Eco-efficiency of cheese making process: DEA vs restricted weightings DEA

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VII International Conference on Life Cycle Assessment in the agri-food sector.
Bari, september 22-24 2010

INTRODUCTION

- The eco-efficiency of production is concerned with the capacity to produce goods and services while causing minimal environmental degradation.

- Although the eco-efficiency concept is well defined, it is not easy to quantify and different models have been proposed to measure the eco-efficiency of processes.

- In this work, we propose two models for evaluating eco-efficiency. The goal of the study is to compare the results from both models.

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ECO-EFFICIENCY MEASUREMENT

$$\frac{\text{Economic Value Added}}{\text{Environmental Damage}}$$

Measurement of economic performance: EVA

- Difference between the sale price of a product and the cost of intermediate inputs (it does not include costs of land, labour and capital goods)

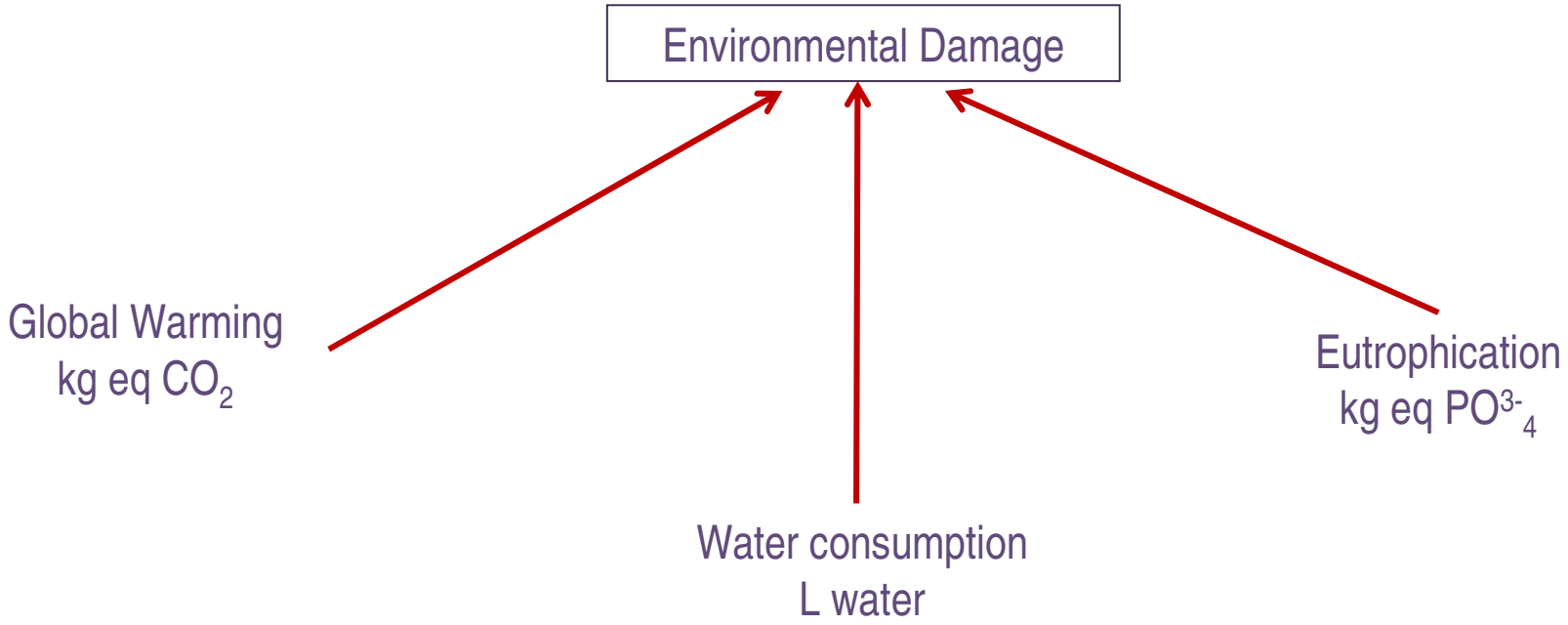
Measurement of environmental impacts: LCA

- Life Cycle Assessment (LCA) is a recognized and accepted tool that analyses in an objective, systematic and scientific way the environmental impact caused by products or processes.

DEA MODEL FOR ECO-EFFICIENCY MEASUREMENT

- Numerator of the ratio: global measure of the production process value as the economic value added.
- Denominator: define a linear function of the environmental damage which involves the problem of determining the weightings of the different environmental impact categories.
- The model measures the relative eco-efficiency of each production scenario by means of an eco-efficiency (EE) ratio that always lies between 0 and 1.
- An EE ratio equal to 1 means that the scenario is eco-efficient, otherwise the scenario is not eco-efficient.

DEA MODEL FOR ECO-EFFICIENCY MEASUREMENT



While humans are good at finding important variables, they are not as good integrating such diverse information sources optimally.

DEA MODEL FOR ECO-EFFICIENCY MEASUREMENT

$$\max_{w} EE_i = \frac{VA_i}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}}$$

Virtual impact

$$s.t.$$

$$\frac{VA_1}{w_1 \cdot z_{11} + w_2 \cdot z_{12} + \ldots + w_n \cdot z_{1n}} \leq 1$$

$$\frac{VA_2}{w_1 \cdot z_{21} + w_2 \cdot z_{22} + \ldots + w_n \cdot z_{2n}} \leq 1$$

$$\ldots$$

$$\frac{VA_m}{w_1 \cdot z_{m1} + w_2 \cdot z_{m2} + \ldots + w_n \cdot z_{mn}} \leq 1$$

$$w_1, w_2, \ldots, w_n \geq 0$$

VA_i: economic added value for scenario *i*

w_j: weighting of environmental impact *category j*

z_{ij}: measure of environmental impact category *j* for scenario *i*

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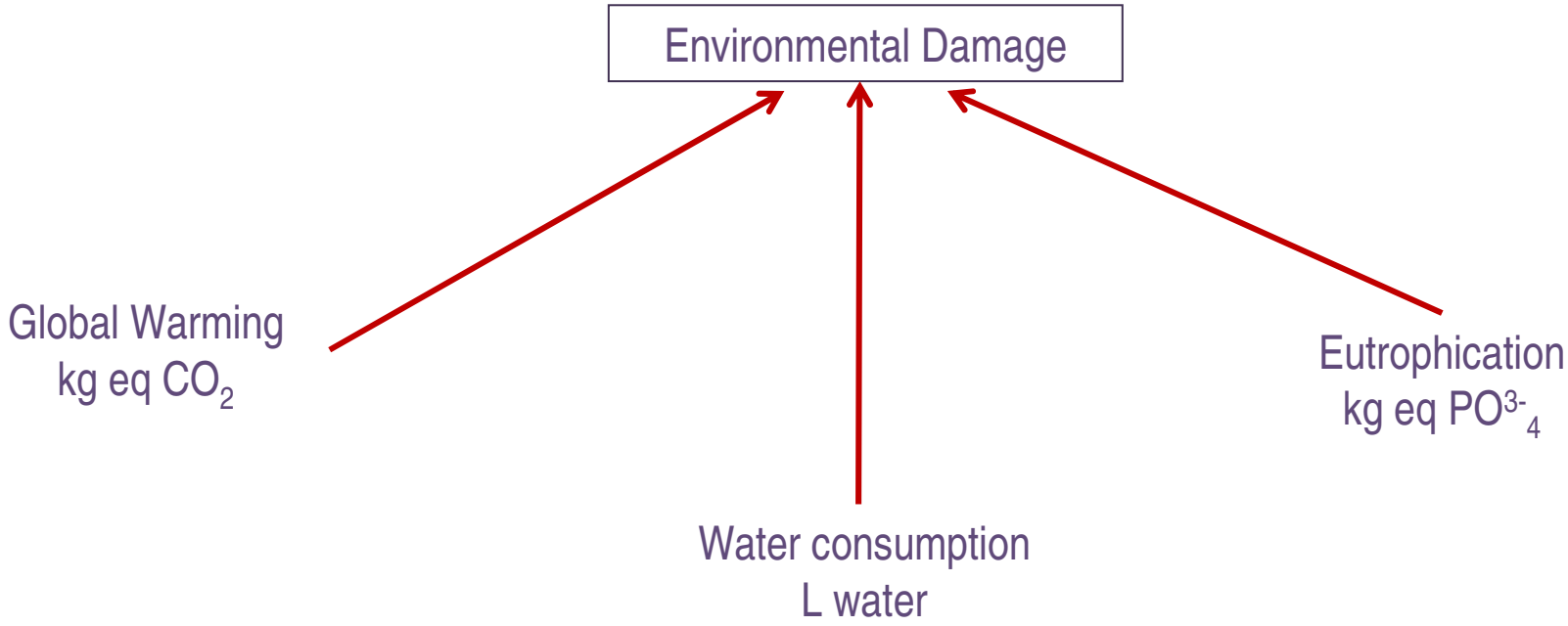
RESTRICTED WEIGHTINGS DEA MODEL

- DEA techniques can help the integration process.
- Nevertheless, large weightings may be assigned to environmental impacts of secondary importance, leaving a zero weight for impact categories that are generally regarded as the important ones.
- To avoid this issue, there is a great diversity of methods for incorporating value judgements in DEA.
- To set the restrictions of the virtual impact, we propose the Analytic Hierarchy Process (AHP).

RESTRICTED WEIGHTINGS DEA MODEL



How to integrate environmental impacts? → **DEA**

How to integrate human acepted views? → **AHP**

RESTRICTED WEIGHTINGS DEA MODEL

Analytic Hierarchy Process (AHP)

- Judgment matrix of impact categories built from pair-wise comparisons made by decision-makers
- Judgments on the comparative importance of the impact categories are captured using a 1-9 rating scale
- The weightings of the impact categories are calculated from the judgment matrix using the eigenvector method

RESTRICTED WEIGHTINGS DEA MODEL

Example pair-wise comparisons

Fundamental scale for paired comparison

Intensity of importance	Definition
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong or demonstrated importance
9	Extreme importance
2, 4, 6, 8	For compromise between above values
Reciprocals of the above	

Pair-wise matrix

	Global warming	Eutrophication	Water consump.
Global warming	1	5	3
Eutrophication	1/5	1	1/3
Water consump.	1/3	3	1

Groups of impact categories	Weighting
Global warming	63,33%
Eutrophication	10,62%
Water consumption	26,05%

RESTRICTED WEIGHTINGS DEA MODEL

$$\max_{w} EE_i = \frac{VA_i}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}}$$

$$s.t.$$

$$\frac{VA_1}{w_1 \cdot z_{11} + w_2 \cdot z_{12} + \ldots + w_n \cdot z_{1n}} \leq 1$$

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$$\ldots$$

$$\frac{VA_m}{w_1 \cdot z_{m1} + w_2 \cdot z_{m2} + \ldots + w_n \cdot z_{mn}} \leq 1$$

$$w_1, w_2, \ldots, w_n \geq 0$$

New restrictions in the shares of the virtual impact

Two restrictions for each impact category

Minimum and maximum bound of each impact category obtained from AHP

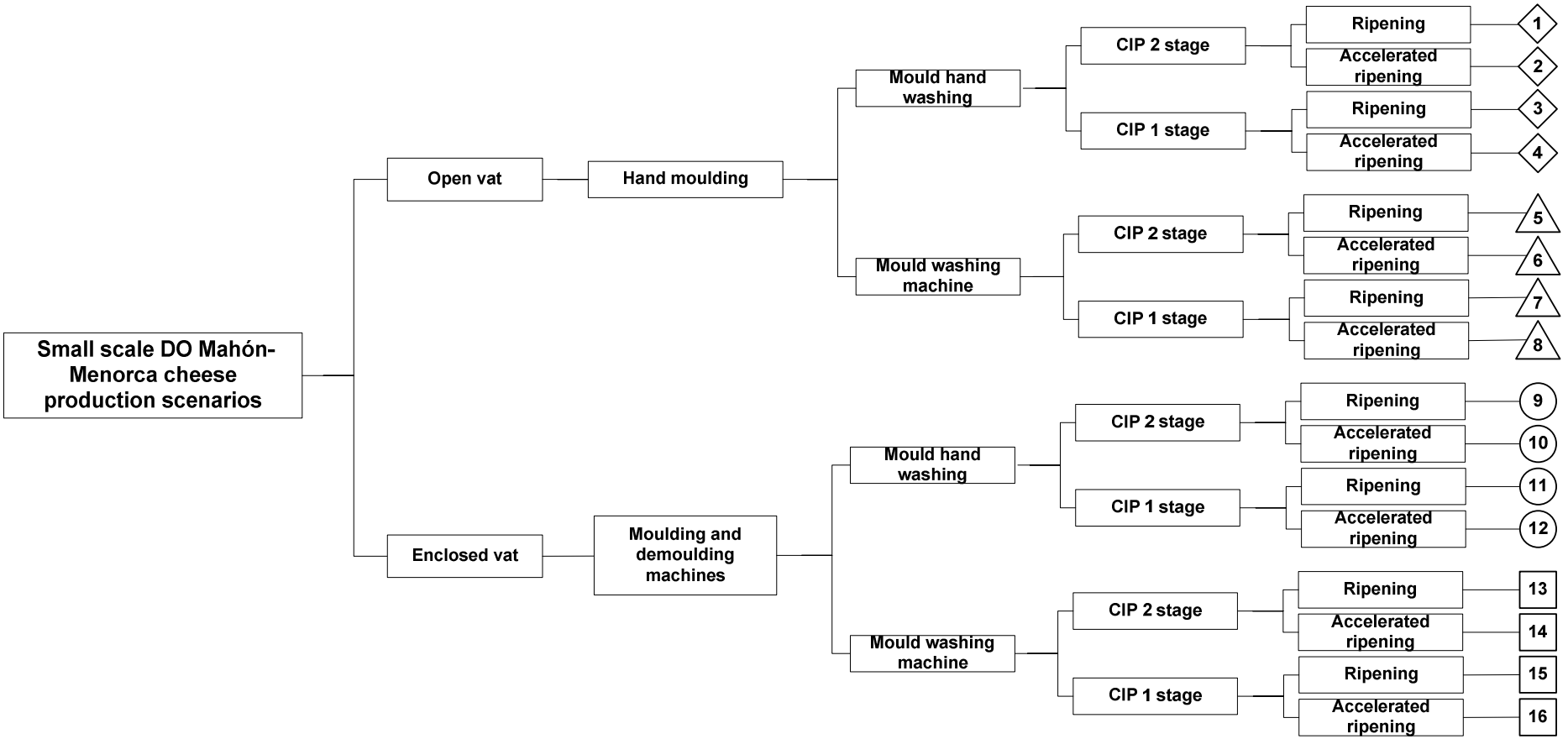
$$\phi_j \leq \frac{w_j \cdot z_{ij}}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}}$$

$$\frac{w_j \cdot z_{ij}}{w_1 \cdot z_{i1} + w_2 \cdot z_{i2} + \ldots + w_n \cdot z_{in}} \leq \psi_j$$

CASE STUDY

- Mahón-Menorca cheese making.
- Small scale of production (average processing capacity of between 3 and 4 million L of milk/year).
- Sixteen scenarios have been built which take both technical (automation degree) and cleaner production criteria into account.
- The goal is to decide which scenario is the most eco-efficient and also to check the possible differences between the results given by each model.

CASE STUDY


Small scale DO Mahón-Menorca cheese production scenarios
Open vat
Hand moulding
Mould hand washing
CIP 2 stage
Ripening
1
Accelerated ripening
2
CIP 1 stage
Ripening
3
Accelerated ripening
4
Mould washing machine
CIP 2 stage
Ripening
5
Accelerated ripening
6
CIP 1 stage
Ripening
7
Accelerated ripening
8
Enclosed vat
Moulding and demoulding machines
Mould hand washing
CIP 2 stage
Ripening
9
Accelerated ripening
10
CIP 1 stage
Ripening
11
Accelerated ripening
12
Mould washing machine
CIP 2 stage
Ripening
13
Accelerated ripening
14
CIP 1 stage
Ripening
15
Accelerated ripening
16

CASE STUDY

- The functional unit is 1 kg of semi-mature cheese ripened for 105 days, packaged and ready for shipment.
- Operations included: milk reception, milk pasteurization and the cheese making process, cheese drying and ripening, cheese packaging, cleaning of the facilities and electricity production.
- Upstream and downstream stages have been omitted from the comparison.
- Mould manufacturing, the manufacturing of cleaning agents and capital goods have not been included

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CASE STUDY

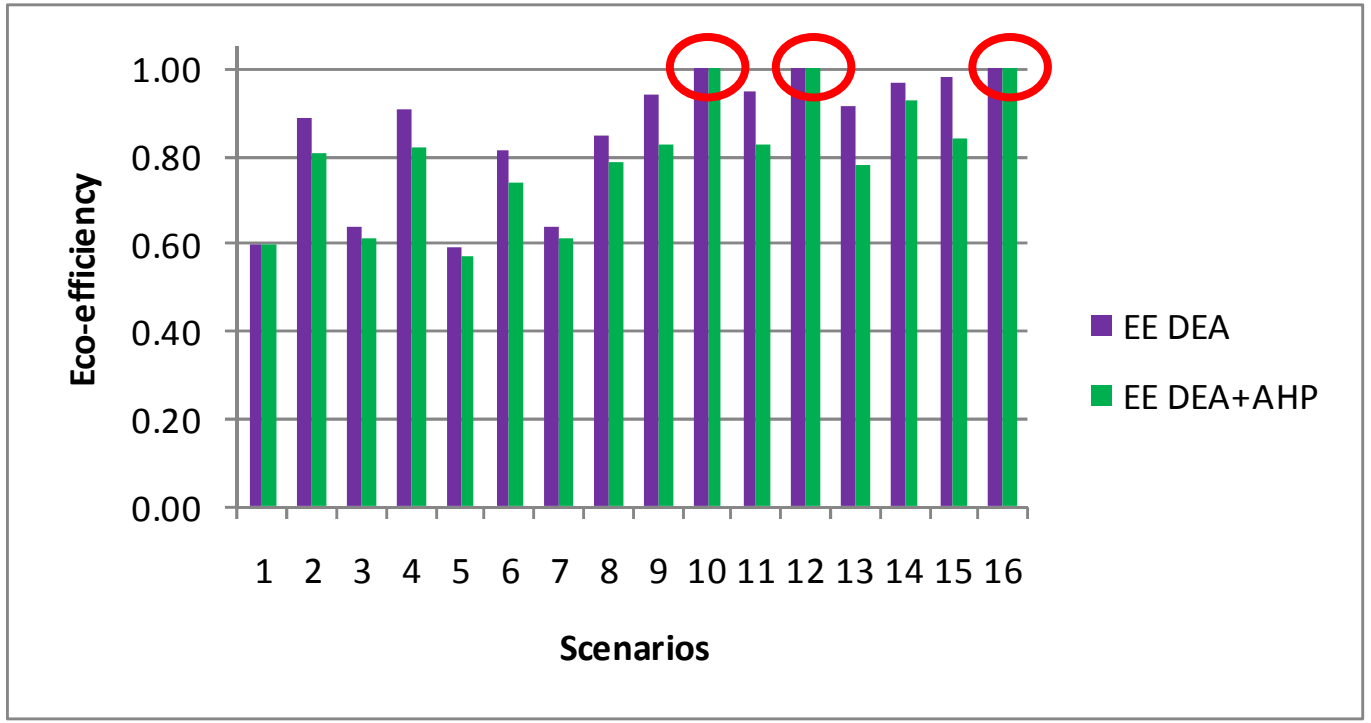
- The data sources used to characterize the scenarios have been cheese firms, machinery manufacturers and the direct measuring of energy consumption in production plants. Wastewater characterization has been carried out, taking into account the composition and dose of the cleaning agents.
- Gabi 4 LCA software (PE International GmbH, Stuttgart) has been used.
- Impact categories: global warming, eutrophication and water consumption.
- In the economic assessment, the variables related to revenues and costs have been obtained in order to estimate net income.

CASE STUDY

- In order to set the minimum and maximum share of the virtual impact for every impact category, ten LCA specialized academic decision-makers filled in the pair-wise comparison matrix.
- They were asked to compare the environmental impact categories as to their importance.

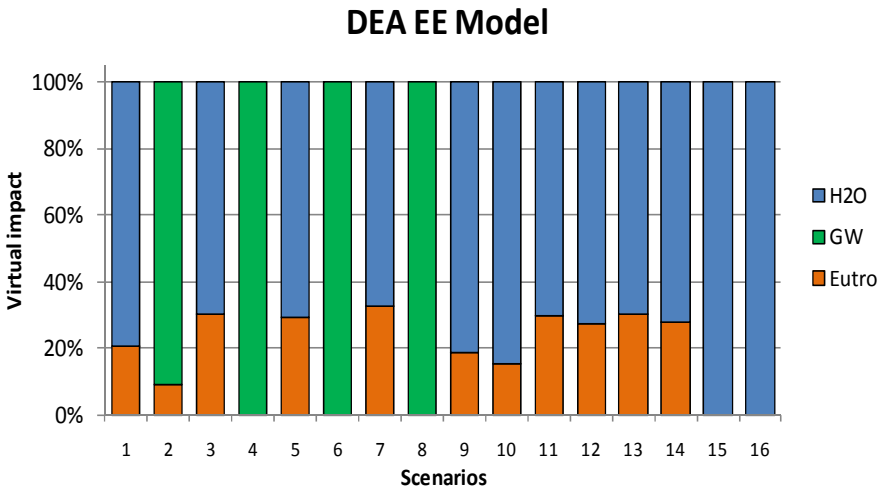
Environmental Impact Category	Min.	Max.
Global warming	40.55%	63.33%
Eutrophication	8.97%	14.29%
Water consumption	26.05%	47.96%

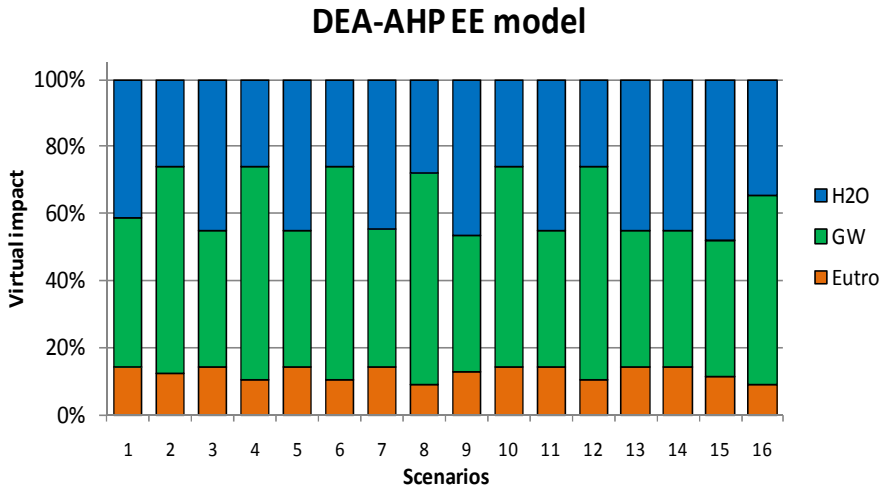
COMPARISON OF RESULTS



- The eco-efficient scenarios 10, 12 and 16, are the same in both models.
- In the rest of the scenarios, the non- eco-efficient ones, the EE ratio is lower in the DEA-AHP model than in the DEA model.

COMPARISON OF RESULTS





- The DEA-AHP EE model succeeds in obtaining a more balanced virtual impact in which every impact category is in the range fixed by the decision-makers.

DISCUSSION

- The combination of DEA with AHP allows the decision-makers opinions to be integrated and, thus, weightings to be obtained within the expected limits.
- In this sense, the model could be useful to discard extreme scenarios that are favored by showing a good performance in just one impact category.
- How to compare the importance of the environmental impact categories. The importance of what exactly? Sustainability, eco-efficiency, human damage,…? Greater definition is needed in this sense

DISCUSSION

- The specific case study may also be important. Should decision-makers take the case study into account when filling in the comparison matrices?

- The proposed DEA-AHP model is a promising technique with which to measure the eco-efficiency of production processes. Nevertheless, research is needed into how experts obtain the weighting ranges.

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