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Gains from trans-boundary water quality management in linked catchment and coastal socio-ecological systems: a case study for the Minho region

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FCT Fundação para a Ciência e a Tecnologia
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POPH POTENCIAL HUMANO

COMPETE

UNECE
6 June 2013

Expert Scoping Workshop on
Quantifying the Benefits of Transboundary Water Cooperation

Outline presentation

- Introduction
- Objectives
- Methodology
- Results
- Conclusions & discussion

Introduction

- **Agricultural land use in coastal catchments**
  … leads to …
  diffuse source water pollution (sediments; nutrients; chemicals)

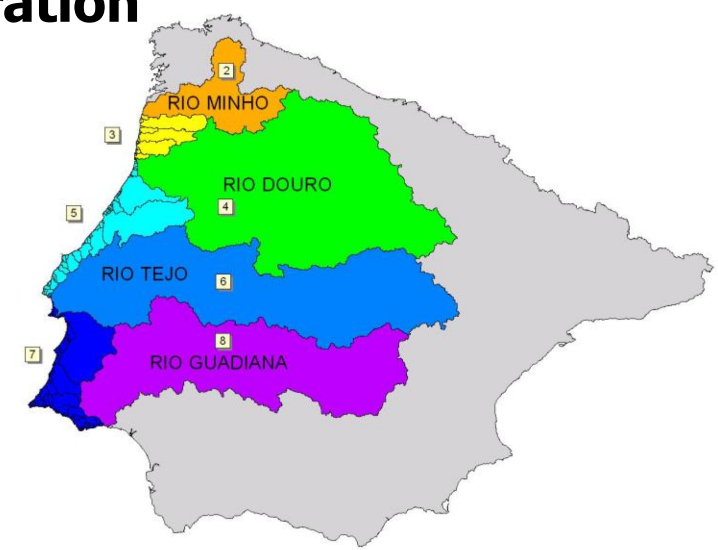
- **Impact on natural freshwater & coastal ecosystems**
  … as well as …
  economic sectors that depend on these for income generation

- **Sustainable economic development of catchment regions requires balancing:**
  ► marginal costs water quality improvement
  &
  ► marginal benefits freshwater/coastal resource appreciation
  ↓

Social welfare maximizing outcomes

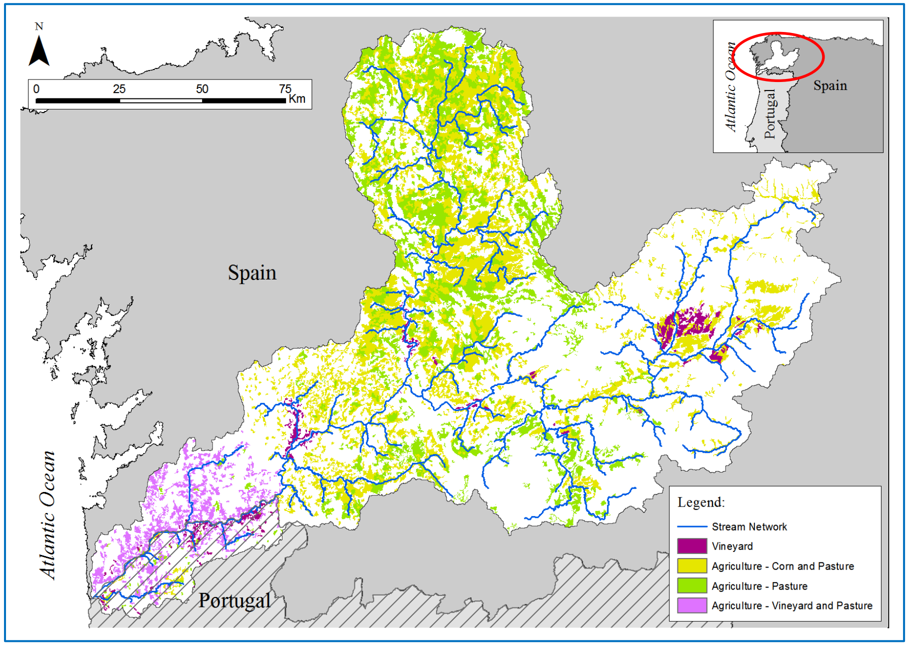
Introduction

- **Sustainable water quality management across trans-boundary catchments complex because winners and losers from water pollution are not one and the same**
- **Example – the Iberian peninsula:**
  - Costs from water quality improvement accrue to ES and/or PT
  - Benefits from water quality improvement accrue to ES and/or PT
- **Private vs. social welfare maximizing outcomes**
- **What are potential gains from cooperation in trans-boundary water quality management?**



Objective

- **Development of an environmental-economic optimal control approach that allows for exploration of private and social welfare maximizing rates of water pollution abatement in trans-boundary catchments**
- **We will compare:**
  - Private welfare maximizing scenario
  - Social welfare maximizing scenario
  - Non-cooperation scenarios
- **Case study:**
  - Minho catchment
  - Dissolved Inorganic Nitrogen (DIN) water pollution



Methodology

- **National vs. trans-national welfare maximization problems**
- **National (private) welfare maximization problems:**

Spain (ES)

$$\underset{R_{t,ES}}{Max}\, W_{ES} = \int_0^\infty \left[B_{ter}(R_{t,ES}) + zB_{coa}(P_t)\right] e^{-rt} dt$$

subject to: $\dot{P}_t = b + R_{t,ES} + R_{t,PT} - aP_t$

Portugal (PT)

$$\underset{R_{t,PT}}{Max}\, W_{PT} = \int_0^\infty \left[B_{ter}(R_{t,PT}) + (1-z)B_{coa}(P_t)\right] e^{-rt} dt$$

subject to: $\dot{P}_t = b + R_{t,ES} + R_{t,PT} - aP_t$

where:

$B_{ter}(R_t)$	Terrestrial benefits … increasing in rate of terrestrial water pollution R_t
$B_{coa}(P_t)$	Coastal benefits … decreasing in level of freshwater/coastal water pollution P_t
z	fraction of trans-national freshwater/coastal benefits accruing to Spain
$(1-z)$	fraction of trans-national freshwater/coastal benefits accruing to Portugal
r	Time discount rate
b	Exogenous 'water pollution'
a	Re-suspension factor

- **Hence, we take individual countries not to be myopic in their catchment-to-coast water quality management decisions**

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Methodology

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Spain (ES)

$$\underset{R_{t,ES}}{Max}\, W_{ES} = \int_0^{\infty} \left[B_{ter}(R_{t,ES}) + zB_{coa}(P_t) \right] e^{-rt} dt$$

subject to: $\dot{P}_t = b + R_{t,ES} + R_{t,PT} - aP_t$

Portugal (PT)

$$\underset{R_{t,PT}}{Max}\, W_{PT} = \int_0^{\infty} \left[B_{ter}(R_{t,PT}) + (1-z)B_{coa}(P_t) \right] e^{-rt} dt$$

subject to: $\dot{P}_t = b + R_{t,ES} + R_{t,PT} - aP_t$

Now taking:

$$B_{ter}(R_{t,ES}) = \alpha_{1,ES} + \alpha_{2,ES} R_{t,ES} - \alpha_{3,ES} R_{t,ES}^2 \qquad B_{ter}(R_{t,PT}) = \alpha_{1,PT} + \alpha_{2,PT} R_{t,PT} - \alpha_{3,PT} R_{t,PT}^2$$

and

$$B_{coa}(P_t) = \beta_1 - \beta_2 P_t$$

The steady state solution ($\delta\lambda/\delta t = \delta P/\delta t = 0$) is given by:

$$R_{ES}^* = \frac{\alpha_{2,ES}(r+a) - (z\beta_2)}{2\alpha_{3,ES}(r+a)} \qquad R_{PT}^* = \frac{\alpha_{2,PT}(r+a) - ((1-z)\beta_2)}{2\alpha_{3,PT}(r+a)}$$

and

$$P^* = \frac{b + R_{ES}^* + R_{PT}^*}{a}$$

Methodology

- **Trans-national (social) welfare maximization problem:**

Spain (ES) & Portugal (PT)

$$\max_{R_{t,ES},R_{t,PT}} W = \int_0^{\infty} \left[B_{ter}(R_{t,ES}) + B_{ter}(R_{t,PT}) + B_{coa}(P_t) \right] e^{-rt} dt$$

subject to: $\dot{P}_t = b + R_{t,ES} + R_{t,PT} - aP_t$

where:	$B_{ter}(R_t)$	Terrestrial benefits … increasing in rate of terrestrial water pollution R_t
	$B_{coa}(P_t)$	Coastal benefits … decreasing in level of freshwater/coastal water pollution P_t
	r	Time discount rate
	b	Exogenous 'water pollution'
	a	Re-suspension factor

- **Again, we take countries not to be myopic in their catchment-to-coast water quality management decisions**

Methodology

- **Trans-national (social) welfare maximization problem:**

Spain (ES) & Portugal (PT)

$$\underset{R_{t,ES},R_{t,PT}}{Max}\ W = \int_0^\infty \left[B_{ter}(R_{t,ES}) + B_{ter}(R_{t,PT}) + B_{coa}(P_t)\right] e^{-rt}\,dt$$

subject to: $\dot{P}_t = b + R_{t,ES} + R_{t,PT} - aP_t$

Now taking:

$$B_{ter}(R_{t,ES}, R_{t,PT}) = (\alpha_{1,ES} + \alpha_{2,ES}R_{t,ES} - \alpha_{3,ES}R_{t,ES}^2) + (\alpha_{1,PT} + \alpha_{2,PT}R_{t,PT} - \alpha_{3,PT}R_{t,PT}^2)$$

and

$$B_{coa}(P_t) = \beta_1 - \beta_2 P_t$$

The steady state solution ($\delta\lambda/\delta t = \delta P/\delta t = 0$) is given by:

$$R_{ES}^{**} = \frac{\alpha_{2,ES}(r+a) - (\beta_2)}{2\alpha_{3,ES}(r+a)} \qquad R_{PT}^{**} = \frac{\alpha_{2,PT}(r+a) - (\beta_2)}{2\alpha_{3,PT}(r+a)}$$

and

$$P^{**} = \frac{b + R_{ES}^{**} + R_{PT}^{**}}{a}$$

Results

- **Private (national) and social (trans-national) welfare maximizing rates of water quality improvement, through (agricultural) water pollution abatement across ES and PT**
- **Using SWAT, terrestrial benefits for ES and PT are estimated:**

$$B_{ter}(R_{t,ES}) = 78.1 + 42.867 R_{t,ES} - 1.9754 R_{t,ES}^2$$

$$B_{ter}(R_{t,PT}) = 13.3 + 17.420 R_{t,PT} - 2.1891 R_{t,PT}^2$$

with $B_{ter}(R_t)$ in m€/yr and R_t in kt DIN/yr

- **Using benefit transfer techniques, freshwater/coastal values are estimated:**

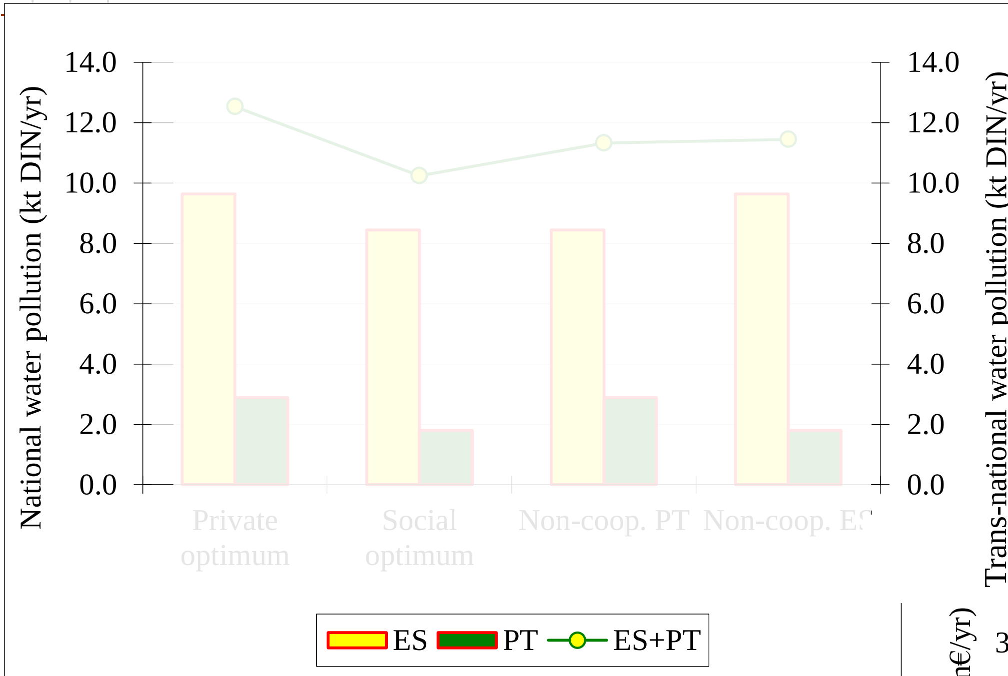
$$B_{coa}(P_t) = (31.8 + \beta_2 P_0) - \beta_2 P_t$$

with $B_{coa}(P_t)$ in m€/yr and P_t in kt DIN

- **And given**:

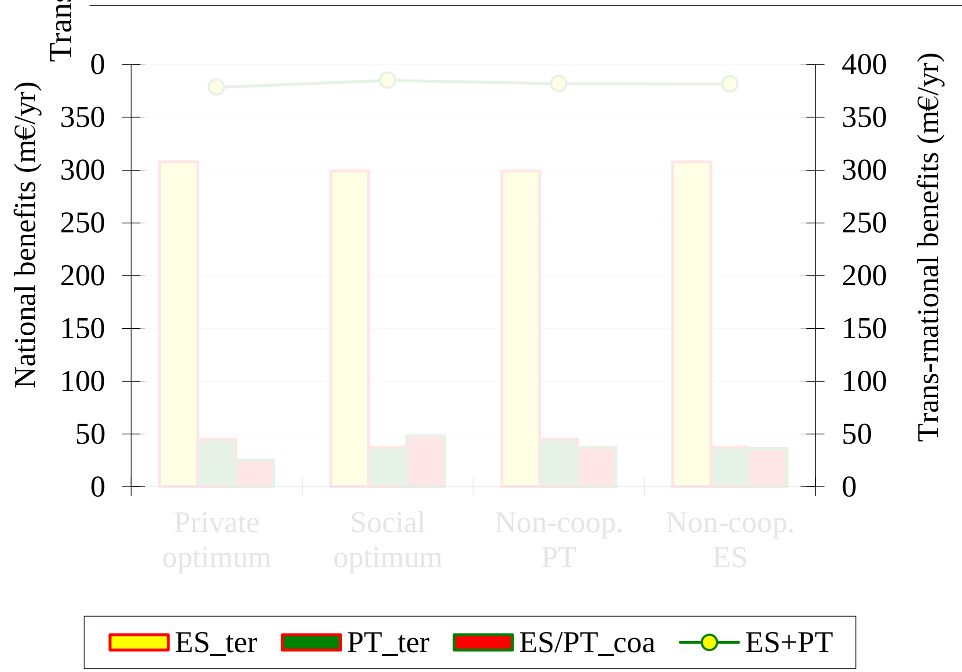
time discount rate	r	= 5%
no re-suspension	a	= 1
no exogenous pollution	b	= 0
pollution costs	β_2	= 10 m€/kt DIN
distribution benefits	z	= 0.5

Results



Regional income (m€)	ES_ter	PT_ter	ES/PT_coa	ES+PT
Myopic	310.6	48.0	2.4	361.1
Private optimum	**307.8**	**45.4**	**25.4**	**378.5**
Social optimum	299.2	37.6	48.3	385.1
Non-cooperation PT	299.2	45.4	37.4	382.0
Non-cooperation ES	307.8	37.6	36.3	381.7

DIN delivery (kt)	ES	PT	ES+PT
Myopic	10.85	3.98	14.83
Private optimum	**9.64**	**2.89**	**12.54**
Social optimum	8.44	1.80	10.24
Non-cooperation PT	8.44	2.89	11.33
Non-cooperation ES	9.64	1.80	11.45



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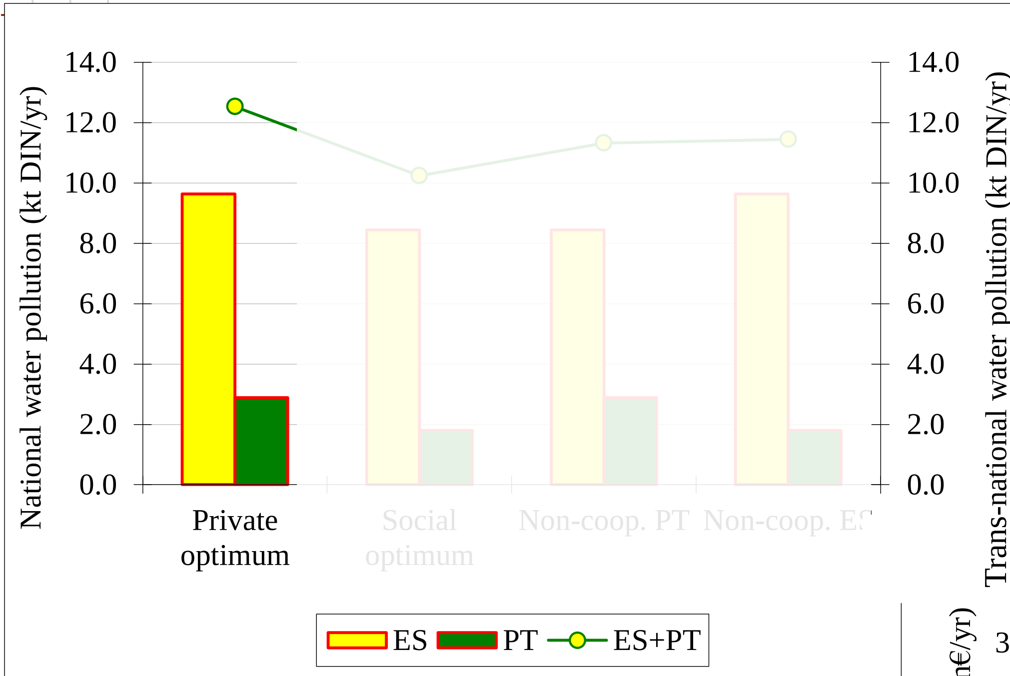

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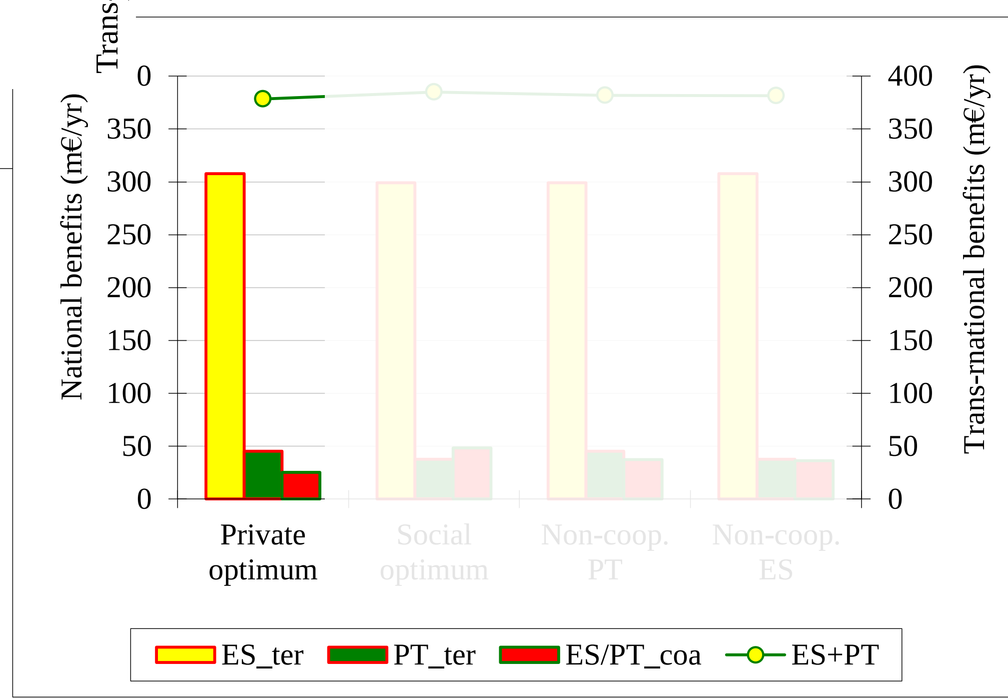

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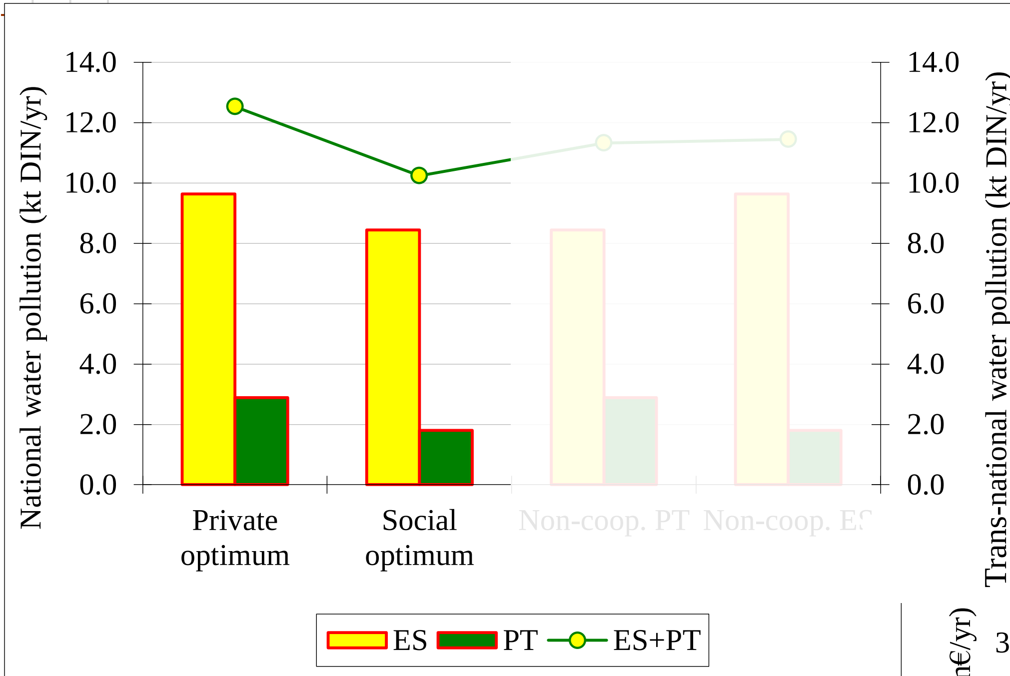

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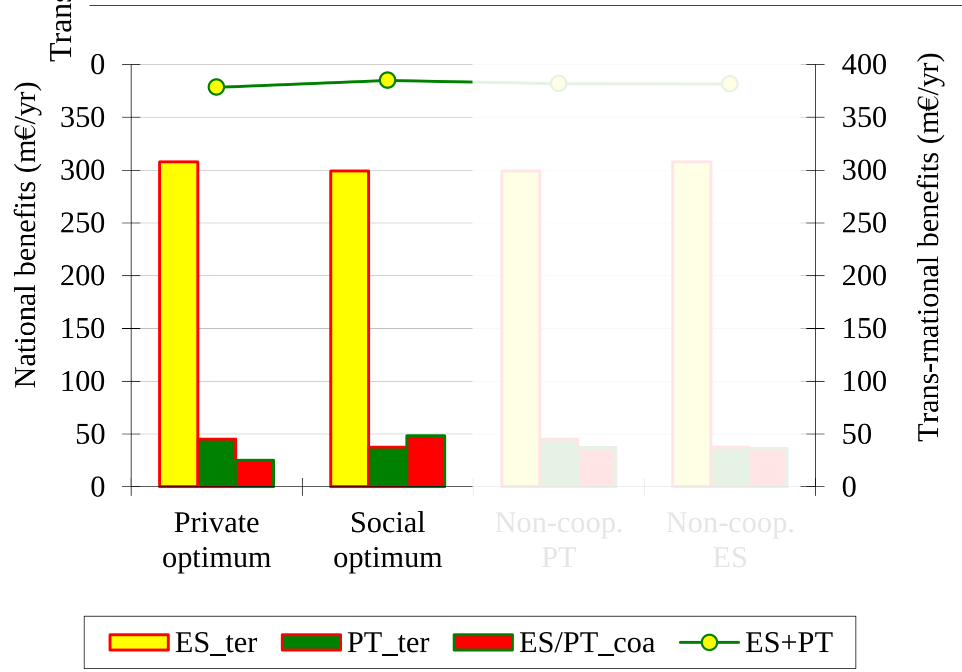

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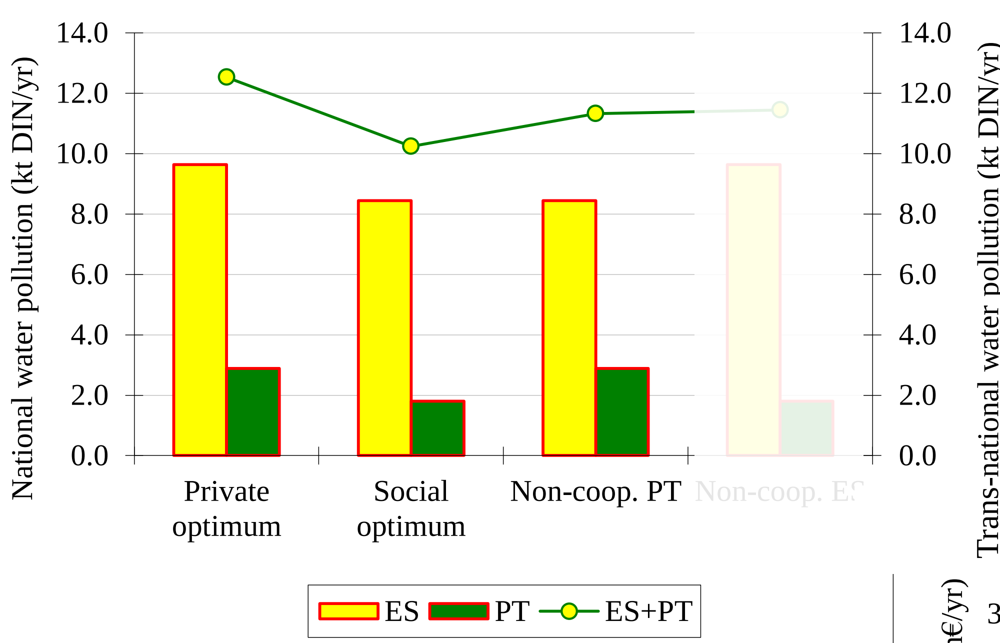

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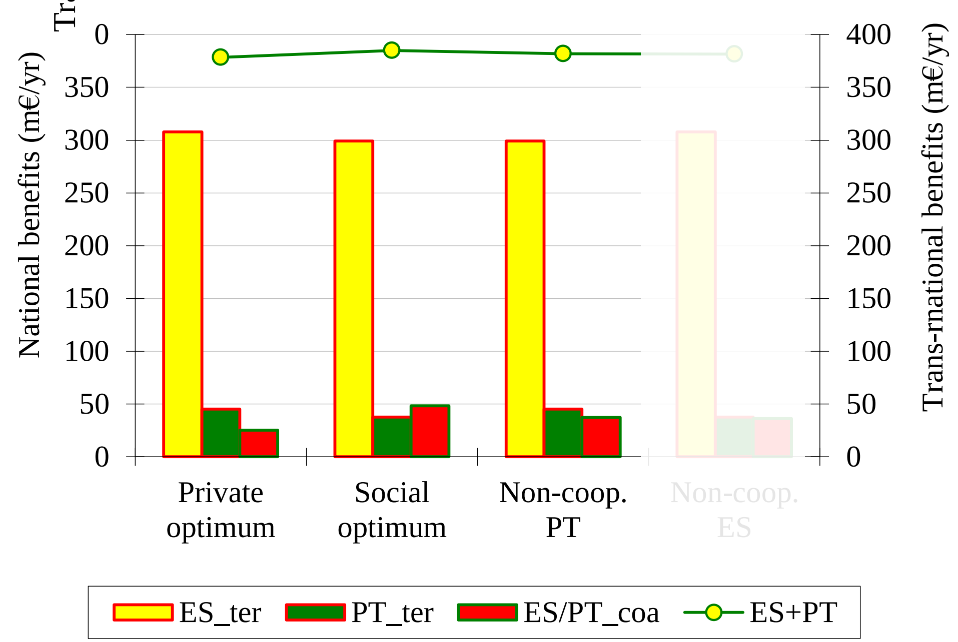

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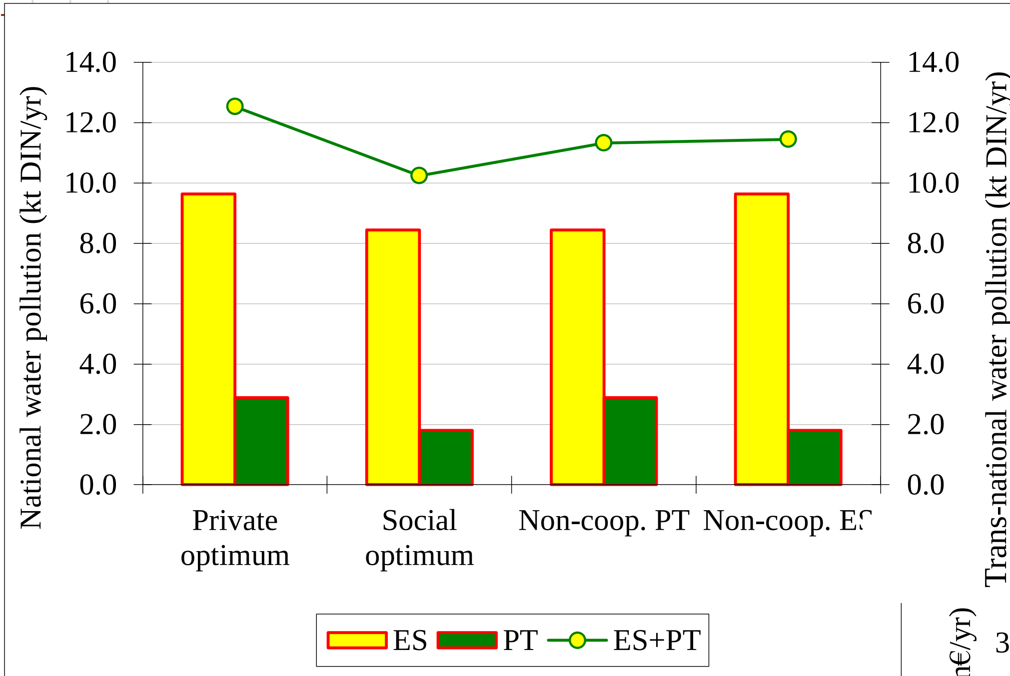

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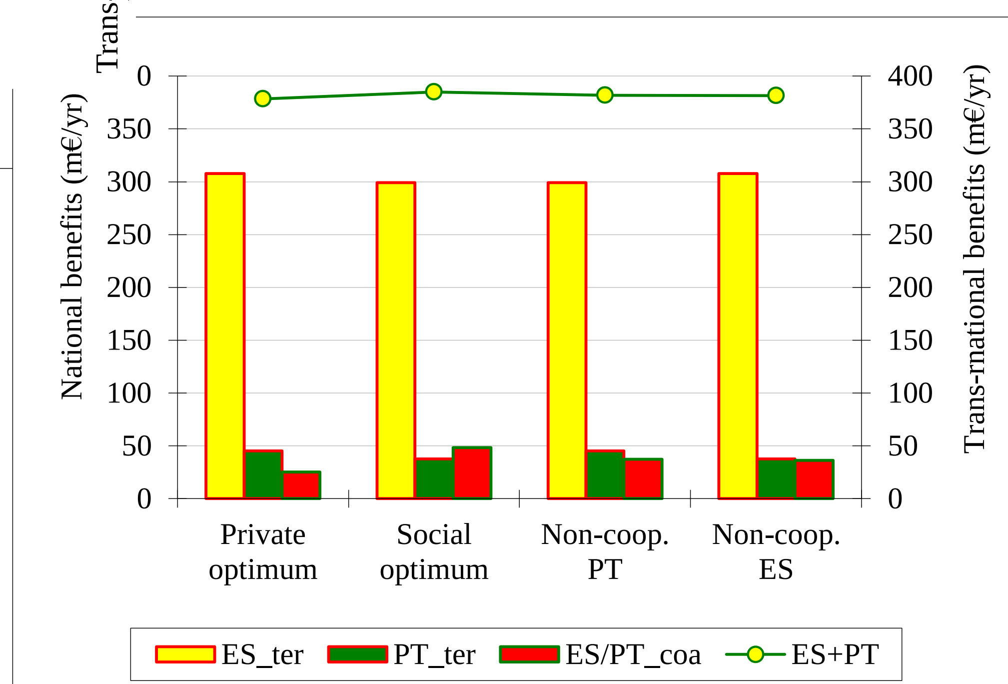

Conclusions & discussion

- **Environmental-economic optimal control approach that:**
  - Relates costs and benefits from water quality management in linked catchment and freshwater/coastal socio-ecological systems
  - Allows for exploration of private (national) and social (trans-national) welfare maximizing rates of water pollution abatement in trans-boundary catchments
  - Allows for estimation of welfare losses from non-cooperation in trans-boundary water quality management
- **For the Minho case-study it is shown that:**
  - Significant reductions in water quality (-18%) and welfare losses (-4.6%) are to be faced under non-myopic water quality management
  - Significant reductions in water pollution (-18%) and some welfare gains (+1.7%) can be obtained through trans-national water quality management
  - Non-cooperation in trans-national (social welfare maximizing) water quality management leads to:
    - increased water pollution (up to +12%) and social welfare losses (up to -0.9%)
    - private (national) welfare gains for defecting nations (up to +3.8%)
- **Future research:**
  - Institutional arrangements that allow for (inter-) national transfer of welfare gains from trans-boundary water quality management
  - Economic instruments to internalize beneficial spill-overs from trans-boundary water quality improvement

Iberian Trans-boundary Water Management

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