Land sharing vs land sparing to protect water from pesticide pollution?

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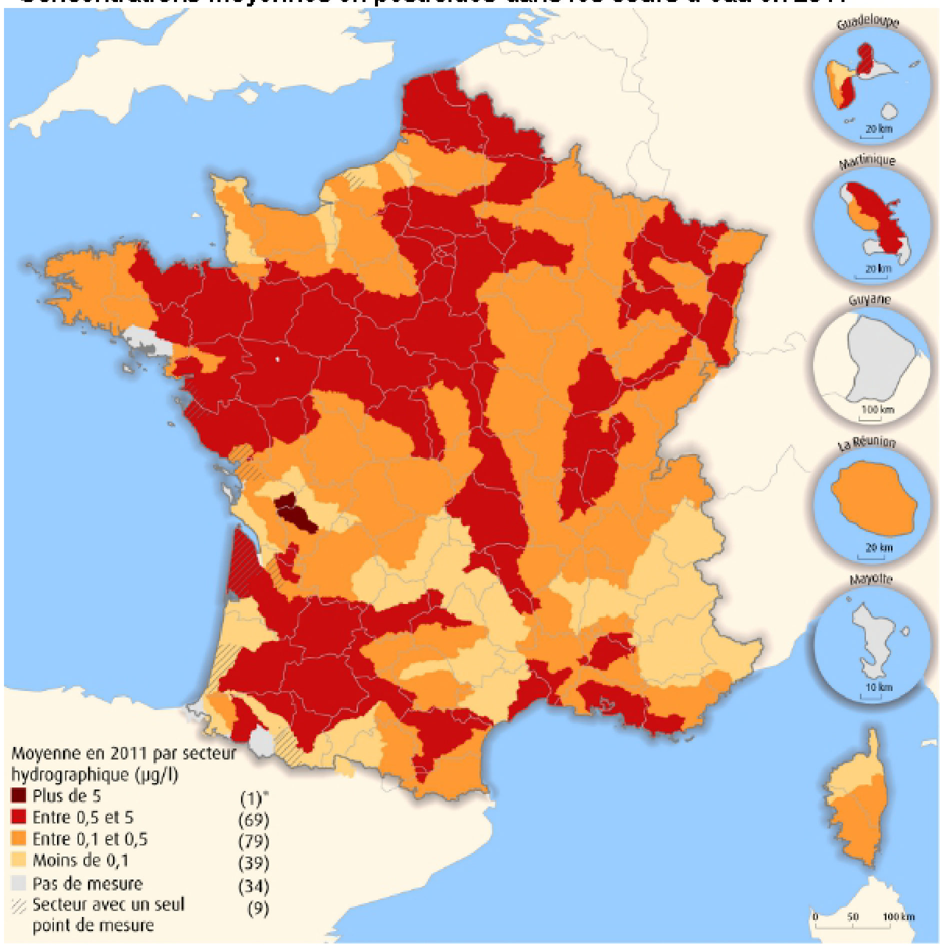
Outline

- Motivations and literature
- Theoretical framework
- Empirical application
- Conclusion and extension

Pesticide concentration and land cover in France

Concentrations moyennes en pesticides dans les cours d'eau en 2011



*: les données de ce secteur sont fortement influencées par une contamination isolée et non nécessairement représentative du secteur dans sa globalité

Source : : SOeS d'après agences de l'eau et offices de l'eau, 2013 – MEDDE, BD Carthage®, 2012

Taux d'occupation des sols par maille hexagonale de 2 km de côté

Source : UE-SOeS, CORINE Land Cover, 2006.

Agricultural financial supports to protect environment

2015-2020 Common Agricultural Policy in France:

160 M€/year for conversion to and conservation of organic farming (European + national budget)

250 M€/year for Climatic Agri-Environmental Schemes (European + national budget)

Land purchase to protect water from pollution

Water policy from french water agencies:

≈ 68 M€ dedicated to the purchase of 13 426 ha of wetlands from 2009 to 2012

Sensitive natural spaces policy from french « Départements »:

2,5 M€ dedicated to the purchase and management of lands for the purpose of water quality preservation between 2002 and 2011

Questions

- What is the best strategy to implement to protect water from pesticide pollution? Land purchase or agricultural financial supports?

- Should both strategies be considered separately or in a combined way?

- Do the answers depend on the land-planner's objective (economic / ecological / economic + ecological)?

Main contribution to the literature

<u>Adaptation of literature on biodiversity conservation:</u>

- Land sharing vs land sparing literature (Green *et al.*, 2005)
- *Ex ante* reserve site selection literature (Ando *et al.*, 1990; Babcock et al., 1996)

<u>To the *ex ante* water preservation case:</u>

- Land sparing = purchasing lands and excluding agricultural production
- Land sharing = agricultural financial supports for the adoption of low pesticide practices

Our analysis of water policy intervention

3 possible types of intervention:

- Land sharing only: subsidies to adopt less input-consuming practices
- Land sparing only: purchase of land put out of production
- A mix of both

3 types of regulators:

- Economic objective: max surface s/t budget
- Ecological objective: max ecological benefits s/t surface
- Economic & ecological objective: max ecological benefits s/t budget

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According to the strategy chosen - sharing ou sparing – a field *i* provides, per surface unit:

<u>An ecological benefit $b_{h,i}$ or $b_{p,i}$:</u>

- amount of pesticides avoided in downstream waterbodies

<u>A cost $c_{h,i}$ or $c_{p,i}$</u>

- $c_{p,i}$: opportunity cost of agricultural production
- $c_{h,i}$: minimum subsidy for farmers to adopt alternative practices

Land sharing only case: the « economic regulator » (A1)

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}, \text{ s.t. } \sum_{i=1}^{I} x_{h,i}.c_{h,i} \leq \text{B and } x_{h,i} \leq s_i$$

Land sharing only case: the « economic regulator » (A1)

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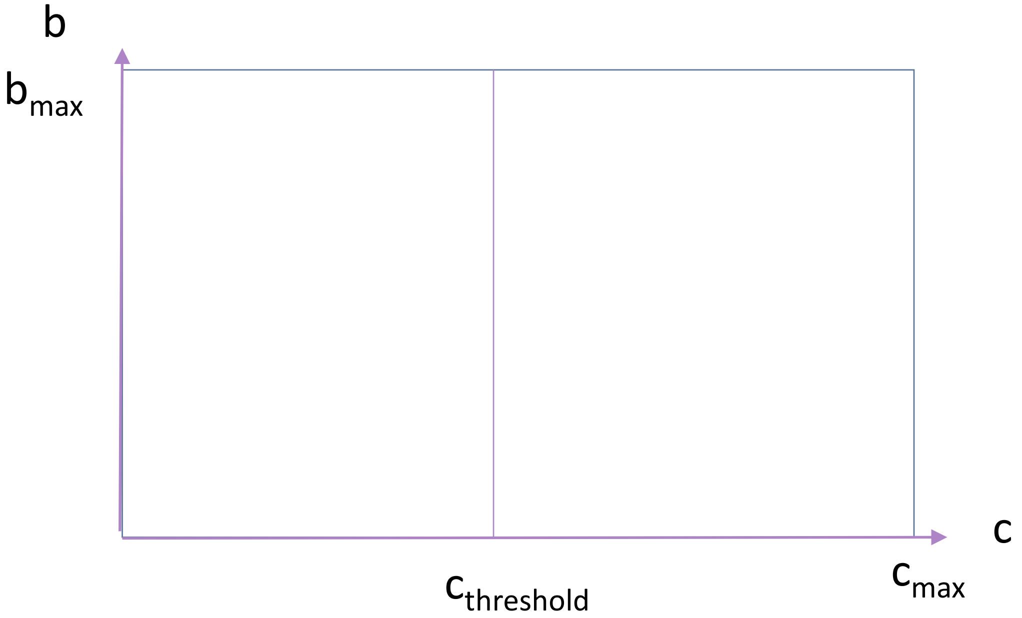
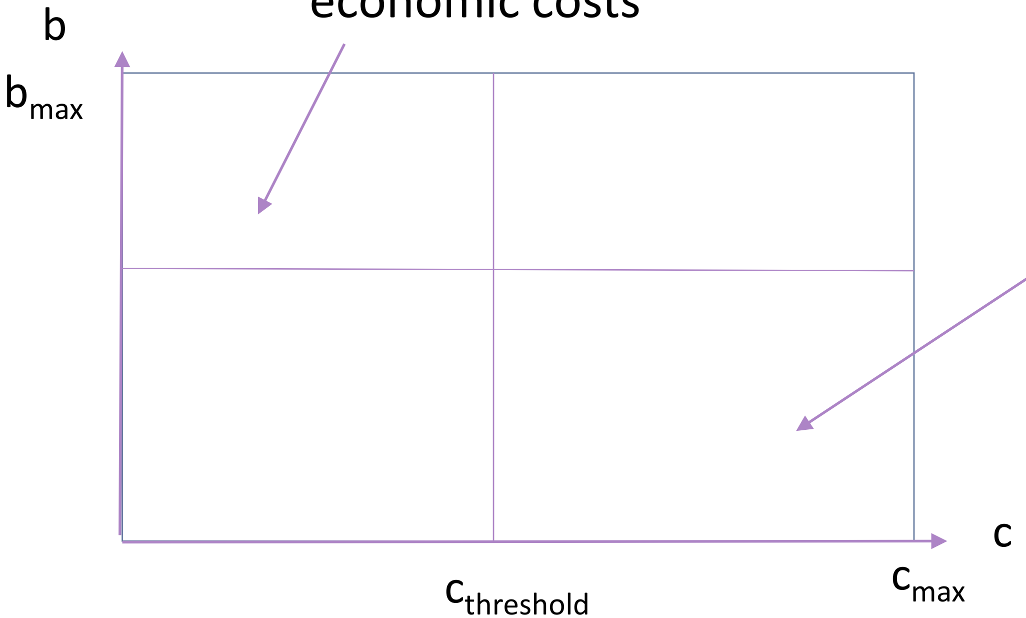


Range of values of ecological benefits and costs per ha

Land sharing only case: the « economic regulator » (A1)

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}, \text{ s.t. } \sum_{i=1}^{I} x_{h,i}.c_{h,i} \leq \text{B and } x_{h,i} \leq s_i$$

Fields with high ecological benefits and low economic costs



Fields with high economic costs and low ecological benefits

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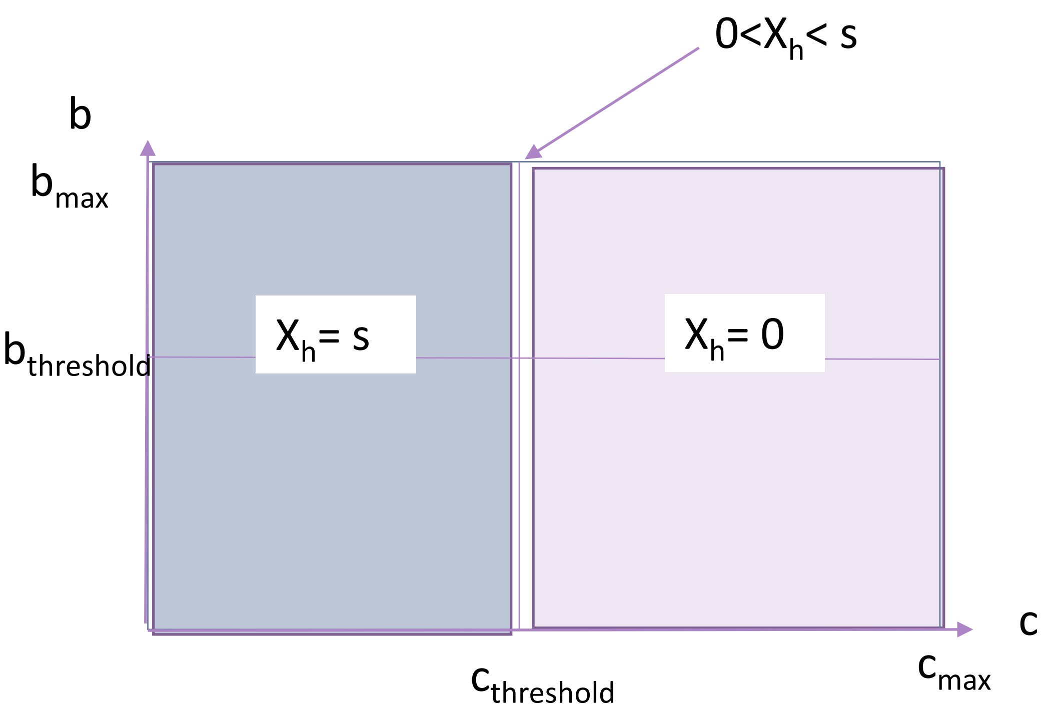

Empirical rule of selection: fields with the lowest cost are selected first

Land sharing only case: the « ecological regulator » (A2)

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i} . b_{h,i} \text{, s.t.} \sum_{i=1}^{I} x_{h,i} \leq \text{A and } x_{h,i} \leq s_i$$

Land sharing only case: the « ecological regulator » (A2)

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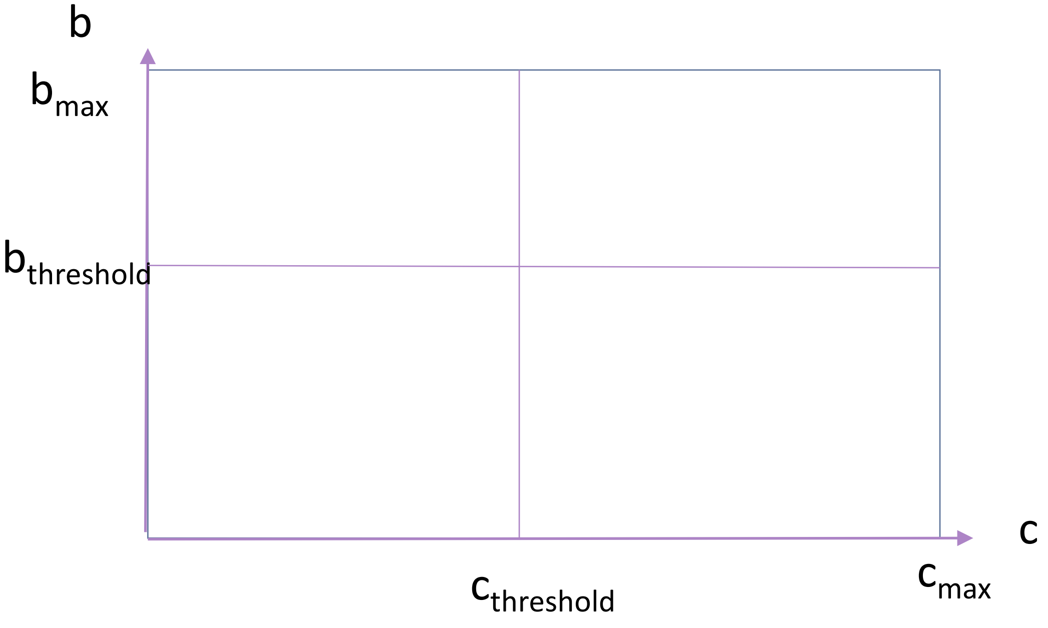

Land sharing only case: the « ecological regulator » (A2)

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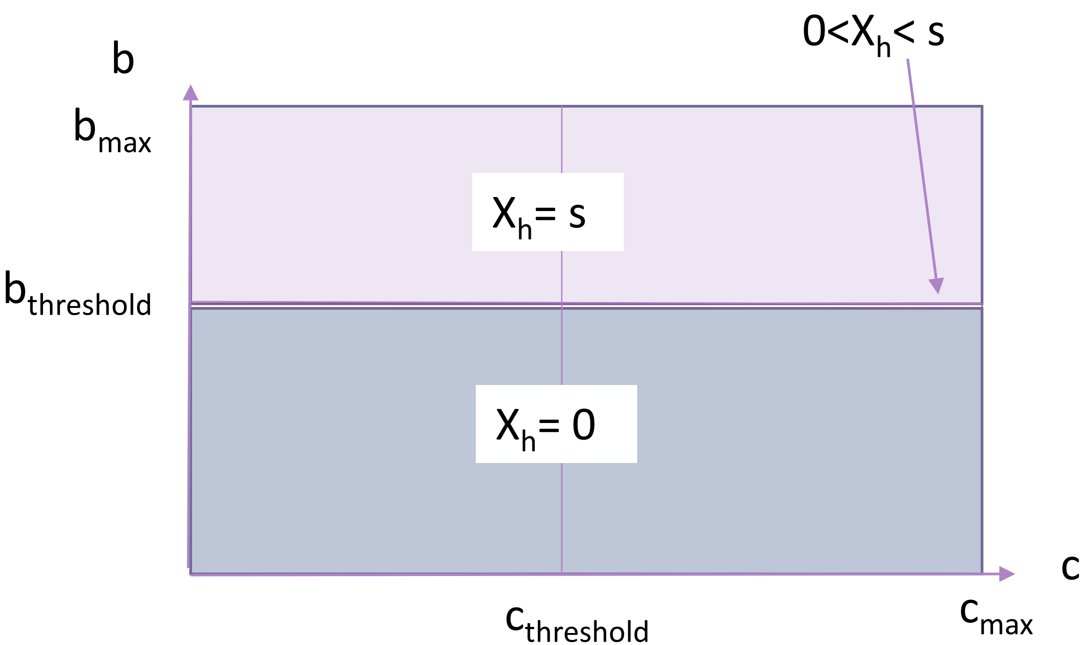


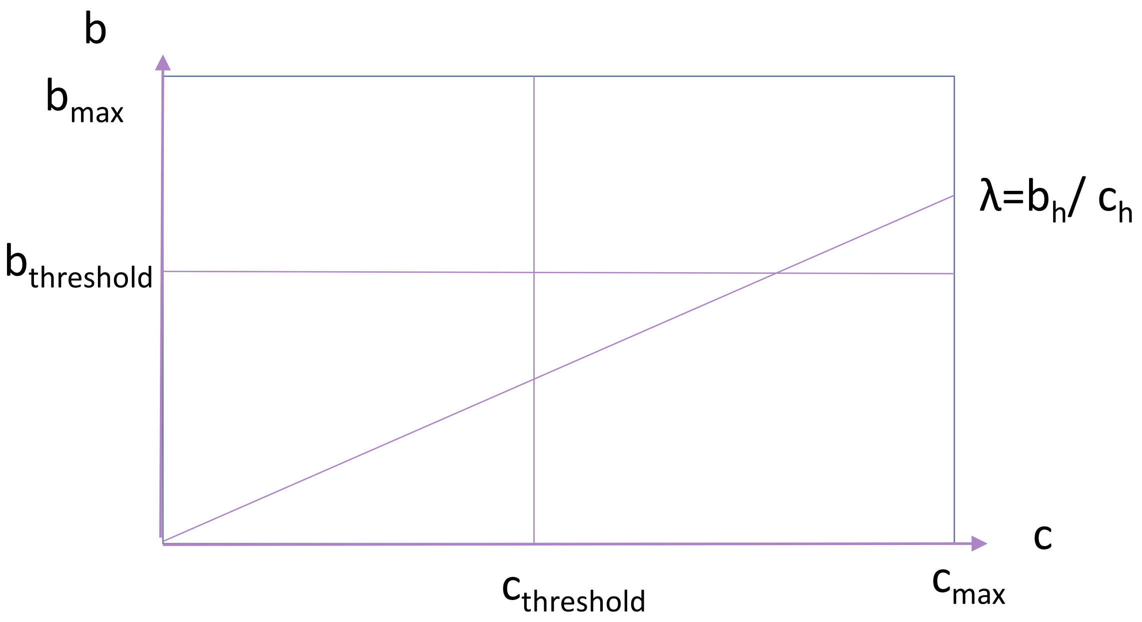
Empirical rule of selection: fields with the highest ecological gain are selected first

Land sharing only case: the « mixed regulator » (A3)

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} \leq \text{B and } x_{h,i} \leq s_i$$

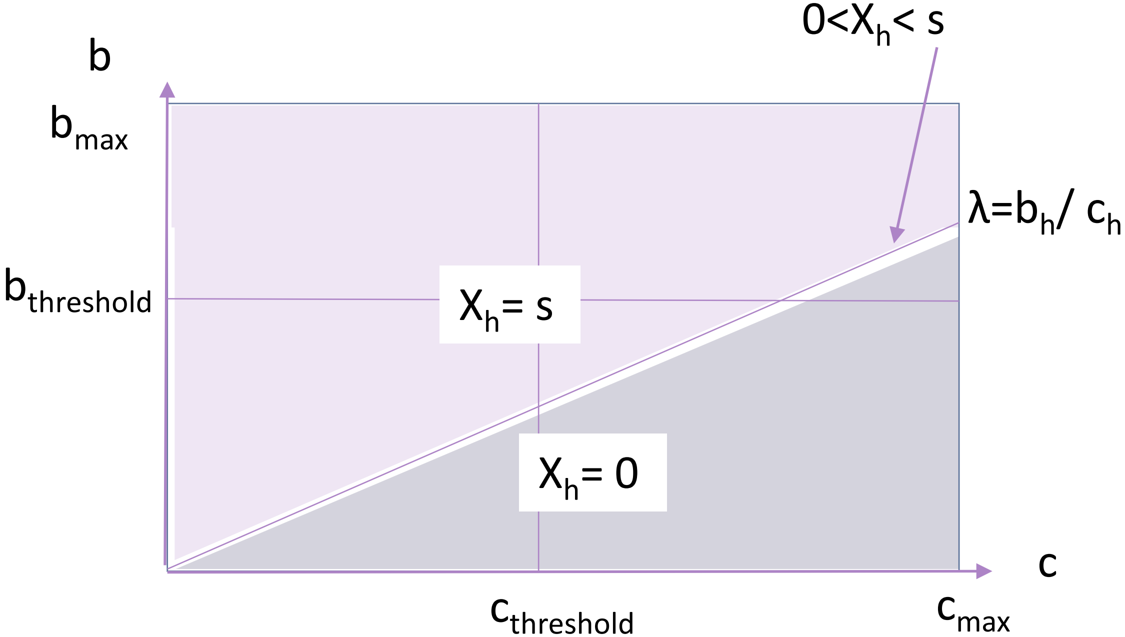
Land sharing only case: the « mixed regulator » (A3)

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i}, \text{ s.t. } \sum_{i=1}^{I} x_{h,i}.c_{h,i} \le \mathrm{B} \text{ and } x_{h,i} \le s_i$$



Land sharing only case: the « mixed regulator » (A3)

$$\max_{x_{h,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i}, \text{ s.t. } \sum_{i=1}^{I} x_{h,i}.c_{h,i} \leq \text{B and } x_{h,i} \leq s_i$$



Empirical rule of selection: fields with the highest ratio are selected first

What happens when strategies can be mixed?

Mixed strategies case: the « economic regulator » (A1)

$$\underset{x_{h,i}\,,\,x_{\mathrm{p},i}}{ma}\sum_{i=1}^{I} x_{h,i}x+\sum_{i=1}^{I} x_{\mathrm{p},i}\,,\ \text{s.t.}\sum_{i=1}^{I} x_{h,i}.c_{h,i}+\sum_{i=1}^{I} x_{\mathrm{p},i}.c_{\mathrm{p},i}\leq \mathrm{B}\ \text{and}\ x_{h,i}+x_{\mathrm{p},i}\leq s_i$$

Mixed strategies case: the « economic regulator » (A1)

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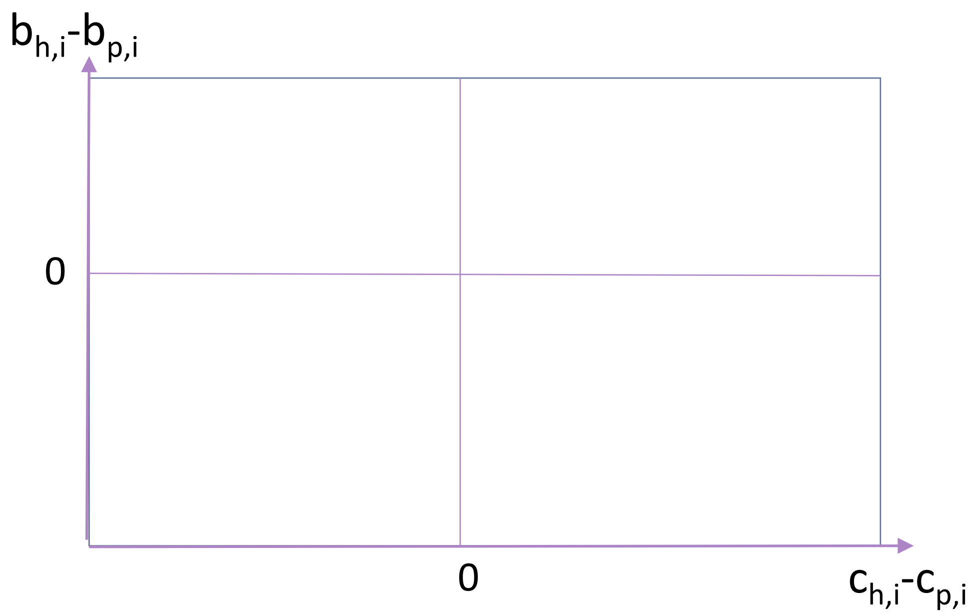
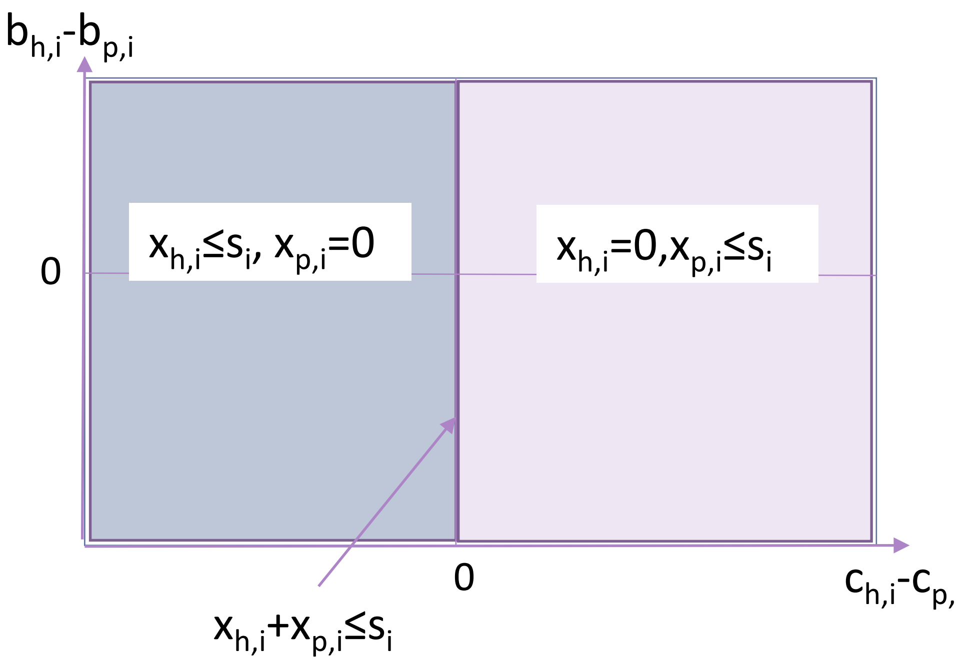


Mixed strategies case: the « economic regulator » (A1)

$$\underset{x_{h,i},\, x_{\mathrm{p},i}}{ma} \sum_{i=1}^{I} x_{h,i}x + \sum_{i=1}^{I} x_{\mathrm{p},i}\,,\ \text{s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}.c_{\mathrm{p},i} < \mathrm{B} \text{ and } x_{h,i} + x_{\mathrm{p},i} \leq s_i$$



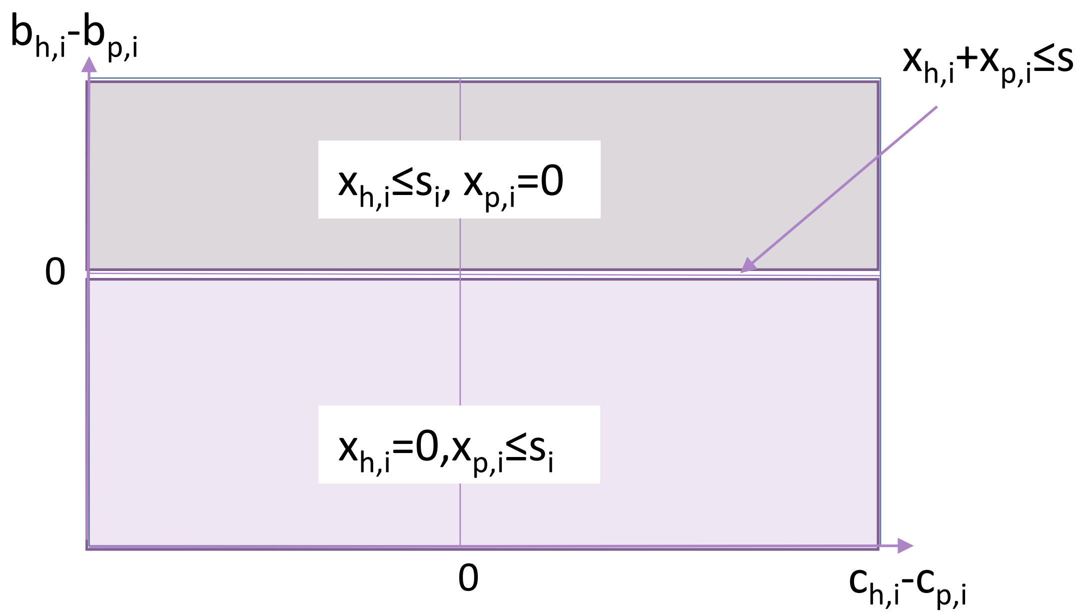
Empirical rule of selection: fields are ranked according the the minimum cost between strategies

Mixed strategies case: the « ecological regulator » (A2)

$$\max_{x_{h,i},x_{\mathrm{p},i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i}.b_{\mathrm{p},i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i} + \sum_{i=1}^{I} x_{\mathrm{p},i} \leq \mathrm{A} \text{ and } x_{h,i} + x_{\mathrm{p},i} \leq s_i$$

Mixed strategies case: the « ecological regulator » (A2)

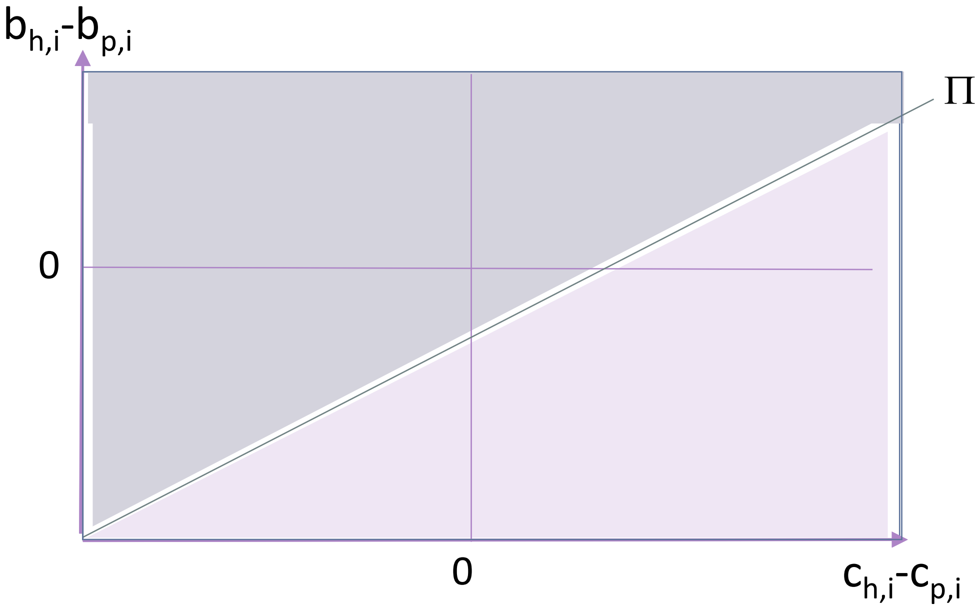
$$\max_{x_{h,i},x_{p,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{p,i}.b_{p,i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i} + \sum_{i=1}^{I} x_{p,i} \leq \text{A and } x_{h,i} + x_{p,i} \leq s_i$$



Empirical rule of selection: fields are ranked according to the maximum ecological benefit between strategies

Mixed strategies case: the « mixed regulator » (A3)

$$\max_{x_{h,i},x_{p,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{p,i}.b_{p,i}, \text{ s.t. } \sum_{i=1}^{I} x_{h,i}.c_{h,i} + \sum_{i=1}^{I} x_{p,i}.c_{p,i} \leq \text{B and } x_{h,i} + x_{p,i} \leq s_i$$



$$\Pi = \frac{b_{h,i} - b_{p,i}}{c_{h,i} - c_{p,i}}$$

Empirical rule of selection: fields are **first** ranked according to the maximum benefit to cost ratio between both strategies.

Mixed strategies case: the « mixed regulator » (A3)

$$\max_{x_{h,i},x_{p,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{p,i}.b_{p,i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} + \sum_{i=1}^{I} x_{p,i}.c_{p,i} \leq \text{B and } x_{h,i} + x_{p,i} \leq s_i$$

A field i is shared if: $\frac{b_{h,i}}{c_{h,i}} > \frac{b_{p,i}}{c_{p,i}}$

A field i is spared if: $\frac{b_{h,i}}{c_{h,i}} < \frac{b_{p,i}}{c_{p,i}}$

A field i is both spared and shared if: $\frac{b_{h,i}}{c_{h,i}} = \frac{b_{p,i}}{c_{p,i}}$

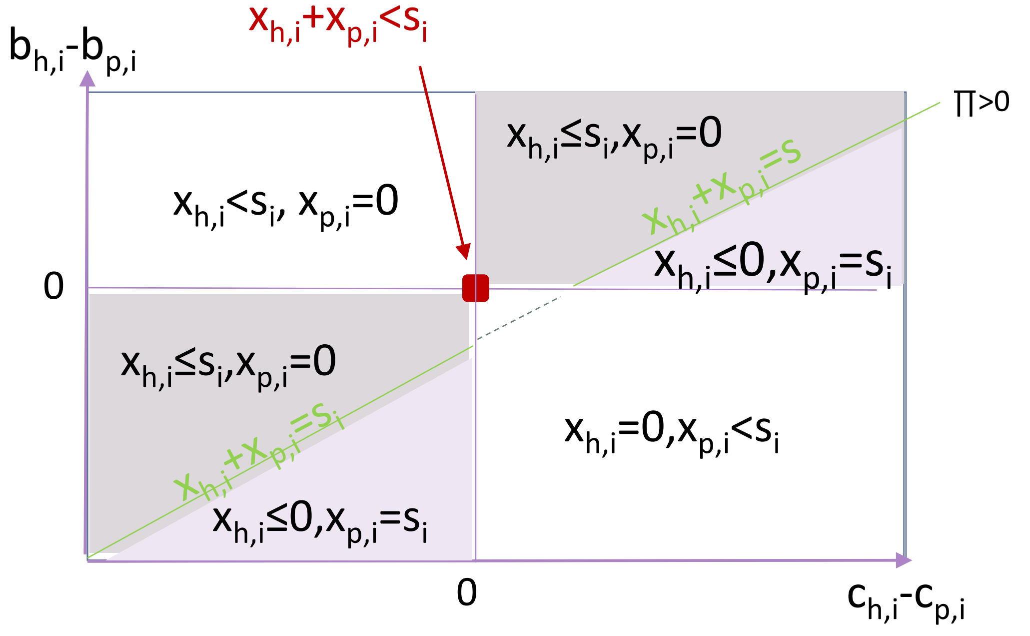
Empirical rule of selection: to be selected, each field *i* must **additionally** satisfy:

$$\max\left(\frac{b_{h,i}}{c_{h,i}}, \frac{b_{p,i}}{c_{p,i}}\right) > \max\left(\frac{b_{s2,j} - b_{s1,j}}{c_{s2,j} - c_{s1,j}}\right)_{j<i}$$

Where j refers to plots already selected. Otherwise, j switches from s1 to s2.

Mixed strategies case: the « mixed regulator » (A3)

$$\max_{x_{h,i},x_{p,i}} \sum_{i=1}^{I} x_{h,i}.b_{h,i} + \sum_{i=1}^{I} x_{p,i}.b_{p,i}, \text{ s.t.} \sum_{i=1}^{I} x_{h,i}.c_{h,i} + \sum_{i=1}^{I} x_{p,i}.c_{p,i} \leq \mathrm{B} \text{ and } x_{h,i} + x_{p,i} \leq s_i$$



To sum up the mixed strategies case

<u>Fields unaffected by the regulator’s type</u>

- NW and SE quadrants
- $b_{h,i}$-$b_{p,i}$ and $c_{h,i}$-$c_{p,i}$ of opposite signs
- « specialized » sharing/sparing fields

<u>Fields switching intervention strategy depending on the regulator’s type</u>

- NE and SW quadrants
- $b_{h,i}$-$b_{p,i}$ and $c_{h,i}$-$c_{p,i}$ of similar signs
- less clear-cut optimal strategy for the field

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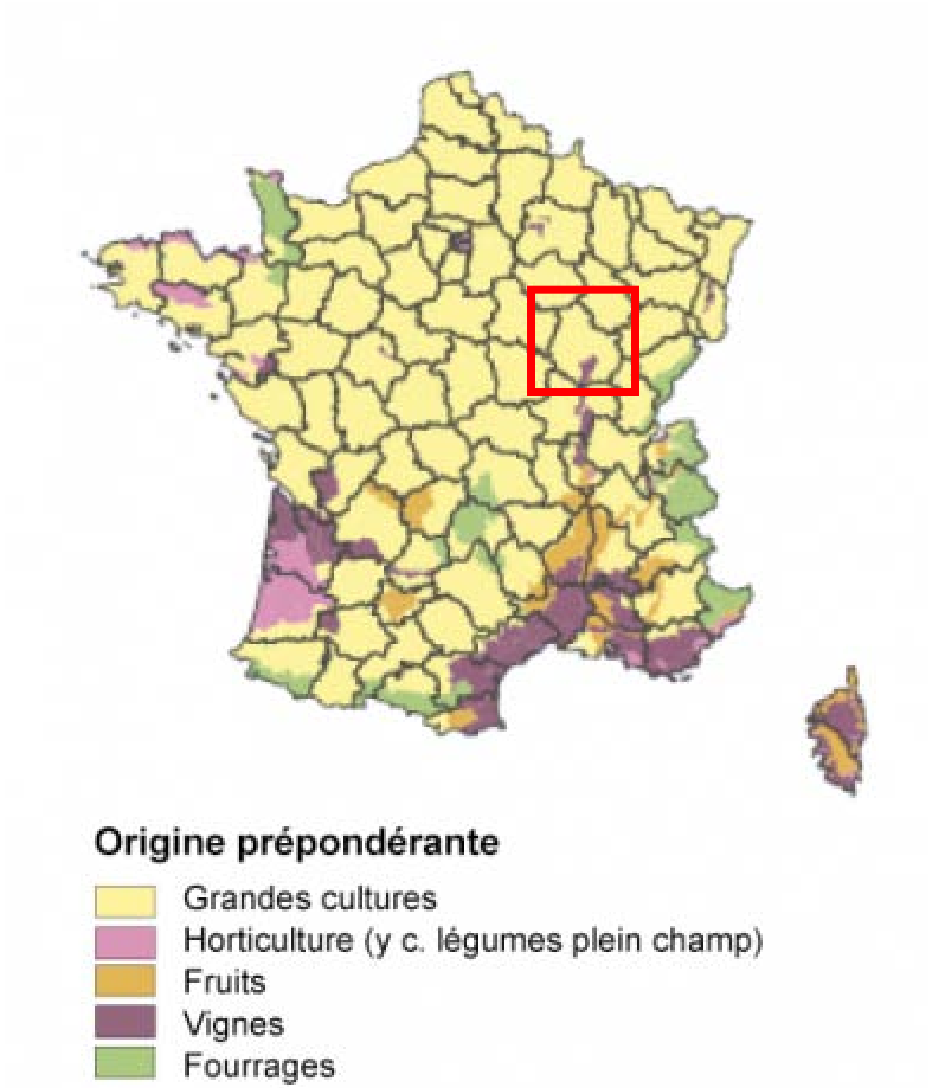
Cereal crops as the main source of pesticide use in France

Source: Butault *et al.* (2010)

Cereal crops as the main source of pesticide use in France



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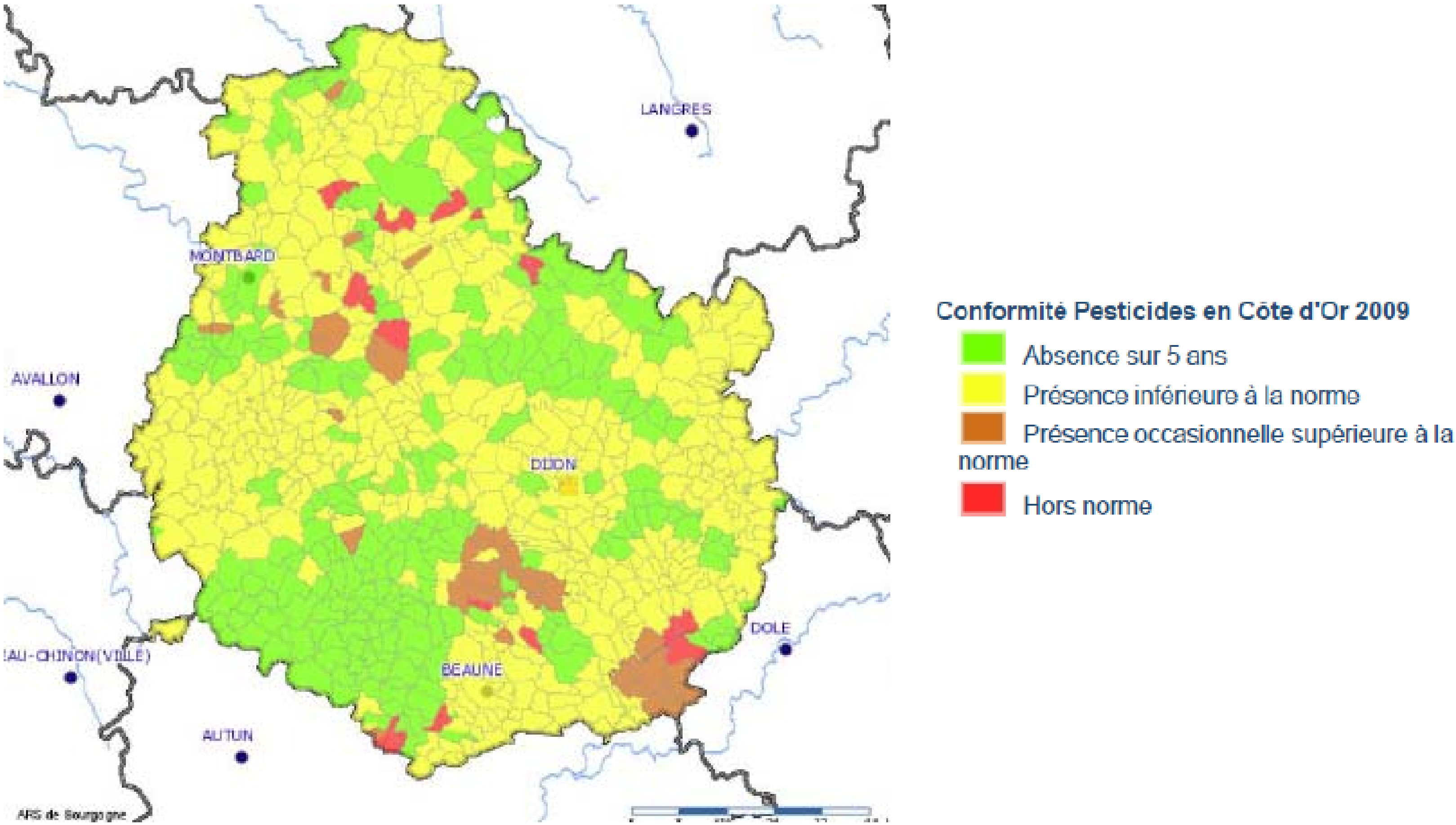
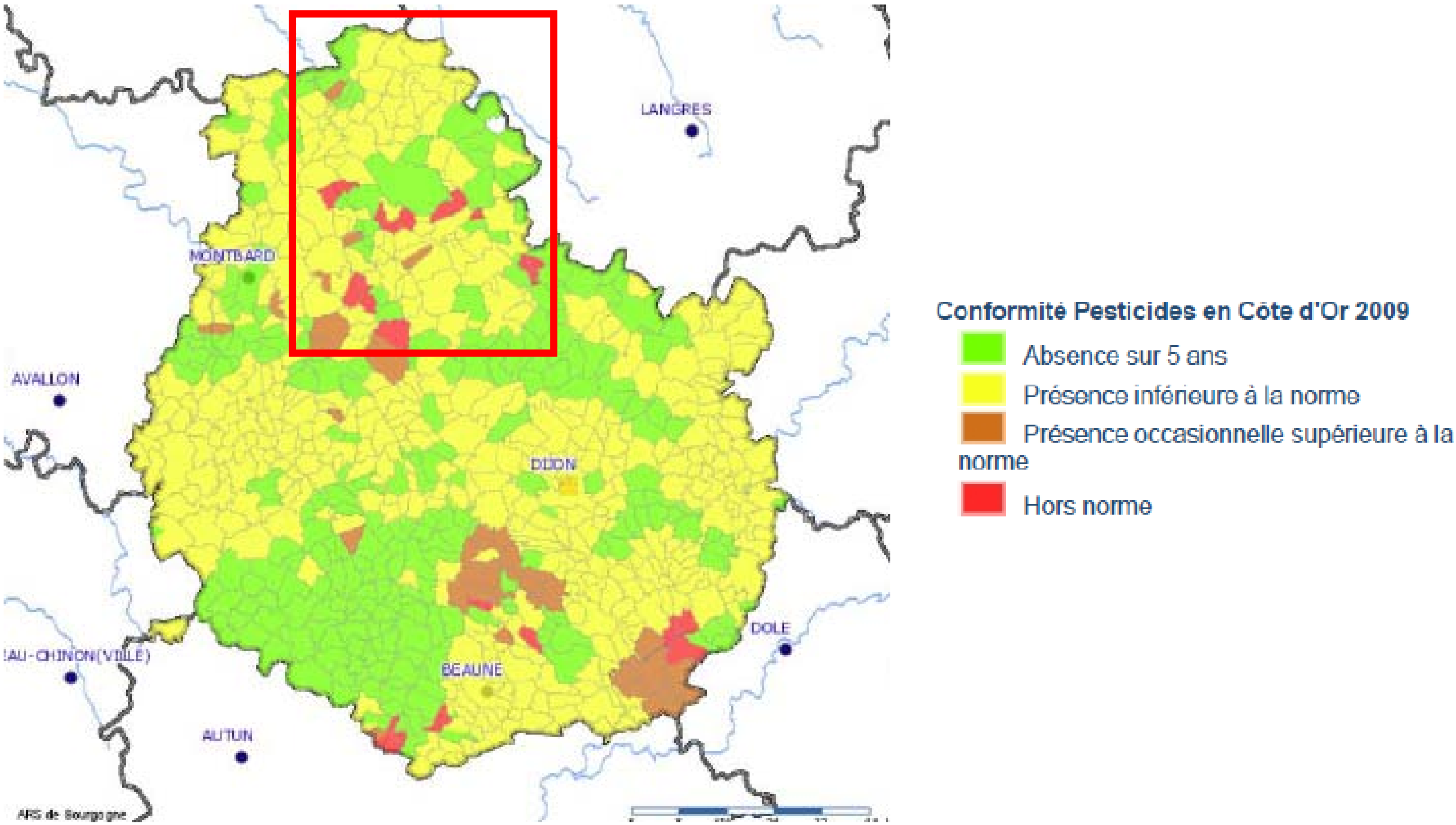
The example of Côte-d’Or



Source: DDASS Côte-d’Or

The example of Côte-d’Or



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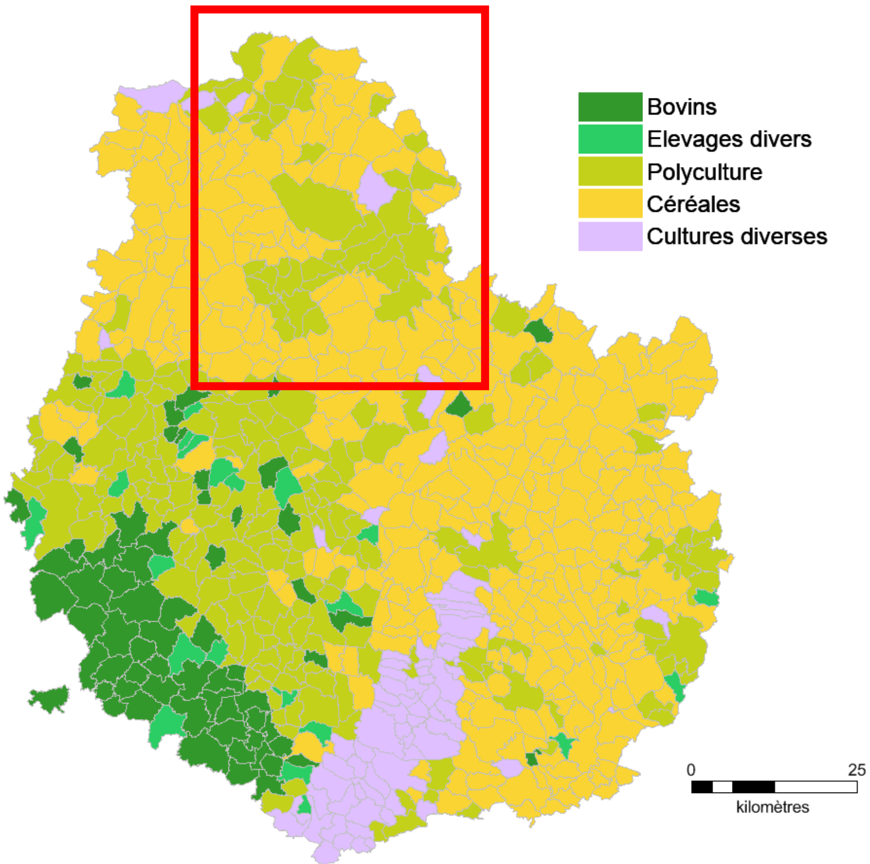
Focus on Seine-Ource catchment

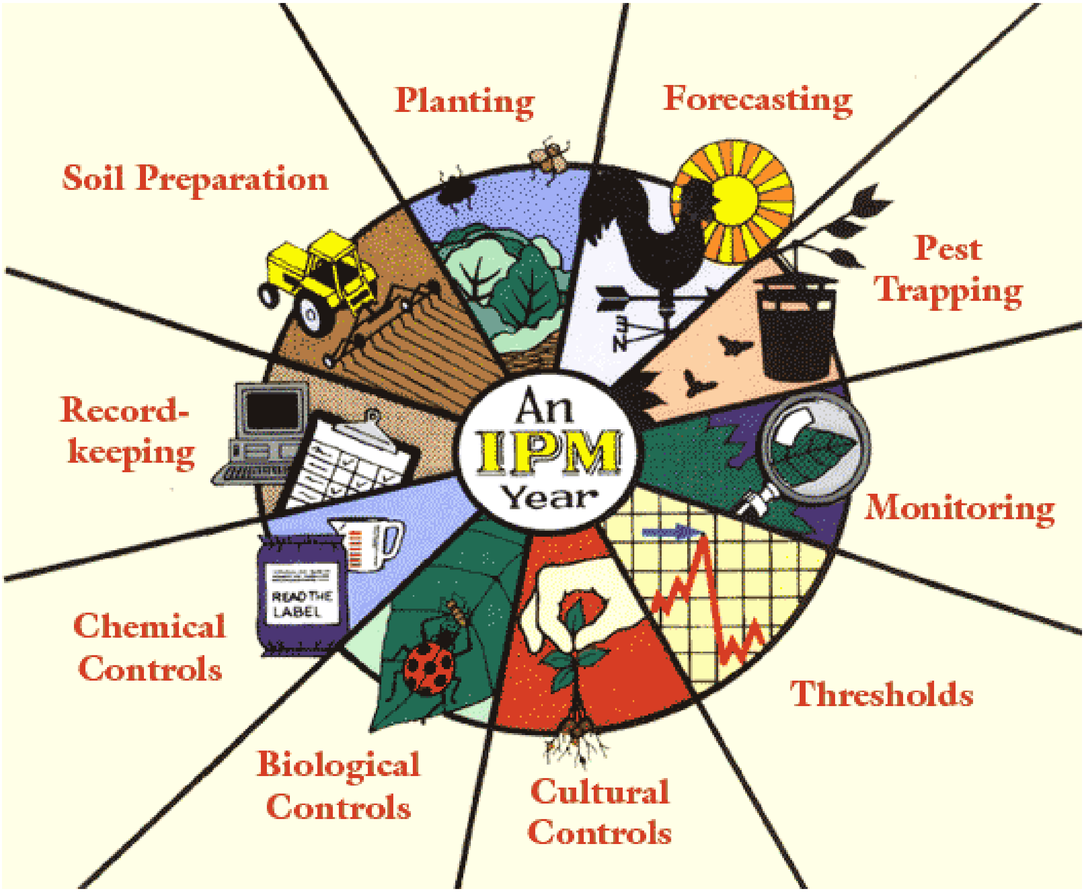


Source: Recensement de l'agriculture 2000, Agreste

<u>Rural area of 80 000 ha</u>

- 59 300 ha of agricultural lands
  - 21% of permanent pastures
  - 63% of cereal crops
  - 16% of fodder production

An original land sharing strategy: Integrated pest management



Source: http://www.nysipm.cornell.edu/ipm_is/ipmwheel.asp

Benefits and costs computations

Cost–land sparing :

- Purchasing cost of agricultural land
- Estimation by the hedonic pricing method

Cost –land sharing :

- Fixed subsidy per ha (50€ for cereal, 15 € for fodder), 15 years, discount rate 4%

Ecological benefits: I-Phy indicator (Bockstaller et al., 2008)

- Risk of contamination of water; at the field scale
- Based on environmental variables (distance to water body, leaching potential, etc.), practice variables (crop, sowing date, etc.), pesticide variables (active material, half-life, etc.)

Descriptive statistics on 2273 fields

	Mean	Standard Deviation	Minimum	Maximum
Surface (ha)	3.76	5.33	0.005	73.65
Land sparing cost (€)	11,410	14,570	115	112,359
Land sharing cost (€)	1,809	2,750	0.95	38,896
Land sparing gain	**8.98**	**0.79**	**4.98**	**9.99**
Land sharing gain	2.89	0.62	0.065	3.83
Land sparing gain/cost	**0.005**	**0.008**	**0.00007**	**0.083**
Land sharing gain/cost	0.029	0.103	0.00003	1.773

Descriptive statistics on 2273 plots

The « economic regulator » (A1)

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Simulations with simple strategies

The « economic regulator » (A1)

	Cost (€)		Env. Gain (and %)		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	**Sparing**	Sharing
A1 case	**200,000**	200,000	**138 (0.7)**	631 (9.6)	**157**	1,140	**15**	353

Descriptive statistics on 2273 plots

The « ecological regulator » (A2)

	Mean	Standard Deviation	Minimum	Maximum
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Land sparing cost (€)	11,410	14,570	115	112,359
Land sharing cost (€)	1,809	2,750	0.95	38,896
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A1 case	**200,000**	200,000	**138 (0.7)**	631 (9.6)	**157**	1,140	**15**	353
A2 case (A1 surface)	**651,346**	569,917	**6,481 (31.8)**	4,020 (61.1)	**157**	1,140	**714**	1,364
A2 case (A3 surface)	**277,261**	234,231	**3,657 (17.9)**	3,116 (47.4)	**43.5**	472	**404**	1,057

Descriptive statistics on 2273 plots

The « mixed regulator » (A3)

	Mean	Standard Deviation	Minimum	Maximum
Surface (ha)	3.76	5.33	0.005	73.65
Land sparing cost (€)	11,410	14,570	115	112,359
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Simulations with simple strategies

The « mixed regulator » (A3)

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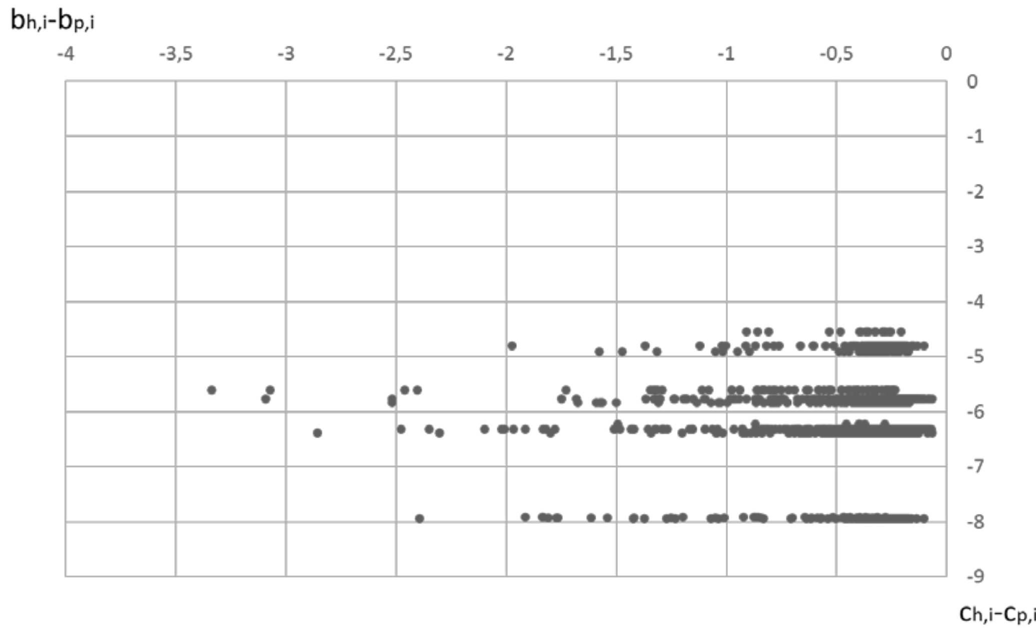
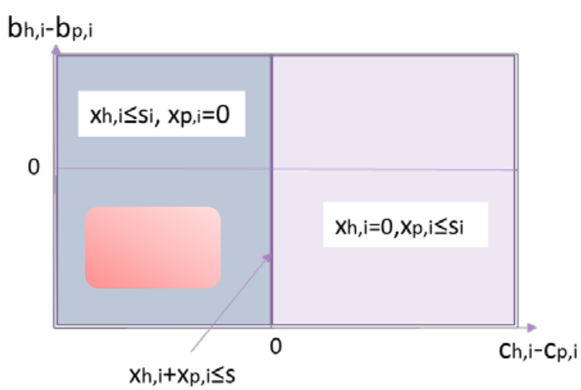
A3 case	**200,000**	200,000	**3,198 (15.7)**	3,012 (45.8)	**43.5**	472	**350**	1,047

Simulations with simple strategies

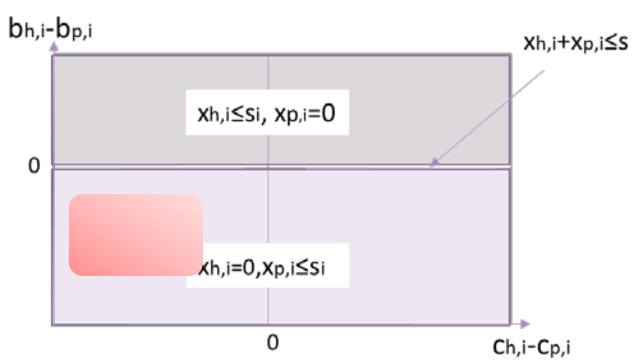
	Cost (€)		Env. Gain (and %)		Surface (ha)		Nb. of parcels		Ratio
	Sparing	Sharing	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	
A1 case	200,000	200,000	138 (0.7)	631 (9.6)	**157**	1,140	**15**	353	>1
A2 case (A1 surface)	651,346	569,917	6,481 (31.8)	4,020 (61.1)	**157**	1,140	**714**	1,364	<1
A2 case (A3 surface)	277,261	234,231	3,657 (17.9)	3,116 (47.4)	**43.5**	472	**404**	1,057	<1
A3 case	200,000	200,000	3,198 (15.7)	3,012 (45.8)	**43.5**	472	**350**	1,047	<1

Simulation with mixed strategies

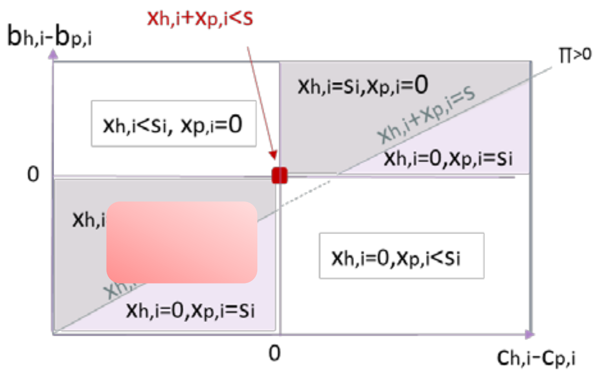




A1



A2



A3

Simulations with mixed strategies

The « economic regulator » (A1)

	Cost (€)		Env. Gain		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	Sparing	Sharing
A1hp case	**-**	200,000	**-**	640	**-**	1,140	**-**	356
A2hp case (A1 surface)	**3,644,718**	-	**12,398**	-	**1,140**	-	**1,376**	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-	**202.6**	-	**793**	-
A3hp case	**126,444**	73,556	**2,319**	1,508	**28.6**	174	**253**	520

Simulations with mixed strategies
The « ecological regulator » (A2)

	Cost (€)		Env. Gain		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	Sparing	Sharing
A1hp case	**-**	200,000	**-**	640	**-**	1,140	**-**	356
A2hp case (A1 surface)	**3,644,718**	-	**12,398**	-	**1,140**	-	**1,376**	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-	**202.6**	-	**793**	-
A3hp case	**126,444**	73,556	**2,319**	1,508	**28.6**	174	**253**	520

Simulations with mixed strategies
The « mixed regulator » (A3)

	Cost (€)		Env. Gain		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	Sparing	Sharing
A1hp case	**-**	200,000	**-**	640	**-**	1,140	**-**	356
A2hp case (A1 surface)	**3,644,718**	-	**12,398**	-	**1,140**	-	**1,376**	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-	**202.6**	-	**793**	-
A3hp case	**126,444**	73,556	**2,319**	1,508	**28.6**	174	**253**	520

Separated vs mixed strategies
The « mixed regulator » (A3)

	Cost (€)		Env. Gain	
	Sparing	Sharing	**Sparing**	Sharing
A1 case	**200,000**	200,000	**138**	631
A2 case (A1 surface)	**651,346**	569,917	**6,481**	4,020
A2 case (A3 surface)	**277,261**	234,231	**3,657**	3,116 (47.4)
A3 case	**200,000**	200,000	**3,198**	3,012 (45.8)

	Cost (€)		Env. Gain	
	Sparing	Sharing	**Sparing**	Sharing
A1hp case	**-**	200,000	**-**	640
A2hp case (A1 surface)	**3,644,718**	-	**12,398**	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-
A3hp case	**126,444**	73,556	**2,319**	1,508

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Outline

- Motivations and literature
- Theoretical framework
- Empirical application
- **Conclusion and extension**

- Importance of considering the possibility to implement a mix of strategies when comparing targeting options to improve water quality
    - Distribution of costs and benefits of the two strategies matters to select the optimal strategy for each field
    - Empirical ranking procedure for field selection

- Here, focus on agricultural land
    - Extension to the urban fringe where competition with the residential land market alters the benefits/costs of the land sparing strategy

Thank you for your attention

Simulations with simple strategies

	Cost (€)		Env. Gain (and %)		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	**Sparing**	Sharing
A1 case	**200,000**	200,000	**138 (0.7)**	631 (9.6)	**157**	1,140	**15**	353
A2 case (A1 surface)	**651,346**	569,917	**6,481 (31.8)**	4,020 (61.1)	**157**	1,140	**714**	1,364
A2 case (A3 surface)	**277,261**	234,231	**3,657 (17.9)**	3,116 (47.4)	**43.5**	472	**404**	1,057
A3 case	**200,000**	200,000	**3,198 (15.7)**	3,012 (45.8)	**43.5**	472	**350**	1,047

Simulations with mixed strategies

	Cost (€)		Env. Gain		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	Sparing	Sharing
A1hp case	**-**	200,000	**-**	640	**-**	1,140	**-**	356
A2hp case (A1 surface)	**3,644,718**	-	**12,398**	-	**1,140**	-	**1,376**	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-	**202.6**	-	**793**	-
A3hp case	**126,444**	73,556	**2,319**	1,508	**28.6**	174	**253**	520

Simulations with mixed strategies

	Cost (€)		Env. Gain		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	Sparing	Sharing
A1hp case	**-**	200,000	**-**	640	**-**	1,140	**-**	356
A2hp case (A1 surface)	3,644,718	-	**12,398**	-	**1,140**	-	**1,376**	-
A2hp case (A3 surface)	808,779	-	7,182	-	202.6	-	793	-
A3hp case	**126,444**	73,556	**2,319**	1,508	**28.6**	174	**253**	520

Simulations with mixed strategies

	Cost (€)		Env. Gain		Surface (ha)		Nb. of parcels	
	Sparing	Sharing	**Sparing**	Sharing	**Sparing**	Sharing	Sparing	Sharing
A1hp case	-	200,000	-	640	-	1,140	-	356
A2hp case (A1 surface)	3,644,718	-	12,398	-	1,140	-	1,376	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-	**202.6**	-	**793**	-
A3hp case	**126,444**	73,556	**2,319**	1,508	**28.6**	174	**253**	520

Separated vs mixed strategies

	Cost (€)		Env. Gain	
	Sparing	Sharing	**Sparing**	Sharing
A1 case	**200,000**	200,000	**138**	631
A2 case (A1 surface)	**651,346**	569,917	**6,481**	4,020
A2 case (A3 surface)	**277,261**	234,231	**3,657**	3,116 (47.4)
A3 case	**200,000**	200,000	**3,198**	3,012 (45.8)

	Cost (€)		Env. Gain	
	Sparing	Sharing	**Sparing**	Sharing
A1hp case	**-**	200,000	**-**	640
A2hp case (A1 surface)	**3,644,718**	-	**12,398**	-
A2hp case (A3 surface)	**808,779**	-	**7,182**	-
A3hp case	**126,444**	73,556	**2,319**	1,508

Cost			Surface			Environmental gains		
Total	Sparing	Sharing	Total	Sparing	Sharing	Total	Sparing	Sharing
€	%	%	ha	%	%		%	%
A1 maximisation								
50,000	0.0	100.0	316	0.0	100.0	171	0.0	100.0
100,000	0.0	100.0	631	0.0	100.0	341	0.0	100.0
150,000	0.0	100.0	947	0.0	100.0	543	0.0	100.0
200,000	0.0	100.0	1,140	0.0	100.0	640	0.0	100.0
250,000	0.0	100.0	1,235	0.0	100.0	737	0.0	100.0
300,000	0.0	100.0	1,329	0.0	100.0	832	0.0	100.0
350,000	0.0	100.0	1,424	0.0	100.0	885	0.0	100.0
400,000	0.0	100.0	1,519	0.0	100.0	935	0.0	100.0
450,000	0.0	100.0	1,613	0.0	100.0	998	0.0	100.0
500,000	0.0	100.0	1,708	0.0	100.0	1,079	0.0	100.0
A2 maximisation – surface constraint from A3 maximisation								
435,464	100.0	0.0	87	100.0	0.0	5,026	100.0	0.0
589,420	100.0	0.0	138	100.0	0.0	6,139	100.0	0.0
729,351	100.0	0.0	178	100.0	0.0	6,828	100.0	0.0
808,779	100.0	0.0	203	100.0	0.0	7,182	100.0	0.0
912,512	100.0	0.0	234	100.0	0.0	7,592	100.0	0.0
1,002,810	100.0	0.0	261	100.0	0.0	7,907	100.0	0.0
1,064,494	100.0	0.0	282	100.0	0.0	8,129	100.0	0.0
1,138,376	100.0	0.0	308	100.0	0.0	8,374	100.0	0.0
1,214,252	100.0	0.0	335	100.0	0.0	8,619	100.0	0.0
1,299,967	100.0	0.0	363	100.0	0.0	8,856	100.0	0.0
A3 maximisation								
50,000	29.7	70.3	87	2.2	97.8	1,907	28.1	71.9
100,000	45.3	54.7	138	6.7	93.3	2,696	42.2	57.8
150,000	54.9	45.1	178	9.8	90.2	3,303	52.1	47.9
200,000	63.2	36.8	203	14.1	85.9	3,828	60.6	39.4
250,000	66.7	33.3	234	16.8	83.2	4,295	65.3	34.7
300,000	69.8	30.2	261	19.3	80.7	4,722	69.4	30.6
350,000	73.4	26.6	282	22.2	77.8	5,114	73.4	26.6
400,000	75.7	24.3	308	24.9	75.1	5,474	76.2	23.8
450,000	77.3	22.7	335	26.5	73.5	5,810	78.6	21.4
500,000	78.1	21.9	363	27.4	72.6	6,121	80.1	19.9