Industrial Innovation Analysis and Evaluation Towards Industrial Symbiosis application in the Circular Economy Transformation

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What is Industrial Symbiosis?

- The Industrial Symbiosis is a process according to which the waste (or by-product) produced by an industrial plant "A" is used by another industrial plant "B" as input (raw material/feedstock) in its production process in order to realize new products;

Through the implementation of Industrial Symbiosis we can realize "circular production schemes" fostering the Circular Economy

- The resources exchanged during an Industrial Symbiosis can be water, material, energy (heat), services, knowledge, expertise and labour.

Economic and Environmental benefits

According to Chertow and Lombardi (2005) we can distinguish between:

- Economic benefits: cost reduction, reputation enhancement (customers perceive the «green factor» of the company);

- Environmental benefits: decrease in consumption of natural resources and emissions (pollutions) to air and water.

Models of Industrial Symbiosis

According to the formation mechanism, we can distinguish between two stylized models of Industrial Symbiosis (*Chertow 2007*):

- *Self-organizing symbiosis model (bottom-up):* green sinergies emerge from the will of private economic actors to reduce costs and increase profits (Kalundborg, Denmark);

- *Planned Eco-Industrial park model (top-down):* green sinergies are the results of a specific planning designed by a central authority (e.g. governmental agency) (US Eco-Industrial park);

Promoting a Self-organized Industrial Symbiosis

In order to foster the birth of Self-organized Industrial simbiosis, policy makers can intervene through three different types of policy measures:

- Market-based policies: landfill tax, economic subsidies (e.g. for R&D activities), fiscal incentives, etc.
- Comand-and-control policies: firms must comply with specific technology and performance standards;
- Voluntary instruments: they are represented by database and other services whose purpose is to favor the match between demand and supply of wastes.

See: *Hepburn 2006; Lamperti 2016; Fraccascia 2016*

Self-organized Industrial Symbiosis = Complex Adaptive Systems

Why are Self-organized Industrial Symbiosis framed as CASs?

- Complex: the system involves multiple sectors and agents that interact with each other;

- Adaptive: the system mutates and changes self-organizing its structure and the adaption is influenced by the interaction between agents. The new emergent orders of the network are determined by this interaction and not by a central central authority/control.

See Chertow (2012) and Albino (2015)

Hybrid modelling approach

In order to model the «economic environment» in which Industrial Symbiosis can be established we adopt:

- Agent-Based Modelling: to capture heterogeneity, complexity of interactions;
- System Dynamics: to model the manufacturing and the management dynamics of firms;
- Process-environment format: the internal structure of various agents are modelled by a System Dynamics structure

The case study

In order to evaluate the effectiveness of policy activities on self-organized industrial symbiosis in terms of environmental impact and economic benefits, the case study takes into account three different industries:

1) Steel industry: steel plants produce their products through Electric Arc Furnace technologies. The resulting waste is represented by «artificial inert»;

2) Paper industry: paper plants produce their products through the Kraft process. The waste resulting is represented by «artificial clinker»;

3) Cement industry: cement plants produce concrete (mixing inert and clinker).

Outline of the Hybrid Model

The model includes:

- The government;
- Steel industry;
- Paper industry;
- Cement industry;
- Natural inert suppliers;
- Natural clinker suppliers.
- Public landfills;

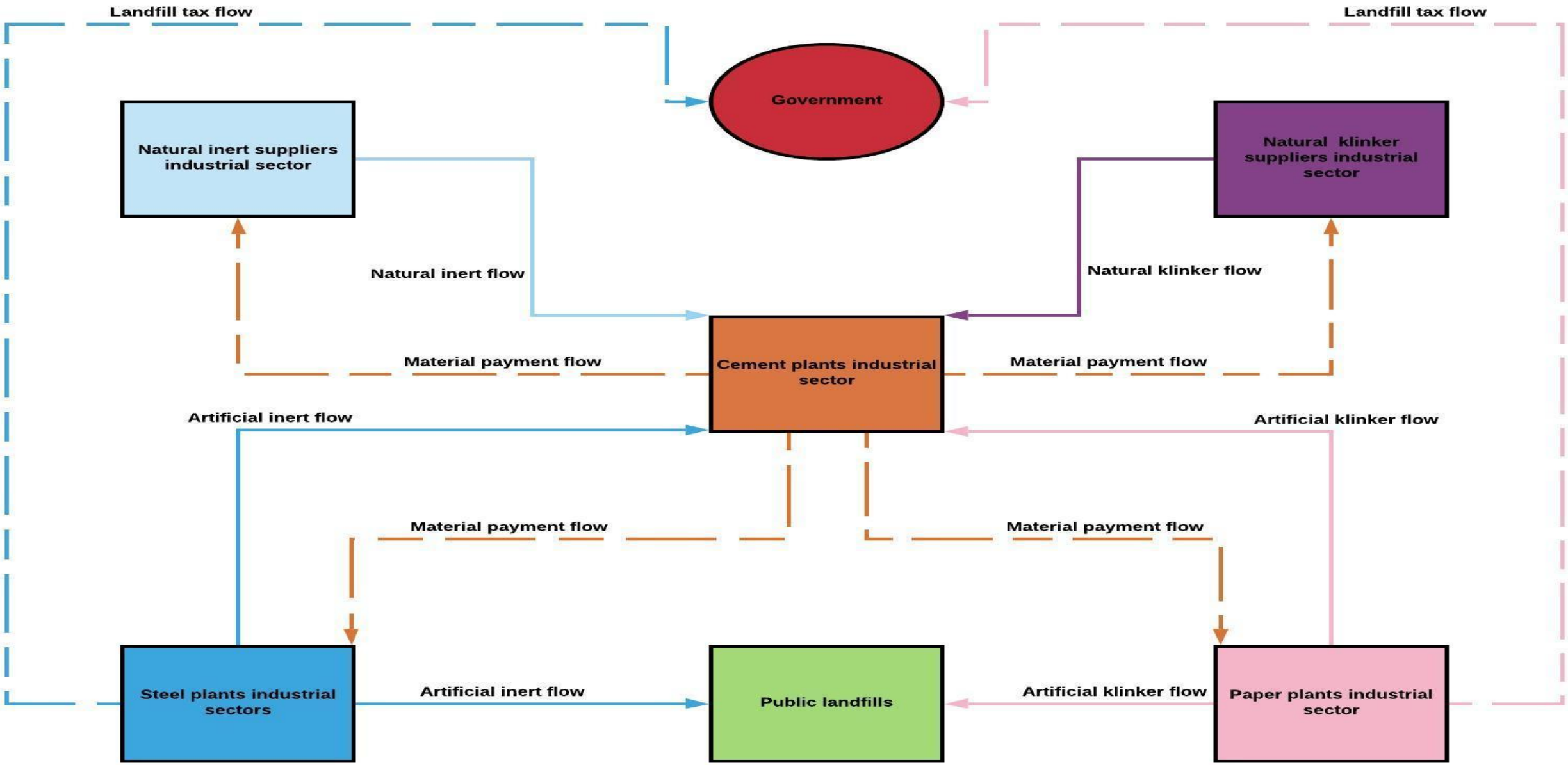
Heterogeneity:

- Geographic location (spatial dimension);
- Production capacity (three industries);

• (Partial) Stock and flow consistency:

- Only for the Industrial Symbisios interest variables;
- Each agent belonging to the three industries has its own balance sheet;

Model overview



Industrial Symbiosis Economic Feasibility

Sellers Fitness condition:

$$c_p - p_w \leq l + c_{tr_l}$$

Where:

c_p: Preprocessing costs of waste;

p_w: Waste selling price ($p_w = h \cdot p_v$);

l: Landfill tax (set by the Government);

c_{tr_l}: Transportation costs to the nearest landfill ($c_{tr_l} = \tau \cdot x$)

Buyers Fitness condition:

$$p_w + c_{tr_{is}} - e \leq p_v + c_{tr_v}$$

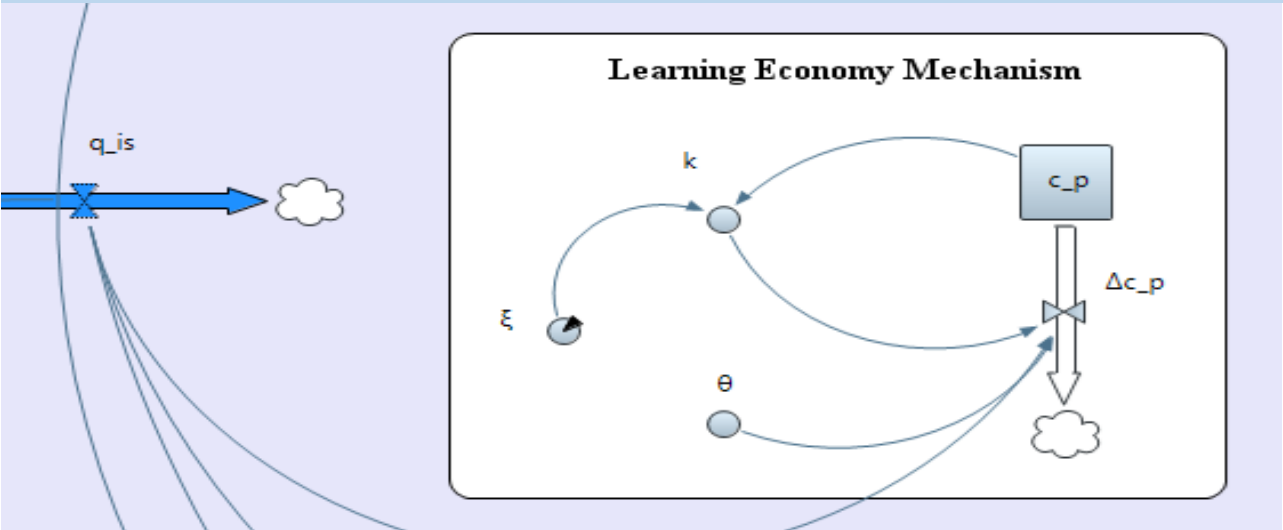
Where:

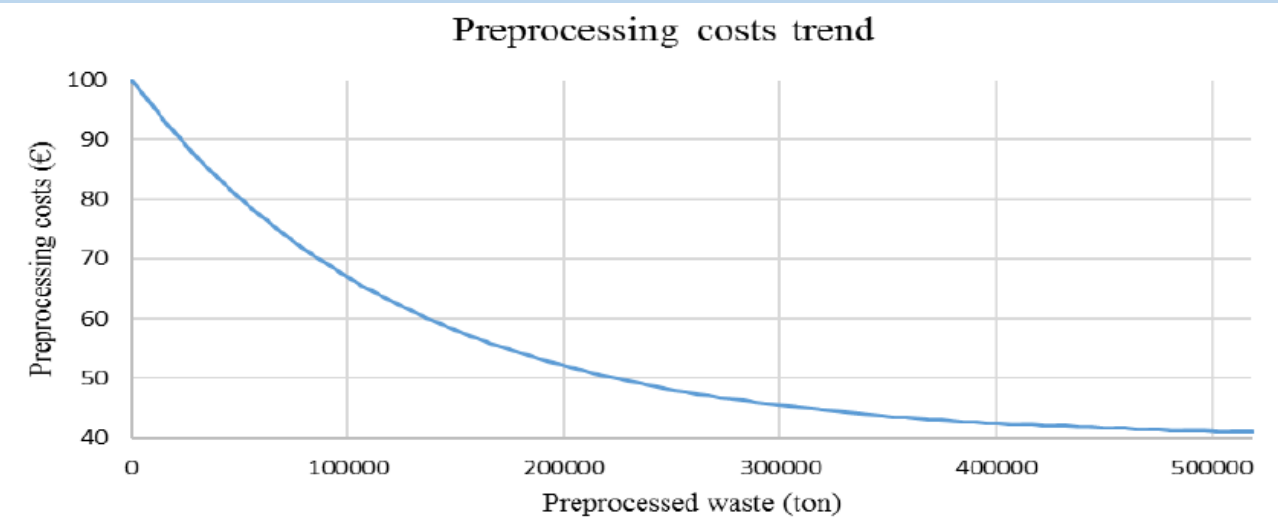
- p_w: Waste selling price;
- $c_{tr_{is}}$: Transportation costs between the CP and the SP/PP;
- p_v: Virgin material price;
- c_{tr_v}: Transportation costs between the CP and the nearest virgin material suppliers;
- e: Economic subsidy.

Learning economies – Preprocessing costs c_p

- They are subjected to mechanisms of learning economies: they depend on the preprocessed waste cumulated ut to a certain moment;

- The learning economies mechanism is represented by a «goal seeking» System Dynamics structure ($\Delta c_p = \theta \cdot k \cdot q_{is}$);





Virgin material price dynamics

- p_v is influenced by the industrial symbiosis: the higher the waste exchanged, the lower the demand of virgin input;

- Through this assumption we represent the attempt of the virgin material suppliers to compete against the Industrial Symbiosis;

$$p_{v,t} = p_{v,t-1} + \left\{ a_{t-1} \cdot \left[\left(\epsilon \cdot \frac{AD_{t-1} - AS}{AS} \right) + g \right] \right\}$$

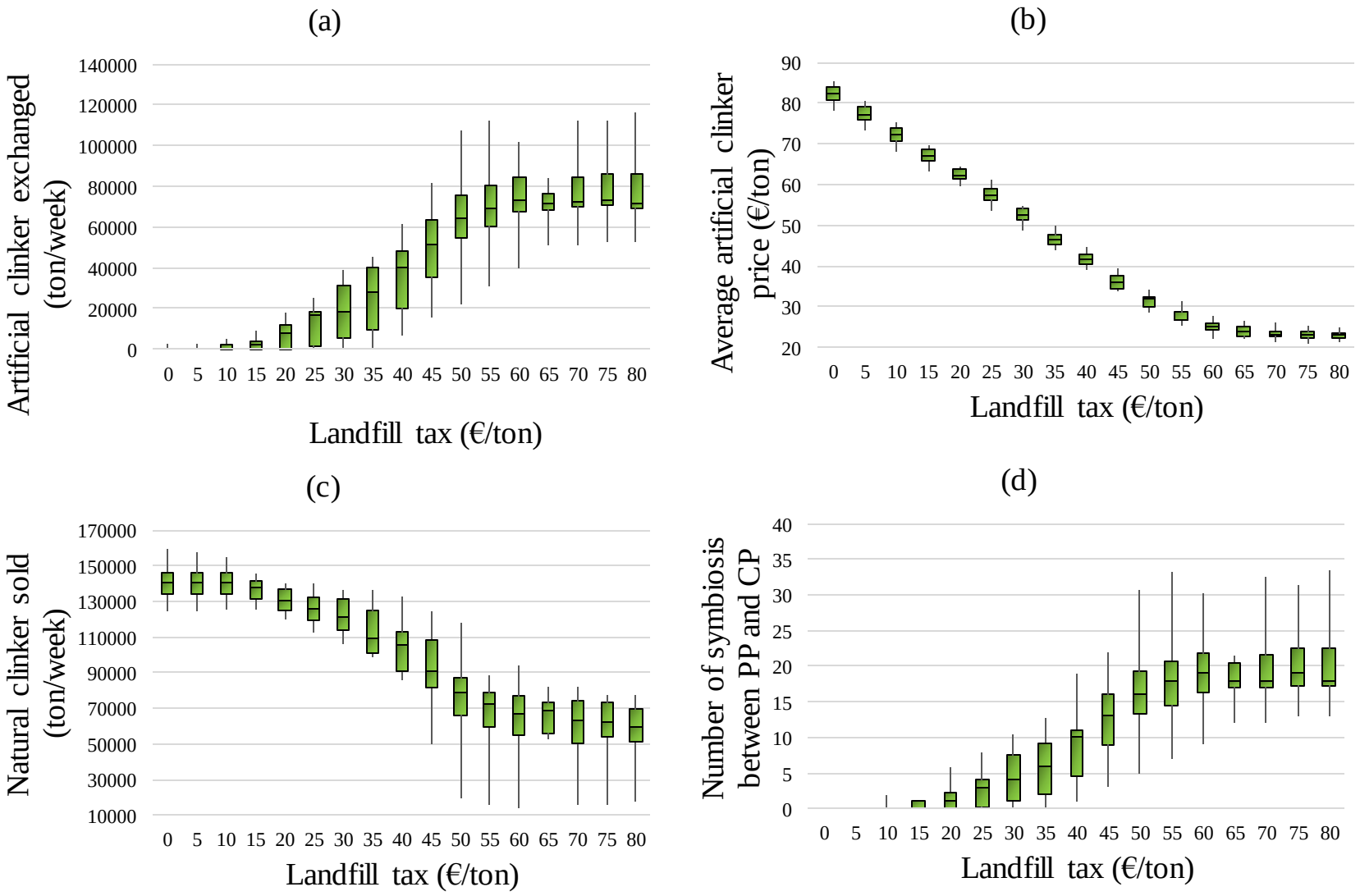
- AD represents the aggregate demands of virgin input;
- AS represents the aggregate supplies of virgin input;

Preliminary results

- **Sensitivity analysis:** test the robustness of the system and explore the relationship between the *Landfill tax / Economic subsidy* (policy measures) and the output of the model;

- Montecarlo Computational experiments;

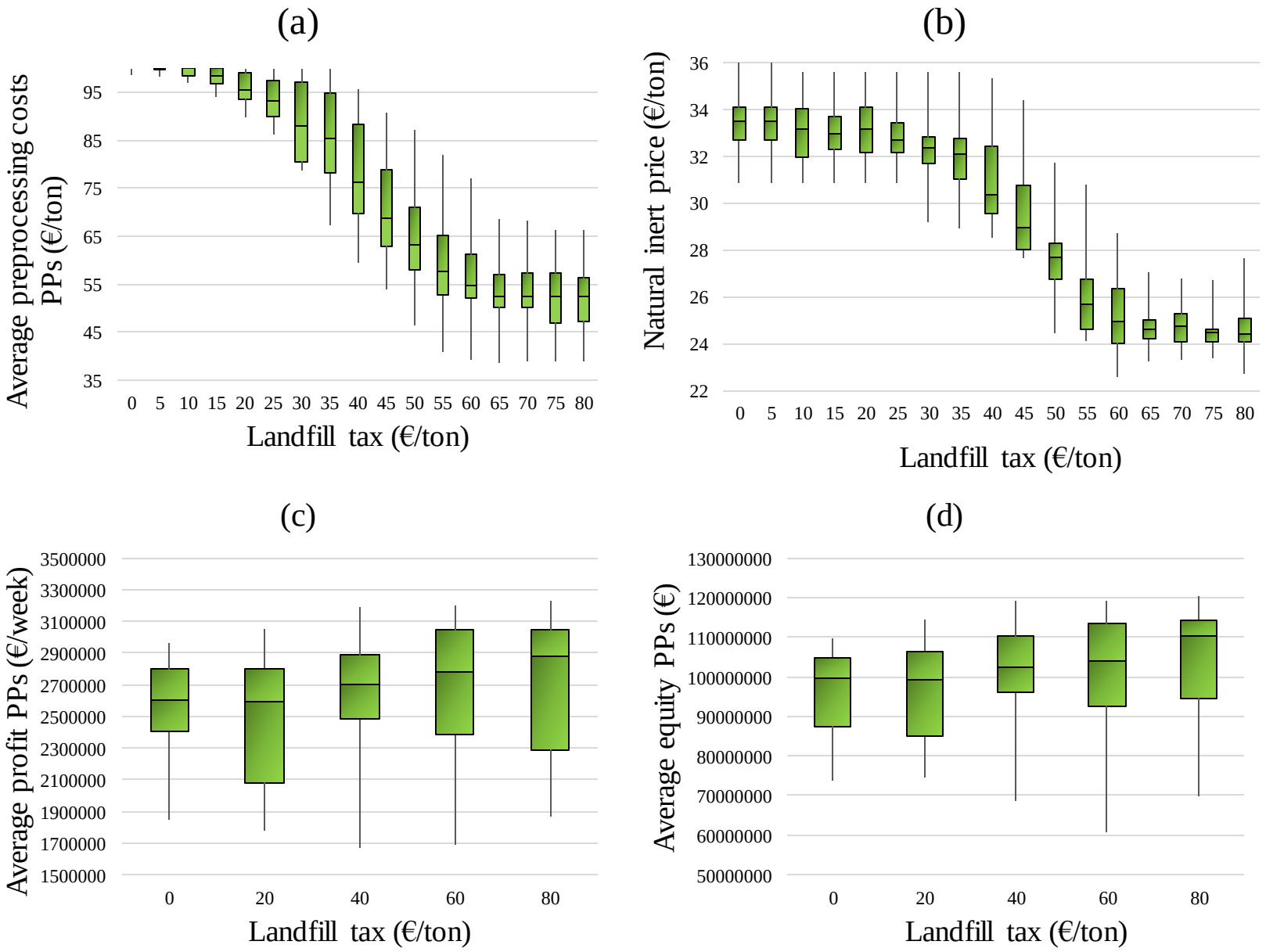
Sensitivity Analysis - Landfill tax (1)



- Economic subsidy (*e*)= 0;
- The artificial clinker exchanged increases with the Landfill tax (a);
- The Landfill tax determines lower prices increasing the demand of waste (b);

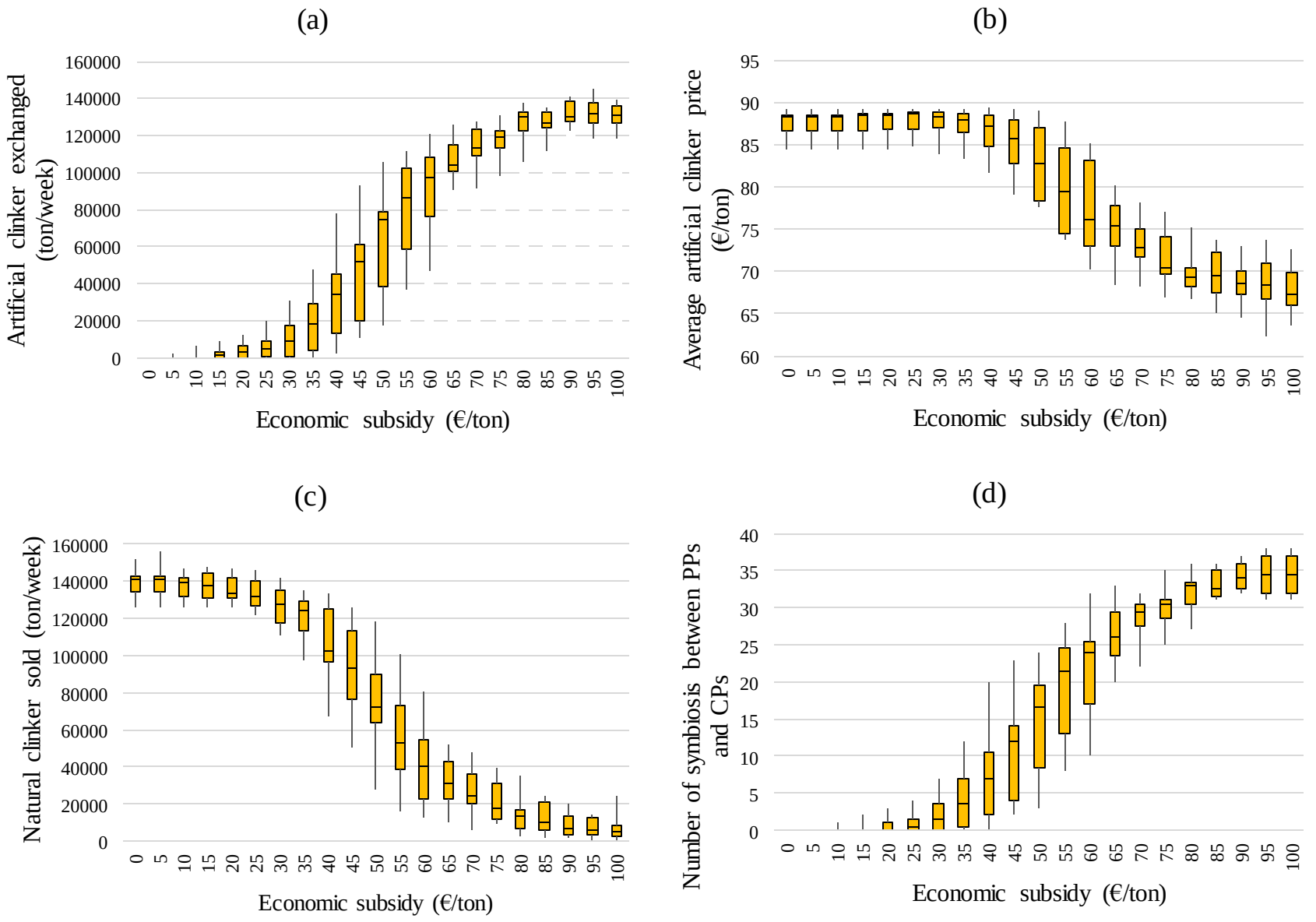
After a certain value, the policy loses its effectiveness.

Sensitivity Analysis - Landfill tax (2)



- The virgin material price decreases because of the competition (b);
- The average equity (d) and profits (c) increase with the landfill tax highlighting the economic benefits deriving from the IS;

Sensitivity Analysis –Economic subsidy (Paper industry)



- Landfill tax (l)= 0;
- The artificial clinker exchanged increases with the Economic subsidy;
- The average artificial clinker price decreases with the subsidy following the trend of the virgin material price;
- The economic subsidy is more effective.

Conclusions and Future Developments

- The system responds effectively to both the policy measures (in accordance with our assumptions);
- After a certain value, the landfill tax loses is effectiveness;
- The economic subsidy is more effective than the landfill tax;

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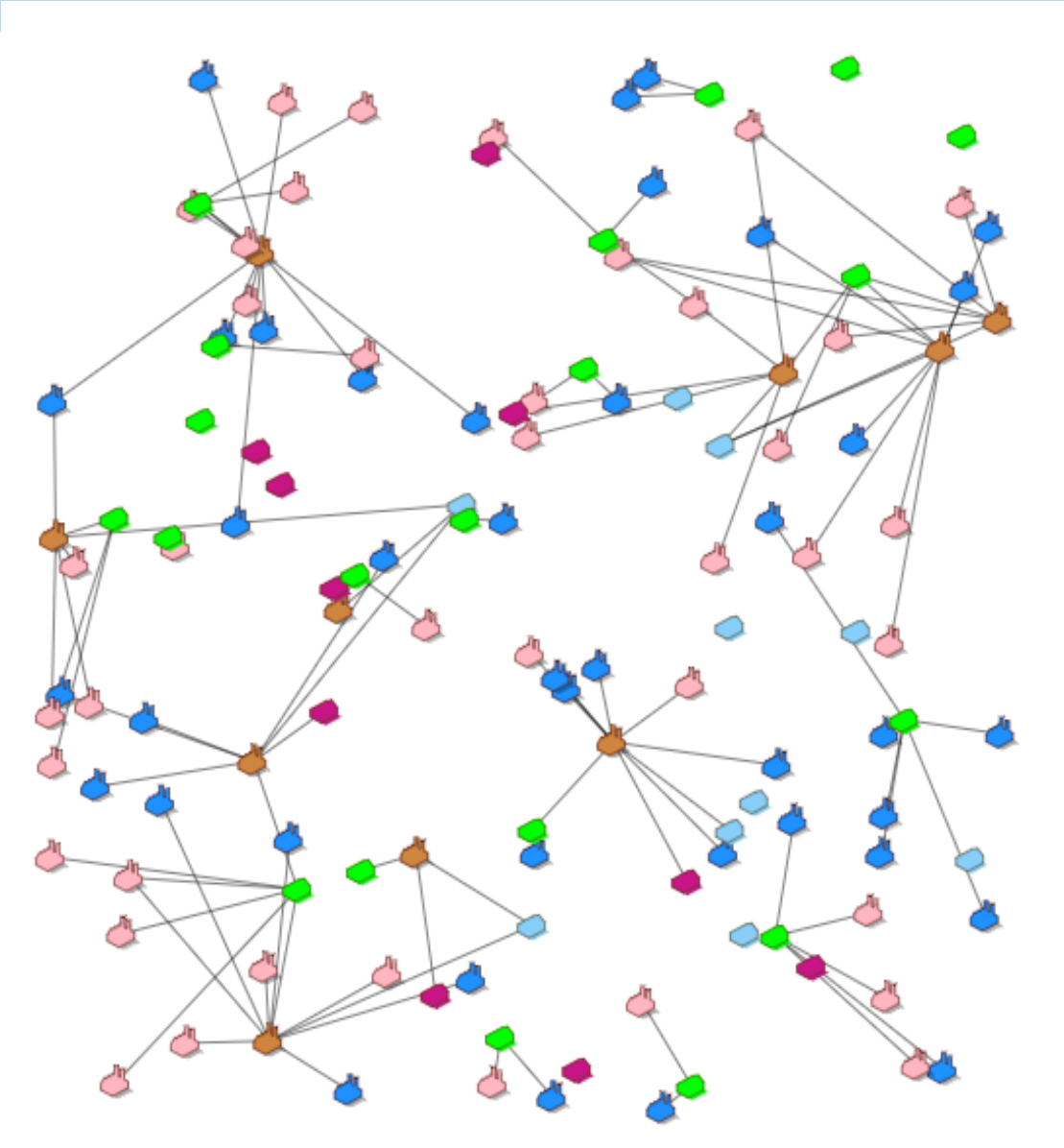
- Policy mix (in which the incomes deriving from the landfill tax finance the Economic subsidies);
- Other policies (CB and MB);
- Dynamic intervention of the Government inside the model.



The end

Background

- In recent years manufacturing companies have shown an increasing interest in moving towards resource efficient business models in order to reduce costs (and improve sustainability);

- Policy makers play a fundamental role in amplifying effects and benefits of the circular economy (by means of public investments, economic subsidies, tax incentives or removing legislative, technological and financial barriers);

- Policy makers can help and foster a «Green Development» and the creation of «Green Sinergies» (Industrial symbiosis) between industrial plants.

Aggregate demands of output

- Aggregate demands = System engine

$$D_t = D_{t-1} + \omega_t$$

Where:

ω_t: random variable (normal distribution or truncated normal distribution)

- To simulate the customer behaviour we use a «logit model»:

$$prob_{n,z} = \frac{\exp(\beta_n \cdot r_z)}{\sum_{z \in Z} \exp(\beta_n \cdot r_z)}$$

Where:

β_n: customer sensitivity to the output unit price;

r_z : reciprocal of the output unit price;

The probability of a generic firm $z \in Z$ of being chosen depends only on its output unit price

Output Unit Price dynamics

The output unit cost is given by the following relation:

$$c_u = \frac{c_f + c_v}{q_i}$$

- Fixed costs c_f: wages, inventories management costs;
- Variable costs c_v: raw materials costs, energy costs, transportation costs, etc.
- Output production q_i.

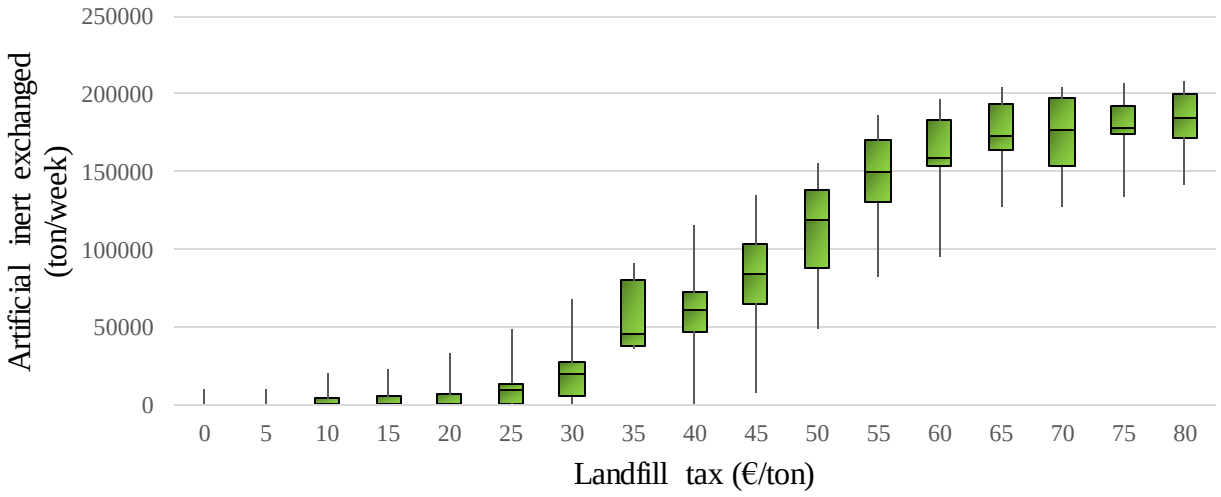
After quantifying the output unit cost, firms set the selling price through a mark up mechanism:

$$p = (1 + u) \cdot c_u$$

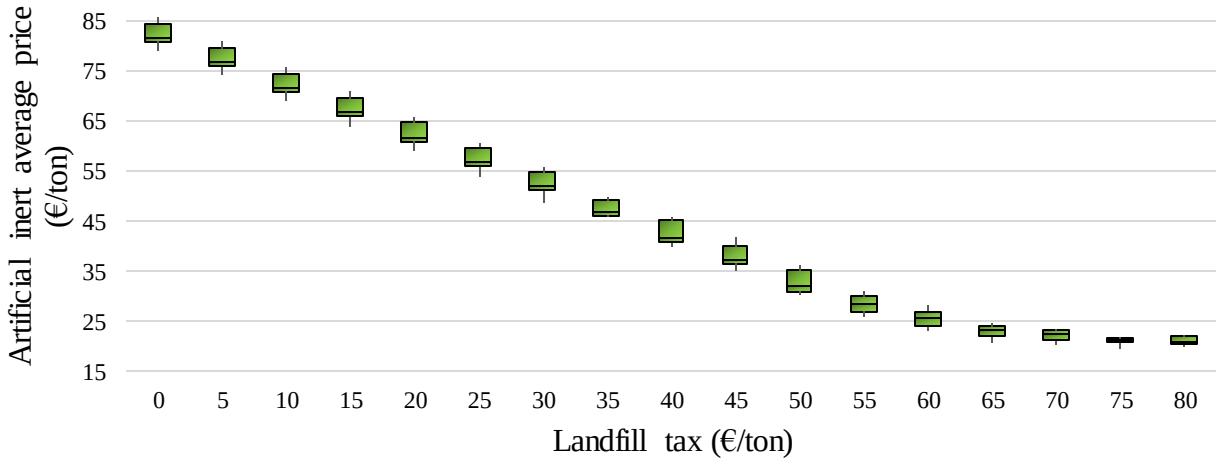
Mark-up percentage u: it can be varied by the firm according to its decision-making strategy (if the firm finds an increase in sales, it decides to enhance u to increase its profits, otherwise it opts for a price reduction in order to assume a better market position)

Sensitivity Analysis -Landfill tax (Steel industry)

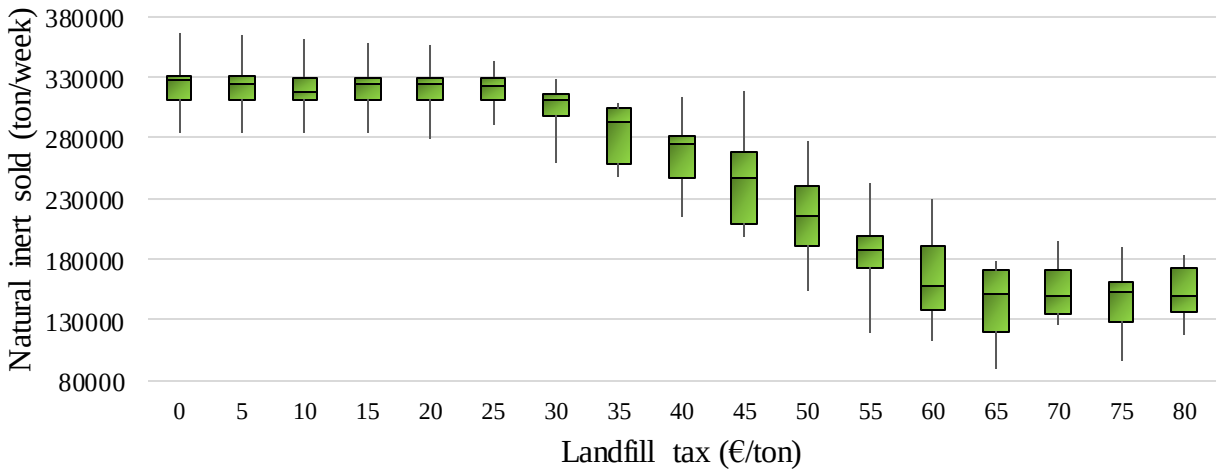
(a)



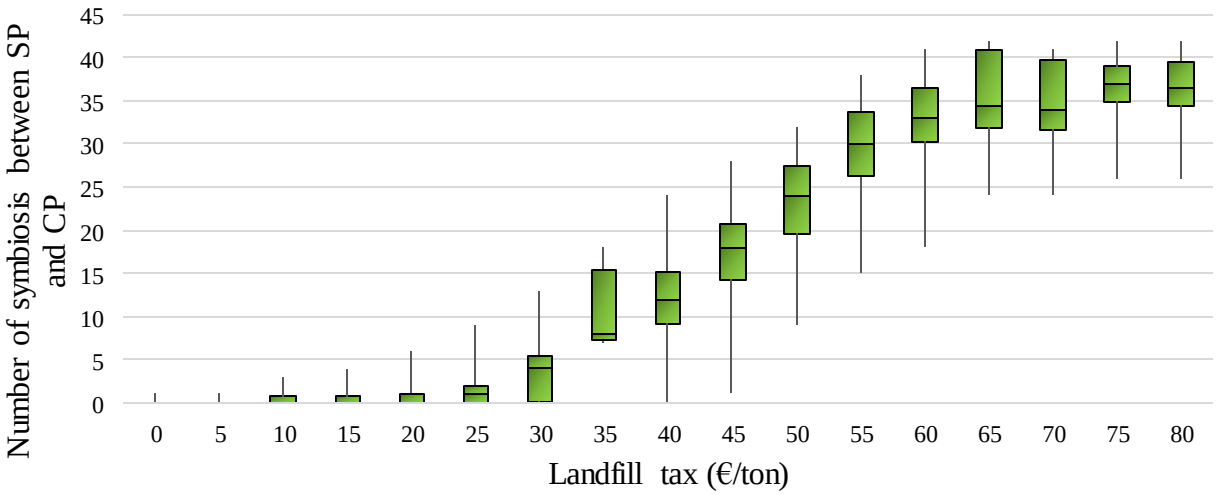
(b)



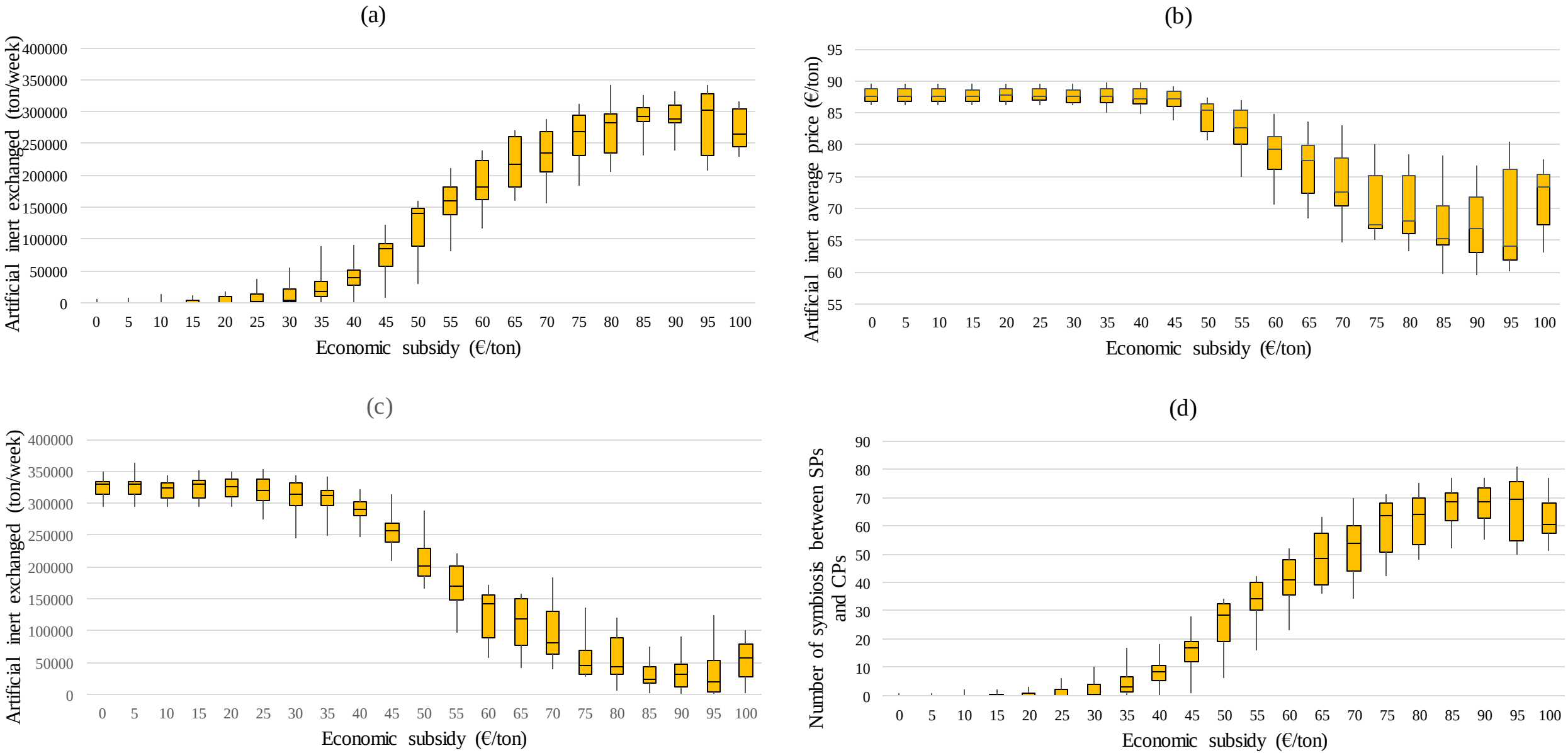
(c)



(d)



Sensitivity Analysis –Economic subsidy (Steel industry)



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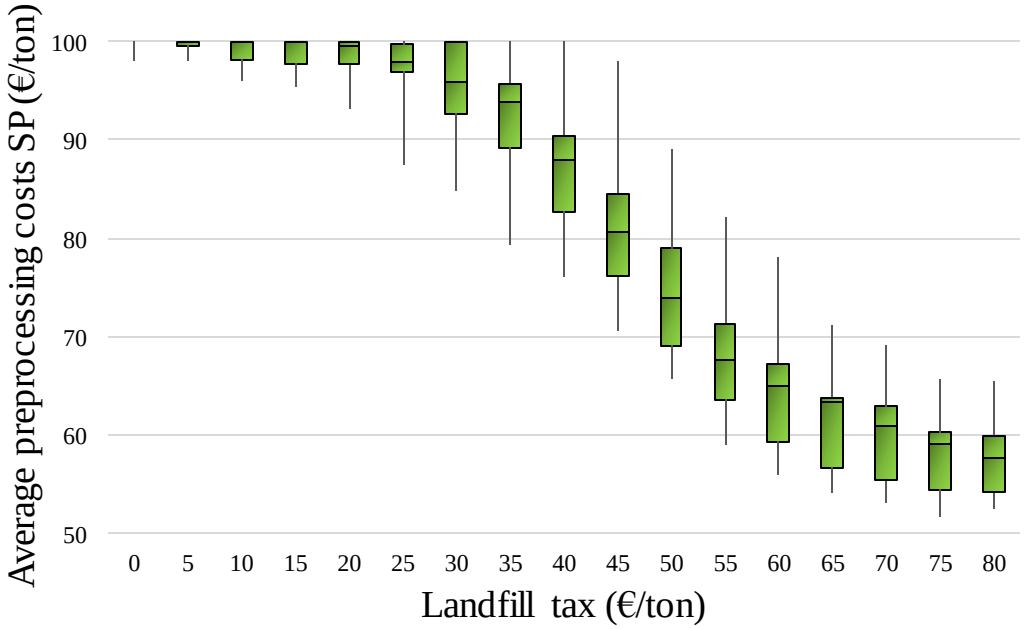
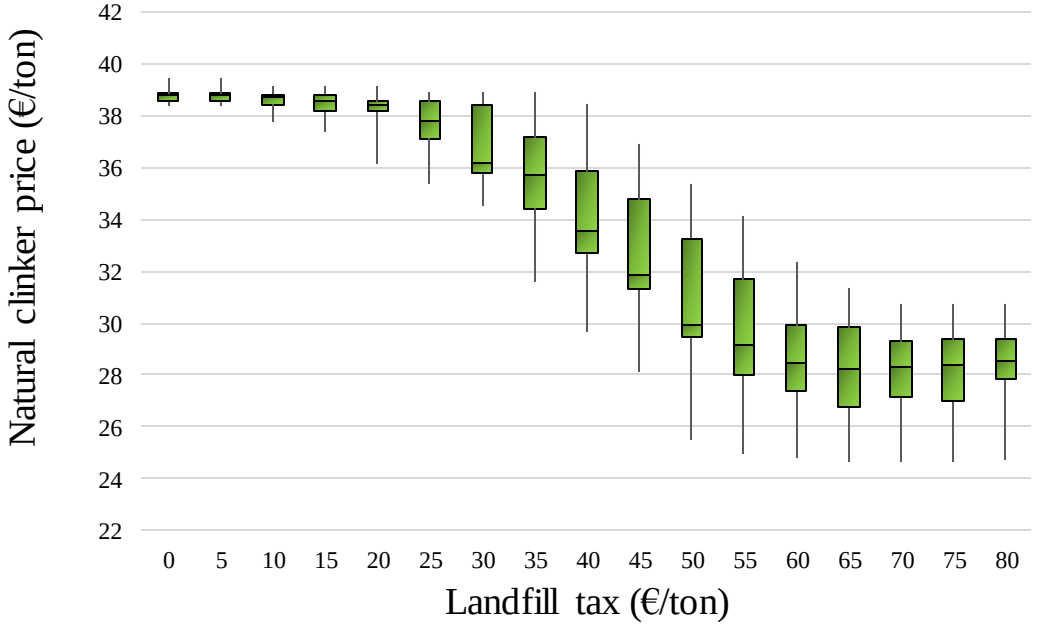
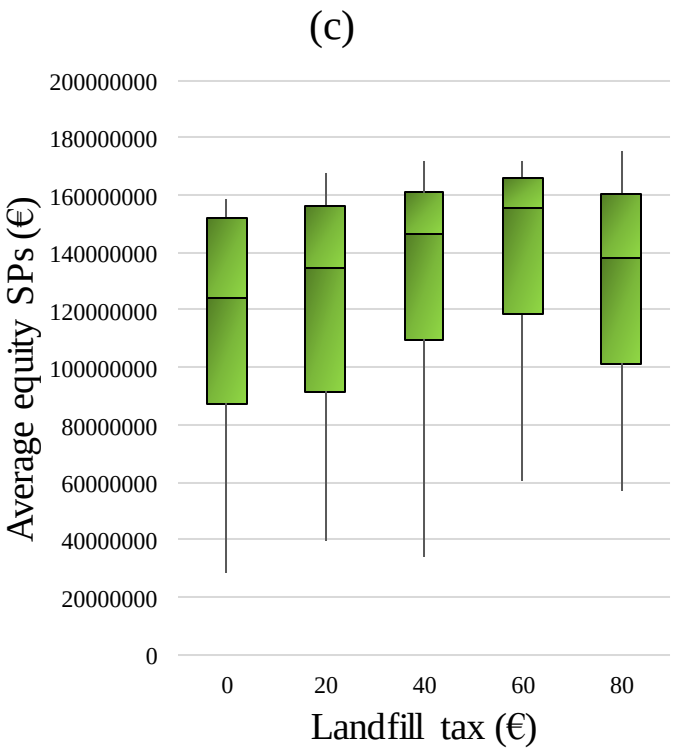
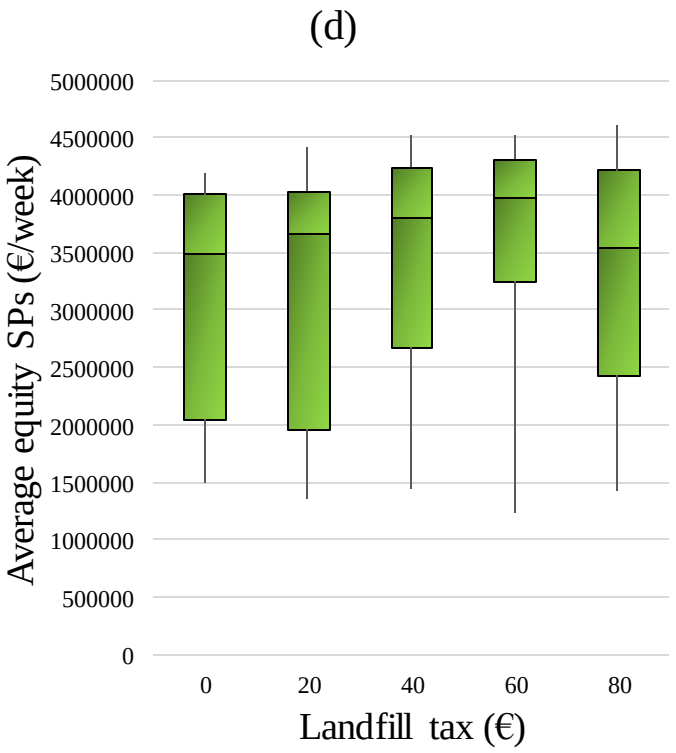

Average preprocessing costs SP (€/ton)
100
90
80
70
60
50
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Landfill tax (€/ton)

(d)


Natural clinker price (€/ton)
42
40
38
36
34
32
30
28
26
24
22
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Landfill tax (€/ton)

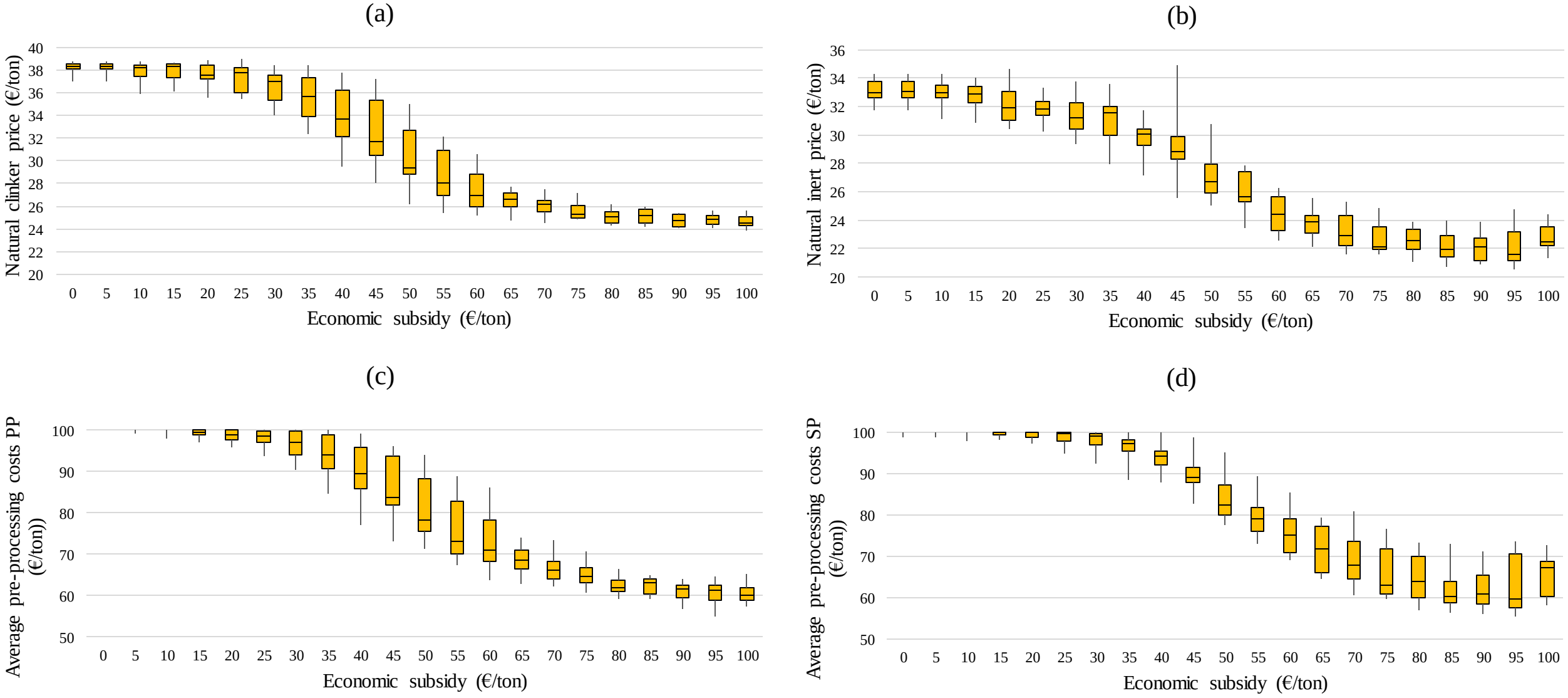
Sensitivity Analysis - Landfill tax
Equity and Profits

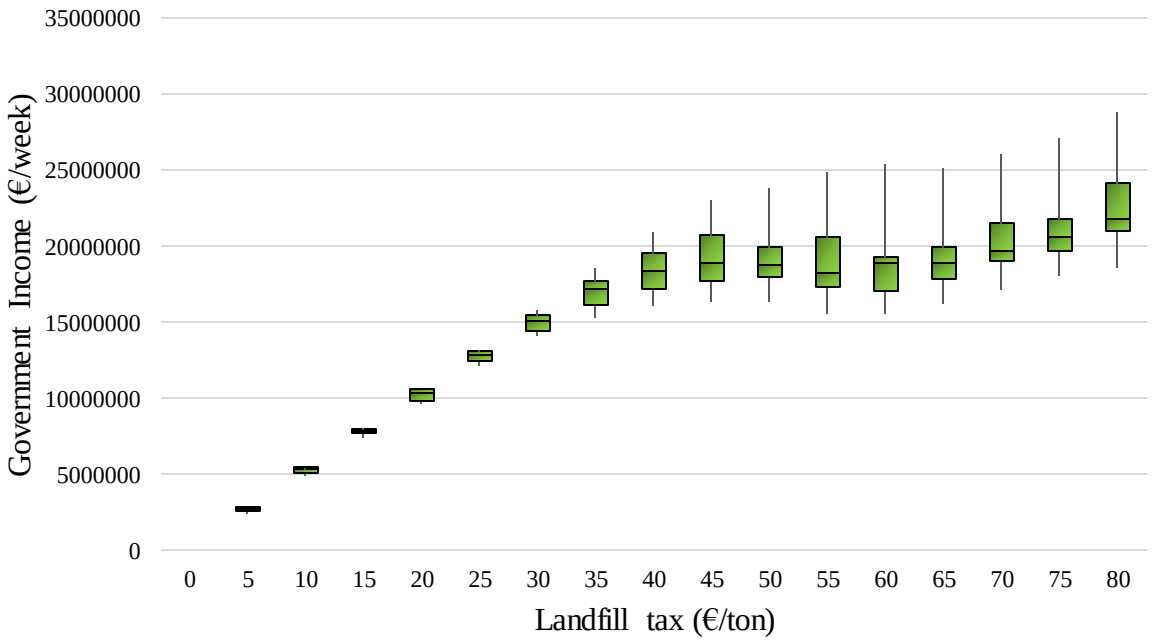


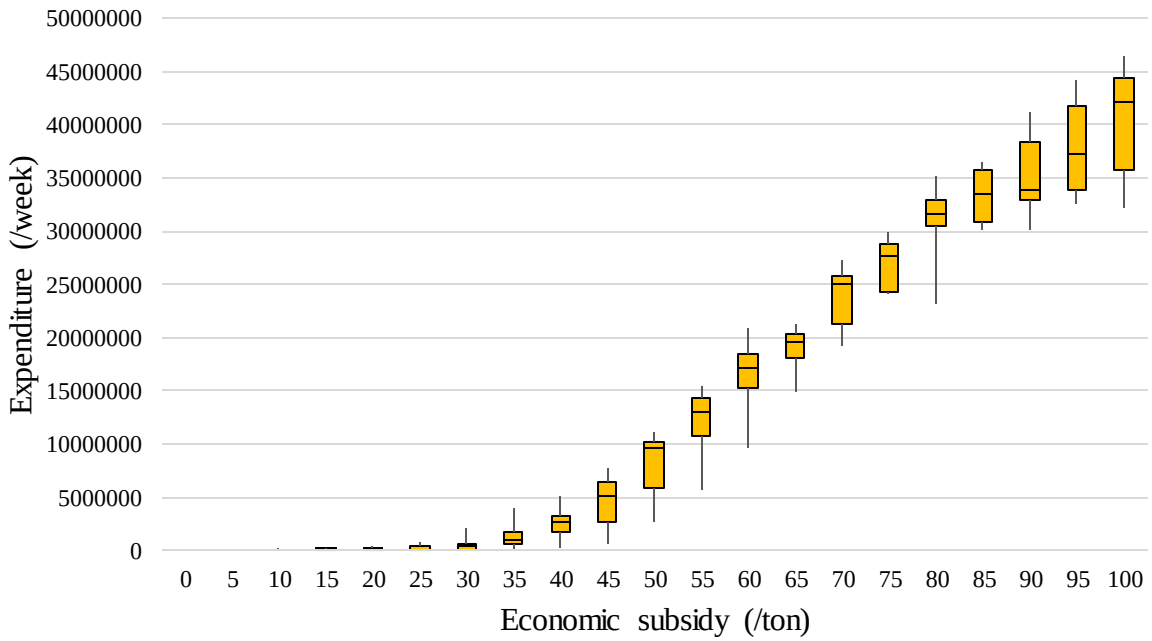


Sensitivity Analysis – Economic subsidy

Virgin material prices and Pre-processing costs




Government Income (€/week)
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80
Landfill tax (€/ton)


Expenditure (/week)
50000000
45000000
40000000
35000000
30000000
25000000
20000000
15000000
10000000
5000000
0
0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Economic subsidy (/ton)