Enhancing the Carbon Border Adjustment Mechanism through Endogenized Value-Added Inputs and Embodied Carbon Prices

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Where you draw the accounting boundary changes CBAM

- **Scope 1 (Direct emission only), Scope 2/3, Consumption-Based Emission …**
- **Standard carbon accounting treats investment and government as exogenous final demand.**
  - Yet, capital goods are emission-intensive inputs that feed back into production (Södersten, Wood, and Hertwich, 2018); the governments provide public services that ultimately serve household consumption and support industrial production.
  - Treating them as standalone endpoints mis-assigns embodied carbon.
- **Explicit carbon price may not be the right metric for CBAM base.**
  - It may ignore the global value chain of carbon price pass-through.

RESEARCH QUESTION

How does endogenizing value-added inputs and embodied carbon pricing change:

(a) consumption-based emissions & the carbon transfer between regions, and

(b) the carbon leakage and GDP outcomes of a CBAM?

Endogenizing final demand through value-added inputs

- **Closed Input–Output Model**
  - The closed model internalizes capital investment and government expenditure via value-added payments. Their responsibility for emissions must sit inside the accounting boundary, not outside it.
  - Capital (K) and government (T) payments re-enter the system as emission-bearing flows [Equations (1)–(3)]
- **Accounting Scopes**

PBE	CBM	CBMeK	CBMeKG
Territorial Emissions	Standard MRIO	+ Endogenized investment	+ Endogenized government
Production-based emissions.	Consumption-based via full MRIO; investment & government kept as separate final demand.	Capital formation folded back into c onsumption.	Government folded in to create the full closed model.

PBE → CBM → CBMeK → CBMeKG

Extended System of Equations for Carbon Content (Building on Bohringer et al. 2018)

$$cc_{gr}^{Y} Y_{gr} = \sum_j (cc_{jr}^{M} + co2_{jgr}^{M}) Z_{jgr}^{M} + \sum_{g'} (cc_{g'r}^{Y} + co2_{g'gr}^{D}) Z_{g'gr}^{D} \quad (1)$$

$$cc_{ir}^{M} M_{ir} = \sum_{s \in R} \left(cc_{is}^{Y} X_{isr} + \sum_{u \in U} cc_{u}^{T} T_{uisr} \right) \quad (2)$$

$$cc_{u}^{T} \sum_{r \in R} T_{ur} = \sum_{r \in R} cc_{ur}^{Y} T_{ur} \quad (3)$$

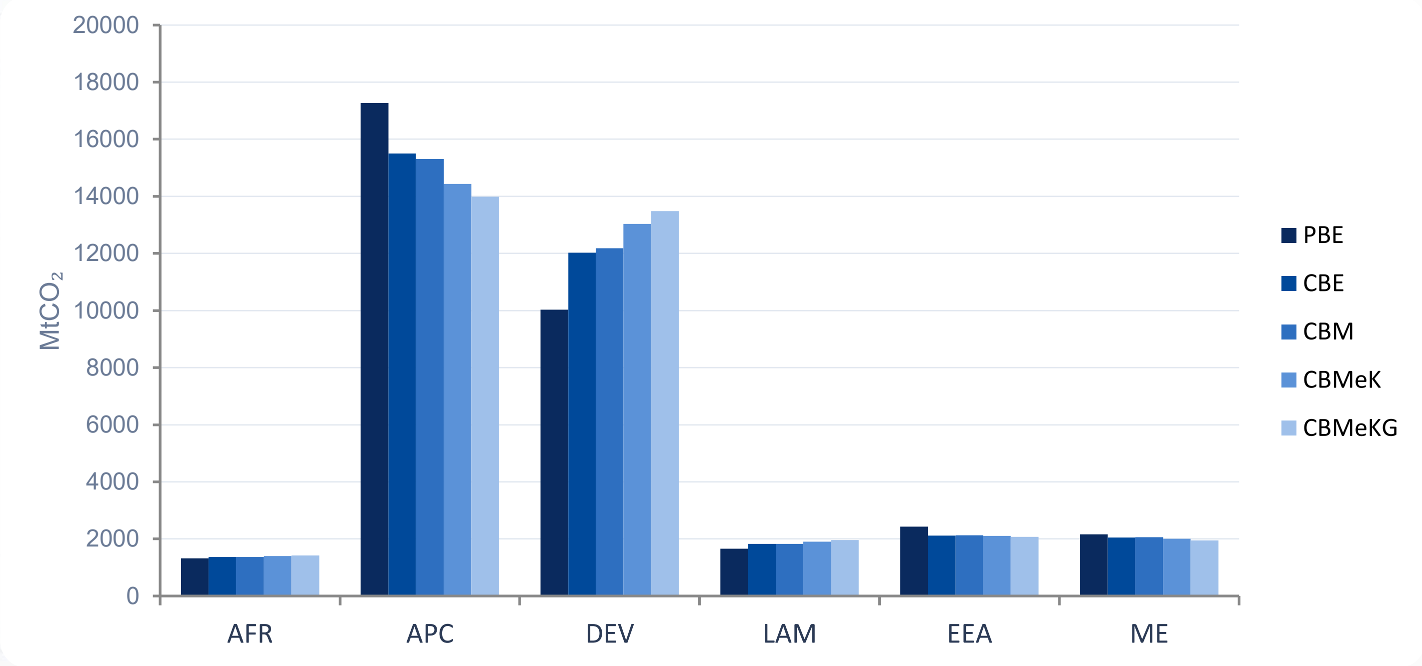
Data, aggregation & three nested accounting scopes

- **Data: GTAP 12, input–output tables for 2023**
  - Sectors: 65 → 21 aggregate sectors.
  - Regions: 163 → 6 IPCC AR6 WG3 groups (AFR · APC · DEV · EEA · LAM · ME)
    → then grouped into IC (= DEV) vs. DC (the other five).
- **Scenarios**

Scenario	Tariff base	Endogenized inputs	Description
BAU	—	—	Baseline; no climate policy.
Ctax	Domestic carbon tax	—	DEV carbon tax for 20% CO_2 reduction; induces leakage.
Cbam0	Direct emission	—	CBAM on direct (Scope-1) emissions of imports.
Cbam	Embodied carbon content	—	CBAM on embodied carbon content.
CbamK	Embodied carbon content	Investment	Carbon Content with endogenized investment.
CbamKG	Embodied carbon content	Investment + government	Carbon Content with endogenized investment & government.
CbamEcp	Embodied carbon price	—	CBAM priced on embodied carbon price (ECP).
CbamEcpK	Embodied carbon price	Investment	ECP with endogenized investment.
CbamEcpKG	Embodied carbon price	Investment + government	ECP with endogenized investment & government.
CbamEcp2w	Embodied carbon price (two-way)		ECP, two-way: import tariff + export subsidy.

All Cbam scenarios: CBAM levied by DEV on imports from all other regions. DEV CO_2 target = −20% throughout.*

Widening the scope shifts embodied carbon to DEV



	AFR	APC	DEV	LAM	EEA	ME
■ PBE	1,323	17,267	10,031	1,655	2,432	2,160
■ CBE	1,359	15,502	12,022	1,823	2,114	2,047
■ CBM	1,366	15,314	12,180	1,820	2,125	2,062
■ CBMeK	1,399	14,436	13,029	1,898	2,101	2,004
■ CBMeKG	1,424	13,983	13,481	1,957	2,076	1,946

NET CARBON IMPORT IN DEV (relative to PBE)

CBE 1,991

* CBE is the consumption-based emission based on embodied emission in bilateral trades (EEBT)

CBM 2,148

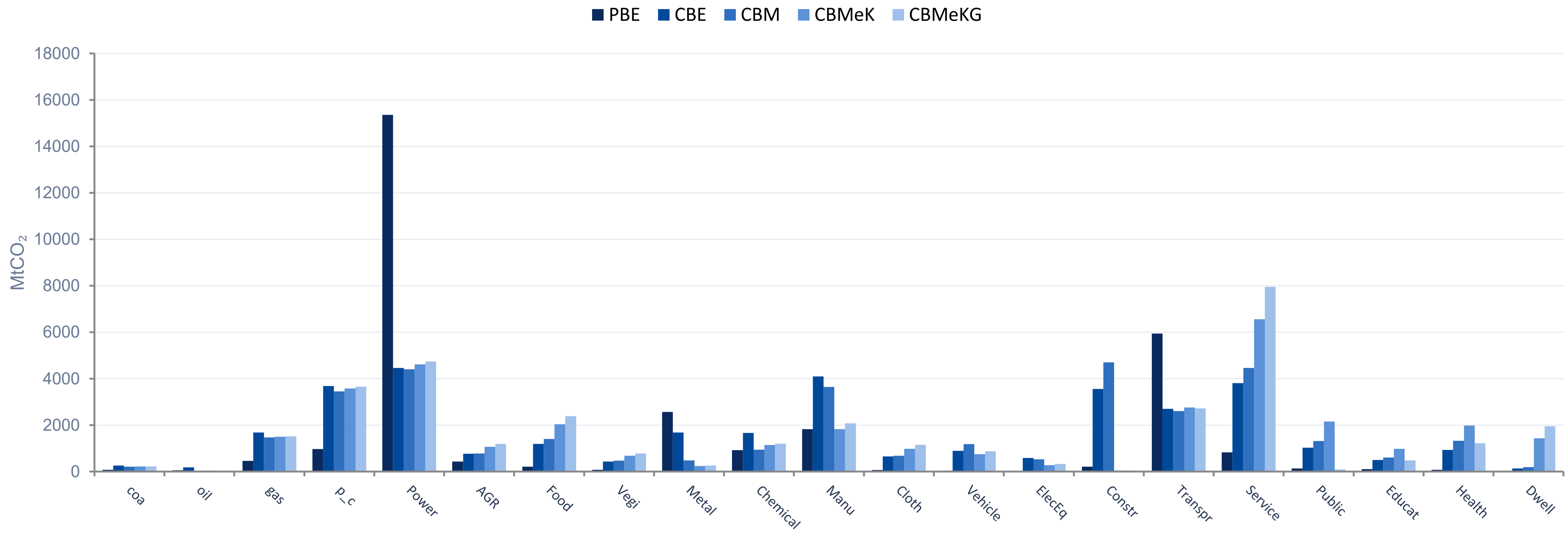
CBMeK 2,998

CBMeKG **3,450**

2,148 → 3,450 $MtCO_2$

≈ 60% larger transfer once capital & government are endogenized (CBM → CBMeKG).

Carbon moves from final demand categories to the demand that pulls it



- **Endogenizing investment and government (CBMeK, CBMeKG) shifts emissions further toward household final demand sectors; emissions shrink in production-heavy sectors, and increase in consumption-linked sectors.**
  - Power, Transport, Metal recede under consumption-based views — output embodied downstream.
  - Service, Food, and Health rise sharply as investment & government demand is folded into consumption.

Embodied Carbon Prices

- **Global supply-chain intensities (carbon content) reflects the global carbon value chain**
  - They include emissions originating in the importing region, which may already price carbon (a Koopman double-counting analog, as for value added in trade).
- **Direct carbon price (cp_r) alone, as a CBAM base, ignores the value chain.**
  - Regions buy and sell intermediate goods globally; a $[cp_r - cp_s]cc_{is}^Y$ tariff misses this.
- **Solution: Embodied Carbon Price (ECP: ecp_{ir}^Y)**
  - A supply-chain propagated effective price that accounts for the fact that a zero-explicit price region can still face a non-zero effective rate if it imports carbon-priced inputs.
  - Correct tariff base: $[ecp_{ir}^Y - ecp_{is}^Y]cc_{is}^Y$

$$ecp_{gr}^Y cc_{gr}^Y Y_{gr} = \sum_j (ecp_{jr}^M cc_{jr}^M + cp_r co2_{jgr}^M) Z_{jgr}^M + \sum_{g'} (ecp_{g'r}^Y cc_{g'r}^Y + cp_r co2_{g'gr}^D) Z_{g'gr}^D \qquad (1')$$

$$ecp_{ir}^M cc_{ir}^M M_{ir} = \sum_{s\in R} \left(ecp_{is}^Y cc_{is}^Y X_{isr} + \sum_{u\in U} ecp_u^T cc_u^T T_{uisr} \right) \qquad (2')$$

$$ecp_u^T cc_u^T \sum_{r\in R} T_{ur} = \sum_{r\in R} ecp_{ur}^Y cc_{ur}^Y T_{ur} \qquad (3')$$

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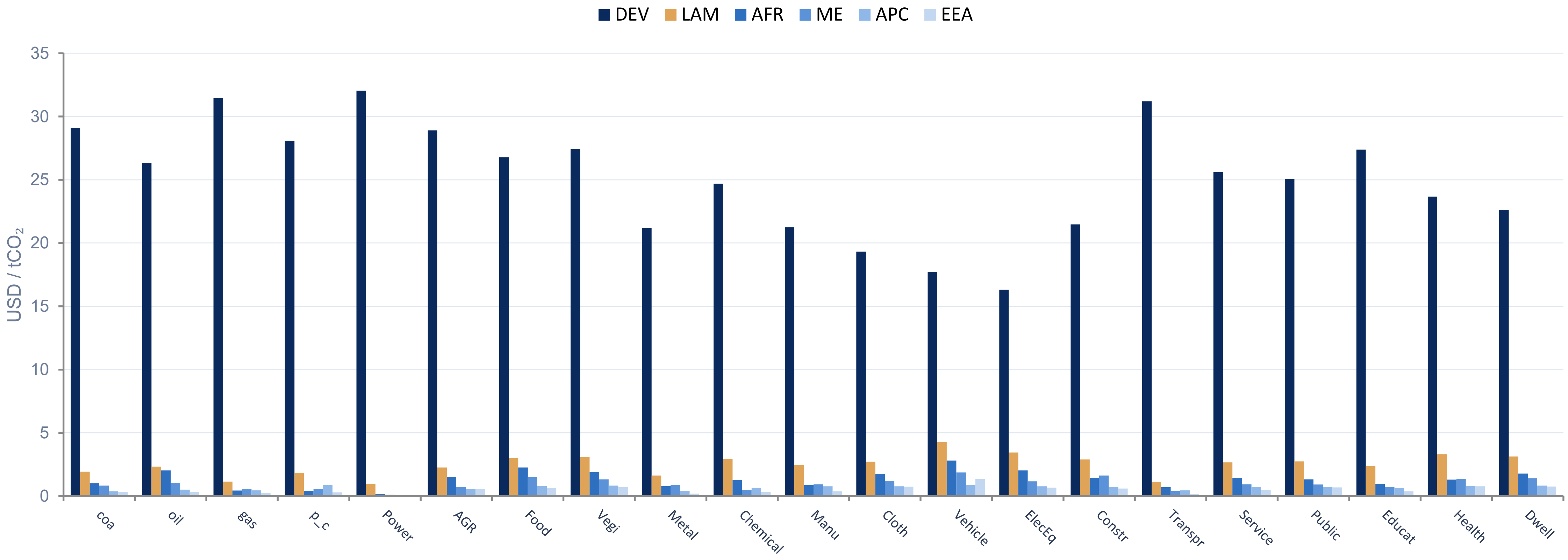
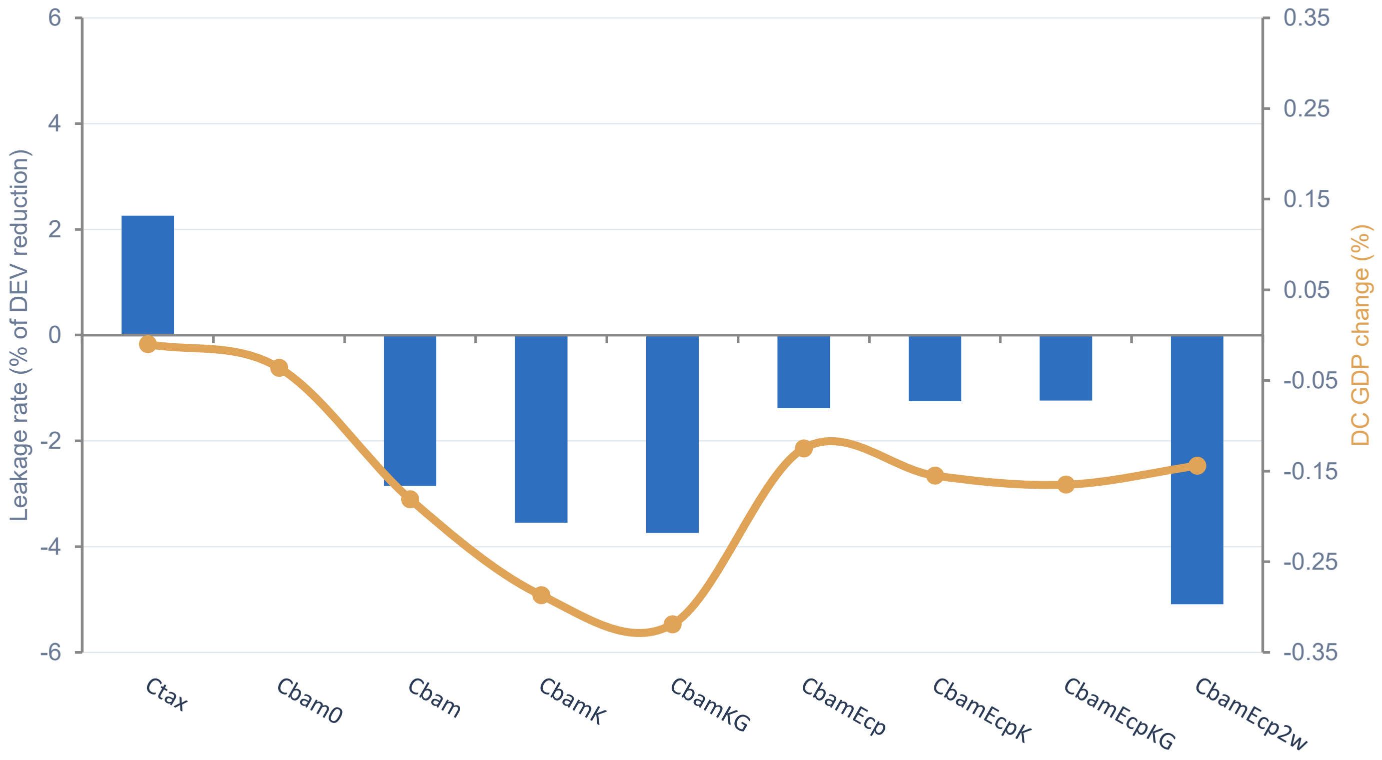
Effective carbon prices diverge from explicit ones



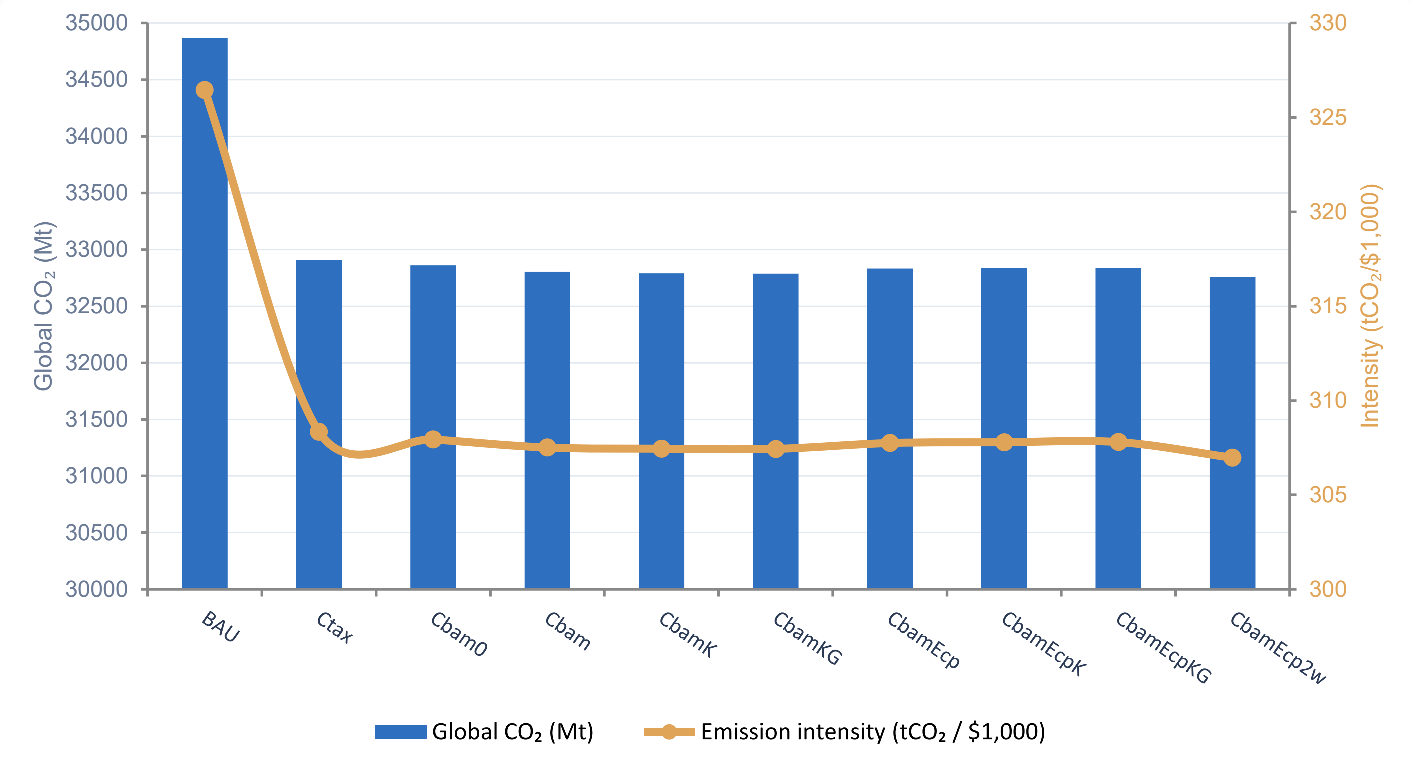
- DEV (dark) sits below its explicit price ≈ USD 32.85/tCO_2.
- Every unregulated region still shows a non-zero ECP from importing carbon-priced DEV goods, with LAM(amber) the highest among them.

Leakage falls as the base widens, at a GDP cost to DC



- **Scope-1 CBAM alone prevents leakage.**
  - Cbam0 (direct emission) cuts leakage to ≈ 0;
  - Scope 3 or closed-model CBAMs push it negative.
- **Wider base → deeper DC GDP loss.**
  - DC GDP falls −0.04% → −0.32% (Cbam0 → CbamKG)
  - DEV's own loss shrinks.
- **Caveat: DEV is > 50% of GDP.**
  - Small leakage is partly mechanical — sensitive to regional grouping.

Every CBAM lowers global emission intensity ~6%



Scenario	GDP (bn $)	CO_2 (Mt)	Intensity (t/$1k)	Δ Int.
BAU	**106,803**	**34,867**	**326.46**	—
Ctax	106,717	32,906	308.35	**-5.55%**
Cbam0	106,713	32,861	307.94	**-5.67%**
Cbam	106,676	32,804	307.51	**-5.81%**
CbamK	106,649	32,790	307.45	**-5.82%**
CbamKG	106,641	32,786	307.44	**-5.83%**
CbamEcp	106,689	32,833	307.75	**-5.73%**
CbamEcpK	106,682	32,836	307.79	**-5.72%**
CbamEcpKG	106,680	32,836	307.80	**-5.72%**
CbamEcp2w	106,716	32,759	306.97	**-5.97%**

BAU intensity 326 → ~307 t/$1,000 (≈ −5.8%). *CbamEcp2w cuts emissions most (−6.05%) with the smallest GDP cost among the CBAMs.*

- **Global GDP loss is modest (–0.08% to –0.15%) across all scenarios; emission cuts dominate the intensity improvement.**

Conclusion

- **Endogenizing value-added inputs gives a more complete picture of trade-embodied carbon and a more comprehensive consumption-based responsibility (net transfer to DEV: 2,148 → 3,450 $MtCO_2$).**
- **Wider accounting scope eliminates leakage and induces reductions in developing regions, but raises global GDP loss and shifts burden to unregulated developing nations**
    - Combined with Embodied Carbon Price (ECP) with export subsidy may be more effective in minimizing global carbon intensity
- **Carbon pricing by the wide group of developed regions may limit carbon leakage in developing regions**
    - A direct-emission (Scope-1) CBAM might be enough to prevent leakage.
- **Limitations & Future Work:**
    - Dynamic model simulation for more systematic evaluation of capital stock dynamics in carbon leakage
    - Deeper analysis of embodied carbon prices, and a fuller evaluation of ECP's role as the CBAM base.
    - Game-theoretic analysis of carbon pricing incentive of non-regulating regions under ECP vs CP-based CBAM

Q&A

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