Emissions Trading System in Policy Mixes

Presented by Coline METTA-VERSMESSEN

May 23rd, 2025

Jury Members

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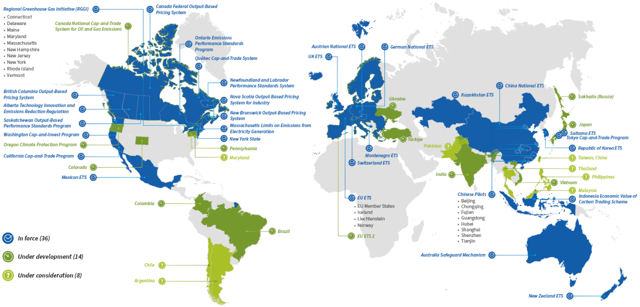
ETSs: From a European Adoption to a Global Wave

➤ **Emissions Trading Systems** (ETSs): *Policy tool where carbon quotas are set and traded by firms, internalizing the cost of pollution.*



ETS in the world in 2025

Source: International Carbon Action Partnership.

Climate Policies Beyond ETS

- ETSs are just the tip of the iceberg,
- Growing importance and number of climate policies,
- Interaction among **climate policy mixes**:
  ➤ overlaps or complementarity?

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Main Open Questions

1. How can we characterize the different interactions between ETSs and additional policies both within and beyond their scope?
2. How do these interactions affect pollution reduction and behaviors across different jurisdictions?
3. How can ETSs and additional policies be designed to create coherent and efficient policy mixes?

My Thesis in a Nutshell

Chap 1
Measuring the Stringency of Climate Policy Mixes

Chap 2 Carbon Contracts for Differences & Hydrogen Development

Chap 3
Short-Run Effects of the EU-ETS2

Chap 4 Cap & Trade Beyond Carbon: Waste Trading System

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ETS–ETS Interactions

ETS & Environmental Externalities

Chapter 1

Beyond Uniformity: Measuring the Stringency of Climate Policy Mixes Across Sectors and Countries

Single Authored

Motivations

Literature Review

Environmental Policy Stringency (EPS):

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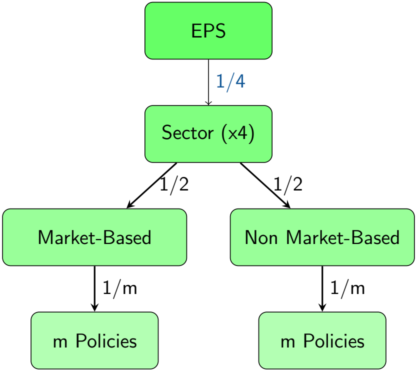
Research Questions:

- How to construct robust and comparable EPS indicators?
- Do more stringent mixes effectively reduce greenhouse gas (GHG) emissions?

Method Overview

1. Construct 4 EPS indicators based on CAPMF data*

— *EPS_OECD*



* Climate Actions and Policies Measurement Framework, OECD Database.

Method Overview

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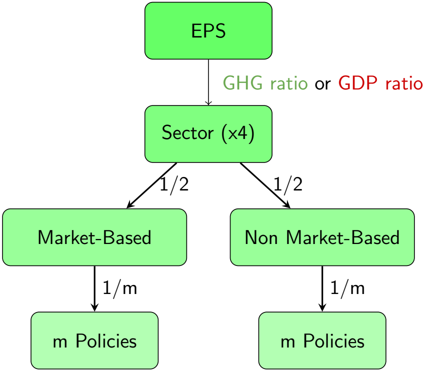

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1. Construct 4 EPS indicators based on CAPMF data*

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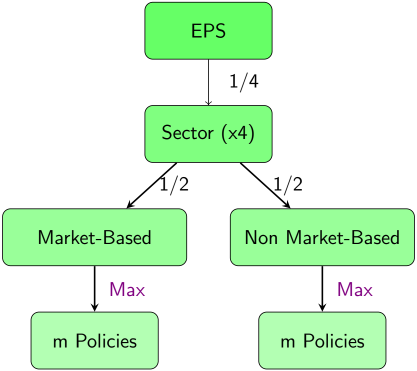
- *EPS_BOD*

(Benefit-of-the-Doubt approach)



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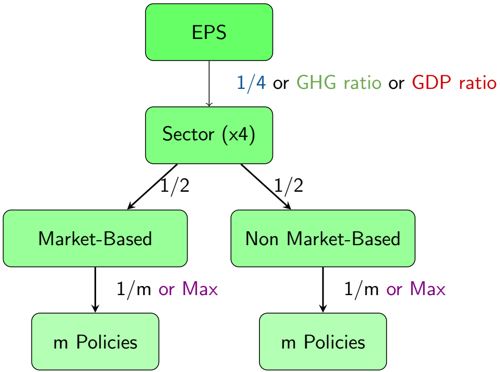

2. Test of their Econometric link with GHG emissions
   - Panel data (49 countries, 1990–2020)
   - Two-way fixed effects OLS
   - Instrumental Variable (Bartik)

Main Results

Are EPSs good proxies?

- Differentiated marginal effects among EPSs
- Differentiated marginal effects within EPS: depending on countries and time
- EPS_GDP: More stable and robust for comparisons.

Does stringency deliver?

- Stricter EPS generally reduces emissions.
- Differentiated effects among sectors.

Conclusion Chapter 1

Contribution

- New methodology to build richer, sectoral EPSs
- Policy Stringency matters for GHG decrease
- Limitations of single measures to capture such complex information

Limitations & Future Research

- Data biased toward OECD countries: include more countries
- EPS still show instability: go towards *de facto* definition

Chapter 2

The Carbon Contract for Differences: A Suitable Tool for Hydrogen Decarbonization?

Co-authored with Corinne Chaton

Revue Economique, 2023/5 Vol. 74

Motivations

▸ H_2 in Europe ▸ CCfD in Europe ▸ Advantages ▸ Characteristics

- The EU ETS alone cannot make expensive clean technologies competitive in time to meet 2050 goals
- Carbon Contracts for Difference (CCfDs) are promising but lack clear rules for effective implementation
- Electrification-based projects like hydrogen via electrolysis are singularly exposed to carbon-driven price increases.

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Research Question: How to design the CCfD for low-carbon hydrogen?

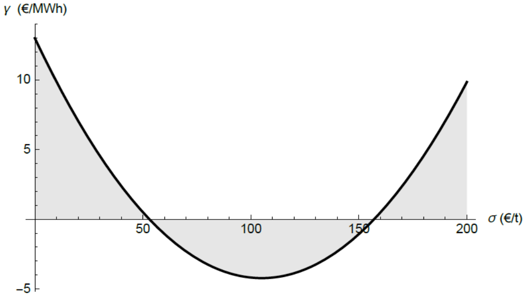
- What are the characteristics of the Strike and Payment?
- Is the CCfD the most efficient tool in this context?

Method Overview

1. Analytical model to equalize marginal costs between steam reforming and electrolysis,
   - Technological choice: Steam reforming vs electrolysis
   - Indirect quadratic cost of carbon emission
   - Study of effect of State Aids
   - Analytical expression of Strike and Payment
2. Numerical application for French and German cases
   - Countries with different electricity mixes
   - Focus on the French example

Main Results

For the French Case – See the ▸ German Case ▸ Confidence Intervals ▸ Sensitivity tests



Payment as a function of the carbon price (σ)

(Coal price = Gas price = 40€/MWh)

- The strike can be a set of prices.
- Need of renegotiation clause or indexation.

Conclusion Chapter 2

Contributions

- A first model on CCfDs and H_2,
- CCfD sensitive to input marginal cost functions: techno-focus, regional contracts,
- Current policies complementing the EU-ETS market do not prevent the implementation of CCfDs.

Limitations & Future Research

- Extend the assessment to other technologies (CCS),
- Investment subsidies + CCfD vs. CCfD covering the entire business plan.

Chapter 3

Carbon price is in the house: short-run effects of the EU-ETS2

Co-authored with Anna Creti

Inspired a litterature review published in Revue D'Économie Financière, 2024, n°155

Motivations

- ETS2 covers transport and building emissions from 2027,
- It extends European carbon quotas and prices,
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Research Questions

- What are ETS2's short-term effects on consumption and emissions across income groups?
- How might ETS2 influence ETS1 prices, particularly via electricity demand?

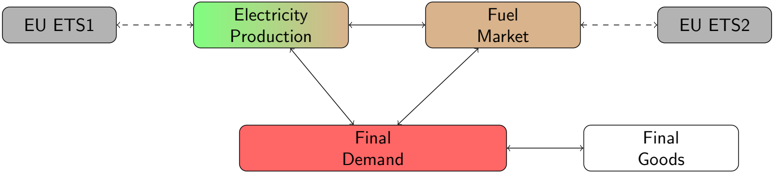
Method Overview

▸ Main Variables ▸ MSR ▸ SCF

A reference model inspired by Eichner and Pethig (2019)

➤ **Construction of analytical model and comparison between 3 scenarios**

1. **Reference Case**: Pre-ETS2 regulation
2. **Benchmark Case**: Introduction of ETS2
3. **Subsidy Case**: ETS2 + redistribution policy



Schematic Representation of the Benchmark Model

Main Results

Reference Benchmark Subsidy

Fossil Fuel prices
ETS2 raises fossil fuel prices for final consumption.

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Reference Benchmark Subsidy

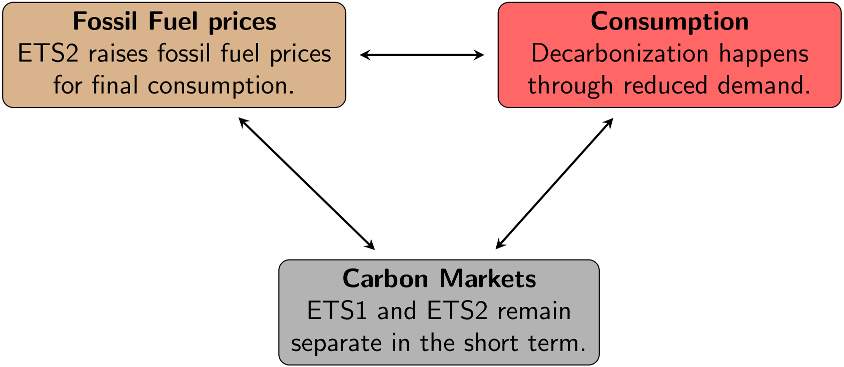
Fossil Fuel prices
ETS2 raises fossil fuel prices for final consumption.

↔

Consumption
Decarbonization happens through reduced demand.

Main Results

Reference Benchmark Subsidy



Conclusion Chapter 3

Capacity Constraint Proportion Revenues

Contributions

- A first Analytical model on ETS2.
- Captures short-term effects on utility function,
- With heterogeneous households.

Limitations & Future Research

- Model focuses on short-run effects,
- Future work: long-term dynamics, investment behavior.

Chapter 4

Waste Trading System: Managing Waste with High Population Density and Low Sorting Rate

Co-authored with Julie Metta
KU Leuven, Tilburg

Motivations

- Landfill waste externalities: soil, air, water pollution.
- Growing importance of waste management, especially in large and dense urban areas.
- Need for tailor-made regulation for waste sorting and reduction.

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Research Question

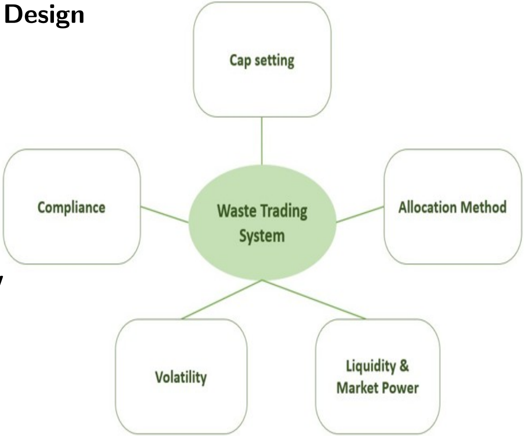
1. What is the potential of a Waste Trading System for Municipal Solid Waste Management?
2. How would it be characterized?

Method Overview

MDC Assumptions MACC Assumptions

Step 1: Waste Trading System Design

- Identification of conditions favouring Cap & Trade
- Characterization based on literature

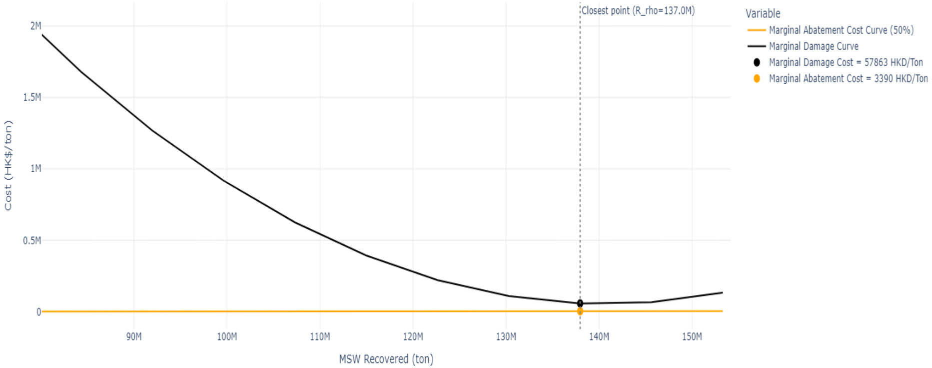


Step 2: Hong Kong Case Study

- Cost/Benefits analysis (Weitzman, 1974)
- Different scenarios (depending on costs)
- Assumption: Citizen's rationality

Main Results: A high potential for Cap and Trade in Hong Kong (HK)

▸ MDC ▸ MACC ▸ MDC Blind–MACC ▸ Facilities



Optimum:
Recovering rate: [73 - 82] %
Marginal Cost: [1,400 - 3,400] HK$/ton

➤ Current tax on bags:
228.69 HK$/ton

Conclusion Chapter 4

Contributions: The Waste Trading System approach

- Can be efficient for large and dense urban areas like Hong Kong,
- Need of a coordination agent to bear the obligation,
- Need an efficient monitoring and non-compliance penalty.

Limitations and further research

- Additional administration costs and possible volatility,
- Further research for European experiences.

General Conclusion and Policy Implications

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Effective climate policy mixes should account for cross-sectoral interactions

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ETS vs Additional Policy

CCfDs must consider the effects of carbon prices on energy ones

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Complementary measures are essential to ensure fairness and effectiveness

ETS–ETS Interactions

General Conclusion and Policy Implications

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Effective climate policy mixes should account for cross-sectoral interactions

ETS vs Additional Policy

CCfDs must consider the effects of carbon prices on energy ones

Complementary measures are essential to ensure fairness and effectiveness

ETS–ETS Interactions

ETSs can address broader environmental goals, if appropriately designed

ETS & Environmental Externalities

Discussion

Thank You

for your attention.

Happy to answer your questions!

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The EPS Index by the OECD

➤ A composite annual national rating (Botta et al. 2014, Kruse et al. 2022).

Structure:

- 3 building blocks: market-based, non-market-based, cross-sectoral,
- 13 policy types.

Scoring Methodology:

- Based on percentiles of observed stringency from 1990-2020 for 40 countries,
- Policies scored 0 (absent) to 6 (highest stringency).

Limits:

- No sectoral decomposition, focus on energy policies,
- Biased aggregation methodology (equal weighting).

The Climate Actions and Policies Measurement Framework

Method

➤ **Dataset** based on EPS, but enlarged and restructured (Nachtigall et al. 2022).

Structure:

- 3 building blocks: sectoral, cross-sectoral, international policies,
- Four sectors: Electricity, Industry, Buildings, and Transport.
- 130 policies

Scoring Methodology:

- Based on EPS one, for 52 countries.
- Policies scored 0 (absent) to 10 (highest stringency).

Advantages and challenges:

- Advantages: User-friendly, customizable via OECD data explorer,
- Challenges: Limited sectoral scope, overlapping indicators.

OCDE stringency scores and Carbon emissions

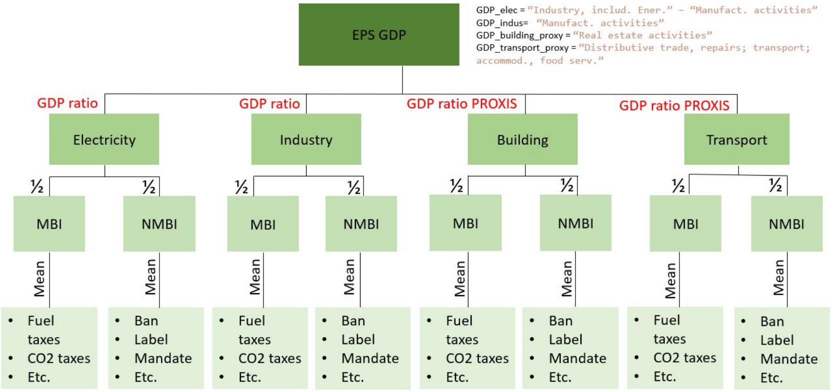
literature Review

- **Large literature** based on the EPS index, but contradictory results:
  - Stringency of environmental policies associated with a reduction in CO2 emissions (Angelis et al. 2019; Ahmed et al. 2018; Yirong 2022).
  - Inverted U-shaped relationship between policy stringency and emissions (Albulescu et al. 2022; Wolde-Rufael et al. 2021).
  - Insignificant/positive effects of EPS on CO_2 (Demiral et al. 2021; Alexandersson 2020).

- The paper the closest to our analysis: Stechemesser et al. 2024,
  - Uses CAMPF database, not directly the EPS score,
  - Highlights causal relationship between sectoral policy mixes and emissions reduction.

Construction of EPS_GDP

Methodology



EPS_GDP Structure

Construction of EPS_BOD

Methodology Calibration

For a country c, a sector s, and a type t, where $p_{c,s,t,i}$ is the score of the i-th policy, with the set of weights $w_{c,s,t} = \{w_{c,s,t,1}, w_{c,s,t,m}\}$

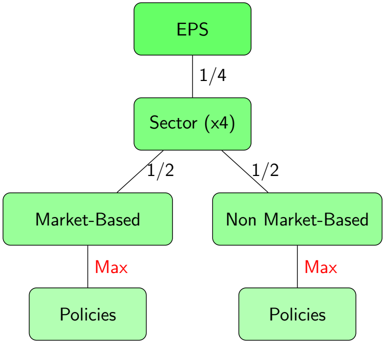
$$\text{EPS\_BOD}_c = \sum_s \sum_t S_{c,s,t}$$

$$S_{c,s,t} = \sum_i w_{c,s,t,i}\, p_{c,s,t,i}$$

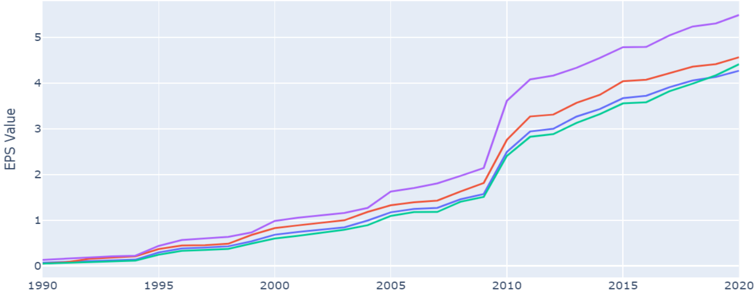
$$w_{c,s,t} = \arg\max_{w_{c,s,t}} S_{c,s,t} - \alpha \text{VAR}(S_{c,s,t})$$

s.t.

1. **Positivity constraint:**
   $w_{c,s,t,i} \geq 0 \quad \forall\, c, s, t, i$
2. **Distribution constraint:**
   $\sum_i w_{c,s,t,i} = \frac{1}{8} \quad \forall\, c, s, t$



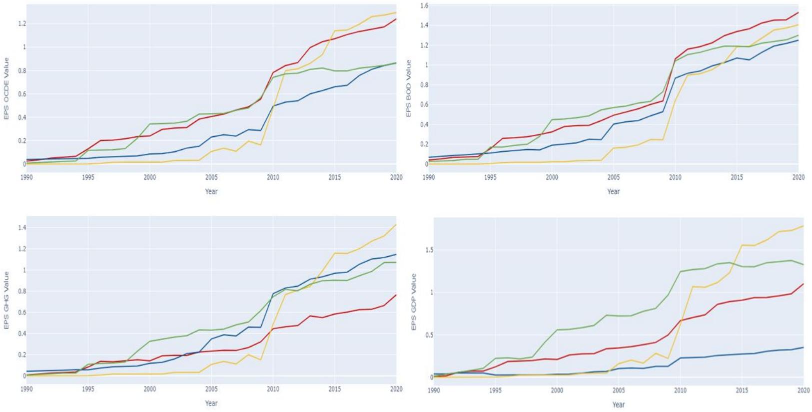
Graphical Comparison of total EPS Indicators



- All indicators show similar upward trends and variations.
- EPS_BOD has higher total values due to score maximization.

EPS_GDP; EPS_OECD; EPS_BOD; EPS_GHG.

Sectoral EPS graphical comparison



Building; Electricity; Industry; Transport.

Econometric Methodology

Method

Step 2: Two-way fixed effects regressions on GHG with panel data

$$\ln(GHG_{cy}) = \beta_0 + \beta_1 X_{cy} + \beta_2 Y_{cyt} + \alpha_c + \gamma_y + \varepsilon_{cy}$$

X_{cy}: Control variables; Y_{cy}: Explanatory variables EPS; α_c, γ_y: Country and Year fixed effects.

- Tests confirm 2-way fixed effect with clustered covariance estimator
- Causality test: Shift-share instrumental variable, lagged EPS
- Robustness checks: per capita, per GDP, total elasticities.

Proxy Assumption: Precision or overlap?

Results Lagged Variables
Per Capita Per GDP

Sectoral EPS Effects on GHG Emissions

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln_GHG - 1119 obs.			
Cov. Est	clustered			
R^2 (Within)	0.4315	0.0470	0.4415	0.4879
R^2 (Overall)	0.9224	0.9086	0.9300	0.9289
F-statistic	154.04	144.12	160.01	162.21
EPS_building	0.0241	0.0764***	-0.1395***	-0.0950***
	(1.0546)	(4.0007)	(-7.9003)	(-5.6734)
EPS_elec	-0.0779**	-0.0366*	-0.0353**	0.0149
	(-3.1460)	(-1.9754)	(-2.9959)	(0.6580)
EPS_indus	-0.1302***	-0.1243***	-0.0168	-0.0765***
	(-7.7360)	(-7.9372)	(-1.2799)	(-9.7827)
EPS_transport	-0.1115***	-0.0576**	-0.1351***	-0.0826***
	(-4.6648)	(-2.7776)	(-7.7816)	(-5.4661)

Results come from a 2WFE OLS including ln(GDP), ln(GDP)^2, ln(POP) and urban growth.

- EPS_GDP is better adjusted
- Confirmation with multicollinearity test (VIF)

Proxy Assumption: A Cross-Country Stable Indicator?

Results

Total EPS Effects on GHG Emissions

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln(GHG)			
Cov. Est	Clustered			
Developed countries (714 obs.)				
R^2 (Within)	0.2585	-0.9936	-0.0665	0.3502
Robust F-statistic	69.961	53.353	64.155	83.806
EPS	-0.0620***	-0.0139*	-0.0466***	-0.0681***
	(-5.7625)	(-2.0557)	(-4.4559)	(-7.6352)
Developing countries (438 obs.)				
R^2 (Within)	0.5086	0.3971	0.4853	0.5575
Robust F-statistic	113.35	100.86	105.93	121.60
EPS	-0.0376***	-0.0170*	-0.0356***	-0.0452***
	(-3.5111)	(-2.1370)	(-3.5488)	(-4.9237)

Results come from a 2WFE OLS including ln(GDP), ln(GDP)^2, ln(POP) and urban growth.

- Small instability between countries' type,
- Robust with GHG/capita and GHG/GDP,
- EPS_GDP is better adjusted

Proxy Assumption: A temporal unstable indicator

Results

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
	Period 1 (1991-2000) - 293 obs			
R^2 (Within)	-0.3946	-0.3085	-0.3387	-0.4154
Robust F-statistic	34.18	34.39	34.28	34.17
EPS	-0.0036	-0.0117	-0.0003	-0.0106
	(-0.1340)	(-0.6929)	(-0.0110)	(-0.4643)
	Period 2 (2001-2010) - 416 obs			
R^2 (Within)	0.0366	-0.0303	0.0536	0.0560
Robust F-statistic	63.08	62.10	64.15	64.37
EPS	-0.0468***	-0.0284***	-0.0469***	-0.0481***
	(-4.3961)	(-4.1823)	(-4.8513)	(-4.8498)
	Period 3 (2011-2020) - 429 obs			
R^2 (Within)	0.0722	-0.2465	0.1748	-0.0375
Robust F-statistic	22.22	20.38	24.45	21.56
EPS	-0.0301**	0.0016	-0.0407***	-0.0204*
	(-2.5525)	(0.2093)	(-3.3879)	(-2.4409)

Results come from a 2WFE OLS including ln(GDP), $\ln(GDP)^2$, ln(POP) and urban growth.

- Temporal instability, only significant between 2001-2010,
- Robust with GHG per capita and GHG per GDP,
- EPS_GDP is better adjusted

Similar effects at total EPS level

Results | Total elasticities

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln(GHG) - 1152 obs			
Cov. Est	clustered			
R^2 (Within)	0.4359	0.0487	0.3522	0.4667
F-statistic	248.05	220.58	240.26	264.75
const	2.3136	0.8602	1.9494	2.7117
	(1.5069)	(0.5425)	(1.2771)	(1.8444)
ln(GDP)	-0.4454***	-0.2922*	-0.4330***	-0.4263***
	(-3.4578)	(-2.2033)	(-3.3965)	(-3.4048)
$\ln(GDP)^2$	0.0421***	0.0371***	0.0413***	0.0419***
	(7.7665)	(6.6155)	(7.6714)	(7.9063)
ln(POP)	0.5151***	0.5333***	0.5345***	0.4790***
	(7.9075)	(7.8432)	(8.1759)	(7.5818)
urban_growth	-0.0457***	-0.0476***	-0.0461***	-0.0470***
	(-6.8966)	(-6.8159)	(-6.7643)	(-7.1460)
EPS	-0.0750***	-0.0378***	-0.0676***	-0.0765***
	(-10.514)	(-7.1395)	(-9.7377)	(-12.314)

- Non-linearity effects of GDP, positive of POP, negative of EPS,
- Similar impact and significance for OECD, GHG, and GDP,
- Adjusted impact of scale effect for BOD, less significant

➤ Robust with SSIV, lag, balanced dataset, GHG/capita and GHG/GDP.

Efficiency Assumption: Ambiguous sectoral effects ▸ Results

EPS effects on Sectoral GHG across model

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable		ln(GHG_building)		
R^2 (Within)	-0.0779	-0.1697	-0.3964	0.0356
EPS	-0.0524*	-0.0345*	-0.0240	-0.0643**
	(-2.5529)	(-2.3847)	(-1.1610)	(-3.3047)
Dep. Variable		ln(GHG_elec)		
R^2 (Within)	0.2832	0.0732	0.2871	0.2984
EPS	-0.0980***	-0.0410**	-0.0996***	-0.1028***
	(-5.5264)	(-2.9942)	(-5.6168)	(-6.7533)
Dep. Variable		ln(GHG_indus)		
R^2 (Within)	0.2994	0.0736	0.2431	0.2492
EPS	-0.0996***	-0.0528***	-0.0894***	-0.0875***
	(-7.8688)	(-6.0117)	(-6.8674)	(-7.3856)
Dep. Variable		ln(GHG_transport)		
R^2 (Within)	0.7012	0.7012	0.7135	0.6984
EPS	-0.0628***	-0.0333***	-0.0522***	-0.0646***
	(-8.4332)	(-5.8209)	(-6.6007)	(-8.8368)

Results come from a 2WFE OLS including ln(GDP), $\ln(GDP)^2$, ln(POP) and urban growth.

Efficiency Assumption: Ambiguous sectoral effects

Results

GHG elec

Summary of Sectoral EPS effects on Sectoral GHG across model

	GHG_building	GHG_elec	GHG_indus	GHG_transport
EPS_building	+	+/-	+/-	-
EPS_elec	/	+/-	-	-
EPS_indus	-	-	-	-
EPS_transport	-	-	-	-

Results come from a 2WFE OLS including ln(GDP), $\ln(GDP)^2$, ln(POP) and urban growth.

- Negative contributions from transport and industry sectors,
- Mixed effect of electricity and building sectors: related to regional and temporal instability?

➤ Interactions in-between sectoral policies?

Sectoral EPS effect on Electricity GHG ▸ Results

Parameter	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
R^2 (Within)	0.2907	0.1168	0.3236	0.3216
F-statistic	45.408	45.002	56.891	50.368
EPS_building	0.1229**	0.2053***	-0.2913***	-0.2061***
	(2.5909)	(5.0527)	(-7.4959)	(-5.9450)
EPS_elec	-0.1122*	-0.0119	0.0294	0.2132***
	(-2.0593)	(-0.2914)	(1.1432)	(4.3014)
EPS_indus	-0.2215***	-0.1881***	-0.0246	-0.0948***
	(-6.3959)	(-5.7996)	(-0.9505)	(-5.0936)
EPS_transport	-0.1674***	-0.1789***	-0.2498***	-0.1182***
	(-3.5965)	(-4.2892)	(-5.6081)	(-3.7890)

Efficiency Assumption: Strong significance of sectoral interactions

Results

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln_GHG - 1119 obs			
Cov. Est	clustered			
R^2 (Within)	0.4980	0.2610	0.4441	0.5375
F-statistic	174.27	149.23	187.66	191.60
EPS_indus	-0.1626***	-0.1401***	-0.0414*	-0.1125***
	(-7.8845)	(-5.3697)	(-2.3584)	(-13.735)
Average effect	-0.0765	-0.0725	-0.0183	-0.0670
EPS(Elec*Indus)	0.0887***	0.0450*	0.0309*	0.2230***
	(3.4372)	(2.0875)	(2.0726)	(5.6624)
Average effect	0.0315	0.0273	0.0137	0.0333
EPS(Elec*Transport)	-0.2374***	-0.1105***	-0.1120***	-0.1792***
	(-7.7560)	(-5.6230)	(-7.4199)	(-6.3228)
Average effect	-0.0753	-0.0800	-0.0467	-0.0322
EPS(Building*Transport)	0.0098	0.0395**	-0.1092***	-0.0853***
	(0.5201)	(3.2285)	(-8.1052)	(-9.8123)
Average effect	0.0049	0.0358	-0.0332	-0.0527

Results come from a 2WFE OLS including control variables and standalone variables (insignificant so withdrawn from the table).

- General-to-specific framework based on EPS_GDP,
- Only EPS_indus conserving a standalone significant effect,
- Strong potential for complementarity in Transport sector.

Typology of EPS Indicators and Their Limitations

OECD Index

➤Using Galeotti et al. 2020 classification:

- **Pollution Abatement Effort:** Measures private (PACE) and public (R&D investments) efforts (Popp 2019; Dechezleprêtre et al. 2014).
- **Direct Regulation Assessment:** Evaluates policies like EU-ETS adjustments (Bel et al. 2018).
  ➤ Not for policy mix, causality issue.
- **Emission-Based Indices:** Uses emission discrepancies to assess stringency (Brunel et al. 2013).
  ➤ Causality issue.
- **Composite Indicators:** Combines multiple metrics like R&D and regulation indices (Jiang et al. 2018).
  ➤ Subjective methodology?

Literature Review

EPS effect Motivations

Study	Method	Findings
Ahmed et al. 2018	Time series	EPS reduces emissions in China
Angelis et al. 2019	FE PanelOLS	EPS reduces CO2.
Albulescu et al. 2020	FE PanelOLS, GMM estimator	Role of regulation not significant.
Alexandersson 2020	FE PanelOLS	No significant impact of EPS
Wolde-Rufael et al. 2020	PMG-ARDL, Cointegration	Inverted u-shaped between EPS and CO2 : impact takes time.
Sezgin et al. 2021	Cointegration	Bilateral causality, EPS decreases CO2.
Demiral et al. 2021	PooledOLS, FE, RE PanelOLS	Higher EPS increases emissions.
Albulescu et al. 2022	FE PanelOLS in quantile k	Asymetric impact, higher for countries with lower emissions.
Yirong 2022	PMG-ARDL	EPS decrease CO2 in the long run

Calibration of the argument alpha

▸ Methodology ▸ EPS_BOD's Construction

	BOD_0var	BOD_10var	BOD_100var
Dep. Variable	ln_GHG - 1308 obs		
R-squared	0.4431	0.4425	0.4697
R-Squared (Within)	0.1271	0.1104	0.3981
Log-likelihood	1157.4	1156.8	1189.4
F-statistic	243.88	243.31	271.44
const	-6.4493***	-6.4926***	-5.5619***
	(-7.9166)	(-7.9744)	(-6.9411)
ln_GDP	0.4135***	0.4143***	0.3803***
	(18.281)	(18.295)	(17.116)
ln_POP	0.7994***	0.8013***	0.7724***
	(15.906)	(15.942)	(15.797)
Urban_growth	-0.0662***	-0.0664***	-0.0650***
	(-11.180)	(-11.213)	(-11.258)
EPS	-0.0150***	-0.0149***	-0.0388***
	(-4.4077)	(-4.2591)	(-9.0438)

An Unbalanced Panel Database

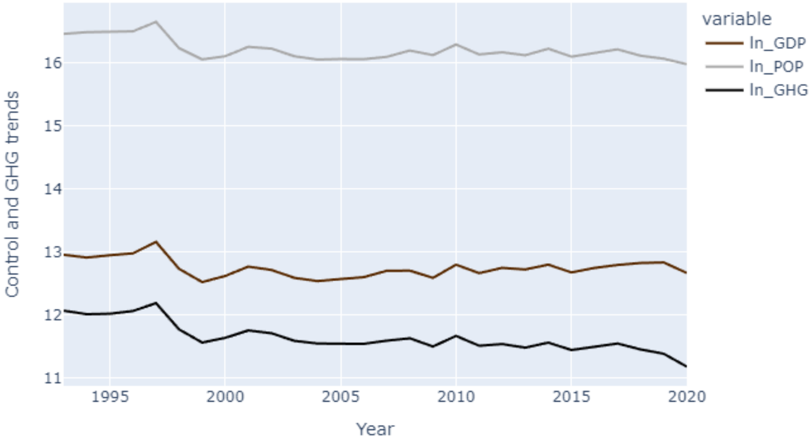
▸ Methodology ▸ Econometrics

Variable	Count	Mean	Std. Dev.	Min	50%	Max
ln_GDP (10^6 USD_{2015})	1119	12.50	1.55	8.80	12.56	15.34
ln_POP (Count)	1119	16.27	1.51	12.50	16.15	21.01
urban_growth (percentage)	1119	0.83	1.02	-3.45	0.78	5.09
ln_GHG (10^3 $CO2_{eq}$)	1119	11.61	1.52	7.52	11.32	14.86
EPS_BOD (0-10 score)	1119	2.69	2.20	0.00	2.07	7.87
EPS_OECD (0-10 score)	1119	2.02	1.70	0.00	1.50	6.23
EPS_GHG (0-10 score)	1119	1.88	1.65	0.00	1.39	6.24
EPS_GDP (0-10 score)	1119	2.08	1.75	0.00	1.51	6.75

- Data from OECD and World Bank, covering 49 countries (1990-2020).
- Unbalanced dataset due to missing data, primarily from 1990-1995.
- Robustness checks with balanced subsets confirm representativeness.

Data Visualization – Control

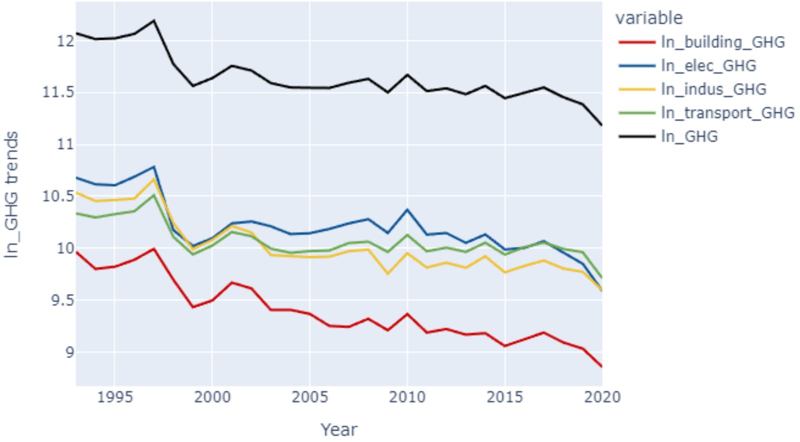
▸ Econometrics ▸ Method



Trends of GHG and control variables

Data Visualization – Carbon trends

▸ Econometrics ▸ Method



Trends of GHG and its sectoral decomposition

Pooled vs random effects vs fixed effects

Methodology Econometrics

	RE	FE Entity	FE Time	FE Entity/Time
Dep. Variable		ln(GHG) 1152 obs		
Cov. Est.		Clustered		
R^2	0.7758	0.5385	0.9409	0.5462
R^2 (Within)	0.5380	0.5385	0.1821	0.4298
AIC	-2311.02	-2359.89	982.82	-2533.31
BIC	-2265.58	-2314.45	1028.26	-2487.86

- No pooled : Heteroskedasticity (White test and Breush-Pagan test),
- Hausman test confirm FE,
- Presence of heteroskedasticity and autocorrelation but no cross-sectional dependence : clustered covariance estimator.

Instrumental Variable using Shift-Share instrument

Methodology
Econometrics | 1st Stage Total | 2nd Stage Total | 1st Stage sector | 2nd Stage sector | 2nd Stage sector GHG

A Shift-Share Instrument

$$\text{Bartik\_instrument}_{cy} = S_c \times Z_t$$

S_c: 1990 GDP share-agriculture and forestry; Z_y: EPS leave-one-out global mean.

First Stage

$$\text{EPS}_{cy} = \beta_0 + \beta_1 X_{cy} + \beta_B \text{Bartik\_instrument}_{cy} + \alpha_c + \gamma_y + u_{cy}$$

Tests:

- F-stat and Robust F-stat > 30
- Shock-level decomposition (Borusyak et al. 2022),
- Other causality test: 3-years lagged EPS

IV 1st Stage Results ▸ SSIV

Dep. Variable	EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
Cov. Estimator		clustered - 1138 obs		
F-statistic	72.235	68.214	72.554	53.961
F-statistic (robust)	61.711	91.671	64.389	48.206
const	73.037***	106.05***	75.052***	76.159***
	(12.834)	(14.837)	(12.514)	(12.645)
ln(GDP)	-6.4855***	-9.4083***	-7.2875***	-6.1004***
	(-12.278)	(-13.884)	(-12.949)	(-11.026)
$\ln(GDP)^2$	0.2634***	0.3999***	0.2854***	0.2554***
	(11.201)	(13.188)	(11.592)	(10.160)
ln(POP)	-1.9321***	-2.9965***	-1.6671***	-2.3364***
	(-7.1209)	(-8.5049)	(-5.9727)	(-7.8395)
urban_growth	0.0328	0.0493	0.0442	0.0102
	(1.2541)	(1.3832)	(1.6179)	(0.3577)
Bartik_instrument	-0.0240***	-0.0250***	-0.0200***	-0.0229***
	(-8.2515)	(-8.8125)	(-6.0326)	(-6.8031)

IV 2nd Stage Results

▸ SSIV ▸ EPS on GHG

	EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
Dep. Variable	ln_GHG - 1138 obs			
Cov. Estimator	clustered			
F-statistic	190.41	189.54	190.54	190.28
F-statistic (robust)	120.28	119.85	120.29	120.46
const	9.4561*	10.120*	12.861**	10.253**
	(2.5181)	(2.5518)	(2.7924)	(2.5832)
ln(GDP)	-1.1418**	-1.1934**	-1.5743***	-1.1002**
	(-3.1721)	(-3.1538)	(-3.3585)	(-3.1353)
$\ln(GDP)^2$	0.0683***	0.0726***	0.0836***	0.0679***
	(4.8781)	(4.7536)	(4.6960)	(4.8672)
ln(POP)	0.3674***	0.3233**	0.3439***	0.2915*
	(3.7708)	(3.0110)	(3.3603)	(2.5513)
urban_growth	-0.0336***	-0.0332***	-0.0299***	-0.0372***
	(-4.7679)	(-4.6510)	(-3.9858)	(-5.5488)
pred_EPS	-0.1642***	-0.1186***	-0.2056***	-0.1675***
	(-3.7525)	(-3.6926)	(-3.7624)	(-3.7348)

Sectoral SSIV 1st Stage Results

▸ SSIV

Dep. Variable	EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
dep. var	EPS_building			
F-statistic	25.013	39.369	36.429	50.727
F-statistic (robust)	20.096	51.428	46.766	56.518
SS_building	-0.0259***	-0.0280***	-0.0587***	-0.0190***
	(-6.1686)	(-7.0733)	(-6.9795)	(-3.7801)
dep. var	EPS_elec			
F-statistic	67.834	45.387	41.321	18.255
F-statistic (robust)	56.061	55.602	54.123	27.131
SS_elec	-0.0280***	-0.0225***	-0.0316***	-0.0281**
	(-5.8881)	(-5.7932)	(-4.4178)	(-3.2053)
dep. var	EPS_indus			
F-statistic	31.399	37.979	30.277	30.100
F-statistic (robust)	25.104	34.166	34.750	29.017
SS_indus	-0.0189***	-0.0220***	0.0003	-0.0249***
	(-3.6946)	(-3.5377)	(0.0574)	(-3.2947)
dep. var	EPS_transport			
F-statistic	40.169	51.073	24.734	37.902
F-statistic (robust)	46.235	56.030	38.602	37.548
SS_transport	-0.0366***	-0.0383***	-0.0370***	-0.0372***
	(-8.2211)	(-8.4082)	(-6.0112)	(-7.2832)

Sectoral SSIV 2nd Stage Results

▸ SSIV ▸ EPS on GHG ▸ 2nd Stage sector_GHG

	EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
Dep. Variable		ln_GHG - 1106 obs		
Cov. Estimator		clustered		
F-statistic	116.94	117.85	117.29	117.95
F-statistic (robust)	71.109	71.356	72.839	72.215
pred_EPS_building	−0.9262	−1.1748	−1.0868	−1.2920
	(−0.7996)	(−0.9624)	(−1.4224)	(−0.7712)
pred_EPS_elec	−0.4521	−0.4227	0.2254	2.6862
	(−0.4275)	(−0.4473)	(0.4103)	(0.9679)
pred_EPS_indus	−0.3301	−0.3500	36.379	−0.7125.
	(-0.5558)	(−0.4462)	(1.2843)	(−1.9091)
pred_EPS_transport	1.1067∗	1.2262.	0.9657	0.3555
	(2.0197)	(1.9490)	(1.5053)	(0.9809)

Sectoral SSIV 2nd Stage Results on Secotral GHG

SSIV

EPS on GHG

		EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
ln(GHG _building)	F-statistic	27.127	26.358	28.778	26.052
	pred_EPS_building	0.5559	0.9740	2.0034	1.2782
	pred_EPS_elec	-3.6281***	-2.1542*	-1.8158*	-2.6860
	pred_EPS_indus	1.3546	0.6760	-3.6517	-0.0730
	pred_EPS_transport	-0.1410	-1.2125	-1.2897	-0.7106
ln(GHG _elec)	F-statistic	32.635	32.340	33.368	33.140
	pred_EPS_building	-1.1423	0.2880	-1.7772	-2.1786
	pred_EPS_elec	0.3056	-0.5987	2.1548*	10.349
	pred_EPS_indus	-2.5596	-2.5435*	173.73**	-2.2502**
	pred_EPS_transport	2.6731*	2.5648**	1.9228	1.0056
ln(GHG _indus)	F-statistic	53.090	53.007	53.177	52.794
	pred_EPS_building	1.2994	0.8770	0.1251	2.6627
	pred_EPS_elec	-0.6222	-1.1111	-0.8436	-5.3039
	pred_EPS_indus	-0.7284	-0.0723	-16.291	-0.1929
	pred_EPS_transport	-0.4454	-0.2725	0.2637	0.0015
ln(GHG _transport)	F-statistic	143.81	143.01	154.08	147.05
	pred_EPS_building	-2.2190*	-3.1612***	-1.6447**	-5.4874***
	pred_EPS_elec	-0.2138	-0.6362	1.0792**	3.6025
	pred_EPS_indus	0.7901**	1.4329**	19.423	0.2967
	pred_EPS_transport	0.8599	1.3226**	-0.0878	0.4592

SSIV robustness: Borusiak's test (2022) SSIV

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
	Period 1 (1991-2000) - 293 obs			
Robust F-statistic	25.98	25.98	26.06	26.07
predicted_EPS	0.055	0.029	0.051	0.051
	(0.53)	(0.47)	(0.65)	(0.67)
	Period 2 (2001-2010) - 416 obs			
Robust F-statistic	36.37	36.37	36.38	36.30
predicted_EPS	-0.105	-0.049	-0.117	-0.142
	(-0.95)	(-0.94)	(-0.97)	(-0.94)
	Period 3 (2011-2020) - 429 obs			
Robust F-statistic	9.44	21.95	11.19	8.52
predicted_EPS	0.131**	0.258***	0.163**	0.083*
	(2.41)	(5.61)	(3.11)	(1.94)
	Placebo - 1138 obs			
F-statistic	177.78	177.78	177.78	177.78
Robust F-statistic	102.52	102.50	102.52	102.52
Placebo	-0.102	-0.083	-0.291	-0.068
	(-0.39)	(-0.41)	(-0.39)	(-0.40)

Cross-Country: EPS on GHG per capita

Cross-country GHG

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln(GHG/cap)			
Cov. Est	Clustered			
Developed countries (713 obs.)				
R^2 (Within)	0.4051	0.3557	0.3950	0.4287
Robust F-statistic	64.861	48.240	47.918	79.883
EPS	-0.0756***	-0.0315***	-0.0330***	-0.0802***
	(-9.3346)	(-5.3005)	(-4.0183)	(-11.721)
Developing countries (438 obs.)				
R^2 (Within)	0.1997	0.2340	0.2270	0.2258
Robust F-statistic	22.311	20.735	21.127	28.815
EPS	-0.0290	-0.0081	-0.0205	-0.0612***
	(-1.7747)	(-0.6448)	(-1.2827)	(-4.7139)

Results come from a 2WFE OLS including ln(GDP/cap), ln(GDP/cap)^2, population and urban growths.

Cross-Country: EPS on GHG/GDP

Cross-country GHG

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable		ln(GHG/GDP)		
Cov. Est		Clustered		
Developed countries (701 obs.)				
R^2 (Within)	0.5044	0.2180	0.3304	0.6914
Robust F-statistic	9.6306	7.0084	7.4091	15.038
EPS	-0.0393***	-0.0111	-0.0238**	-0.0598***
	(-4.4347)	(-1.8832)	(-2.6957)	(-6.2303)
Developing countries (429 obs.)				
R^2 (Within)	0.2070	0.0722	0.1573	0.2489
Robust F-statistic	35.189	32.593	32.635	36.620
EPS	-0.0314*	-0.0113	-0.0263*	-0.0358**
	(-2.3853)	(-1.1353)	(-1.9677)	(-3.2150)

Results come from a 2WFE OLS including ln(POP) and the growths of GDP, GDP^2 and urbanization.

Cross-Country: Sectoral EPS on GHG

▸ Cross-country GHG ▸ Sectoral EPS

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln(GHG)			
Cov. Est	Clustered			
Developed countries (709 obs.)				
R^2 (Within)	0.0955	-1.2084	0.0972	0.2891
Robust F-statistic	46.269	51.467	83.607	64.411
EPS_building	0.0528*	0.1526***	-0.1297***	-0.0182
	(2.0830)	(7.8518)	(-5.5334)	(-0.9194)
EPS_elec	-0.0749**	-0.0255	-0.0167	0.0224
	(-2.9018)	(-1.3604)	(-1.3098)	(1.3278)
EPS_indus	-0.1123***	-0.1120***	0.0285*	-0.0703***
	(-5.6858)	(-6.7414)	(2.0748)	(-7.0064)
EPS_transport	-0.0874***	-0.0570**	-0.1322***	-0.1074***
	(-3.3026)	(-2.5874)	(-7.6825)	(-6.2825)
Developing countries (410 obs.)				
R^2 (Within)	0.5676	0.4620	0.4864	0.5889
Robust F-statistic	73.682	67.456	65.322	80.022
EPS_building	0.0017	-0.0077	-0.1047*	-0.0442
	(0.0444)	(-0.2248)	(-2.6555)	(-1.1765)
EPS_elec	0.0570	0.0613	-0.0003	0.1248**
	(1.1737)	(1.6815)	(-0.0127)	(2.7227)
EPS_indus	-0.1100***	-0.1049***	-0.0621	-0.0908***
	(-3.7592)	(-3.4357)	(-1.8194)	(-5.7446)
EPS_transport	-0.0796	0.0013	0.0084	-0.0242
	(-1.7233)	(0.0325)	(0.2030)	(-1.0042)

Period decomposition: EPS on GHG per capita

total GHG

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
	Period 1 (1991-2000) - 292 obs			
R^2 (Within)	-0.3143	-0.2324	-0.2914	-0.3272
F-statistic	12.85	13.12	12.88	12.87
EPS	-0.0041	-0.0175	-0.0012	-0.0079
	(-0.1528)	(-0.9902)	(-0.0419)	(-0.3549)
	Period 2 (2001-2010) - 416 obs			
R^2 (Within)	0.2627	0.2197	0.2766	0.2631
F-statistic	52.25	51.26	53.94	52.42
EPS	-0.0500***	-0.0305***	-0.0484***	-0.0520***
	(-5.1817)	(-4.7785)	(-5.3698)	(-5.8069)
	Period 3 (2011-2020) - 429 obs			
R^2 (Within)	0.1612	-0.2013	0.1746	-0.1097
F-statistic	14.18	15.61	14.41	14.19
EPS	0.0048	0.0201*	-0.0050	0.0108
	(0.4525)	(2.4934)	(-0.5019)	(1.1829)

Results come from a 2WFE OLS including ln(GDP/cap), $\ln(GDP/cap)^2$, population and urban growths.

Period decomposition: EPS on GHG per GDP

total GHG

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
	Period 1 (1991-2000) - 284 obs			
R^2 (Within)	0.0275	0.0949	-0.0165	0.0319
Robust F-statistic	3.37	3.60	3.34	3.38
EPS	-0.0093	-0.0190	0.0013	-0.0092
	(-0.3049)	(-1.0123)	(0.0411)	(-0.3675)
	Period 2 (2001-2010) - 416 obs			
R^2 (Within)	0.3434	0.2924	0.3045	0.3613
Robust F-statistic	12.08	11.14	11.09	13.38
EPS	-0.0486***	-0.0282***	-0.0420***	-0.0524***
	(-4.4144)	(-3.8471)	(-4.2191)	(-5.3073)
	Period 3 (2011-2020) - 429 obs			
R^2 (Within)	-0.0719	-0.1157	0.0177	-0.0245
Robust F-statistic	14.54	15.38	14.35	14.38
EPS	0.0118	0.0187*	-0.0020	0.0047
	(1.0359)	(2.1101)	(-0.1782)	(0.4577)

Results come from a 2WFE OLS including ln(POP) and the growths of GDP, GDP^2 and urbanization.

Causality Test: 3-year lag

Methodology Econometrics SSIV Sectoral Results

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln_GHG - 1078 obs.			
Cov. Est	clustered			
R^2 (Within)	0.3638	0.1166	0.1960	0.3595
F-statistic	124.29	118.00	115.08	124.76
EPS_building_lag	0.0129	0.0480*	-0.1283***	-0.0657***
	(0.5450)	(2.3491)	(-6.8722)	(-3.7268)
EPS_elec_lag	-0.0576*	-0.0048	-0.0410*	0.0464
	(-1.9996)	(-0.2252)	(-3.1150)	(1.9158)
EPS_indus_lag	-0.1072***	-0.1198***	0.0102	-0.0681***
	(-5.0549)	(-5.9609)	(0.6670)	(-6.9836)
EPS_transport_lag	-0.1459***	-0.0886***	-0.1087***	-0.0959***
	(-6.0642)	(-4.4767)	(-6.4564)	(-6.5120)

Total EPS - GHG/Capita

EPS on GHG

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable		ln(GHG/cap) - 1151 obs.		
R^2 (Within)	0.4197	0.1355	0.3421	0.4513
F-statistic	133.33	119.54	128.53	142.24
const	-3.6387***	-3.7585***	-3.7123***	-3.2774***
	(-11.225)	(-11.180)	(-11.240)	(-10.674)
ln(GDP/cap)	0.0470	-0.0046	0.0256	0.1952
	(0.3353)	(-0.0318)	(0.1790)	(1.4748)
$\ln(GDP/cap)^2$	-0.0458**	-0.0536***	-0.0477***	-0.0315*
	(-3.1355)	(-3.5300)	(-3.2031)	(-2.2710)
POP_growth	0.0647***	0.0702***	0.0635***	0.0550**
	(3.4993)	(3.8726)	(3.4601)	(3.0102)
urban_growth	-0.1025***	-0.1064***	-0.1016***	-0.0975***
	(-6.9974)	(-7.4850)	(-7.0315)	(-6.8056)
EPS	-0.0523***	-0.0234***	-0.0452***	-0.0572***
	(-7.2095)	(-4.1911)	(-5.9202)	(-8.7088)

Results come from a 2WFE OLS.

Total EPS - GHG/GDP

▸ EPS on GHG

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable		ln(GHG/GDP) - 1130 obs.		
R^2 (Within)	0.1010	-0.0534	-0.0052	0.2479
F-statistic	46.103	44.037	44.553	50.872
const	-1.1259	-1.3368	-1.3036	-0.6938
	(-0.9422)	(-1.1309)	(-1.1070)	(-0.5700)
ln(POP)	0.4462***	0.4576***	0.4559***	0.4214***
	(6.1103)	(6.3273)	(6.3258)	(5.6752)
GDP_growth	-0.5435***	-0.5394***	-0.5469***	-0.5250***
	(-3.4618)	(-3.4178)	(-3.4590)	(-3.4072)
GDP_growth^2	-2.3536	-2.5310**	-2.4242	-1.9625
	(-1.8363)	(-1.9734)	(-1.8675)	(-1.5292)
urban_growth	-0.0592***	-0.0590***	-0.0592***	-0.0600***
	(-6.7360)	(-6.7416)	(-6.7380)	(-6.7903)
EPS	-0.0216**	-0.0065	-0.0128	-0.0340***
	(-2.8579)	(-1.2035)	(-1.6686)	(-4.3890)

Results come from a 2WFE OLS.

Sectoral EPS - GHG/Capita

Methodology Econometrics Sectoral Results

	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
Dep. Variable	ln(GHG/cap) - 1118 obs.			
Cov. Est	clustered			
R^2 (Within)	0.4213	0.1505	0.4413	0.4826
F-statistic	83.639	80.354	93.418	91.823
EPS_building	0.0127	0.0726***	-0.1257***	-0.0958***
	(0.5384)	(3.9377)	(-7.4807)	(-5.3137)
EPS_elec	-0.0006	0.0085	-0.0078	0.0683**
	(-0.0246)	(0.4414)	(-0.6490)	(2.9698)
EPS_indus	-0.1190***	-0.1174***	-0.0015	-0.0509***
	(-7.1608)	(-7.3934)	(-0.1063)	(-6.1554)
EPS_transport	-0.0883***	-0.0493*	-0.1315***	-0.0736***
	(-3.6796)	(-2.5059)	(-7.9832)	(-5.2508)

Results come from a 2WFE OLS including ln(GDP/cap), ln(GDP/cap)^2, population and urban growths.

Sectoral EPS - GHG/GDP

Methodology Econometrics Sectoral Results

Dep. Variable	ln(GHG/GDP) -1118 obs.			
Cov. Est	clustered			
R^2 (Within)	0.1273	-0.0946	0.0516	0.1957
F-statistic	29.798	30.318	32.988	37.523
EPS_building	0.0254	0.0910***	-0.0492*	0.0328
	(1.0288)	(4.3883)	(-2.5472)	(1.7673)
EPS_elec	0.0413	-0.0201	0.0028	0.0577**
	(1.4750)	(-0.9609)	(0.2274)	(2.6499)
EPS_indus	-0.0803***	-0.0715***	0.0364*	-0.0550***
	(-3.9391)	(-3.8667)	(2.3785)	(-5.0019)
EPS_transport	-0.0575*	-0.0164	-0.0962***	-0.0483**
	(-2.2376)	(-0.7704)	(-5.6033)	(-2.8836)

Results come from a 2WFE OLS including ln(POP) and the growths of GDP, GDP^2 and urbanization.

Total elasticities

▸ Methodology ▸ Econometrics ▸ EPS on GHG

	EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
Dep. Variable	ln(GHG) - 1152 obs			
Cov. Estimator	clustered			
R^2 (Within)	-0.2585	-0.6990	-0.4028	-0.1494
F-statistic	205.88	198.58	203.31	211.21
const	-1.4011	-2.2398	-1.6172	-1.1257
	(-0.9107)	(-1.4257)	(-1.0630)	(-0.7507)
ln(GDP)	0.0184	0.0689	0.0063	0.0130
	(0.1431)	(0.5209)	(0.0485)	(0.1009)
$\ln(GDP)^2$	0.0257***	0.0235***	0.0259***	0.0261***
	(4.6917)	(4.1780)	(4.6878)	(4.8156)
ln(POP)	0.5443***	0.5753***	0.5634***	0.5281***
	(7.9415)	(8.2339)	(8.3718)	(7.9629)
urban_growth	-0.0490***	-0.0510***	-0.0496***	-0.0491***
	(-6.9095)	(-7.0035)	(-6.8905)	(-7.0314)
ln(EPS+1)	-0.1061***	-0.0494*	-0.0853***	-0.1206***
	(-4.4039)	(-2.3714)	(-3.8485)	(-5.2014)

Sector elasticities

	EPS_BOD	EPS_OECD	EPS_GHG	EPS_GDP
Dep. Variable		ln(GHG)		
Cov. Estimator		clustered		
R^2 (Within)	0.3061	-0.1304	0.3692	0.2761
F-statistic	144.72	139.61	145.46	143.01
ln_EPS_building	0.0705	0.1415***	-0.1823***	-0.0844**
	(1.8449)	(4.0828)	(-5.6716)	(-2.5244)
ln_EPS_elec	-0.1186**	-0.0260	-0.0388	0.0070
	(-3.1110)	(-0.8701)	(-1.7112)	(0.1651)
ln_EPS_indus	-0.2272***	-0.2433***	-0.0671**	-0.1669***
	(-8.6296)	(-8.9687)	(-2.8177)	(-9.1621)
ln_EPS_transport	-0.1116**	-0.0422	-0.1839***	-0.0696**
	(-2.9264)	(-1.1683)	(-5.4653)	(-2.4993)

Multicolinearity test

Sectoral Results

VIF Comparison Across Sectoral Models

Variable	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
ln(GDP)	22.30	23.45	24.33	21.49
$\ln(GDP)^2$	23.65	24.26	25.61	22.94
ln(POP)	1.24	1.23	1.23	1.31
urban_growth	1.11	1.10	1.11	1.10
EPS_building	1.91	2.48	1.24	1.42
EPS_elec	1.84	2.21	1.21	1.24
EPS_indus	1.74	2.07	1.29	1.22
EPS_transport	1.51	1.73	1.21	1.33

Sectoral Multicolinearity Tests

Interaction Results

Variable	EPS_OECD	EPS_BOD	EPS_GHG	EPS_GDP
VIF Comparison (all variables)				
ln(GDP)	26.03	26.32	26.94	24.18
$\ln(GDP)^2$	25.96	26.07	27.16	24.44
ln(POP)	1.33	1.39	1.31	1.39
urban_growth	1.12	1.13	1.17	1.11
EPS_elec	12.74	10.54	3.99	11.55
EPS_indus	13.67	19.21	10.39	6.85
EPS_building	5.37	9.33	7.48	6.44
EPS_transport	4.32	6.62	3.62	2.61
EPS(Elec*Indus)	30.58	53.95	8.88	8.90
EPS(Elec*Transport)	30.99	67.36	11.16	13.61
EPS(Building*Transport)	32.83	65.42	11.92	11.44
EPS(transport*indus)	33.46	67.61	9.96	7.88
EPS(building*elec)	64.11	86.81	10.29	14.76
EPS(indus*building)	35.47	65.23	13.57	7.61
VIF Comparison (best model)				
ln(GDP)	24.13	24.76	25.20	22.67
$\ln(GDP)^2$	24.00	24.82	25.36	23.20
ln(POP)	1.24	1.25	1.22	1.25
urban_growth	1.09	1.10	1.13	1.08
EPS_indus	3.12	6.22	2.38	2.17
EPS(Elec*Indus)	6.56	10.33	4.33	5.24
EPS(Elec*Transport)	7.15	8.01	2.86	5.38
EPS(Building*Transport)	3.75	5.23	1.85	1.52

Context

▸ Motivations

Low-carbon hydrogen benefits from a strong push in Europe

- At the European level: *"The Hydrogen Strategy for a Climate-Neutral Europe"* - EU, 2020
  → Electrolysis production capacity targets
  - 6 GW by 2024
  - 40 GW by 2030

  → European Hydrogen Bank (2023)
- At the Member States level
  - Strategies favoring electrolysis,
  - Efforts to support R&D (IPCEI, Innovation Fund, Horizon 2020 program, $\cdots$)

➤ Insufficient efforts: electrolysis development projects represent 36% of the European target for 2024 and 23% of that for 2030 (Hydrogen Europe, 2020)

Motivations

Motivations

The CCfD, a tool that raises interest

- Need for an effective carbon price to combat the competitiveness gap

- Need for intervention by the EU and/or Member States
  - **European Commission**:
    - *A hydrogen strategy for a climate-neutral Europe*, 2020
    - *Revision of the EU-ETS - Directive EU 959*, 2023
  - **Germany**: *The National Hydrogen Strategy*, 2020, First CCfDs launched in 2024
  - **Netherlands**: *SDE++ 2020 Stimulation of Sustainable Energy Production and Climate Transition*, CCfD/floor price launched in 2022

Motivations - Literature

Motivations

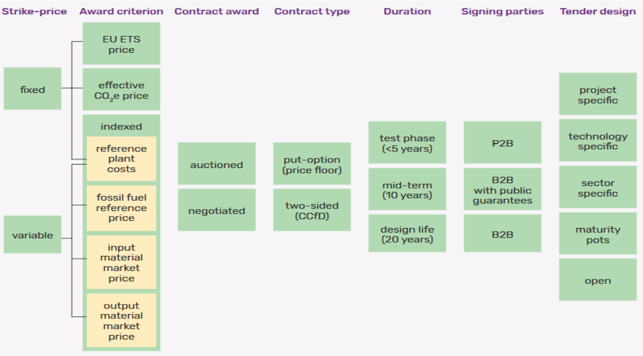
A tool with multiple advantages

- A hedging tool for low-carbon innovations
  - Hedging against *damage* and *variable cost* risks (Jeddi et al, 2021)
  - Temporal consistency (Chiappinelli & Neuhoff, 2020)
  - Bridging the financing gap (Richstein, 2017)
  - Reducing the required CO_2 price (Richstein & Neuhoff, 2020)
- An attractive tool due to its political feasibility
  - Low political cost (Chiappinelli & Neuhoff, 2020)
  - Consistency with the policy framework (Sartor & Bataille, 2020)
  - Post-covid recovery context (Chiappinelli et al., 2022)

Motivations - A tool with little-studied characteristics

▸ Motivations

CCfD Characteristics - Gerres and Linares, 2022



➤ The Strike is rarely detailed in the literature, considered only as an "effective" carbon price.

A technological choice ‣ Methodology

Between steam reforming and electrolysis

Hydrogen, a self-consumed product

2/3 of hydrogen production is self-consumed (Hydrogen Europe, 2020).

Hyp: $D_i = q_i$

A choice based on the difference in marginal costs

For producers-consumers to switch from steam reforming to electrolysis, the costs of the latter must be at most equal to those of steam reforming.

Hyp: Transport, storage, and purification costs are neglected.

Specification of Marginal Costs

Methodology

Marginal cost of H_2 by steam reforming

$$c_v(\sigma, p_g) = p_g r_v + e_v \sigma. \quad (1)$$

Marginal cost of H_2 by electrolysis

$$c_e(\sigma, p_g) = p_e(\sigma, p_g) r_e, \quad (2)$$

$$p_e(\sigma, p_{gr}) = \beta_0 + \beta_1 \sigma + \beta_2 \sigma^2 + \beta_3 p_g, \quad (3)$$

with β_1 and β_2 of opposite sign and $\beta_0 = \beta_{0,c} + \beta_c p_c$.

Illustration (sources: Hydrogen Europe, Eurostat and RTE) $r_v = 80\%$; $r_e = 50\%$ and $e_v = 0.328 gCO_2/MWh$.

Assumption for data selection

▸ Methodology

Illustration

- No hourly and daily production flexibility
- CCfD payment monthly or annually

⟶ Use of monthly data

- Impacts of Covid19 and the war in Ukraine on energy prices, the EU ETS, consumption and production behaviors

⟶ Data from January 2019 to May 2022

- **Average monthly wholesale electricity prices**
- Carbon emissions futures
- Rotterdam coal futures
- Natural gas wholesale market prices: PEG / GASPOOL

Specification of electricity Costs

Methodology

Illustration: Application to France and Germany

Var. exp	Parameter	Estimate	$P(>\|t\|)$
	β_0	7.8296	0.0040
σ^2	β_2	0.0031	0.1020
p_g	β_3	2.0544	7.5×10^{-19}

R^2 adjusted $= 0.977$

France Case

Var. exp	Parameter	Estimate	$P(>\|t\|)$
	$\beta_{0,c}$	-44.3292	0.0130
p_c	β_c	3.2423	0.0284
σ	β_1	2.7047	0.0020
σ^2	β_2	-0.0319	0.0075
p_g	β_3	0.869	0.0262

R^2 adjusted $= 0.9566$

Germany Case

Marginal Costs In the presence of State Aids

Methodology

Free allocations

Considering free allocations as unit subsidies, denoted $a \in [0; e_v]$, reducing the marginal cost of CO_2 emissions for steam reforming producers, then c_v is rewritten

$$c_v^a(\sigma, p_g) = p_g \rho_v + (e_v - a)\sigma. \quad (4)$$

Compensation for the indirect carbon cost

A subsidy b is possible for H_2 up to 75

$$c_e^b(\sigma) = c_e(\sigma) - b(c_e(\sigma) - c_e(0)). \quad (5)$$

Expression of the CCfD strike

Methodology French results

Strike and natural gas threshold price

Definition of the contract strike

The strike is defined by the solution(s) in σ ($\sigma \in \mathbb{R}$) that cancel the quadratic equation

$$\gamma(\sigma) = c_e(\sigma) - c_v(\sigma).$$

Definition of the gas threshold price

The gas price that cancels the polynomial's discriminant is denoted $\bar{p}_g$

Illustration: $\bar{p}_g = 58.59$ €/MWh for F and $-15.6193 + 4.4351 p_c$ for A.

CCfD efficiency condition

Theorem

Proposition

1. If $p_g > \bar{p}_g$ and if $\beta_2 < 0$ then $\forall\sigma$, $\gamma(\sigma, p_g) < 0$.
2. If $p_g > \bar{p}_g$ and if $\beta_2 > 0$ then $\forall\sigma$, $\gamma(\sigma, p_g) > 0$.
3. If $p_g = \bar{p}_g$ then $\gamma(\sigma) = 0$ has a solution: $\bar{\sigma}$.
4. If $p_g < \bar{p}_g$ then $\gamma(\sigma) = 0$ has 2 solutions: $\bar{\sigma}_1$ and $\bar{\sigma}_2$.

Illustration: For F: $\beta_2 > 0$, if $p_g > 58.59$€/MWh the CCfD is inefficient. For A: $\beta_2 < 0$, if $p_g > -15.6193 + 4.4351 p_c$ the CCfD is unnecessary

If $p_c = 40$€/MWh then $\bar{p}_g \approx 161.78$€/MWh

Strike and natural gas threshold price ▸ Theorem

Property

There exists a threshold gas price denoted p_g^M such that

- If $\beta_2 < 0$ (Case A) and if $p_g > p_g^M$ then $\min(\bar{\sigma}_1, \bar{\sigma}_2) > 0$ otherwise $\min(\bar{\sigma}_1, \bar{\sigma}_2) \leq 0$.
- If $\beta_2 > 0$ (Case F) and
  - if $p_g^M < 0$ then $\min(\bar{\sigma}_1, \bar{\sigma}_2) > 0$,
  - if $p_g^M > 0$ then $\min(\bar{\sigma}_1, \bar{\sigma}_2) > 0$ only if $p_g < p_g^M$.

Illustration:
For F: $p_g^M < 0$
For A: $p_g^M = -60.6383 + 4.4351 p_c$
If $p_c = 40€/\text{MWh}$ then $p_g^M \approx 116.766€/\text{MWh}$

Theroem: sign and number of strikes

Results Proposition Property

Strike and natural gas threshold price

Theorem

The CCfD will be implemented if and only if $(\mathbb{E}[p_g] < \bar{p}_g)$ and

- if $\beta_2 < 0$ and if $p_g > p_g^M$, $(\bar{\sigma}_1; \bar{\sigma}_2)$ **constitutes the strike**,
- if $\beta_2 < 0$ and if $p_g < p_g^M$ **the strike is** $\bar{\sigma}_2$,
- if $\beta_2 > 0$ and if $p_g^M < 0$, $(\bar{\sigma}_1; \bar{\sigma}_2)$ **constitutes the strike**
- if $\beta_2 > 0$ and if $p_g^M > 0$, $(\bar{\sigma}_1; \bar{\sigma}_2)$ **constitutes the strike if and only if** $p_g < p_g^M$ **otherwise the strike is** $\bar{\sigma}_1$.

Specification of the payment: $\bar{\gamma}$

▸ Methodology ▸ French results

The formula for CCfD payment

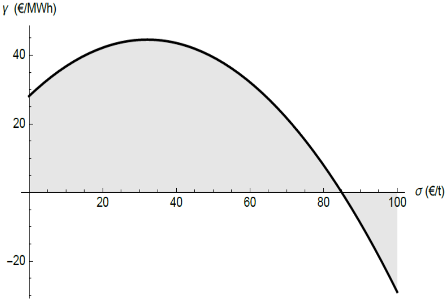
$\bar{\gamma}(\sigma)$ is the difference between marginal costs, i.e.,

$$\bar{\gamma}(\sigma_t) = c_e(\sigma_t) - c_v(\sigma_t). \tag{6}$$

An amount proportional to production: unit tax or subsidy

Results: The German Case

French results



Payment as a function of σ ($p_c = 40$€/MWh and $p_g = 40$€/MWh)

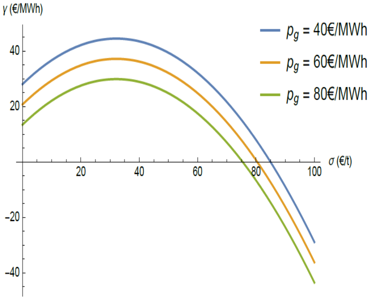
Confidence Intervals

Sensitivity tests

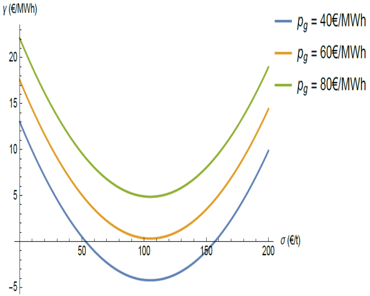
Curve of the payment: γ

French results

Payment as a function of σ ($p_c = 40$€/MWh) - sensitivity analysis relative to p_g



Germany

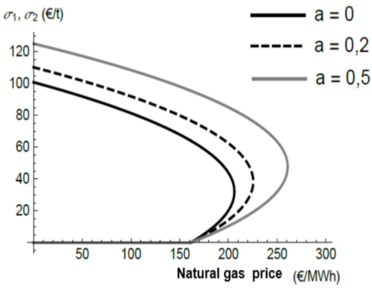


France

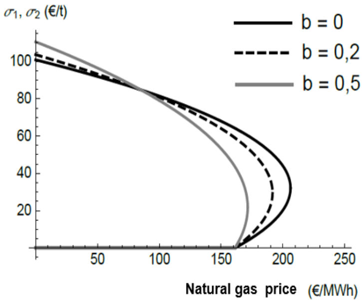
Reference value $\neq$ actual value: CCfD renegotiation clauses or strike indexation on gas price

Free allocations and compensation for the indirect carbon cost

Germany



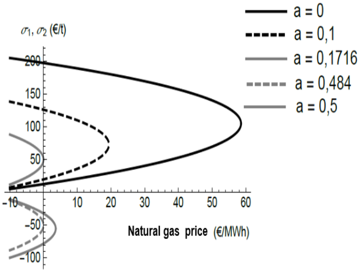
Free allocations



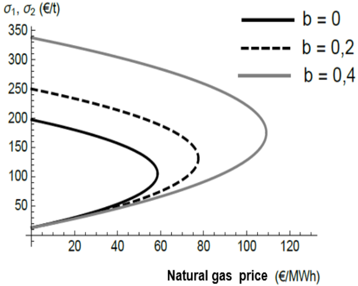
Indirect cost compensation

Free allocations and compensation for the indirect carbon cost

France



Free allocations



Indirect cost compensation

Electricity Prices in France

Back Case with β_1

Linear regression results for the French case with p_c and p_g

Var. ex.	Parameter	Estimate	t Statistic	$P(>\lvert t\rvert)$
	$\beta_{0,c}$	24.54	2.09	0.04
p_c	β_c	-0.08	-1.36	0.17
σ_t	β_1	-0.71	-1.29	0.21
σ_t^2	β_2	0.96	1.86	0.07
p_g	β_3	2.22	14.20	2.53

R^2 Adjusted $= 0.9777$

Electricity Prices in France

Back Case with coal

Linear regression results for the French case with β_1

Var. ex.	Parameter	Estimate	t Statistic	$P(>\|t\|)$
	$\beta_{0,c}$	22.59	1.91	0.06
p_g	β_3	2.09	16.44	1.36
σ_t	β_1	-0.71	-1.28	0.08
σ_t^2	β_2	0.94	1.80	0.08

R^2 Adjusted $= 0.9788$

Electricity Prices in Germany

Back

Linear regression results for Germany, without p_c

Var. exp	Parameter	Estimate	t Statistic	$P(>\|t\|)$
	$\beta_{0,c}$	-19.52	-1.42	0.17
σ_t	β_1	1.86	2.46	0.02
σ_t^2	β_2	-2.01	-1.91	0.06
p_g	β_3	1.62	8.49	2.34

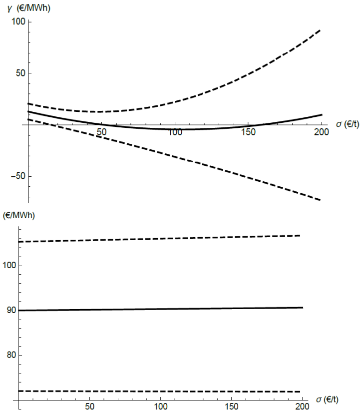
R^2 Adjusted $= 0.9430$

Confidence Intervals

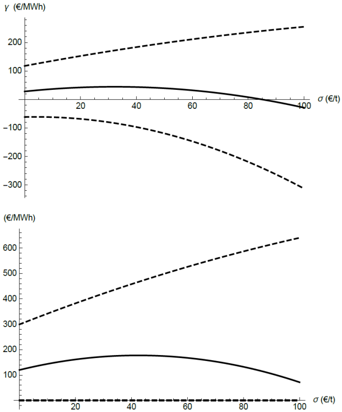
Back

CCfD payment and electricity price as a function of σ_t.

French case



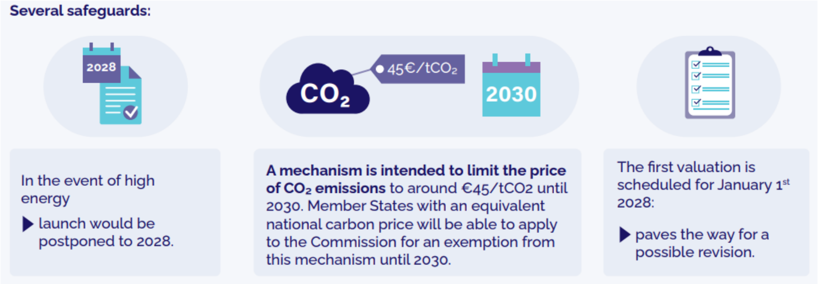
German case.



Characteristics Inspired by ETS1

Motivations

- Allowances based on 2024 emission levels, decreasing annually.
- Reduction rate: 5% annually.
- No risk of leakage: 100% auctioned permits.



Market Stability Reserve (MSR) - 2027

Method

Key Points:

- Starts with 600M allowances (in addition to cap)
- Purpose Stabilize prices by adjusting allowances.

Triggers:

- If Total Allowances in Circulation $<$ 210M: Release 100M allowances.
- If Total Allowances in Circulation $>$ 440M: Store 100M allowances in MSR2.
- Price $>$ €45/t (2 months): Release up to 40M allowances.
- Rapid price increase: 50M (2x price), 150M (3x price).

Limitations:

- Max 150M allowances/year.
- Delays in activating measures.

The Social Climate Fund

Method

Risk of High Prices in ETS2

▸ Motivations ▸ Method ▸ Results

Price Estimates for 2030 (without complementary policies):

- €180/t (France, Germany, Poland) Jon Stenning et al. 2021.
- €174/t (France, Spain, Poland) Maj et al. 2021.
- €297/t (EU-wide) Rickels et al. 2023.
- €275/t (REMIND EU model) Pietzcker et al. 2021.

Price Estimates for 2030 (with complementary policies):

- Range: €175/t to €360/t Abrell et al. 2024.
- Price reductions with complementary policies: €71/t (PRIMES model) Günther et al. 2024.

Impact on Households and Inequalities

Motivations

Key Concerns:

- Inequalities: Higher cost burden for the poorer Hübler et al. 2024. Significant concerns between and within countries Jacobs et al. 2022.
- Climate Social Fund (CSF): Redistributes revenue from 150M allowances, **may be insufficient** for full progressive redistribution Gore 2022.

Sector-Specific Effects of ETS2:

- Transport: Reduces regressivity of existing taxes Jacobs et al. 2022.
- Buildings: Redistribution struggles to offset costs for poorest tenants George et al. 2023.

Complementary Policies:

- Necessary to mitigate inequalities Görlach et al. 2022 and improve social acceptability Braungardt et al. 2021.

Main Variables

Method

e:	Electricity supply	p_e:	Electricity price
f:	Fuel supply	p_f:	Fuel price for production
f_n:	Fuel final demand	p_{fn}:	Fuel price for consumption
f_e:	Fuel demand for electricity	a_1:	Emission price EU ETS1
r_f:	Composite input for fuel	a_2:	Emission price EU ETS2
r_e:	Composite input for electricity	$\bar{p}_r$:	Price of composite input
x:	Final good demand	p_x:	Final goods price, *numéraire*

Description of main variables

Results Reference case

Results

$e^0 = \phi[\frac{\mu}{\bar{p}_r}\alpha\beta R]^{\mu} F_1^{1-\mu}$	$p_e^0 = \frac{1}{\phi}(\frac{\bar{p}_r}{\mu})^{\mu}(\frac{\alpha\beta R}{F_1})^{1-\mu}$
$f^0 = F_1 + f_n^0$	$p_f^0 = \frac{\bar{p}_r}{\phi} = p_{fn}^0$
$f_n^0 = \frac{\phi\alpha(1-\beta)R}{\bar{p}_r}$	$f_{ni}^0 = \frac{R_i f_n^0}{R}$
$x^0 = (1-\alpha)R$	$U_i^0 = (e_i^0)^{\alpha\beta}(f_{ni}^0)^{\alpha(1-\beta)}(x_i^0)^{1-\alpha}$
$f_e^0 = F_1$	$a_1^0 = \frac{\alpha\beta R(1-\mu)}{F_1} - p_f^0$
$r_f^0 = \frac{(F_1+f_n^0)}{\phi}$	$r_e^0 = \frac{\mu}{\bar{p}_r}\alpha\beta R$

Results Benchmark case

Results

$e^* = \quad e^0$	$p_e^* = \quad p_e^0$
$f^* = \quad F$	$p_f^* = \quad p_f^0$
$f_n^* = \quad F_2 = \varphi f_n^0$	$p_{fn}^* = \quad \frac{\alpha(1-\beta)R}{F_2} = \frac{\bar{p}_r}{\phi\varphi} = p_f^0 + a_2^*$
$f_{ni}^* = \quad \frac{R_i F_2}{R} = \varphi f_n^0 \frac{R_i}{R}$	$U_i^* = \quad (e_i^0)^{\alpha\beta}(\frac{R_i F_2}{R})^{\alpha(1-\beta)}(x_i^0)^{1-\alpha}$
$f_e^* = \quad F_1$	$a_1^* = \quad a_1^0$
$r_f^* = \quad \frac{(F_1+F_2)}{\phi}$	$a_2^* = \quad \frac{\alpha(1-\beta)R}{F_2} - p_f^0 = \; p_f^0(\frac{1}{\varphi} - 1)$
$r_e^* = \quad r_e^0$	$x^* = \quad x^0$

Results Subsidy case

▸ Results

$f_n^\gamma =$	$F_2 = \varphi f_n^0$	$p_{fn}^\gamma =$	$\frac{\alpha(1-\beta)R}{F_2} = \frac{\bar{p}_r}{\phi\varphi} = p_f^0 + a_2^\gamma$
$f_{ni}^\gamma =$	$\frac{R_i F_2}{R} = \varphi f_n^0 \frac{R_i}{R}$	$a_2^\gamma =$	$\frac{\alpha(1-\beta)R}{F_2} - p_f^0 = p_f^0(\frac{1}{\varphi} - 1)$
$U_i^\gamma =$	$(e_i^0)^{\alpha\beta}(\frac{R_i F_2}{R})^{\alpha(1-\beta)}(x_i^0)^{1-\alpha}$		

Capacity constraint

▸ Conclusion

We define the threshold beyond which the capacity constraint becomes binding by solving for the level of f_{ni} that would imply $e_i > \bar{e}_i$. The constraint is binding if and only if:

$$\lambda_{2i} > 0 \quad \Leftrightarrow \quad p_{fn} > \frac{p_e}{f_{ni}} \cdot \frac{1-\beta}{\beta} \bar{e}_i \tag{7}$$

Revenues Collected

Conclusion

While there is an utility drop, there are also revenues R_a collected from the implementation of the ETS2:

$$R_a^* = a_2^* f_n^* \tag{8}$$
$$= f_n^0 p_{fn}^0 (1 - \varphi) \tag{9}$$
$$= \alpha(1 - \beta) R (1 - \varphi). \tag{10}$$

We can compare the utility drop with the revenues collected:

$$\frac{\Delta U*}{R_a^*} = \frac{U^0(1 - \varphi^{\alpha(1-\beta)})}{\alpha(1 - \beta)R(1 - \varphi)} \tag{11}$$
$$= C \cdot (\alpha(1 - \beta))^{\alpha(1-\beta)-1} \frac{1 - \varphi^{\alpha(1-\beta)}}{1 - \varphi} \tag{12}$$

where

$C = \psi^\alpha \cdot \bar{p}_r{}^{-\alpha[1-\beta(1-\mu)]} \cdot F_1^{(1-\mu)\alpha\beta} \cdot R^{\alpha\beta(\mu-1)} \cdot (1 - \alpha)^{1-\alpha} \cdot (\alpha\beta)^{\alpha\beta\mu}$

Proportion of Households type

Conclusion

$$\frac{d}{d\Gamma}\left(\frac{U^{\gamma}}{U^{*}}\right) = -\alpha(1-\beta)\cdot\frac{\gamma R_2}{R^2}\cdot\left(\frac{R_1 A_1(\Gamma)+R_2 A_2(\Gamma)}{R\cdot D(\Gamma)^2}\right) < 0 \qquad (13)$$

Interpretation: Increasing Γ reduces the relative utility $\frac{U^{\gamma}}{U^{*}}$.

Cap & Trade for waste management: a barely explored policy

▸ Research Question ▸ Lit. Review

⟶ In Practice ▸ Contemporary approach

- Packaging Recovery Note in the UK (Hansjürgens et al. 2011; Walls 2006; Vaudey et al. 2007)
- Waste-to-Energy in Australian carbon market Australian Waste Plan
- New Zealand ETS includes Waste sector EU ETS, NZ Climate Response Act
- Incineration in EU-ETS for 2026 Euractiv, 2023

⟶ In Literature

- *New areas for the application of tradable permits: solid waste management*, Salmons 2002
- *A Review of the Potential for a Permit Scheme for Sterilized Clinical Waste in the UK*, Bailey et al. 2004
- *If invisible carbon waste can be traded, why not visible construction waste?*, Peng et al. 2022

Condition Favoring a Cap-and-Trade ▸ Method

⟶ situation-related advantages

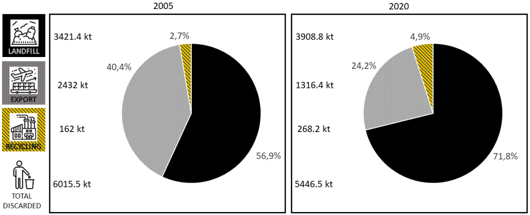
- With uncertainty and urgency: give certainty on pollution level (Weitzman 1974)
  ⟶ Cost-benefit analysis
- Variety of abatement costs: cost-effectiveness
  ⟶ Role of Property Management Companies

⟶ Endogenous conditions: market power, transactions costs, etc.

Credits: Wilson Hui

Waste issue in Hong Kong

▸ Method ▸ MSW Chain ▸ Waste Volumes ▸ Waste policies



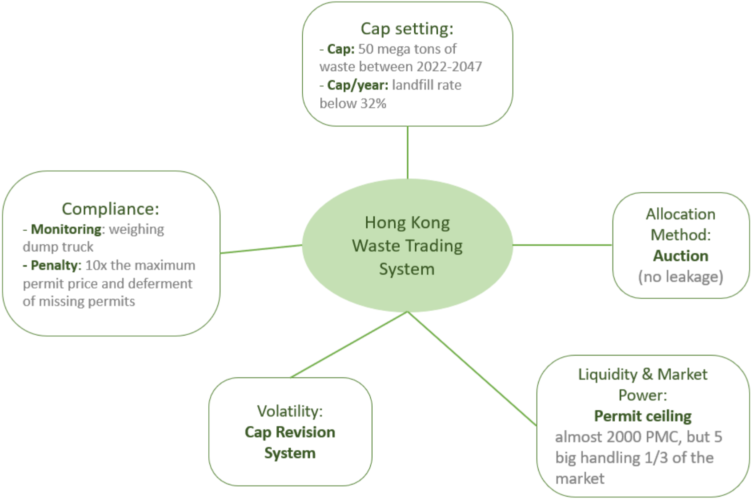
Hong Kong waste management strategies

⟶ **High land costs from landfilling:** space scarcity, saturation of landfills, export difficulties (Operation Green Fence)

⟶ **Lots of infrastructures but no sorting from citizens:** extra costs, psychological barrier, lack of education (Chung et al. 1994; Lo et al. 2018; Yau 2010)

Hong Kong WTS Design

▸ Conclusion ▸ Monitoring ▸ Penelaty



Limitations

▸ Conclusion

- Additional administrative costs
  (Vaudey et al. 2007)
- Transaction costs and volatility risk
  (Tietenberg 2002)
- Rationality assumption
  (Yau 2010; Lo et al. 2018)

Source: Unsplash

Contemporary prevalence of CAC and Tax-based approach

▸ Cap and Trade approach ▸ L.R. Sorting rates

Existing MSW policies and recovery rate in 2015

Country	MSW recovered	Separation	Bans	Recyc. target	Restriction	PPP	EPR	DRS
Hong Kong	35%	0	0	1	0	0	1	0
Japan	89.90%	1	1	1	1	1	1	1
Germany	56.10%	1	1	1	0	0	1	1
Taiwan	55%	1	0	0	0	1	1	1
Korea	53.70%	0	1	1	0	1	1	1
Austria	53.60%	1	1	0	0	0	0	1
Switzerland	49.70%	1	1	1	0	1	1	1
Italy	49.70%	1	0	1	0	1	1	1
Belgium	49.40%	1	1	1	1	1	1	1
Netherlands	46.30%	1	1	1	1	1	1	1
Slovenia	45.60%	1	0	1	1	1	0	0
UK	44.50%	1	1	1	1	1	1	0
France	39.60%	1	1	1	0	0	1	0
Singapore	30%	1	0	1	0	0	0	0

Sources: OECD (2021); EEA (2016, 2017). PPP: Polluter pays principal; EPR: Extended Producer Responsability; DRS: Deposit Return Scheme.

Additionnal literature

▸ CAC & Tax approach

⟶Waste Trade - Leackages: Bernard 2015; Khan 2020; Copeland 2001; Barrie et al. 2022

⟶ Arguments in favour of limited time frame to increase efficiency of cap and trade: Lange 2012; Kling et al. 1997; Montero 1998; Malueg et al. 2009; Narassimhan et al. 2018; Kang et al. 2016

⟶Reduce generation of waste is hard – it is easier to increase sorting for consumers: Chung et al. 2001; Chung et al. 1999; Rousta et al. 2017; Minelgaitė et al. 2019

⟶Japan citizens and sorting rate: Kinnaman et al. 2014; Hotta et al. 2014; Tanaka 1999

Comparing Policy Tools: A Literature Review

Market-Based Approach

Command and Control (CAC) versus Market-Based Instrument (MBI)

- CACs not suitable when uncertain costs and damage function (Hepburn 2006; Acuff et al. 2013; Pearce et al. 1993; Goddard 1995; Hettiarachchi et al. 2018);
- Social acceptability (Barragán-Beaud et al. 2018; Hong 1999; Wan et al. 2014; Tsai et al. 2020; Wan et al. 2015).

Price versus quantity

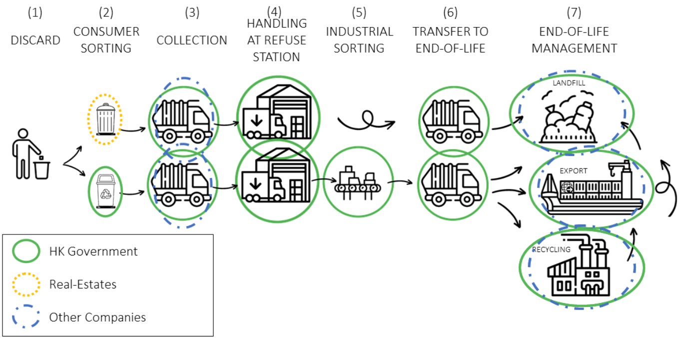
- Weitzman theorem (Weitzman 1974; Adar et al. 1976; Fishelson 1976);
- Extensions for error-correlation (Stavins 1996) and time-correlation (Newell et al. 2003).

Literature about Waste Trading Design ▸ Method

- **Definition of the cap**: on the targeted agent, see Montgomery 1972, Vaudey et al. 2007. On time flexibilities, see Weitzman 2020.
- **Allocation method for the permits**: On output-based, see Meunier et al. 2018.
- **Liquidity and Market Power**: On market power from State-owned companies on the CH-ETS, see Munnings et al. 2016.
- **Volatility**: On the necessity to adapt the cap, see Kollenberg et al. 2016. On the MSR, see Quemin et al. 2019.
- **Compliance**: On the need for an efficient penalty, see Schaeffer et al. 2000 and Yan et al. 2020. On the penalty in case of linkage, see Haites et al. 2001.

MSW Management chain

MSW in HK

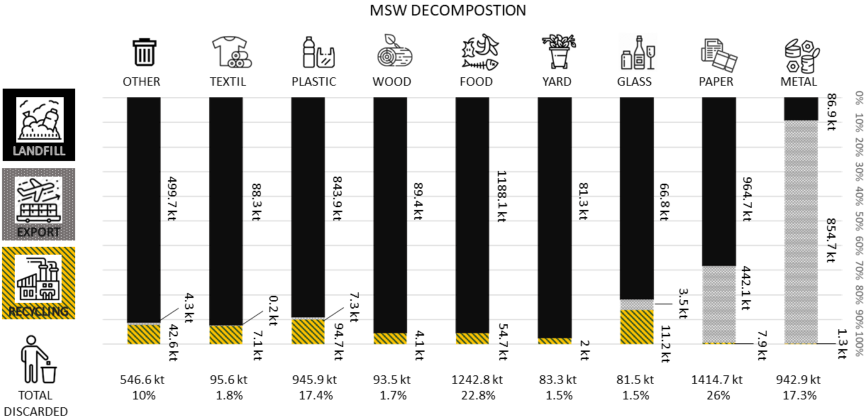


MSW management in HK

⟶ **Lots of infrastructures but no sorting from citizens:** extra costs, psychological barrier, lack of education (Chung et al. 1994; Lo et al. 2018; Yau 2010)

Volumes per types of MSW and management

Waste in Hong Kong



MSW main streams and their types of management in 2020

Source: Environment Bureau 2021 - Data are provided by the HK government, which

A debatable current strategy

▸ MSW in HK ▸ Results

→ **Infrastructure isn't everything**

→ The Government strategy:

- Waste targets
- Education campaign
- Voluntary Program on Source Separation of Waste
- Tax garbage bags (0.013€/L)

Hong Kong MSW charge trial fees *Source: EPD (2021)*

HK and China Pollution targets

HK waste management | Hong Kong Strategy

China & Hong Kong pollution reduction targets

Area	Type of pollutant	Target	Ref. Year	Target Year	Pub. Year	Source
HK	MSW per capita reduction	-40%	2011	2022	2013	EPD 2020
HK	MSW absolute reduction	-40%	not mentioned	2035	2021	ENB 2030
HK	MSW recycling intensity increase	+55%	not mentioned	2035	2021	ENB 2030
China	MSW reuse intensity increase	+60%	2015	2025	2020	CIRCULARONLINE 2020
HK	CO2 intensity reduction	-65-70%	2005	2030	2016	ENB 2030
HK	CO2 absolute reduction	-26-36%	2005	2030	2016	ENB 2030
HK	CO2 per capita reduction	-3.3-3.8 tons	2005	2030	2016	ENB 2030
China	CO2 intensity reduction	-60-65%	2005	2030	2015	ORG 2020

Notes: Only targets which refer to MSW and CO2 are presented here. "Ref. Year" stands for the year taken as reference for the target. "Pub. Year" stands for the publication year when the target was publicly announced.

Conservative Assumptions for the BAU

▸ Method ▸ Results

Baseline data of 2020 to build the BAU

Parameter	Value
MSW_L/Pop	0.553
MSW landfilled	4,145,670
MSW Generated	5,990,000
MSW Landfilled (%)	69.2%
MSW_G/Pop	0.799
Population	7,494,578
Annual Growth Rate	-0.09
Year	2021
Disc. Rate	3%

Sources: UN, 2022; US, 2022; EPD, 2022; Gollier, 2021

Assumptions MD

Method MACC assumption Results

The following assumptions are taken for the calculation of the MDC :

- Land cost: - 6% (conservative according to current to Bloomberg[1])
- Social cost of CO2 emissions : trends from the US gov.
- Health cost: following trend for social cost of CO2 emissions
- Capital costs for new landfills: step function, real current price
- Discount rate: 3% Gollier 2016

[1] bloomberg.com visited on October 15, 2022

Assumptions for the MACC

Method Results

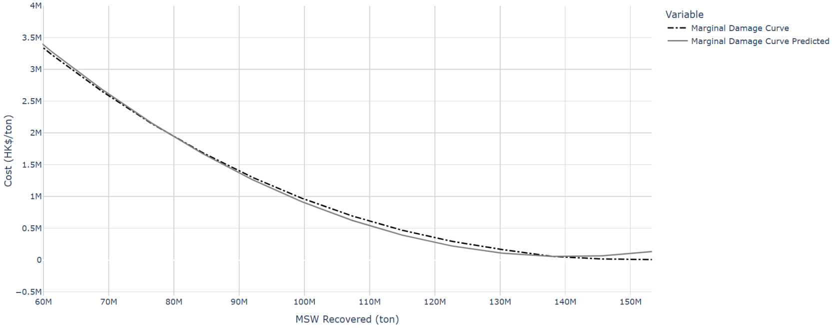
Tech.	Full capacity (10^3 ton)	Total additional costs (10^6 HK$)	Marginal Cost of abatement (HK$/ton)	Sources
Opark	4425.625	3350	757	LegCo website & Opark website
EcoPark	8103.157493	8819	1088	HK Gov website & Greening HK website
Ipark	26553.75	40223	1515	SCMP website & EPD notice
Ypark	531	2013	3790	EPD website & EPD notices
WEEEpark	728	3727	5123	WEEE park website

Marginal cost of treatment facilities for the MACC

Legend: O-Parks, a set of three facilities recycling organic waste; Eco-Park, an industrial center composed of several industries recycling glass, plastic, metal and fabric; I-Park, an incineration plant with energy recovery; Y-Park, recycling yard; WEEE-park, recycling up to 30 kilotons per year of electric MSW.

Marginal damage curve (ref. scenario)

Results Assumptions MDC Blind

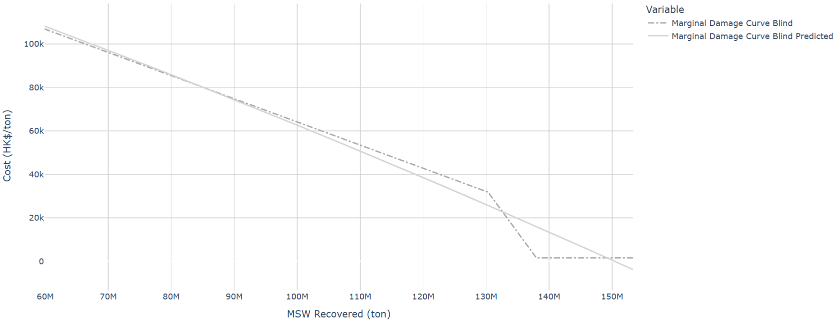


Marginal Damage Curve, reference scenario, original and predicted values

Marginal damage curve (blind scenario)

Results Assumptions

intersection with MACC

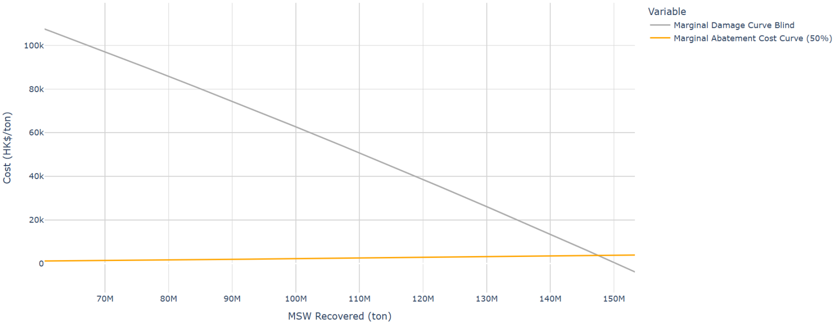


Marginal Damage Curve, blind scenario, original and predicted values

MDC blind and MACC intersection (blind scenario)

Results

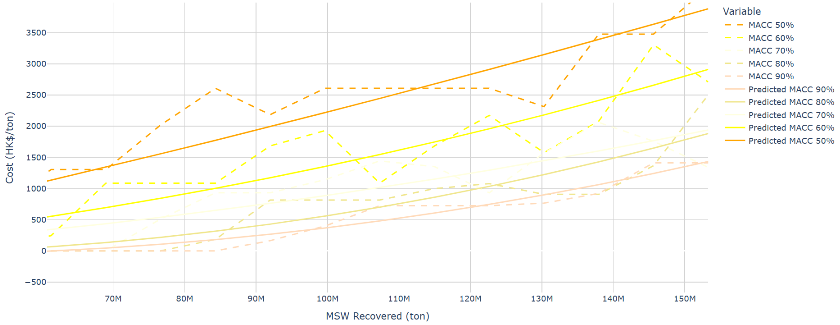
Assumptions | MDC blind | MDC ref.



MDC blind and MACC 50 intersection

MACC

▸ Results ▸ BAU assumptions ▸ intersection with MACC



Marginal Abatement Costs Curves for Hong Kong

Empirical Results

Results

MACC Scenarios	50%	60%	70%	80%	90%
Opark	6	4	3	3	2
EcoPark	5	4	3	3	2
Ipark	5	4	3	2	2

Need for additional waste recovering facilities

⟶ Target of the obligation: Property Management Companies = owners and/or managers of the building. They are already in charge of gathering waste, as a by-product of their activity.

Strong monitoring

▸ Conclusion

Hong Kong sorting containers being monitored.

Photo by J. Metta in 2019

Geographic distribution of sorting bins and perception

▸ Conclusion

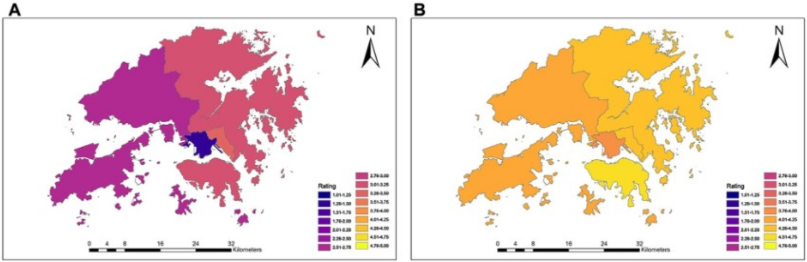


FIGURE 8
The public rating of about **(A)** the adequacy of the recycling bins and **(B)** their initiatives to support waste reduction.

Ma et al. 2023

Non-compliance penalty

Conclusion

⟶ What the literature says:

- Becker 1968: Expected penalty = probability of detection * penalty cost. Efficient penalty = hight penalty cost, low monitoring to reduce costs.
- Key for the efficiency of an ETS: need to be high and symbolic (Yan et al. 2020);
- In case of linkage: penalty (M_i) $\geq$ abatement cost (M_j) (Haites et al. 2001).

Potential penalty

To be efficient in Hong Kong, we can imagine a penalty of the form: fine + deduction of shortfall permits from next allocation period. The fine could be ten times the permit price (ex: EU ETS1)