A tractable TCO model to identify (ir)relevancy domains of modal options for urban deliveries

(Work in very progress – please, do not quote)

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Motivations

- Contradiction between the negative impacts of UL & the growing importance (for firms and households) of this economic sector
- Co-existence of a variety of UL markets & of transport modes

- Most of the TCO literature in economics (vs. OR) focuses on vehicles (vs. fleets) & fails in considering the main operational constrains of UL

- We aim at developping a tractable-easy to calibrate TCO model that helps identifying the relevancy domains, from both private and public perspectives, of different modes wrt key features of UL (e.g. parcels weight, warehouse location, trafic speed, customers density)

What we do

- We consider two specific UL markets: (BtC) e-commerce and (BtB) shipping
- Given exogenous parameters & operational constrains of UL, we determine the fleet size for E-cargobikes, LDV, E-LDV, HGV & E-HGV, for each market
- Given these fleet sizes, we compute the TCO & the volume of GHG emissions (in a tentative LCA framework) for each available technology
- We run (deterministic) sensitivity tests to isolate some parameters that make some modal options (ir)relevant for some circumstances

What we do not do (yet)

- We ignore financial costs related to charging stations & warehousing
- We ignore external costs of local pollutants, noise, congestion, accidents as well as the impacts on public finance
- We do not consider the overall combinations of sensitivity tests
- We ignore futuristic modal options

- (The case of « mixed fleet » is out of the scope of this article)

Vehicles under study

TCO formula

- Over a time period of N years, for the modal option j:

$$TCO_j = n_j^v p_j^v \frac{N}{N_j^V} + - \frac{n_j^v p_j^v \frac{N}{N_j^V} \left(1 - a_j^v\right)^t}{(1+r)^{t+1}} + \sum_{t=1}^{N} \frac{\left(n_j^v d_j \left(e_j p_j^e + p_j^m\right) + t_j n_j^v p_j^L\right) n^y + n_j^v p_j^I}{(1+r)^t}$$

With n_v the size of the fleet, p_v the unit price of vehicles, N_v their life duration, r the firm discount rate, a_v the depreciation rate of vehicles, d the daily driven distances, e the kilometric consumption of vehicles, p_e the energy price, p_m the maintenance costs, t the daily working time of drivers, p_L their hourly wage rate, p_I the annual insurance costs and n_y the number of working days per year

- Straightforward to understand that the TCO is driven by the number of vehicles composing the fleet n_v
- GHG emissions are also a function of n_v (especially in a LCA framework)

Demand adressed to the firm

- The firm's supply must satisfy:

$$N^{TOT} \leq n^v n^t n^p n^c$$

With N_Tot the daily number of parcels to be delivered, n_t the number of daily rounds per vehicle, n_p the number of stops per round and n_c the number of parcels to be delivered per stop

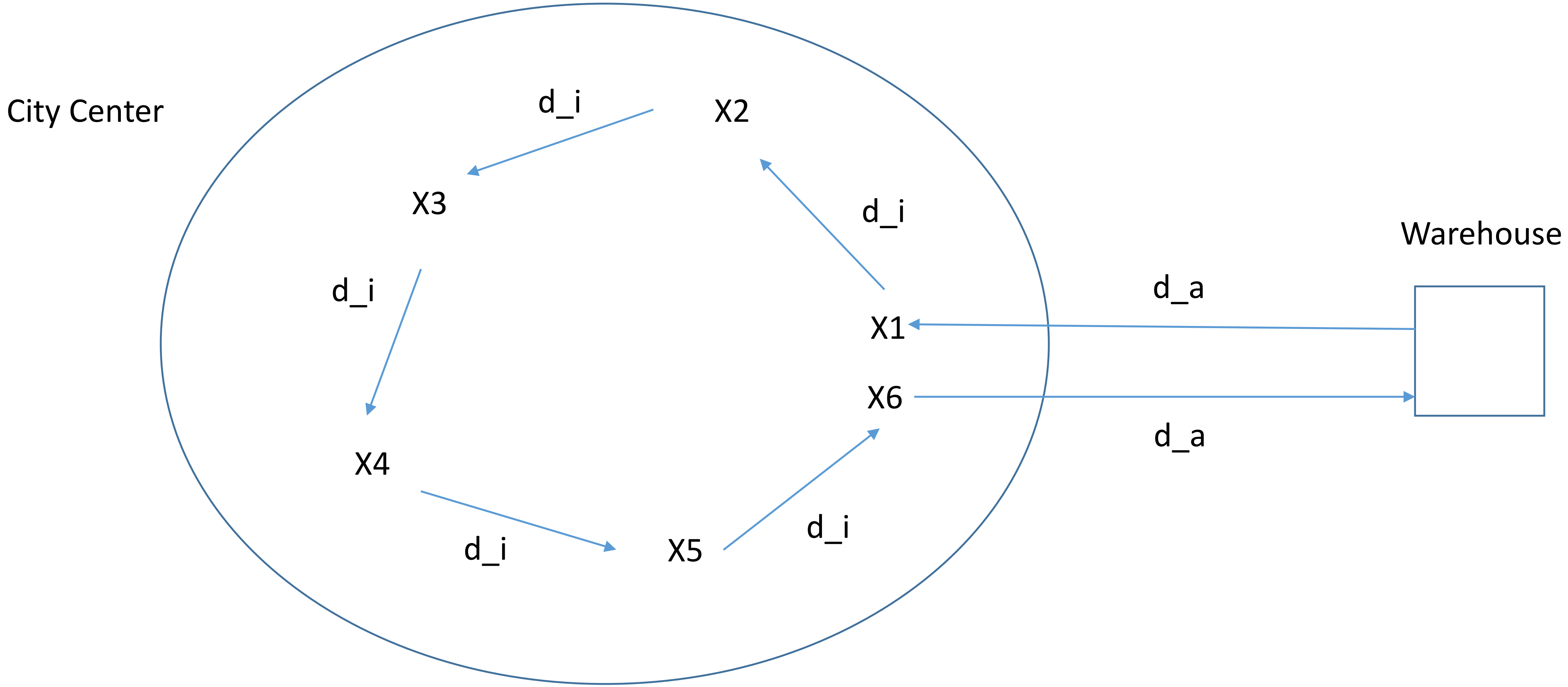
- Assuming fixed demand:

$$n^v \geq \frac{\widehat{N^{TOT}}}{n^t n^p n^c}$$

- The size of the round n_p is determined by three operational constrains:

Vehicle capacity, Vehicle autonomy, Working duration

Round organization



Operational constrains

- Vehicle capacity (VC): $pn^p n^c \leq \text{Ø}K \;\; \leftrightarrow \;\; n_K^p = \left\lfloor \frac{\text{Ø}K}{pn^c} \right\rfloor$

With p the average weight of parcel, K the max load of vehicles, Ø an efficiency index

- Vehicle autonomy (VA): $2d^a + d^i(n^p - 1) \leq A \;\; \leftrightarrow \;\; n_A^p = \left\lfloor \frac{A - 2d^a}{d^i} \right\rfloor + 1$

With d_a the distance between the warehouse and the city center, d_i the distance between the clients, A the autonomy of vehicles

- Working duration (WD): $2t^a + n_H^p n^c t^c + \left(n_H^p - 1\right)t^i \leq H \;\; \leftrightarrow \;\; n_H^p = \left\lfloor \frac{H - 2t^a + t^i}{n^c t^c + t^i} \right\rfloor$

With t_a the time between the warehouse and the city center, t_c the delivery+cruising time, t_i the inter-clients travel time, H the maximal time (e.g. legal working time)

Operational constrains (cont'd)

- In order to determine the fleet size, we first check which constrain applies by computing n_p for each situation
- If WD is « hard », easy:

$$n^v = \left\lceil \frac{\widehat{N^{TOT}}}{n_H^p n^c} \right\rceil$$

- If VA or VC apply, we must additionally:

  1) Check if one vehicle can (or not) realize more than 1 delivery round per day

  2) Compute the total number of clients per vehicle and per day when delivery rounds are (or not) incomplete

  3) Determine the fleet size on that basis

  NB: the final formula is globally similar, details available upon requests

Data sources

- We are grateful to:
  - A. Bouter & C. Ternel (IFPEN) for providing us access with some results from the E4T (2018) project on transport electrification (IFPEN-Ademe): emissions factors, costs and technical components for LDV and HGV (12t)
  - B. Mukhanova & N. Mohktari (PSE-ENPC) for the work made during the Capstone Project: costs and technical components for LDV and cargobikes
- Other datasources: MTE, ETMV, authors' or experts' knowledge…

- More work required to fix our benchmark parameters
- Put differently, the following results are preliminary!

Parameters for the TCO analysis

	VUL D	VUL E	PL D	PL E	Cargo E
Capacité (kg)	1200		4150		150
Batterie (kWh)	NA	40	NA	170	0.5
Conso. (l ou kWh/100km)	17.3	30.5	25.6	102.9	2.4
Autonomie (km)	NA	265	NA	195	50
Prix véhicule (€)	28990	36980	87110	149200	7476
Prix batterie (€)	NA	14000	NA	59500	504
Subvention véhicule (€)	NA	6300	NA	6300	NA
Coût entretien (€/km)	0.09	0.03	0.07	0.18	0.08
Energie (€/l ou kWh)	1.40	0.12	1.40	0.12	0.12
Coût assurance (€/an)	1782	2273	1307	2238	750

- Life duration of vehicles = 12 years = duration of analysis, life duration of batteries = 6 years, 1 year = 255 days, 1 day = 10 hours, 1 hour = 15.8 €, discount rate = 8%, depreciation rates = 20-8%, charging time = 5 hours

Parameters for GHG emissions

- Based on Ecoinvent for LDV and HGV, literature review for cargobikes
- End-life emissions = +35% factor wrt to production phases
- For batteries, emission factor / kWh produced (Ademe)
- Life duration of tires = 40000 km

	VUL D	VUL E	PL D	PL E	Cargo E
Véhicules (kg eqCO2/unit)	7133	7126	30012	23805	350
Batteries (kg eqCO2/unit)	NA	6871	NA	29131	86
Pneus (kg eqCO2/unit)	85		966		9
Usage (kg eqCO2/l ou kWh)	3.16	0.05	3.16	0.05	0.05

Parameters for the fleet size

- We consider one firm facing a given demand of 800 parcels/day
- Input parameters have been fixed to be consistent with the average size of delivery rounds for each UL markets
- We target 97 parcels/round for e-commerce & 26 parcels/round for shipping

	E-trade	Shipping
Average weight of parcels (kg)	2	18
Between-clients distance (km)	0.2	2
Cruising + delivery time (min)	4.5	8
Warehouse location (km)	20	18

- We also consider trafic speeds between 12 – 30 km/h

Benchmark results

E-commerce (97 colis de 0,2 kg)					
	VUL D	VUL E	PL D	PL E	Cargo E
Nombre de véhicules / tournées	9 / 1	9 / 1	9 / 1	9 / 1	37 / 2
TCO (M€)	3.85	3.78	4.39	5.57	8.75
Dont investissements	4.5%	9.4%	12.2%	29.9%	2.4%
Coût unitaire (€/colis)	1.57	1.55	1.79	2.28	3.57
GES (t CO2)	959.0	215.2	1628.6	858.8	34.8
Dont circulation	92.9%	11.1%	81.0%	9.4%	37.5%
Emissions unitaires (kg/colis)	0.39	0.09	0.67	0.35	0.01

Messagerie (26 colis de 18 kg)					
	VUL D	VUL E	PL D	PL E	Cargo E
Nombre de véhicules / tournées	28 / 1	28 / 1	28 / 1	28 / 1	91 / 2
TCO (M€)	12.3	11.7	14.2	17.6	26.6
Dont investissements	4.4%	9.5%	11.8%	29.4%	1.9%
Coût unitaire (€/colis)	5.04	4.77	5.78	7.20	10.9
GES (t CO2)	4243.6	707.7	6979.9	2840.6	84.9
Dont circulation	94.9%	15.2%	85.4%	12.8%	37.2%
Emissions unitaires (kg/colis)	1.73	0.29	2.85	1.16	0.03

Benchmark results (cont'd)

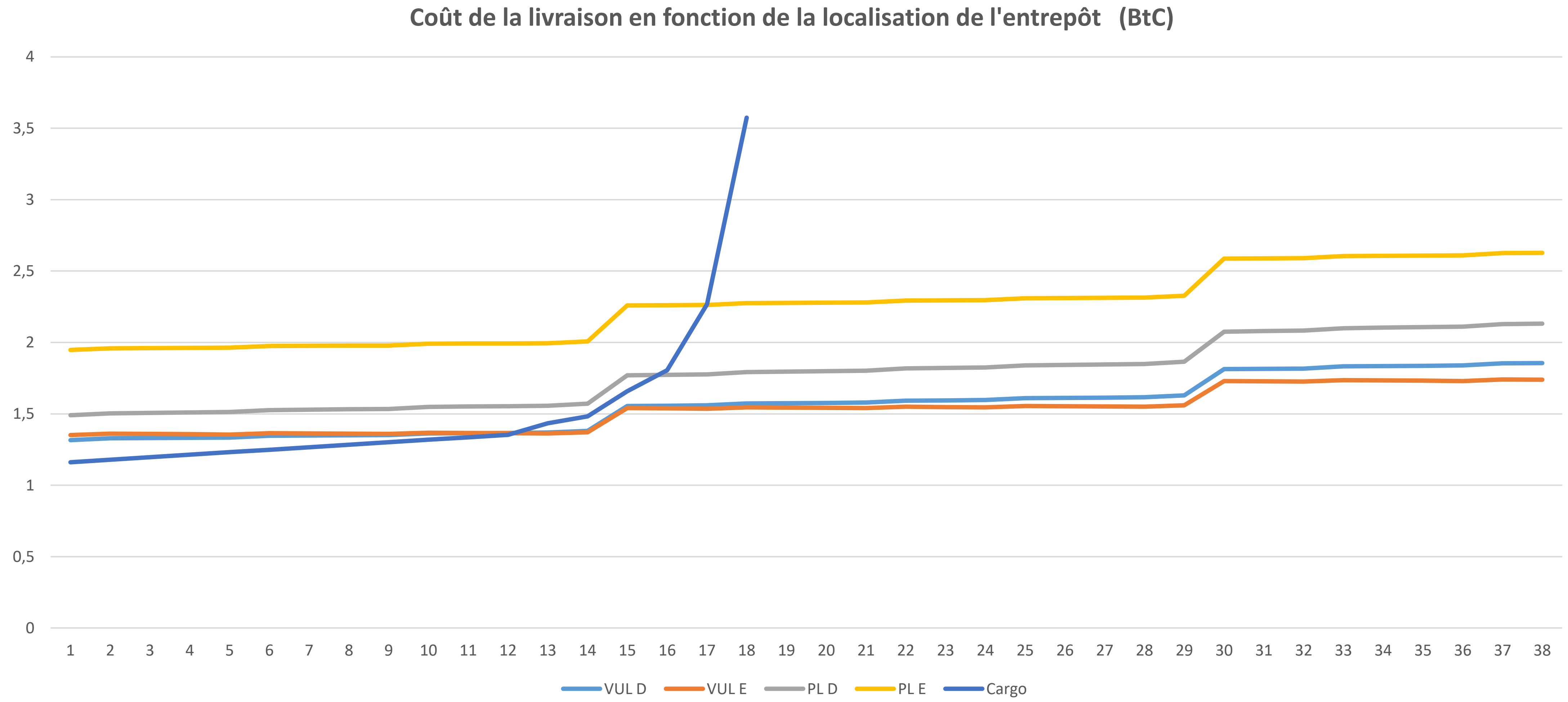
- Given these input parameters, E-LDV should be selected for both BtC and BtB deliveries (lowest TCOs & fairly good in terms of GHG)

- Excess investment costs of electric vehicles are outweighted by (currently) low energy costs

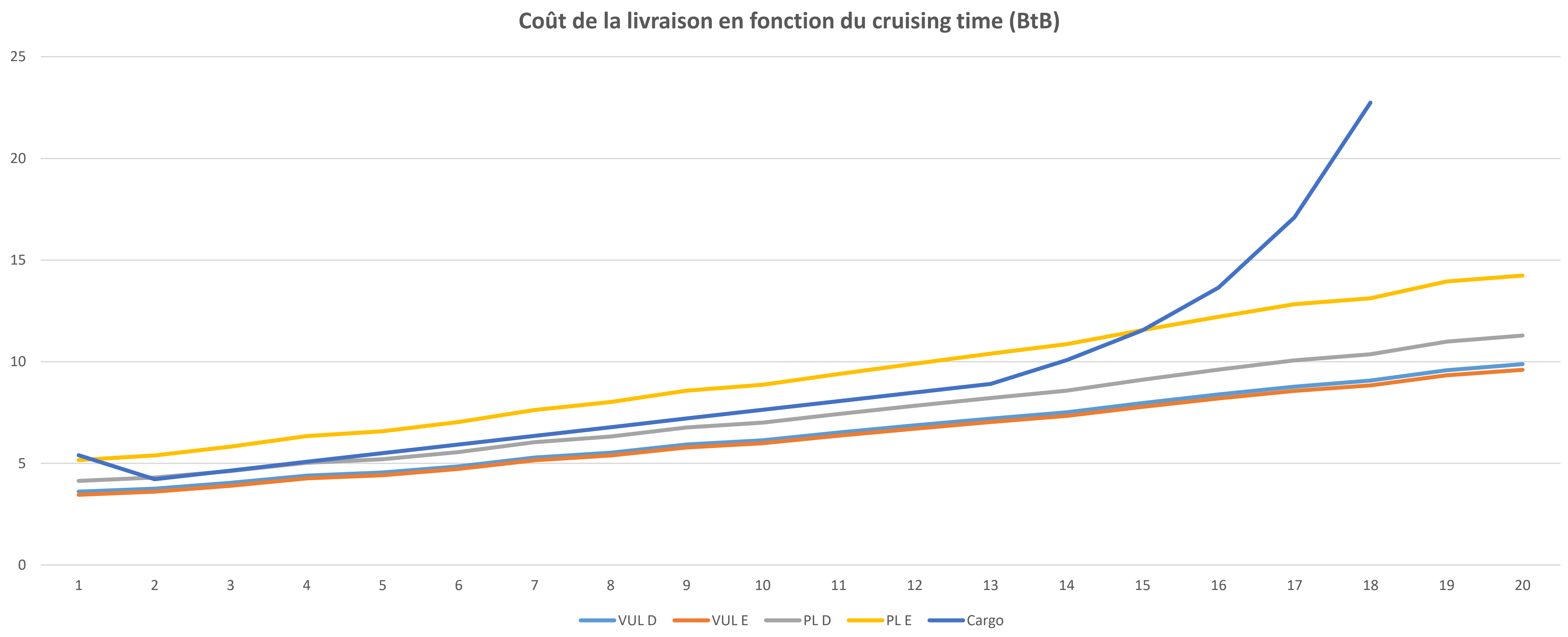
- GHG emissions linked to usage phases are modest for electric vehicles, needs for life cycle considerations

- Given these input parameters, cargobikes are good only from an environmental perspective (large fleet + high labour costs)

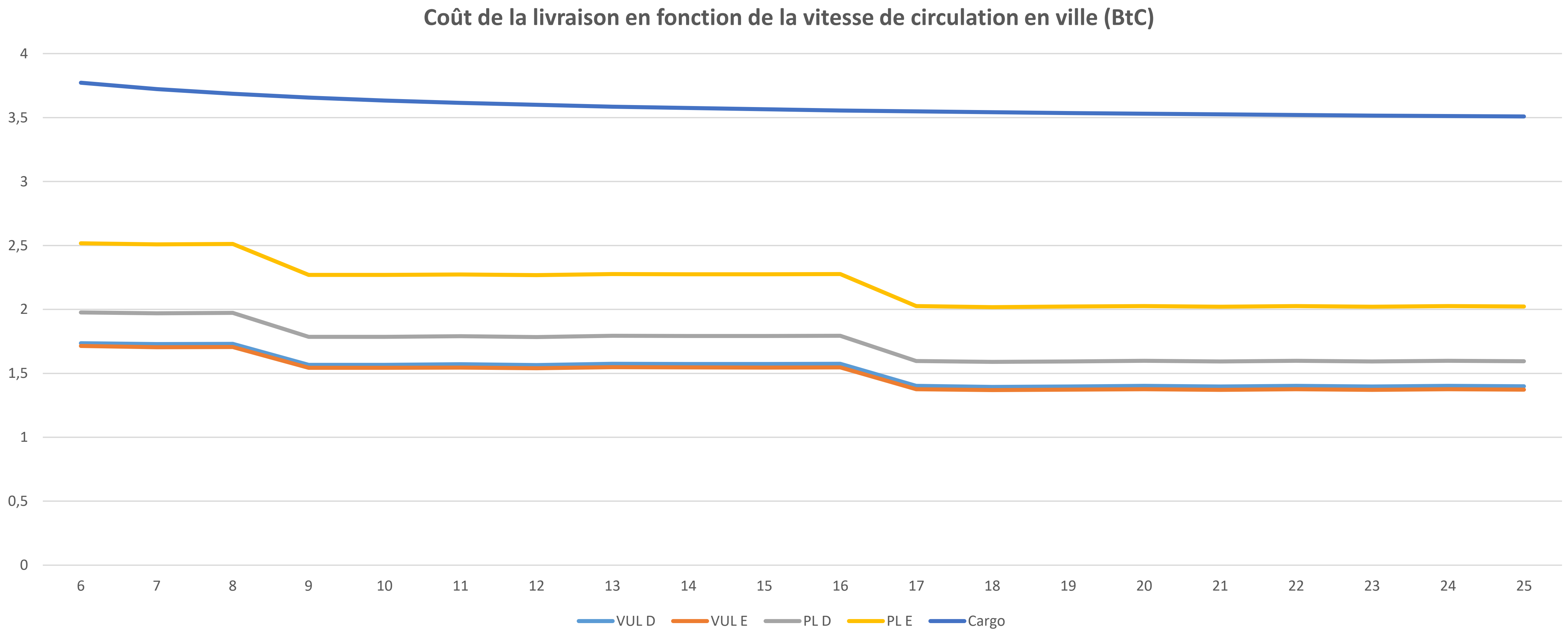
Sensitivity analyses



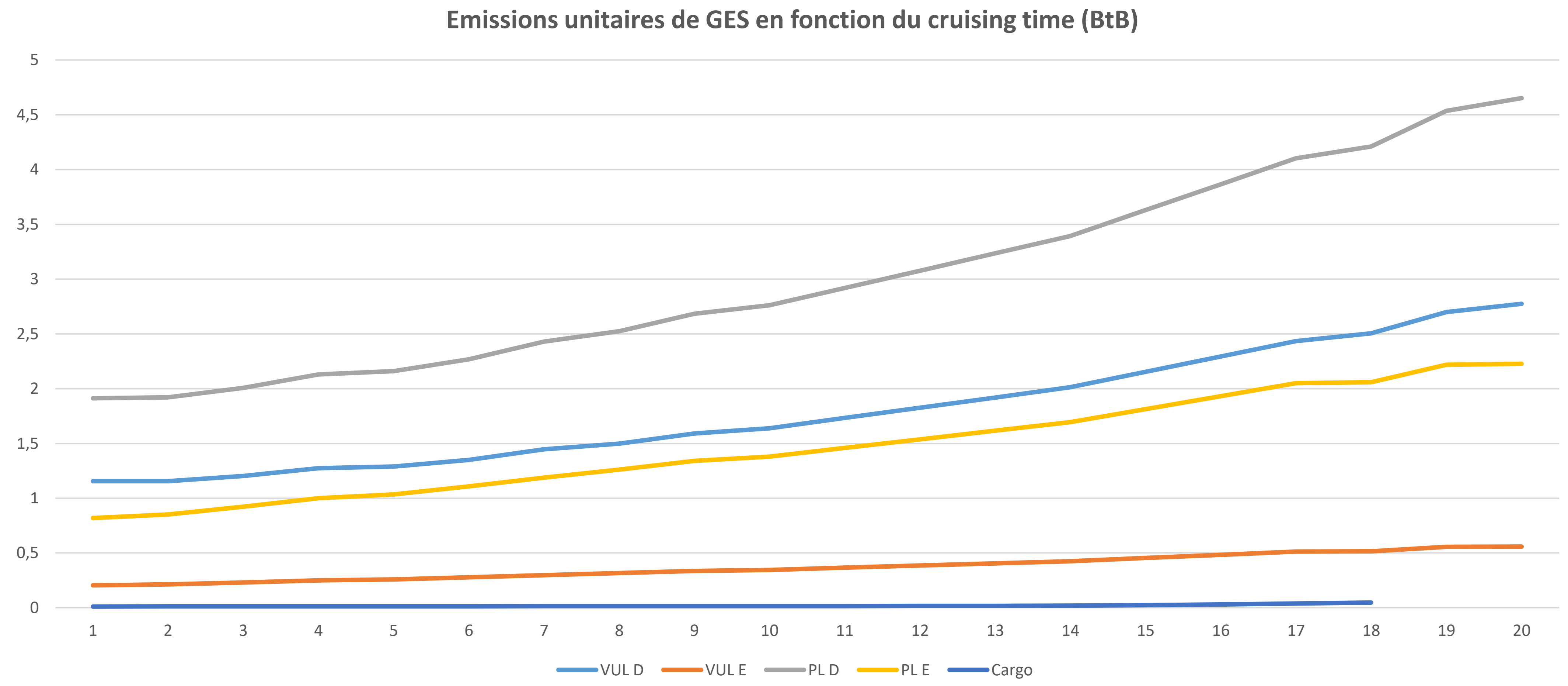
Sensitivity analyses (cont'd)



Sensitivity analyses (cont’d)



Sensitivity analyses (cont'd)



Conclusions

- Given our current framework, additionnal efforts required to:
  - Improve the consistency of input parameters (maintenance costs)
  - Identify the factors that significantly impact the attractiveness of HGV
  - Combine (and visualize) different types of sensitivity tests

- Further extensions:
  - Consider other external costs, impacts on public finance (which policies to be implemented?), charging stations and warehousing costs
  - Question the relevancy of TCO (what about ROCE?)
  - Extend the model:
    - To allow for a given vehicle to be used by different individuals within the same day
    - To consider other UL markets (instant deliveries)
    - To question the relevancy of autonomous vehicles, drones, mobile depots