Measuring the eco-efficiency of cheese production scenarios: integrating environmental impacts and economic results with DEA techniques

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Introduction

DEA and Eco-efficiency

The first proposal of aggregation using DEA to quantify eco-efficiency according to its definition (Economic value added/Environmental damage) comes from Kuosmanen and Kortelainen (2005).

Nevertheless, DEA models have been widely applied to integrate undesirable outputs in measuring the technical efficiency of production processes.

DEA and Eco-efficiency

The definition of efficiency in DEA is based on the engineering concept of total factor productivity .

It is specified as the ratio of the weighted sum of outputs to the weighted sum of inputs of a production unit.

A linear programming model is solved for each assessed production unit, that seeks to derive weights for the inputs and outputs that would maximise its efficiency.

$$Eficiency = \frac{Outputs}{Inputs} \Longrightarrow Eco-efficiency = \frac{Economic\ Value\ Added}{Environmental\ Damage}$$

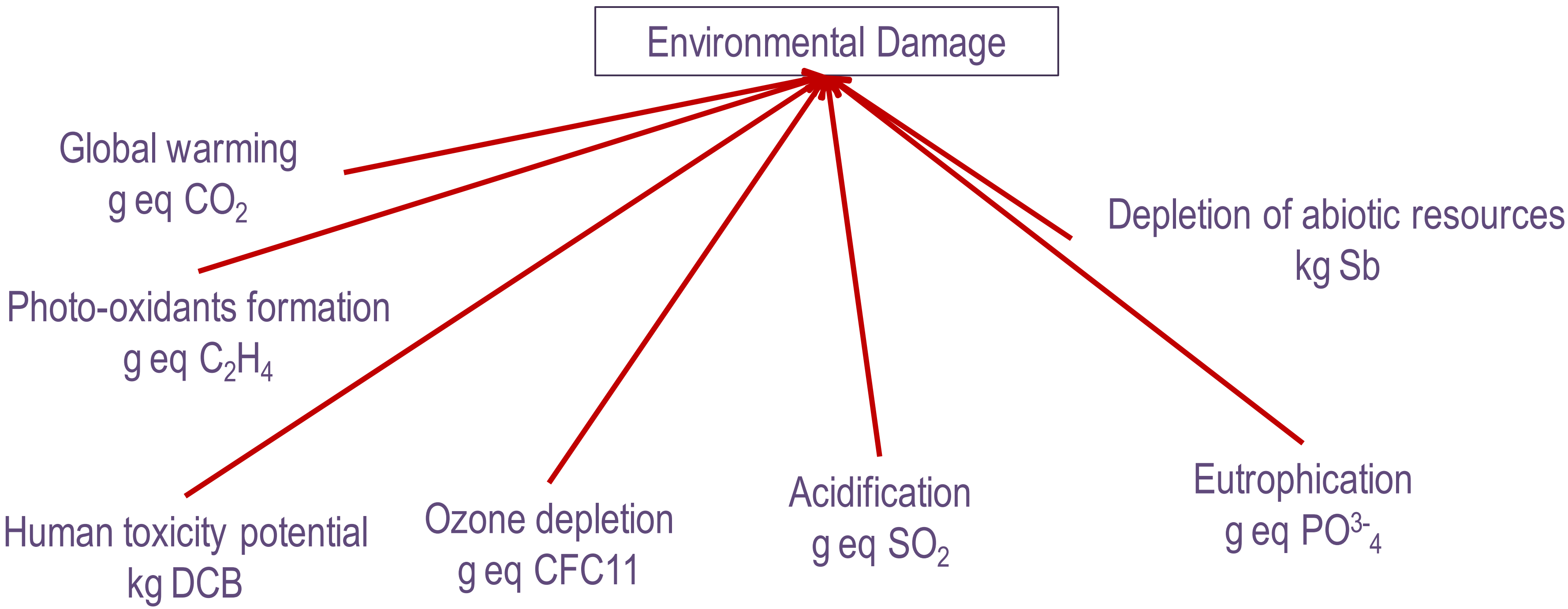
Eco-efficiency issue

Lack of measures like market prices for waste and emissions (undesirable outputs)

Economic Value Added: Currency Unit

Environmental assessment: Different Units

Eco-efficiency issue



Relative Weights and specific weights?
Absolute weights, shadow prices?
Common Set of Weights

Methodology

Methodology to measure eco-efficiency

$$Eco-efficiency = \frac{Economic\ Value\ Added}{Environmental\ Damage}$$

Decission Making Units →Production Scenario

Economic Value Added = Revenues – Intermediate Costs

Environmental Impacts → Life Cycle Assessment

Integration through DEA techniques

Models

DEA Eco-efficiency: Kuosmanen and Kortelainen (2005). RW

Single Price Model: Ballestero (1999). RW+CSW

Absolute Shadow Prices: Kortelainen and Kuosmanen (2007). AW

Models: DEA

$$EE = \max \left[\frac{VA_q}{\sum_{h=1}^{m} w_{hq} \cdot Z_{hq}} \right]$$

Virtual impact

$$s.t.$$

$$\frac{VA_j}{\sum_{h=1}^{m} w_{hq} \cdot Z_{hj}} \leq 1 \qquad \forall j$$

$$w_{hq} \geq 0$$

VA: economic value added for scenario *q*

W_{hq}: weighting of environmental impact *h* for scenario *q*

Z_{hq}: measure of environmental impact *h* for scenario *q*

Models: SPM

Two phase model

Phase 1: equivalent to DEA BCC

$$
\begin{aligned}
&\min \varphi_p \\
&s.t. \\
&\sum_{k=1}^{N} \varphi_k \cdot VA_{ik} \geq VA_{ip} \qquad \forall i \\
&\sum_{k=1}^{N} \varphi_k \cdot Z_{hk} \geq Z_{hp} \qquad \forall h \\
&\sum_{k=1}^{N} \varphi_k = 1 \\
&\varphi \geq 0
\end{aligned}
$$

Models: SPM

Phase 2: with EE scenarios.

$$Min\left[VA_q - \sum_{i=1}^{s} w_{hq} \cdot Z_{hq}\right]$$

$$s.t.$$

$$VA_q - \sum_{i=1}^{s} \beta_{hq} \cdot Z_{hj} \geq 0 \quad \forall j$$

$$\beta_{iq} \geq 0$$

$$Z_{hq} \geq 0$$

Adding and subtracting $\sum_{h=1}^{m} \beta_{hq} \cdot Z_{h\max}$ in objective function and in restrictions

And making the change: $Z_{\lambda j} = Z_{h\max} - Z_{h\,j}$

$$\gamma = \frac{1}{\sum_{i=1}^{m} \beta_{hq} \cdot Z_{h\max}} \quad and \quad \gamma_{hq} = \frac{Z_{hq}}{\sum_{i=1}^{m} \beta_{hq} \cdot Z_{h\max}}$$

Models: SPM

Thus original model becomes:

$$\min \gamma \cdot VA + \sum_{i=1}^{m} \gamma_{iq} \cdot Z_{iq}$$

$$s.t.$$

$$\gamma \cdot VA + \sum_{i=1}^{m} \gamma_{iq} \cdot Z_{iq} \geq 1 \quad \forall j$$

$$\gamma \geq 0$$

Models: SPM

The eco-efficient scenarios are non-dominated points on the eco-efficiency frontier

The eco-efficient frontier is bounded by the points:

$$\left(Z_{0*}, Z_{1*}, Z_{2*}, \ldots, Z_{j-1*}, Z_j^*, Z_{j+1*} \ldots, Z_{m*}\right) \forall j$$

Where Z^* denotes the ideal or anchor value while Z_*, denotes the anti-ideal value or nadir value.

These points on the frontier are introduced with a new family of restrictions:

$$\gamma_0 \cdot VA^* + \gamma_{1q} \cdot Z_{1*} + \gamma_{2q} \cdot Z_{2*} + \ldots + \gamma_{mq} \cdot Z_{m*} = 1$$

$$\gamma_0 \cdot VA_* + \gamma_{1q} \cdot Z_1^* + \gamma_{2q} \cdot Z_{2*} + \ldots + \gamma_{mq} \cdot Z_{m*} = 1$$

$$\ldots$$

$$\gamma_0 \cdot VA_* + \gamma_{1q} \cdot Z_1 + \gamma_{2q} \cdot Z_{2*} + \ldots + \gamma_{mq} \cdot Z_m^* = 1$$

Models: ASP

Absolute Shadow Prices

$$\max EE_q$$

$$s.t.$$

$$EE_q \leq \left(VA_q - \sum_{h=1}^{m} w_{hq} \cdot Z_{hq} \right) - \left(VA_n - \sum_{h=1}^{m} w_{hq} \cdot Z_{hn} \right) \qquad \forall n$$

$$VA_q - \sum_{h=1}^{m} w_{hq} \cdot Z_{hq} \geq 0$$

$$w_{hq} \geq 0$$

Eco-efficiency of scenario *q*: difference between environmental added value of scenario *q* and the best scenario of the group at the given prices

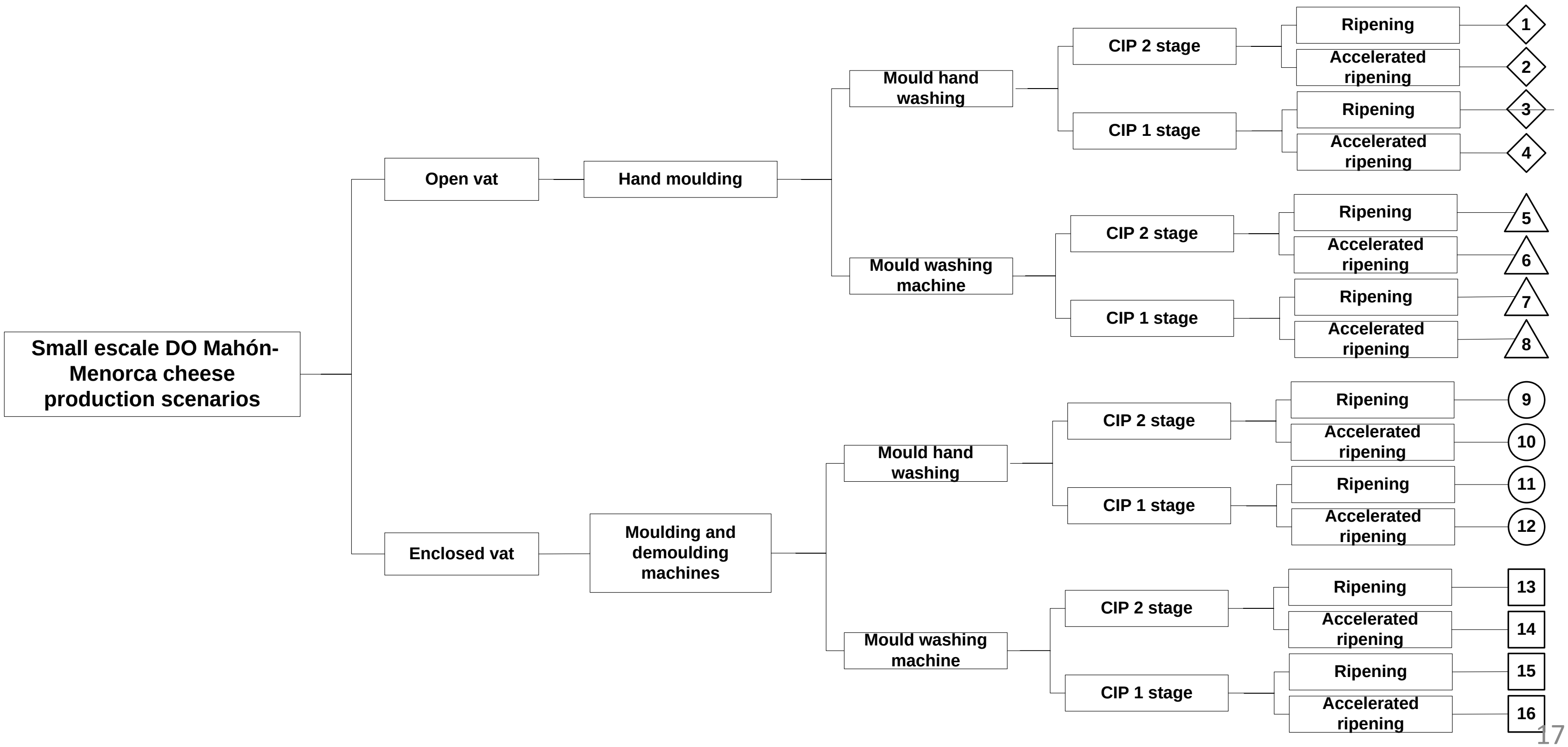
Case study

Case study

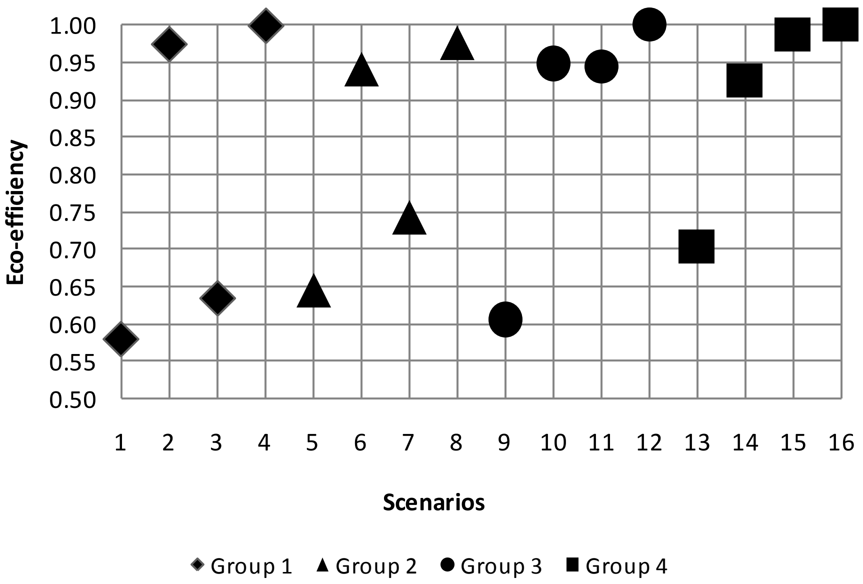
Mahón-Menorca cheese small scale production in Spain

16 scenarios: different automation degrees and cleaning techniques

Impact categories: water consumption, global warming and eutrophication



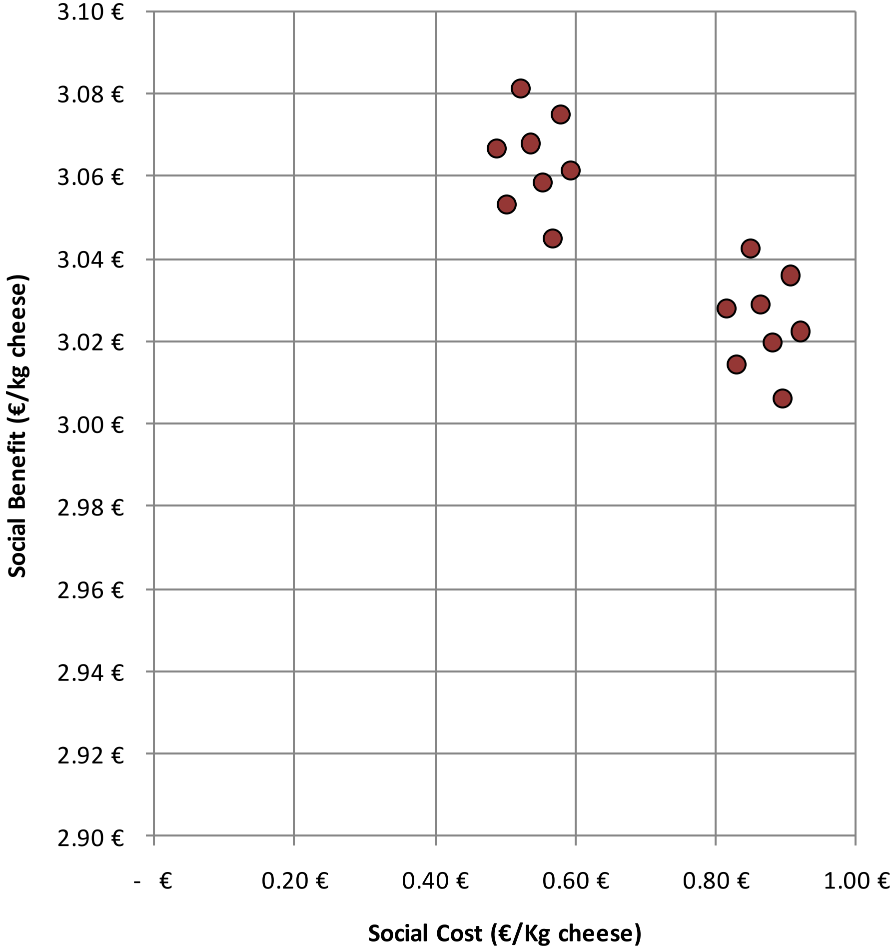
Results DEA



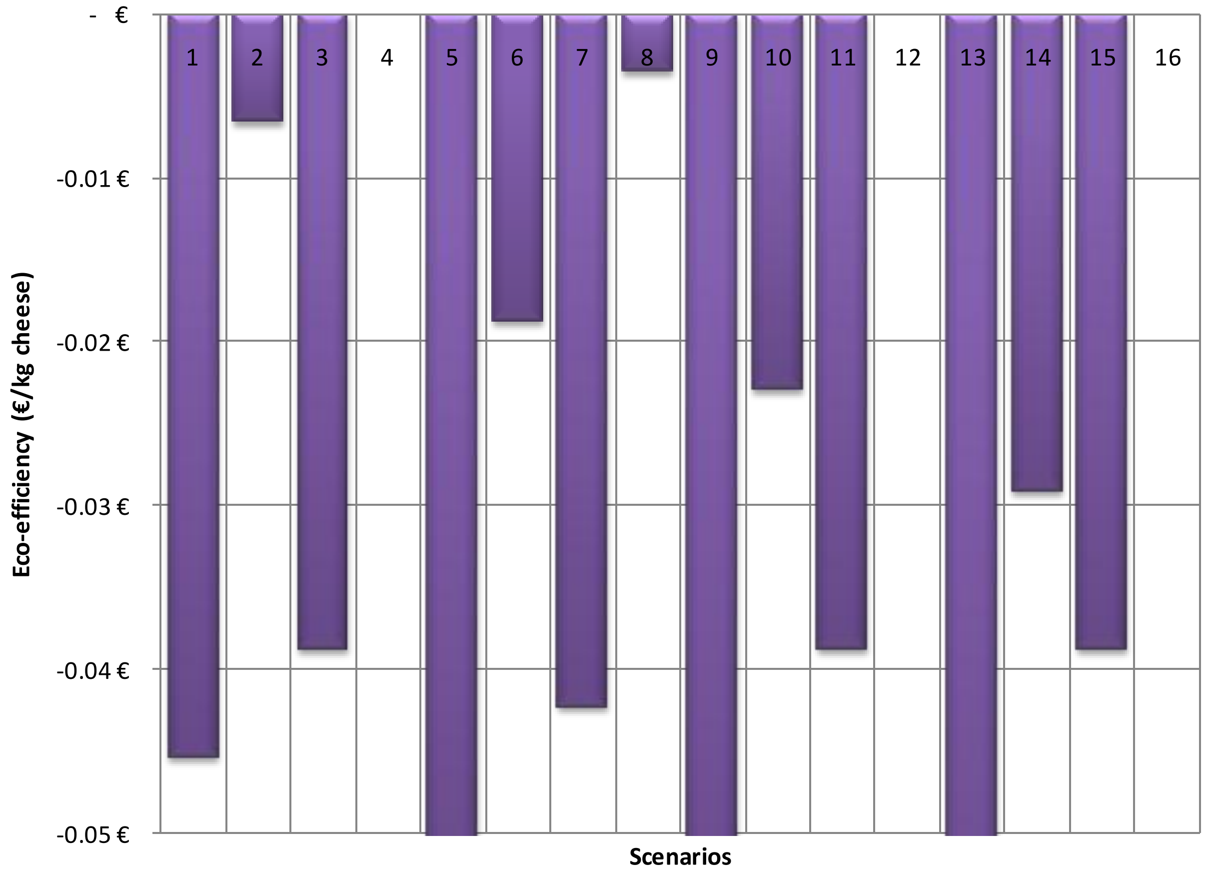
Virtual impact

Sc	W_1Z_1	W_2Z_2	W_3Z_3
1	0,17	0,83	**0,00**
2	**0,00**	1,00	**0,00**
3	1,00	**0,00**	**0,00**
4	0,05	0,93	0,02
5	1,00	**0,00**	**0,00**
6	0,11	0,89	**0,00**
7	1,00	**0,00**	**0,00**
8	0,10	0,90	**0,00**
9	1,00	**0,00**	**0,00**
10	0,12	0,88	**0,00**
11	0,81	**0,00**	0,19
12	0,48	0,45	0,06
13	1,00	**0,00**	**0,00**
14	0,10	0,90	**0,00**
15	1,00	**0,00**	**0,00**
16	0,43	0,43	0,14

Results SPM


3.10 €
3.08 €
3.06 €
3.04 €
3.02 €
3.00 €
2.98 €
2.96 €
2.94 €
2.92 €
2.90 €
Social Benefit (€/kg cheese)
- €
0.20 €
0.40 €
0.60 €
0.80 €
1.00 €
Social Cost (€/Kg cheese)

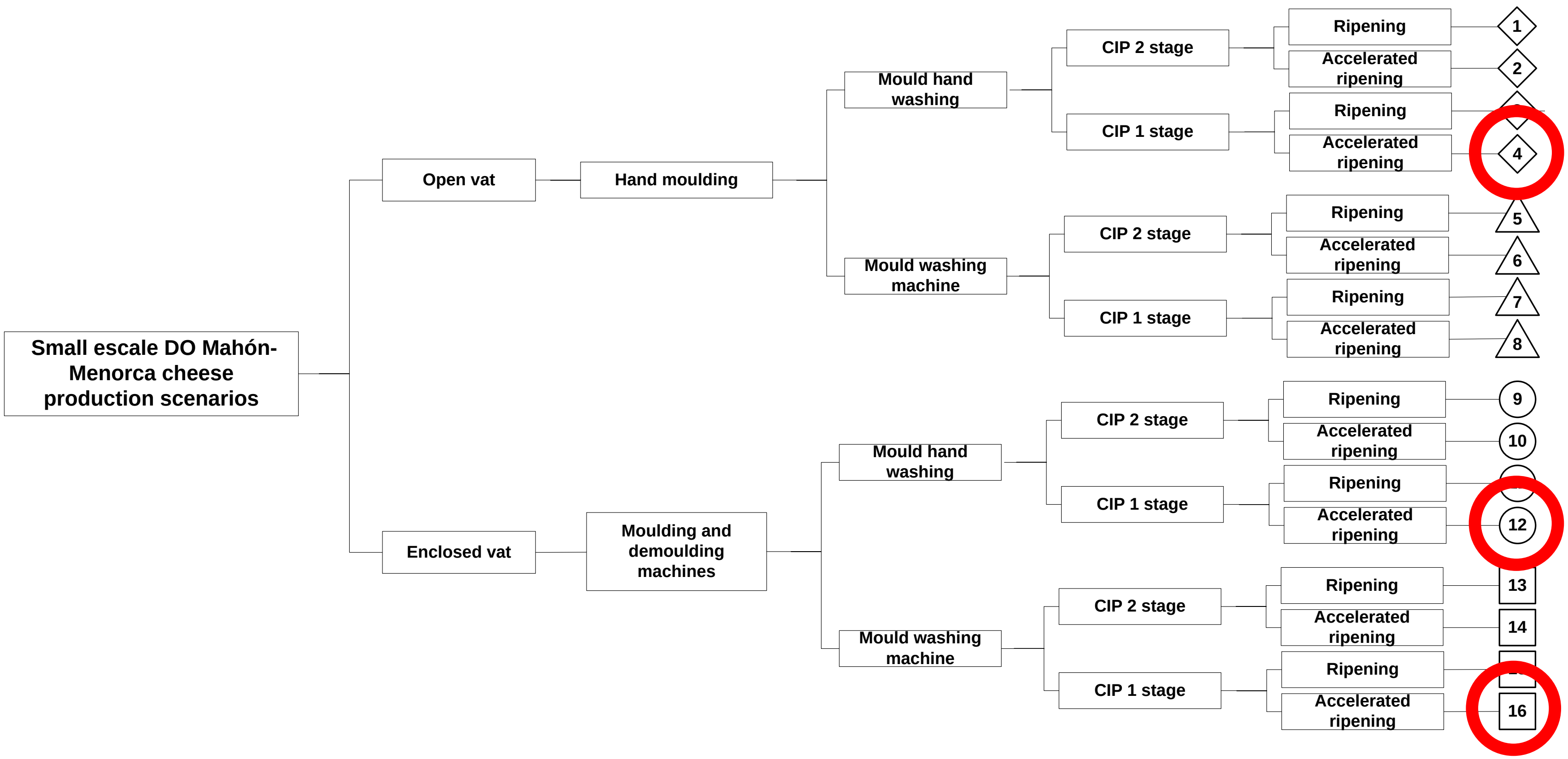
Results ASP



EE: minimum monetary social loss per unit of product in scenario *q* compared to the best alternative

Results comparisons

Same set of eco-efficient scenarios



Weights

DEA Weights	Water Consumption	Global Warming	Eutrophication
4	0,02	8,42	16,77
12	0,21	3,99	219,88
16	0,23	3,60	239,56
SPM Weights	Water Consumption	Global Warming	Eutrophication
	0,01	1,20	8,54
	€ (m^3 water) $^{-1}$ (kg cheese)$^{-1}$	€ (g eq CO_2)$^{-1}$ (kg cheese)$^{-1}$	€ (g eq PO_4^{3})$^{-1}$ (kg cheese)$^{-1}$
ABS Weights	Water Consumption	Global Warming	Eutrophication
4	0,04 €	7,94 €	0,27 €
12	0,23 €	0,23 €	312,62 €
16	0,23 €	4,73 €	0,23 €

DEA Virtual Weights	Water Consumption	Global Warming	Eutrophication
4	5%	93%	2%
12	48%	45%	6%
16	43%	43%	14%
SPM Virtual Weights	Water Consumption	Global Warming	Eutrophication
4	15%	78%	7%
12	12%	86%	2%
16	10%	87%	3%
ABS Virtual Weights	Water Consumption	Global Warming	Eutrophication
4	12%	88%	0%
12	82%	4%	14%
16	44%	56%	0%

Discussion

Discussion

Numerator: Economic Value Added or Benefit?

In EVA: labor costs and amortizations not included

Is DEA suitable to integrate environmental impacts in an EE ratio?

- Objective method of weighting the environmental impacts, irrespective of individual thoughts and preference.
- Problems to understand the meaning of the weights

- First model: eco-efficient frontier
- Second model: discrimination power + bidimensional space
- Third model: stronger link between economic result and environmental impacts

- Zero problem: unbalanced shares of the denominator: more restrictions?