Greening Urban Delivery in Paris: Costs and (mostly health) Benefits

Victor Chapuis – Gustave Eiffel University— SPLOTT

Context & Motivation (1)

→ **Poor air quality remains a public health issue in Paris.**

- Despite improvements over the years, NO_2 still ≈ 23–50 µg/m³ in Paris (2021–2023), i.e. 2–5× above WHO guideline of 10 µg/m³ (Respire, 2025).
- In Paris, emissions from transport are estimated to contribute to around 11 premature deaths per 100,000 inhabitants due to exposure to $PM_{2.5}$ and ozone (ICCT, 2019).

→ **Air pollution generates substantial economics costs.**

- The economic burden of air pollution in the Paris region, including health damages, is estimated at €28 billion per year (Airparif, 2025)

→ **Urban freight transport (LCVs & HDVs) accounts for a large share of pollutants emitted.**

- UFT accounts for only **6% of trips and 8% of distances traveled**, but **36% of the total damages** caused by pollutant emissions from road traffic in IdF (N. Coulombel et al., 2018).
- UTF is associated with higher emission factors, intensive stop-and-go driving, frequent circulation in dense urban areas.

Aim of this study

→Develop a cost-benefit framework for a freight vehicle electrification policy (LCVs & HDVs) in Paris.

→ Examine the effectiveness of a strict LEZ (100% electric freight fleet) in improving air quality.

→ Highlight the costs associated with such a measure.

Relevant literature

Authors	Title	Location	Geographic Scope	Method	Pollutants Included	Key Findings / Results
Nishitateno, Burke & Arimura, 2024	Road Traffic Flow and Air Pollution Concentrations	Japan	National (nationwide monitoring data)	Dynamic panel model (system GMM) with hourly data	NOx, CO, NMHC, PM2.5	Short-run elasticities of 0.04–0.05 for traffic on NOx, CO, NMHC; PM2.5 not statistically linked to traffic flows
L.Letrouit & M.Koning, 2022	How Large Are the Costs of Local Pollution Emitted by Freight Vehicles? Insights from the COVID-19 Lockdown in Paris	Paris, France	Urban (intra-mural Paris)	Econometric analysis exploiting an exogenous shock (COVID-19 first lockdown) to isolate freight vs. car effects on pollution.	NO_2, NOx, PM10	~6 lives were lost due to freight-related pollution during the lockdown.
J. Chang & S. Park, 2023	Structural Causality Between Road Traffic and Particulate Matter Concentrations in Urban Areas	South Korea	Urban	Structural equation / causal modeling	PM (unspecified)	Established causal links between traffic and particulate concentrations
A.P. Patton et al., 2024	Assessment of long-term exposure to traffic-related air pollution: an exposure framework	Multi-(global context)	Multi-scale (neighborhood/urban/regional)	Exposure assessment framework for traffic-related air pollution	Multi-pollutant	Provides framework to identify TRAP exposure contrasts
F. Bedoya-Maya et al., 2022	Estimating the effect of urban road congestion on air quality in Latin America	Latin America	Multi-city / regional	Econometric	Urban pollution levels	Quantifies congestion impacts on air quality
Aldrin & Haff, 2005	Generalised additive modelling of air pollution, traffic volume and meteorology	Oslo, Norway	Local urban case	Generalised additive modeling; traffic + meteorology	NOx, PM10, PM2.5	Traffic volume substantially affects air pollution; meteorology also significant

Modeling chain

1) Econometric estimation of the impact of traffic flow on air pollution

2) Fleet greening scenario (*What reduction in air pollution can be expected from fleet electrification?*)

3) HIA (*How many illnesses and premature deaths can be avoided thanks to reduced air pollution, what is their monetary valuation?*)

4) Accounting for additional benefits for decarbonisation :

- Noise reduction
- CO_2 emissions reduction

5) Costs : public spending & total cost of ownership

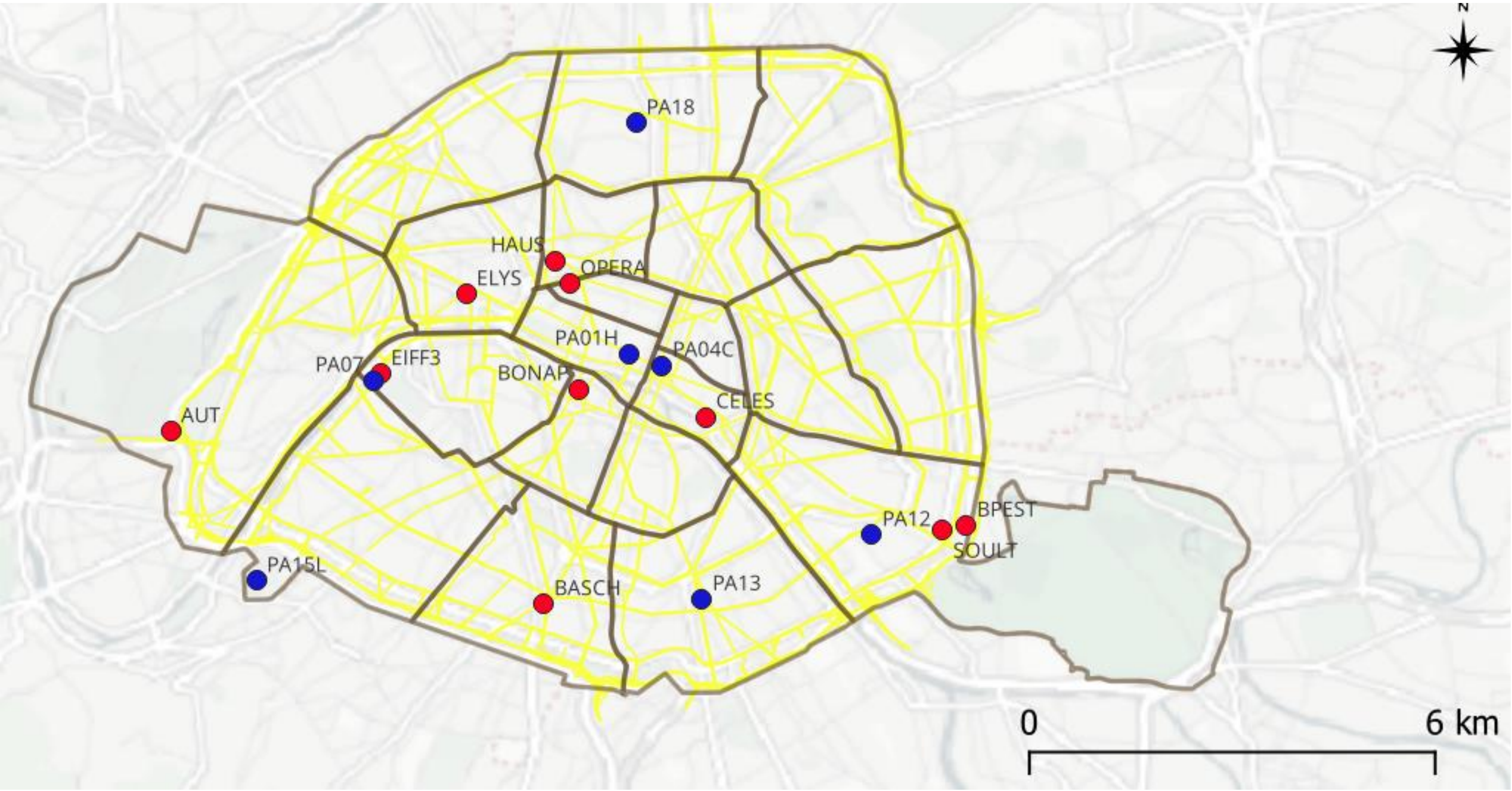
6) Cost-benefit analysis

Data

Hourly observations for Paris *intra-muros* between 2018 and 2025.

- **Air pollutant concentration** (NO_2, PM_{10}, $PM_{2.5}$) from Airparif stations
- **Traffic counters** from Paris Open data
- **Weather** (temperature, wind speed, rain, relative humidity) from MeteoFrance
- **Boundary Layer height** from Aeris data
- **Electricity consumption** in Paris Metropolis from ODRE (Open data Reseaux-Energies)
- **Relevant dummys** : strikes, covid lockdown.

Map of Airparif measurement stations and traffic counters



Background stations

Traffic stations

Paris' administrative districts

Traffic counters' road

Descriptive statistics (1) 2018-2024

Variable	min	mean	median	max
PM2.5 ($\mu g/m^3$)	0	13,3	11	193
NO2 ($\mu g/m^3$)	0	35,5	29,7	322,8
Average traffic flow– 200m (veh/km/h)	0	858	429	11112,667
Temperature (°C)	-9,5	13,2	12,6	41,9
Wind speed (km/h)	0	5,3	4,3	29,2
Precipitation height(mm)	0	0,074	0	39,1
Relative humidity(%)	14	71	74	100
Electric consumption (MW/h)	0	4130	3988	8164
Boundary layer height(m)	22,5	1098	1002	4361

Descriptive statistics(2)

Year	Mean PM2.5 ($\mu g/m^3$)	Mean NO2 ($\mu g/m^3$)	Average traffic flow(veh/km/h)
2018	16.03295	45.95076	1000.076
2019	14.98195	41.56362	932.9703
2020	12.42483	30.64915	756.1715
2021	14.13007	33.53106	758.9763
2022	13.20931	33.50360	820.2514
2023	11.01671	28.05946	851.1023
2024	12.49964	34.18163	857.7592

Econometric model

$$\ln(\mathrm{P}_{\mathrm{s,t}}) = \lambda \ln(\mathrm{Q}_{\mathrm{s,t}}) + \gamma' \mathrm{M}_{\mathrm{t}} + \delta' Z_t + \rho Year + F_s + F_m + \mathrm{F}_{\mathrm{h}} * F_d + \varepsilon_{\mathrm{s,t}}$$

$\mathrm{P}_{\mathrm{s,t}}$: air pollutant concentration at station s and time t

$Q_{\mathrm{s,t}}$: average traffic flow (number of vehicles per kilometer per hour)

M_t : vector of meteorological variables

Z_t : vector of other control variables and dummys (covid lockdown, strike)

F_s, F_m and $F_h * F_d$: station, month, and hour-by-day-of-week fixed effects, respectively.

Impact of average traffic flow

	(1) NO_2 Traffic stations	(2) NO_2 Background stations	(3) PM_{10} All stations	(4) $PM_{2.5}$ All stations
Log (average traffic flow, 200 m)	0.1270**	0.1085***	0.0842*	0.0777**
	(0.0328)	(0.0133)	(0.0255)	(0.0142)
Observations	440,641	188,763	321,023	153,102
Within R^2	0.3303	0.3612	0.2842	0.3208
Adjusted R^2	0.6899	0.5687	0.4217	0.4058

Notes: Standard errors clustered at the station level in parentheses. All models include station fixed effects, month fixed effects, and hour × day-of-week fixed effects. Significance levels: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, . $p < 0.1$.

λ = 0.127 → a 1% increase in traffic flow raises NO_2 by ~0.127%.

Impact of weather

	(1) NO_2 Traffic stations	(2) NO_2 Background stations	(3) PM_{10} All stations	(4) $PM_{2.5}$ All stations
Temperature	-0.0055	0.0281*	-0.0120	-0.0356**
	(0.0097)	(0.0091)	(0.0078)	(0.0066)
Temperature^2	0.0006*	-0.0007**	0.0006*	0.0013***
	(0.0002)	(0.0001)	(0.0002)	(0.0001)
Atmospheric pressure	0.0051**	0.0066***	0.0113***	0.0105***
	(0.0013)	(0.0002)	(0.0003)	(0.0008)
Wind speed	-0.0489**	-0.0227	-0.0293**	-0.0395.
	(0.0116)	(0.0128)	(0.0078)	(0.0154)
Precipitation height	0.0139*	0.0087	-0.0499***	-0.0312**
	(0.0044)	(0.0060)	(0.0061)	(0.0054)
Relative humidity	0.0019.	0.0067***	-0.0023*	0.0046***
	(0.0009)	(0.0006)	(0.0008)	(0.0006)
Boundary Layer Height	0.00009**	0.00013***	0.00008***	0.00005***
	(0.00002)	(0.00001)	(0.00001)	(0.00000)
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Impact of policy and time controls

	(1) NO_2 Traffic stations	(2) NO_2 Background stations	(3) PM_{10} All stations	(4) $PM_{2.5}$ All stations
Electricity consumption (MW)	0.00019***	0.00027***	0.00013***	0.00014***
	(0.00003)	(0.00002)	(0.00002)	(0.00002)
Lockdown	-0.2361***	-0.0930**	0.0191	0.0953
	(0.0469)	(0.0171)	(0.0343)	(0.0597)
Strike	0.0561.	0.0754.	0.1311***	0.0775*
	(0.0290)	(0.0316)	(0.0246)	(0.0245)
Annual trend	-0.0563***	-0.0467***	-0.0071	-0.0068*
	(0.0070)	(0.0037)	(0.0095)	(0.0023)
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Estimating fleet composition (PCs, LCVs, HDVs)

→The coefficient λ measures the effect of an *average vehicle* on air pollution. However, vehicle types do not have the same impact : electrifying an LCV reduces pollution more than electrifying a PC.

→Solution : estimate, for each vehicle type (PCs, LCVs, HDVs) and each powertrain (internal combustion, electric…), a relative emission factor using **COPERT.**

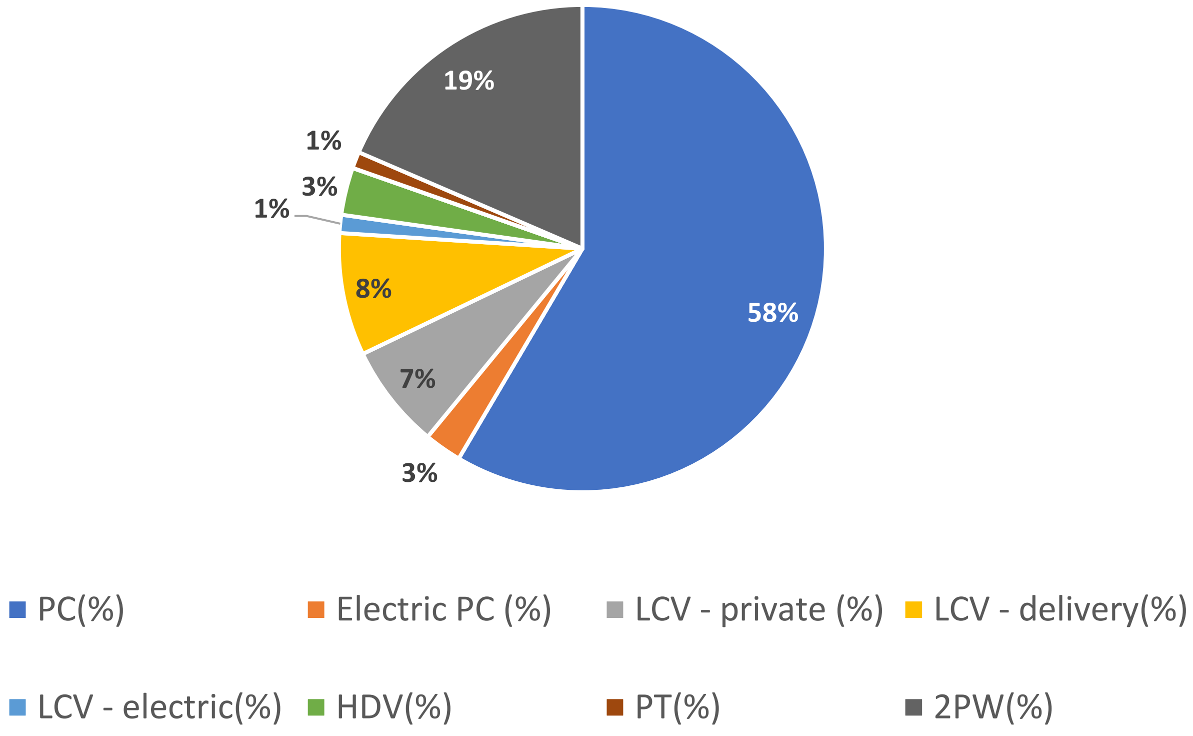
Estimating fleet composition (PCs, LCVs, HDVs)

→ Data sources used to determine…

1. Vehicle type distribution : **traffic composition data** from the City of Paris.
2. Powertrain distribution (electric / internal combustion) : **SDES data** on the IDF vehicle as of 2024.

Estimating fleet composition (PCs, LCVs, HDVs)

Fleet composition based on Paris *compotrafic* survey (2022)



Emission factors for NO2 (g/km) based on SDES and estimated with COPERT

Speed (km/h)	PC - ICE	PC - EV	LCV - ICE	LCV - EV	HDV - ICE	HDV - EV	Average Vehicle
12	0.10	0.00	0.26	0.00	0.67	0.00	0.13
14	0.10	0.00	0.25	0.00	0.60	0.00	0.12
16	0.09	0.00	0.24	0.00	0.55	0.00	0.12
18	0.09	0.00	0.23	0.00	0.51	0.00	0.11

Health benefits (HIA) — Steps

1) Convert scenarios into ΔNO_2 at steady state.

2) Use epidemiological dose–response to estimate avoided non-accidental deaths.

3) Monetise using Value of a Statistical Life (3.2 M€).

Greening scenarios - ΔNO2 concentrations

Scenarios	delta NO2 $(\mu g/m^3)$ (low)	delta NO2 $(\mu g/m^3)$ (median)	delta NO2 $(\mu g/m^3)$ (max)
1) 50% electric LCV	-0,41	-0,51	-0,62
2) 50% electric HDV	-0,38	-0,48	-0,58
3) 100% electric LCV, HDV	-1,96	-2,44	-2,92

Health impact assessment – relative risk

Pollutant	Long term effect	Age	RR for 10 $\mu g/m^3$
NO2	Total mortality	> 30	1,023 [1,008-1,037]

Source: HIA intervention guide, Sante publique France, 2019.

Health impact assessment (HIA)

$$\Delta y = y_0 \cdot \left(1 - e^{-\beta \cdot \Delta C_{NO_2}}\right)$$

- Δy: number of avoided cases.
- y_0: number of observed cases at the initial pollution level.
- $\beta = \frac{\ln(RR)}{10}$

Health impact assessment – results

Scenarios	Avoided deaths (min)	Avoided deaths (median)	Avoided deaths (max)	Min (M€)	Median (M€)	Max (M€)
1) 50% LCV	**4**	**15**	**29**	13,4	47,9	92
2) 50% HDV	**4**	**14**	**27**	12,8	45	86
3) 100% LCV, HDV	**20**	**71**	**136**	63,9	227,6	435

Costs & Co-benefits: Methodology

- Step 1: Unit values (€/veh·km·h)
  - Costs:
    - **TCO**: average of discounted flows of expenditures and revenues over 8 years
    - **Public spending**: average of discounted fiscal flows (EV subsidies vs. fuel tax revenues).
  - Co-benefits:
    - **CO2 reduction**: diesel emissions (gCO_2/km) – electric consumption ($kWh/km \times gCO_2/kWh$)
    - **Noise reduction**: unit cost differential between diesel and electric vehicles (based on noise cost factors)

- Step 2: Scaling to network operations

Annual total = **unit cost/benefit** × **observed vehicle flow** (veh/km/h, by mode) x **network length** (1,561 km) × **hours of operation** (16 h/day) × **operational days** (260 days/year).

Total cost of ownership (1)

- **TCO (€/veh·km·h):**
  - For each diesel vehicle age (1–8 years): compare annual TCO (diesel vs. electric).
  - Inputs (French official data): acquisition price (with subsidy), resale value (diesel), energy consumption & price, maintenance, insurance, labor cost.

Total cost of ownership – electric vehicle

$$TCO_j^E = \frac{\underbrace{d_0\left[\left(1-\sigma_j\right)P_{j,0}^E + B_j - P_j^{T,old}VR(a)\right]}_{\textbf{new electric vehicle purchase}} - \underbrace{d_9 VR(8) P_{j,0}^E}_{\textbf{resale t = 9}} + \underbrace{\sum_{t=1}^{8} d_t\left[(p_t^E c_j^E + m^E)K_j J_j + qP_{j,0}^E + \omega H J_j\right]}_{\textbf{operation costs}}}{\sum_{t=1}^{8} d_t K_j J_j}$$

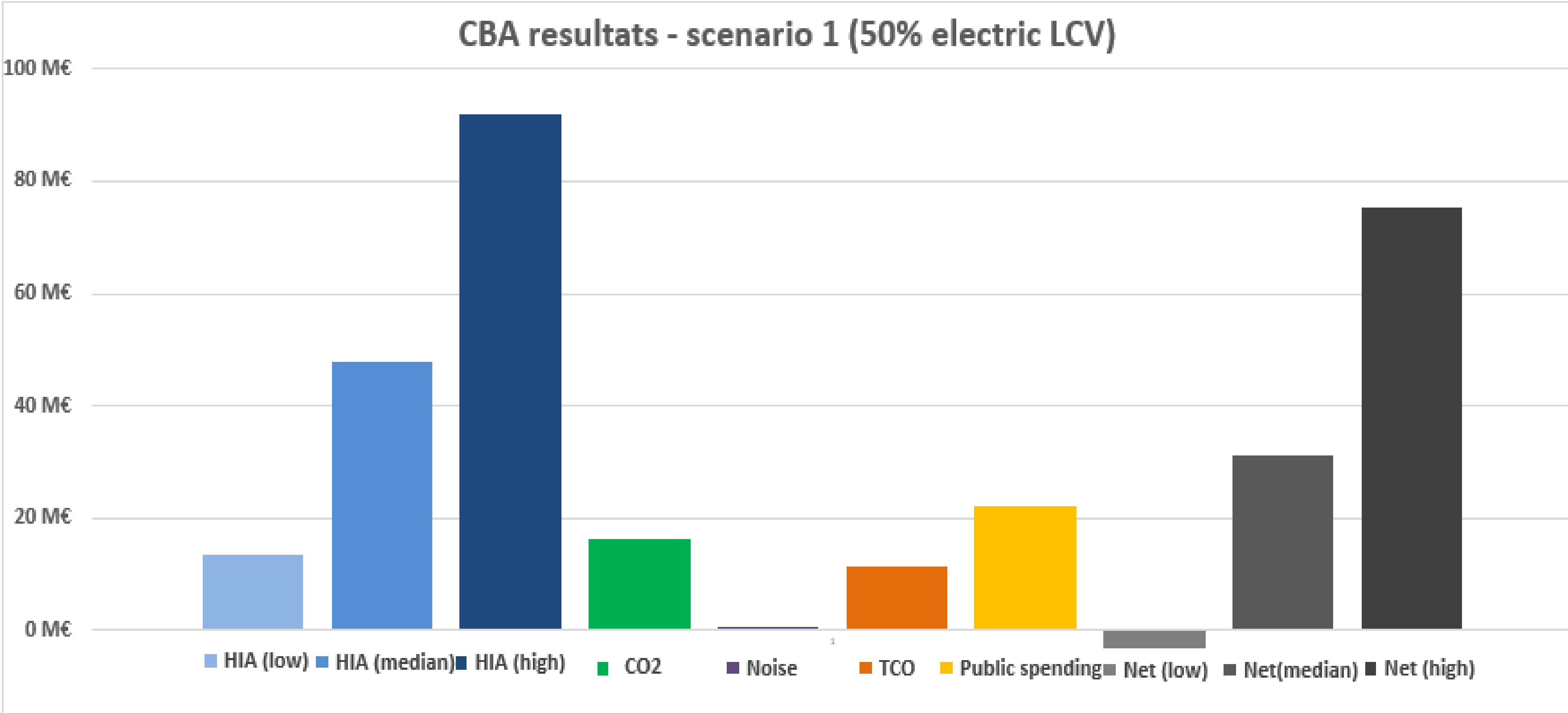
Purchase price (2025) – (P_j^E)
Charging station – (B_j)
Energy efficiency certificate subsidy – (σ_j)
Electricity consumption (kWh/km) – (c_j^E)
Electricity price excl. tax (€/kWh, 2025–2032)
Electricity tax (€/kWh) – (τ^E)
Maintenance cost (€/km) – (m^E)
Hourly wage – (ω)
Insurance rate (% of purchase price) – (q)

Total cost of ownership – ICE vehicle

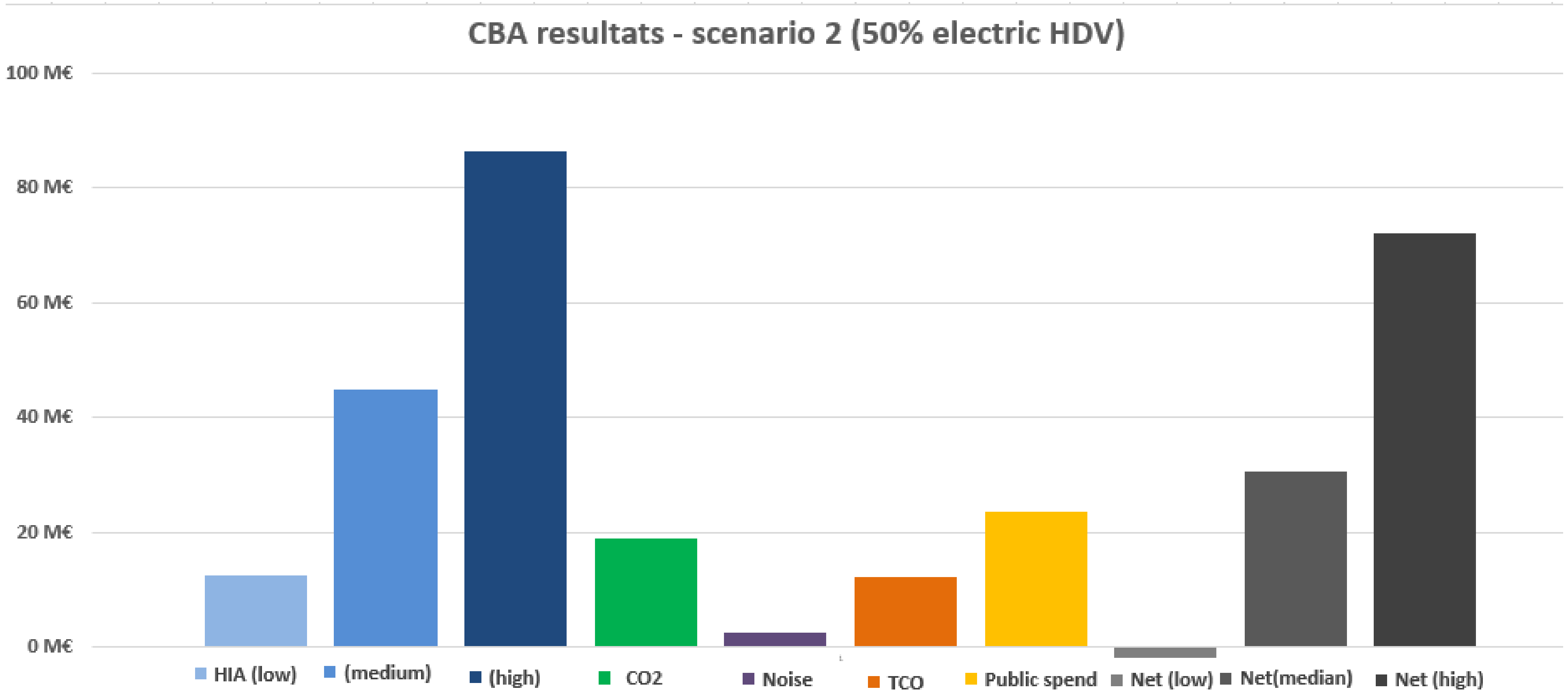
$$TCO_j^T(a) = \frac{\underbrace{\sum_{t=1}^{\gamma(a)-1} d_t\left[(p_t^T c_{j,a}^{T,old} + m^{T,old})K_jJ_j + qP_j^{T,old} + \omega HJ_j\right]}_{\textbf{Operation of the existing vehicle}} + \underbrace{d_{\gamma(a)}\left[P_{j,\gamma(a)}^T - VR(8)P_j^{T,old}\right]}_{\textbf{Replacement}} + \underbrace{\sum_{t=\gamma(a)}^{8} d_t\left[(p_t^T c_{j,\gamma(a)}^{T,new} + m^{T,new})K_jJ_j + qP_{j,\gamma(a)}^T + \omega HJ_j\right]}_{\textbf{Operation of the new vehicle}} - \underbrace{d_9 VR\big(9-\gamma(a)\big)P_{j,\gamma(a)}^T}_{\textbf{Resale of the new vehicle}(t=9)}}{\sum_{t=1}^{8} d_t K_j J_j}$$

Purchase price – (P_j^T)
Fuel consumption (L/km) – ($c_{j,a}^T$)
Fuel price excl. tax (€/L) – ($c_{j,t}^T$)
Fuel tax (€/L) – (τ^T)
Maintenance cost (€/km) – (m^T)

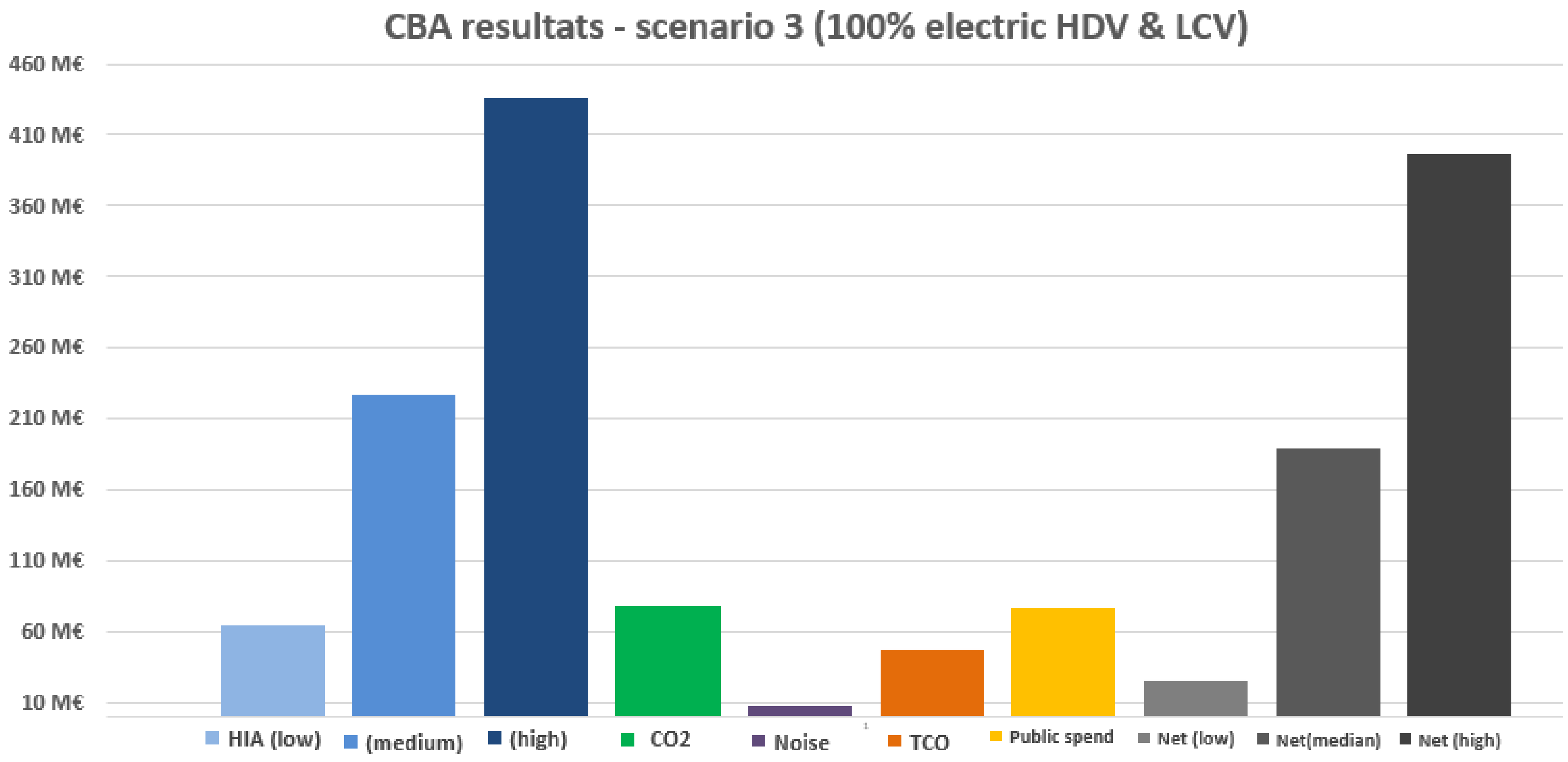
Results – scenario 1



Results – scenario 2



Results – scenario 3



Results - overview

	HIA median (M€)	CO2 avoided (tonnes)	CO2 (M€)	Noise (M€)	TCO (M€)	Public spending (M€)	Net median (M€)
1) 50% LCV	48	92 854	16	0,76	11	22	31
2) 50% HDV	45	107 749	19	3	12	24	30
3) 100% LCV, HDV	228	443 741	77	7	47	77	188

Results – Cost benefit ratios

	Low C-B ratio	Median C-B ratio	High C-B ratio
1) 50% LCV	1,10	0,52	0,31
2) 50% HDV	1,06	0,54	0,33
3) 100% LCV, HDV	0,83	0,40	0,24

Conclusion

- CBA results suggest that freight-fleet greening policy should be beneficial in the long run, although further examination is required (see limits & future work).

- Although CBA suggest overall positive impact of the strict LEZ policy, private and public costs should not be underestimated.

Limits & future work

- Limits:
  - Paris ring road boundary: upstream/downstream emissions not taken into account;
  - implementation & enforcement costs not included.

- Future work:
  - Economic model : inclusion of lagged pollutant variable;
  - Inclusion of modal shifts (cargo-bikes);
  - Sensitivity analyses (TCO parameters, subsidies…)

Thank you for your attention!

Appendix

TCO parameters (1)

General TCO Parameters	Value
Daily distance, hours per day, working days per year (LCV)	75 km/day; 8 h/day; 260 days/year
Daily distance, hours per day, working days per year (HDV)	170 km/day; 8 h/day; 260 days/year
Hourly wage – (ω)	€15/hour
Discount rate – (r)	6%
Insurance rate (% of purchase price) – (q)	2.7%
Residual value for LCV & HDV – ($VR(a)$)	After 1 year: 88% After 2 years: 76% After 3 years: 64% After 4 years: 52% After 5 years: 40% After 6 years: 30% After 7 years: 20% After 8 years: 10%

TCO parameters (2)

TCO Parameters – Internal Combustion LCV	Value (2017–2032)
Purchase price – (P_{LCV}^{T})	€33,600 – €35,679
Fuel consumption (L/km) – ($c_{LCV,a}^{T}$)	0.13 – 0.10
Fuel price excl. tax (€/L) – ($c_{LCV,t}^{T}$)	0.8605 – 1.0355
Fuel tax (€/L) – (τ^{T})	0.6075
Maintenance cost (€/km) – (m^{T})	0.078

TCO parameters (3)

TCO Parameters – Electric Light Commercial Vehicle (Electric LCV)	Value
Purchase price (2025) – (P_{LCV}^{E})	€51,238
Charging station – (B_{LCV})	€5,383
Energy efficiency certificate subsidy – (σ_{LCV})	10%
Electricity consumption (kWh/km) – (c_{LCV}^{E})	0.42
Electricity price excl. tax (€/kWh, 2025–2032)	0.1236 – 0.1296
Electricity tax (€/kWh) – (τ^{E})	0.0364
Maintenance cost (€/km) – (m^{E})	0.055

TCO parameters (4)

TCO parameters – Thermal HDV	**Value**
Purchase price – (P_{HGV}^{T})	€87,600 – €92,976 (2017–2032)
Fuel consumption (L/km) – ($c_{HGV,a}^{T}$)	0.28 – 0.21
Fuel price excl. tax (€/L)	0.8605 – 1.0355
Fuel tax (€/L) – (τ^{T})	0.6075
Maintenance cost (€/km) – (m^{T})	0.078

TCO parameters (5)

TCO parameters – Electric HDV	Value
Purchase price (2025) – (P_{HGV}^{E})	€199,442
Charging station – (B_{HGV})	€29,590
Energy efficiency certificate subsidy – (σ_{HGV})	20%
Electricity consumption (kWh/km) – (c_{HGV}^{E})	1.10
Electricity price excl. tax (€/kWh, 2025–2032)	0.1236 – 0.1296
Electricity tax (€/kWh) – (τ^{E})	0.0364
Maintenance cost (€/km) – (m^{E})	0.055

Co-benefits' parameters

Vehicle type	Noise cost factor 2015 (€/1000 vkm)	Noise cost factor 2025 (€/1000 vkm)	Source
ICE LCV	2,76	3,94	Didier Rouchaud, « Mobilités : coûts externes et tarification du déplacement », MTE, 2020
Electric LCV	0,00	0,00	Ibid
ICE HDV	27,60	39,36	Ibid
Electric HDV	13,8	19,68	Assumption based on corporate reports

	Value (€)	Unit	Source
Shadow price of 1 ton CO_2	256	€/t	France Stratégie, Quinet report, « La valeur de l'action pour le climat » (2025)
Electric LCV consumption	0,22	kWh/km	ADEME, Base empreinte
Electric HDV consumption	1,10	kWh/km	ADEME, Base empreinte
Carbon intensity electric consumption	60	gCO_2/kWh	ADEME, Base empreinte
Emission factor ICE LCV	494	gCO_2/km	ADEME, Base empreinte
Emission factor ICE HDV	1300	gCO_2/km	ADEME, Base empreinte