Decarbonation as a service:

An economic analysis of innovative shuttles for freight on French highways

(Work in progress – please, do not quote)

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Context

- Transport = 29% of French GHG emissions
- Trucks = 7% of French GHG emissions
- Highways = 60-70% of trucks’ traveled kilometers
- Very modest results of past mode shift policies in France (e.g. railways)
- Highway managers (HM) are willing to reduce their CO_2 scope-3 emissions

⇒ Fairly reasonable to assume that “*the road towards sustainable development will depend on the development of sustainable roads*”

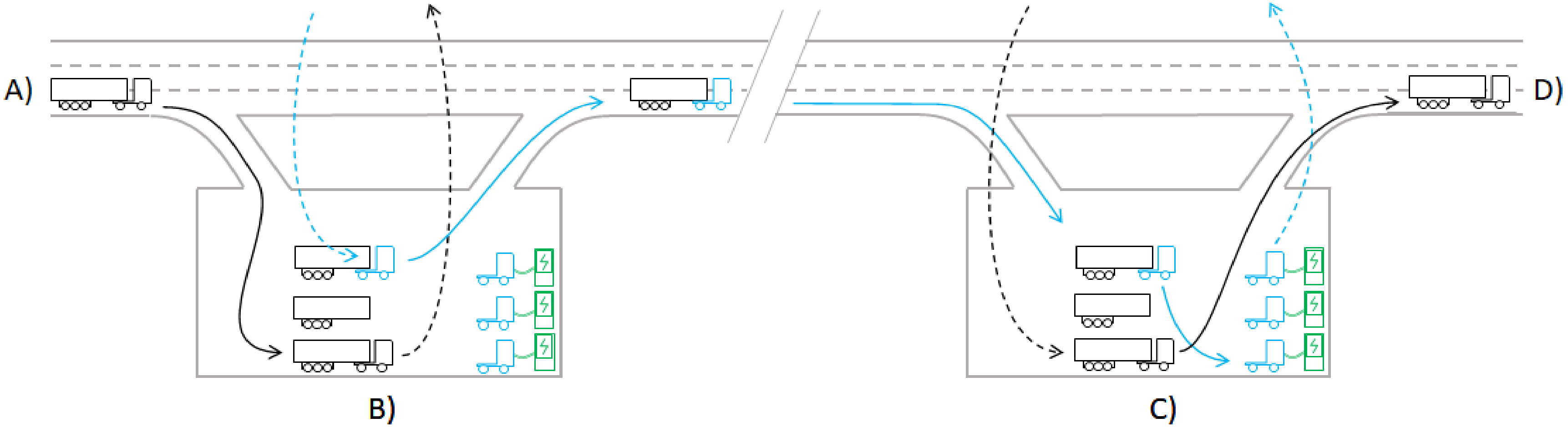
In this research

We study the socioeconomic relevancy of a **new transport service proposed by HM aimed at moving shipments instead of freight operators (or carriers) with the help of decarbonized shuttles (including Electric Road System, ERS)**

In practice:

- We develop an analytical model to determine various pricing schemes
- We calibrate this model empirically for different technologies
- We discuss some policy implications

Operational scheme



- The truck of the carrier (or of the transport operator) enters a platform (A) where the shipment is unloaded / loaded onto a decarbonized vehicle operated by the HM (B) which drives towards an « exit platform » where the goods are again unloaded / loaded onto a vehicle (C) owned by the carrier (or the transport operator) before joining the final destination (D)
- The vehicles operated by the HM can refuel on platforms and, once loaded with new shipments, go back to the origin

Pricing schemes

The service price (p1) can be chosen :

- By the HM who **maximizes his total joint profit** (private optimum):

$$\pi = \underbrace{(1-\tau_0)p_0Q_0 + (1-\tau_1)p_1Q_1}_{\text{Net of taxes revenues made on the new service (Q1) and on the standard trucks (Q0)}} - \underbrace{I_1}_{\text{New service production costs}} - \underbrace{u(Q_0+Q_1)}_{\text{Pavement damages}}$$

- By a benevolent planner who **maximizes the social welfare** (collective optimum):

$$SW = \pi - \underbrace{Q_0CG_0 - Q_1CG_1}_{\text{Total generalized costs}} + \underbrace{\alpha FP}_{\text{Public funds}} - \underbrace{Q_0E_0 - Q_1E_1}_{\text{Environmental costs}}$$

Regulation schemes

We consider two types of public interventions:

- **Kilometric subsidy** aimed at maximizing the social welfare, given the pricing strategy of the HM : second-best collective optimum

- **Fixed subsidy / tax** aimed at cancelling losses of HM in the case the private optimum would not be profitable (without modifiying p1) : current model of concession contracts

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To summarize

Private optimum:

- HM is free to chose the price
- There may be a subsidy from the state for the service to be profitable

First-best collective optimum:

- The price is fixed by the state
- There may be a subsidy from the state for the service to be profitable

Second-best collective optimum:

- HM is free to chose the price
- The state provides a per vehicle-kilometer subsidy

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Impacts on service's users

Generalized cost functions (for a trip over AD, with segment BC on highway):

- If the freight operator <u>does not use</u> the new service (index 0)

$$CG_0 = \underbrace{c_d d_{AD}}_{\text{Money costs linked to vkm}} + \underbrace{p_0 d_{BC}}_{\text{Highway toll}} + \underbrace{(c_w + c_k + c_g)(t_{AD} + t_{break})}_{\text{Time costs linked to drivers, capital and goods}}$$

- If the freight operator <u>uses</u> the new service (index 1)

$$CG_1 = c_d(d_{AB} + d_{CD}) + \underbrace{p_1 d_{BC}}_{\text{Service price}} + (c_w + c_k + c_g)(t_{AB} + t_{CD}) + c_g(t_{BC} + \underbrace{2t_{load}}_{\text{Goods' immobilization}})$$

Demand function : $Q_1 = a - b(CG_1 - CG_0)$

Impacts on the service operator (HM)

Production costs (for the technology θ) :

Shuttles' costs — Platform costs

$$I_1^\theta = \left(c_k^\theta t_C^\theta + c_w(t_R + t_{BC}) + c_d^\theta d_{BC}\right)Q_1^\theta + K_P + \left(k_P\left(t_R + t_L^\theta\right) + k_L^\theta t_L^\theta\right)Q_1^\theta$$

Money and time costs linked to drivers and vehicles — Fixed cost — Parking costs — Charging station costs

The analytical model also concludes that:

- The fleet size and the number of charging stations are determined by the peaks' demand
- The parking capacity is determined by the off-peaks' demand

Private equilibrium price

- Maximizing the profit of HM, we find:

$$p_1^{\theta} = \frac{1}{2d_{BC}}\left(\frac{a}{b} + c_d d_{BC} + (c_k + c_w)(t_{BC} + t_{break}) + c_g(t_{break} - 2t_{load}) + \frac{p_0 d_{BC}(2-\tau_0-\tau_1)+\frac{\partial I_1^{\theta}}{\partial Q_1^{\theta}}}{1-\tau_1}\right)$$

- Importantly, fixed costs of the platform's and of the ERS' building are not considered within (delta I_1) / (delta Q_1) (wich includes vehicles, parking places and charging stations)
- For the empirical exercise, the price is « capped » so that the service demand cannot exceed 100% nor be negative

First-best equilibrium price

- Maximizing the social welfare, we find:

$$p_1^{\theta SW} = \frac{1}{2\, d_{BC}} \Big(\frac{a}{b} + \frac{1}{\alpha\tau_1} \Big(-\ (1 -\ \alpha\tau_1)[c_d d_{BC} +\ (c_k + c_w)(t_{BC} + t_{break}) + c_g(t_{break} -\ 2t_{load})] + p_0 d_{BC}\, \alpha\, (\tau_0 + \tau_1) + \frac{\partial I_1}{\partial Q_1} +\ (1 +\ \alpha)[k_0(t_{BC} + t_P) -\ k_1^{\theta}(t_{BC} + t_L + 2\, t_R +\ t_w) + d_{BC}(r_0 - r_1^{\theta})] -\ d_{BC}\, (x_0 - x_1^{\theta} + p_{tCO2}(\gamma_0 - \gamma_1^{\theta}))\Big)\Big)$$

- As compared to before, the price includes costs and revenues for public finance (k, r and Ʈ), moderated by the marginal opportunity cost of public funds, as well as CO2 and local pollution costs

Second best equilibrium-best

- Maximizing the social welfare, we find:

$$p_1^{\theta 2nd} = \frac{1}{2d_{BC}\alpha(2-\tau_1)}\left(\frac{\partial I_1{}^{\theta}}{\partial Q_1{}^{\theta}}\ (1+\alpha) - c_d\ d_{BC}\ (1-\alpha\ (3-2\ \tau_1)) + c_g\ (\left(3-2\ \tau_1\right)\alpha - 1)\ \left(t_{break} - 2\ t_{load}\right)\right.$$

$$+ (c_w + c_k)(\left(3-2\tau_1\right)\alpha - 1)\left(t_{BC} + t_{break}\right) + k_0\left(t_{BC} + t_{break}\right)(1+\alpha) - k_1\ t_C\ (1+\alpha) + (r_0 - r_1)\ d_{BC}\ (1+\alpha)$$

$$\left. + \left(x_1 - x_0\right) d_{BC} - p_{tCO2}\left(\gamma_0 - \gamma_1\right) d_{BC} + a\ \alpha\ \frac{3-2\ \tau_1}{b}\right) + p_0$$

- As compared to before, the price includes costs and revenues for public finance (k, r and Ʈ), moderated by the marginal opportunity cost of public funds, as well as CO2 and local pollution costs

Technologies under study

Euro 6 D-truck as benchmark vehicle

Shuttles will consume either **electricity**, or **LNG** or **hydrogen**

4 possible configurations for E-trucks:

- **Static charging** (for an autonomy of 400km)
  - **Fast** = 1h
  - **Slow** = 4h
- **Dynamic charging**, via **ERS** :
  - 70% of the corridor equipped + medium-sized batteries (200km autonomy)
  - 100% of the corridor equipped + small batteries (20km autonomy)

Option	**Diesel**	**BEV fast charge**	**BEV slow charge**	**LNG**	**Hydrogen**	**ERS70**	**ERS100**
Energy vector unit	*L*	*kWh*	*kWh*	*kg*	*kg*	*kWh*	*kWh*
Consumption [unit/km]	0,300	1,410	1,410	0,257	0,085	1,410	1,410
Energy price excl. tax [€/unit]	0,440	0,117	0,117	0,810	9,300	0,117	0,117
Energy tax [€/unit]	0,452	0,023	0,023	0,077	0,000	0,023	0,023
Energy price incl. tax [€/unit]	0,892	0,140	0,140	0,887	9,300	0,140	0,140
Vehicle purchase price [€]	**150k**	**375k**	**375k**	**190k**	**450k**	**203k**	**170k**
Vehicle purchase subsidy [€]	**0**	**50k**	**50k**	**0**	**50k**	**50k**	**50k**
Tax depreciation bonus	0%	40%	40%	40%	40%	40%	40%
Usage emissions [g/km]	**837**	**57**	**57**	**130**	**250**	**57**	**57**
Other emissions [g/km]	66	103	103	26	56	83	68
Charging time [h]	**0,17**	**0,80**	**3,20**	**0,17**	**0,17**	**0,30**	**0,08**
Charging station [€]	**-**	**500k**	**150k**	**1500k**	**2500k**	**500k**	**500k**
Station operating [€/station/y]	-	5000	1500	27080	25000	5000	5000
Other investments [€]	**-**	**2M**	**2M**	**1,5M**	**1,5M**	**450M**	**642M**

Other important information

Highway corridor of 320 km (+ 2 x 50 km upstr. & downstr.) with a flow of 350 veh/h

The service operates 230 days/year et 24h/day (vs. 10h/day for D-trucks)

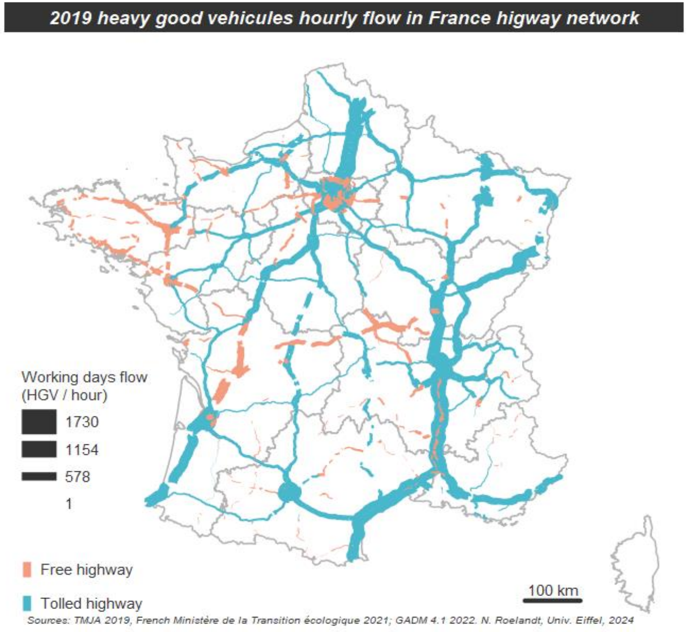
For the benchmark, break of 45 minutes per driving time of 4h30

Wages of shuttles' drivers = 20 eu/h (vs. 24 eu/h for the benchmark)

Standard highway toll = 0.11 eu/km

Loading / unloading time = 2 x 30 minutes

CO2 cost = 200 €/tonne



Carte réalisée par Nicolas Roelandt à partir de données du portail opendata du MTE

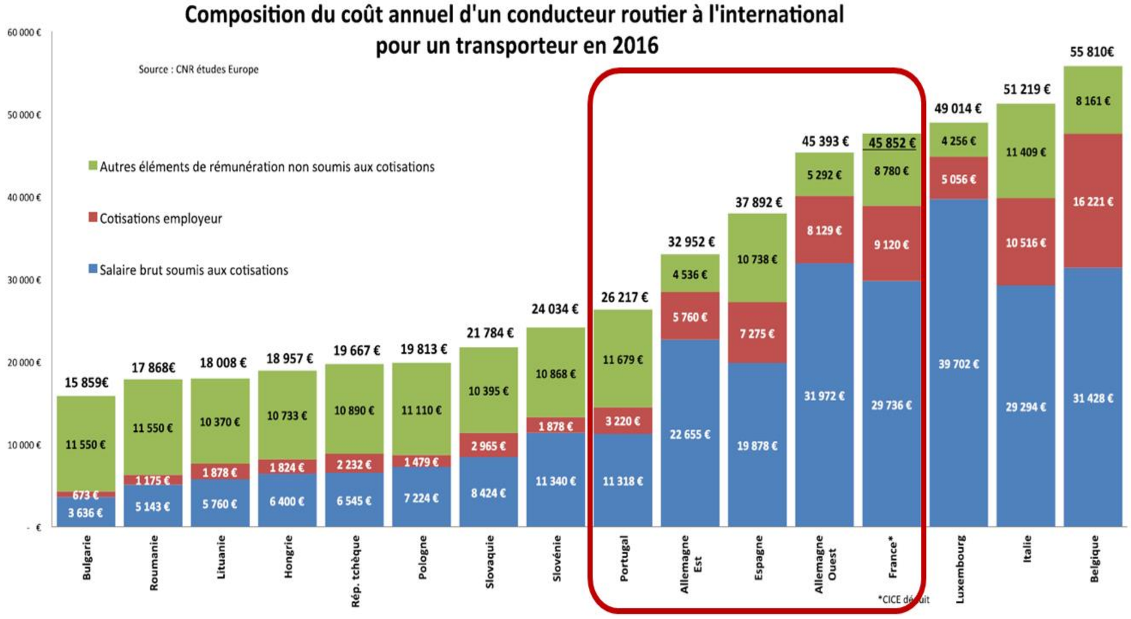
Demand function calibration (a = -130 ; b = 4,5)

$$Q_1 = a - b(CG_1 - CG_0)$$

We assume:

- 0% demand if the service costs as much as trucks with French drivers
- 100% demand if the service costs as much as trucks with Portugese drivers

We add a 30 euros penalty to the decarbonized solution



Comparatif des conditions d'emploi et de rémunération des conducteurs routiers internationaux en Europe, CNR (2016)

Results – Private optimum (1)

Option	Diesel	BEV fast charge	BEV slow charge	LNG	Hydrogen	ERS70	ERS100
Service price [€/km]	-	0,994	0,994	0,987	0,994	0,927	0,914
Market share	**-**	**0%**	**0,0%**	**2,9%**	**0,0%**	**27,2%**	**33,0%**
Fleet size [#]	-	0	0	76	0	722	838
Charging stations [#]	-	0	0	3	0	41	14
Joint profit [€/h]	7616	7616	7616	7628	7616	4083	3073
Δ joint profit	-	0,0%	0,0%	0,2%	0,0%	-42,4%	-59,6%
Δ social welfare	-	0,0%	0,0%	-0,3%	0,0%	-1,9%	-2,4%
ΔGHG emissions	**-**	**0,0%**	**0,0%**	**-1,8%**	**0,0%**	**-17,3%**	**-21,3%**
Abatement cost [€/tCO_2e]	-	-	-	-9,68	-	59,7	57,7
Subsidy ex-post [€/h]	**-**	**0**	**0**	**0**	**0**	**3235,9**	**4546,2**
Abatement bis [€/tCO2e]	-	-	-	**-9,68**	-	**87,6**	**89,8**

Results – Private optimum (2)

In the case the HM would fix the price in order to maximize his joint profit:

- **LNG** trucks would be the only viable option

  “Double dividend” with negative abatement costs

  BUT the market share is very limited (4%), as the CO2 savings

- **ERS** options could have a market (15-18%) and save some CO2 (10%)

  BUT ERS imply very large fixed costs (non-covered in a marginal price setting)

  Corresponding losses for the HM would require high subsidies (26M/y), which would increase the CO2 abatement costs (> the CO2 value of 150eu/t)

Results – First-best optimum (1)

Option	Diesel	BEV fast charge	BEV slow charge	LNG	Hydrogen	ERS70	ERS100
Service price [€/km]	-	0,751	0,994	0,751	0,994	0,751	0,751
Market share	-	**100,0%**	**0,0%**	**100,0%**	**0,0%**	**100,0%**	**100,0%**
Fleet size [#]	-	2900	0	2584	0	2650	2542
Charging stations [#]	-	400	0	84	0	150	42
Joint profit [€/h]	7616	-20815	7616	-17266	7616	-9596	-8794
Δ joint profit	-	-373,3%	0,0%	-326,7%	0,0%	-226,0%	-215,4%
GHG emissions [tCO_2e/h]	133	50	133	49	133	48	46
ΔGHG emissions [tCO_2e/h]	-	**-62,7%**	**0,0%**	**-63,0%**	**0,0%**	**-64,1%**	**-65,3%**
Abatement cost [€/tCO_2e]	**-**	**54,4**	**-**	**-12,5**	**-**	**-102,5**	**-115,4**
Subsidy ex-post [€/h]		28430,7	-	24882,3	-	17208,9	16410,1
Abatement BIS [€/tCO2e]		**122,8**	-	**47,0**	-	**-62,1**	**-77,6**

Results - First-best optimum (2)

In the case the State would set the price to maximize the social welfare:

All options, but **E-trucks with slow (static) charging** and **hydrogen** (not viable), would catch 100% of the demand

Social welfare gains of 10%, CO_2 savings of 65%

BUT huge losses for the HM that require **huge subsidies**

Once losses compensated, lowest abatement costs for **ERS** and **E-trucks with fast (static) charging**

Results – Second-best optimum (1)

Option	Diesel	BEV fast charge	BEV slow charge	LNG	Hydrogen	ERS70	ERS100
Optimal subsidy [€/km]	**-**	**0,279**	**-0,016**	**0,388**	**-1,184**	**0,620**	**0,691**
Service price with subsidy [€/km]	-	0,859	0,994	0,787	0,994	0,751	0,751
Market share	**-**	**55,4%**	**0,0%**	**85,2%**	**0,0%**	**100,0%**	**100,0%**
Fleet size [#]	-	1608	0	2200	0	2650	2542
Charging stations [#]	-	222	0	71	0	150	42
Joint profit [€/h]	7616	15715	7616	26755	7616	59869	68563
Δ social welfare	-	1,9%	0,0%	4,5%	0,0%	6,9%	6,9%
GHG emissions [tCO_2e/h]	**133**	**87**	**133**	**61**	**133**	**48**	**46**
Abatement cost [€/tCO_2e]	-	128,9	-	91,0	-	60,6	63,0

Results – Second-best optimum (2)

Considering a kilometric optimal subsidy:

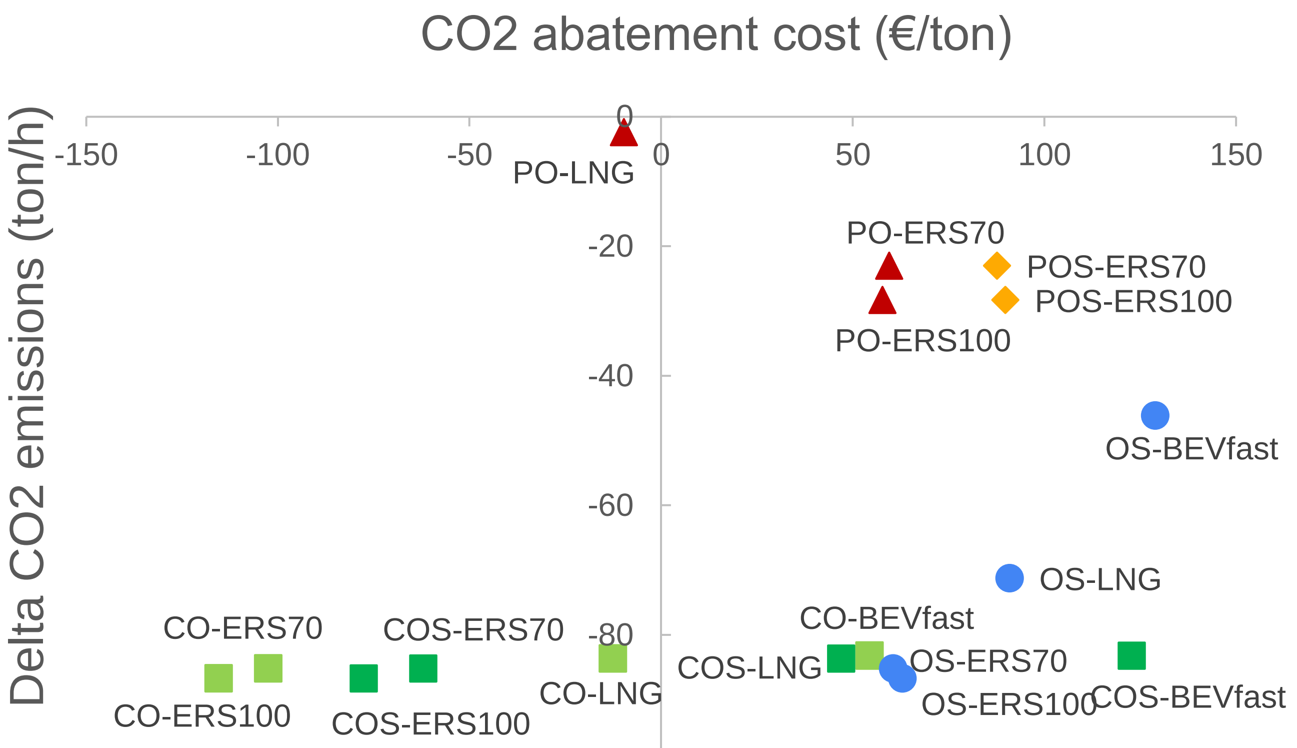
- **ERS options** could catch 100% of the market

  BUT the required subsidy is large (> 0.4 eu/km) and would necessitate an important tax to make this option politically feasible (?)

- **E-trucks with fast (static) charging** could catch 40% of the demand with a lowest subsidy (0.3 eu/km)

According to the abatement cost criterion and the CO2 savings criteria : **ERS100** is the best option

To summarize (1)



PO : Private optimum
POS : Private optimum with ex-post subsidy
CO : 1st best optimum
COS : 1st best optimum with ex-post subsidy
OS : 2nd best optimum subsidy

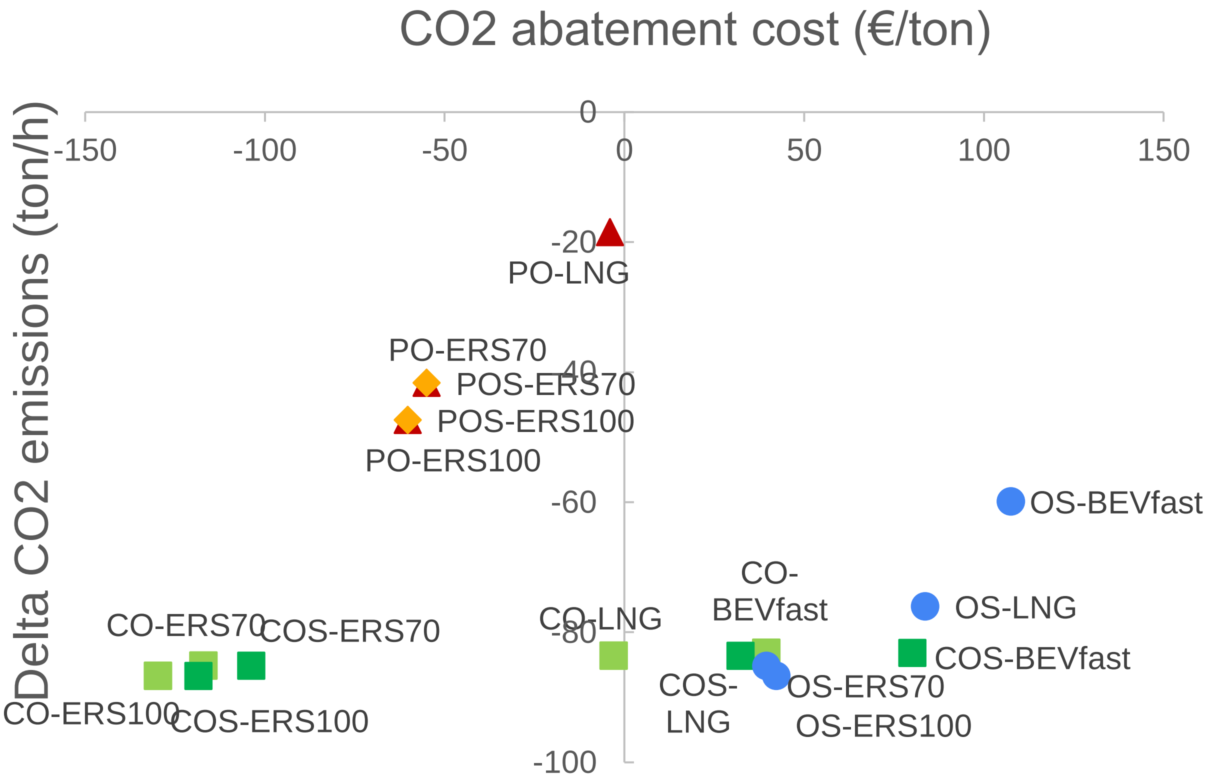
To summarize (2)

- Hydrogen is NEVER a good option for the shuttles
- Without any public intervention, LNG trucks is the only attractive option for the HM but collective benefits are very limited
- With public intervention but without ERS investment, LNG trucks

- Two public policies could have similar results:
  - Concession contract where the State caps the price and subsidies ex post the HM
  - Proposing a direct subsidy
- Which policy would be the most credible / easy to implement?
- Three technologies dominate : E-fast, ERS100 et ERS70

⇒ Cost vs. volume of CO_2 saved?

Sensitivity test on energy prices



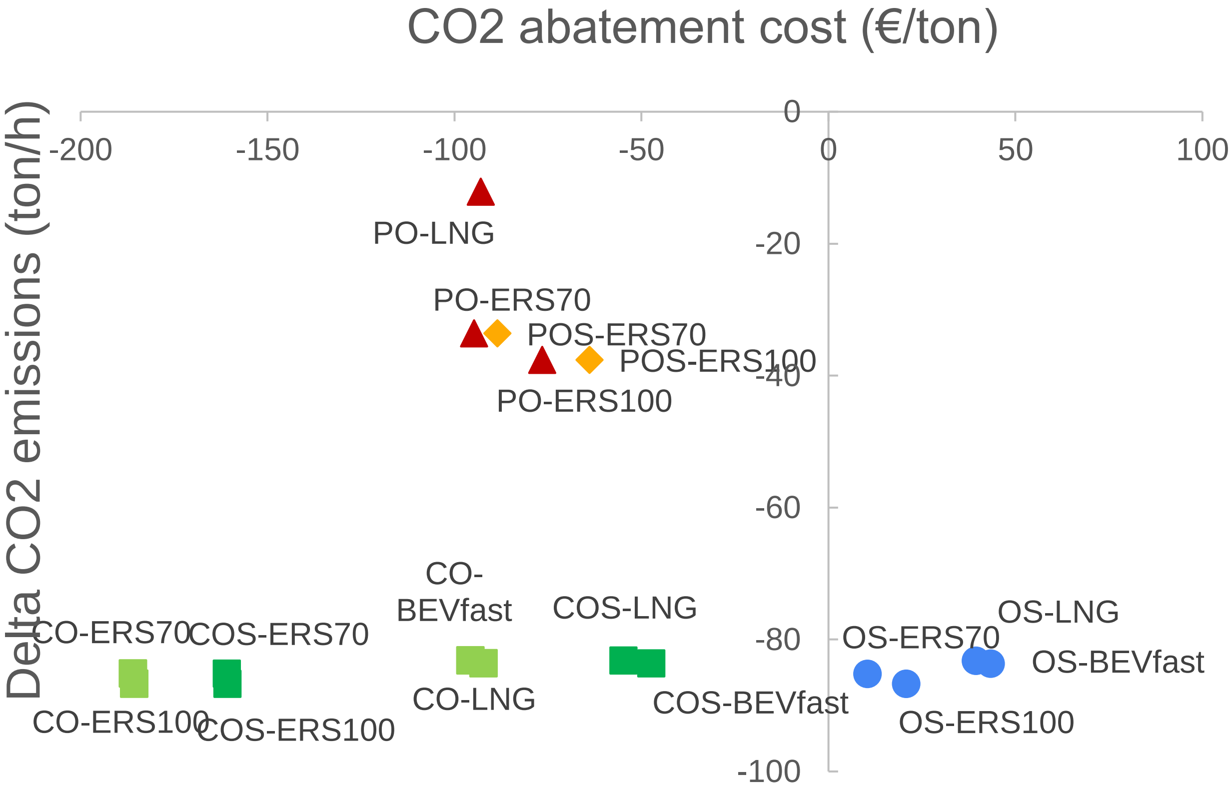
Assumption:

- diesel price will increase by 70%, other energies by 40%

Consequences:

- BEV slow charge and hydrogen remain irrelevant
- Decarbonation becomes financially viable without support
- ERS is still the most efficient corridor option

Sensitivity test on vehicle prices



Assumption:

- diesel trucks price will increase by 10%, other trucks will be less expensive by 30%

Consequences:

- BEV slow charge and hydrogen remain irrelevant
- Financial viability of decarbonated alternatives is improved
- ERS is still the most efficient corridor option

Further research

What could additionnally be done:

- Consider, for the 2040 horizon, E-trucks as benchmark
- Endogenize waiting time (« Mohring effect »)
- Make vary the price of electricity (for ERS vs static charging)
- Consider the fleet management strategy of freight operators for upstream and downstream trips
- Move from a corridor- to a network-based analysis

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- http://afet-asso.fr/manifestations/conferences-de-lafet/seconde-conference-de-lafet-novembre-2024

Inscriptions ouvertes jusqu'au 8 novembre

Thanks in advance for your comments!

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