0.284	Air pollution	0.80
		Land Consumption	0.20
Technological	0.157	Technical maturity	0.21
		EROEI	0.55
		Reliability	0.24

Spillover

Energy Security

Land  
consumption

Reliability

## Partial results

Inconsistency: 0.06395

BG 1,000 ~		0.22890
BG 300 kW		0.08960
BM 1,000 ~		0.44907
BM 500 kW		0.23243

Inconsistency: 0.01629

BG 1,000 ~		0.19983
BG 300 kW		0.07809
BM 1,000 ~		0.52224
BM 500 kW		0.19983

Inconsistency: 0.03044

BG 1,000 ~		0.12727
BG 300 kW		0.47699
BM 1,000 ~		0.08460
BM 500 kW		0.31114

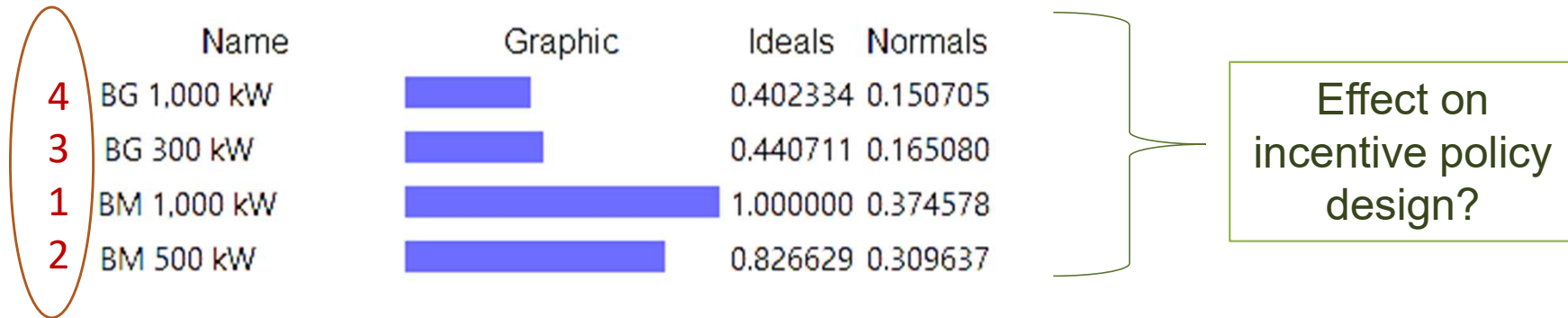
Inconsistency: 0.00772

BG 1,000 ~		0.36289
BG 300 kW		0.32608
BM 1,000 ~		0.16304
BM 500 kW		0.14800

# The model Results

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## Prioritization of alternatives



## Additional Prioritizations

Consider:

- Different feedstocks
- Valuable by product
  - Green taxes