Micro-economic analysis of the Electric Road System for road freight decarbonation
Preliminary results

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Context

- Road freight decarbonation is necessary, but remains difficult
- The main direction for road freight decarbonation is battery electric vehicles, but it is expensive (orders of magnitude: 800kWh of capacity > 3 tons; more than ~100k€, charging power ~1MW)
- The Electric Road System (ERS) concept consists in implementing the road infrastructure with a dynamic charging system, reducing drastically the autonomy requirements on trucks

The Electric Road System

Overhead catenary lines

Conductive rail

Contact-less induction charging

The Electric Road System

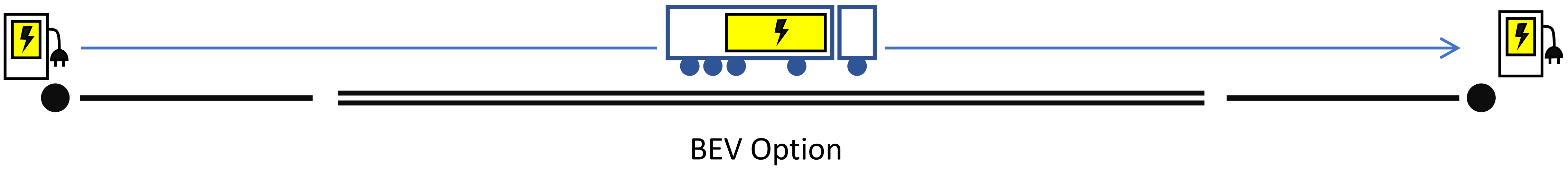
Overhead catenary lines

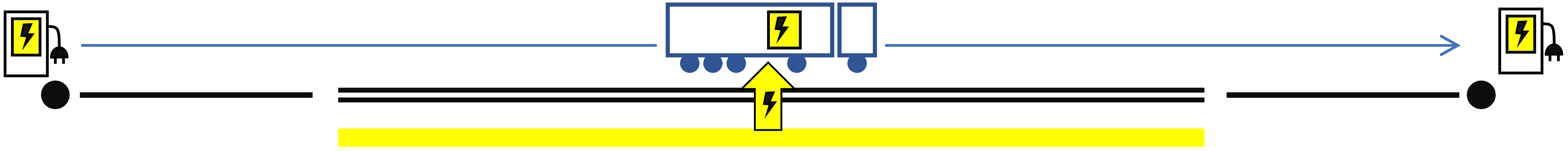
PROJET PIA 4 CHARGE AS YOU DRIVE

Conductive rail

Contact-less induction charging

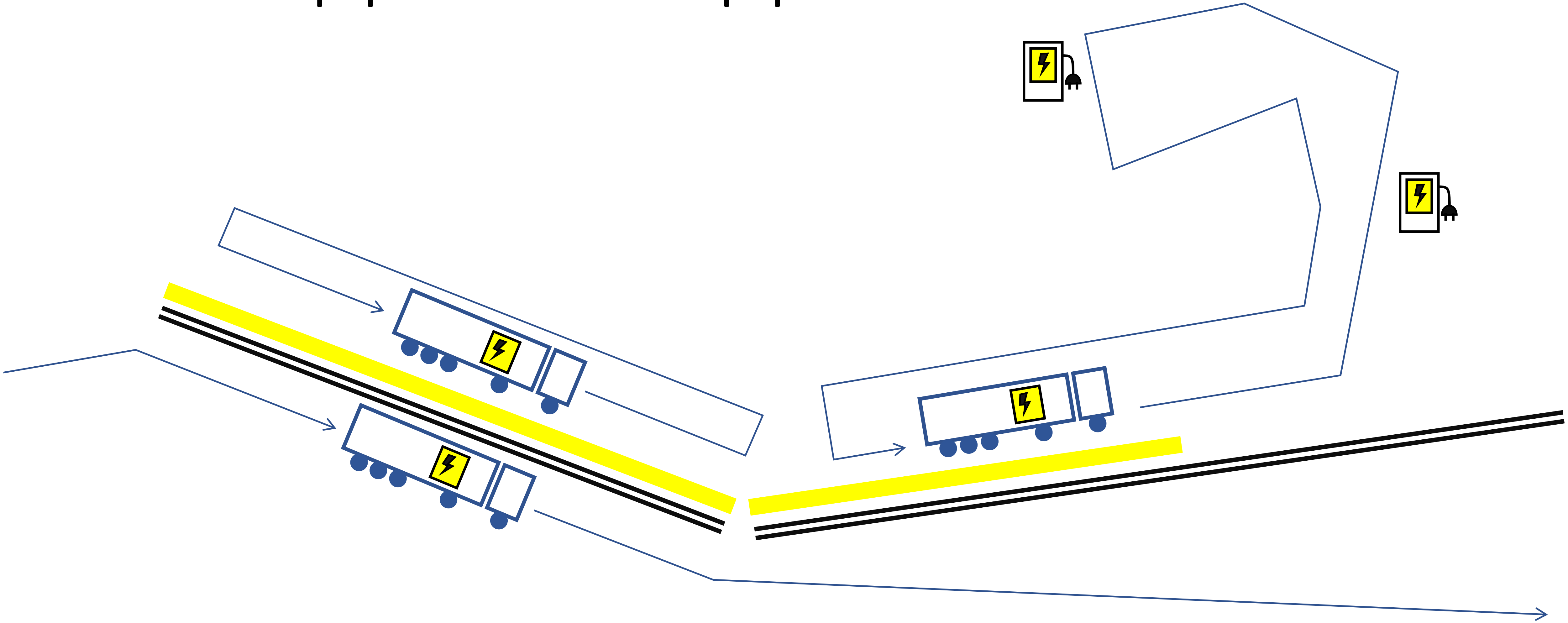
The Electric Road System





- Main gain: reduced battery requirements (and reduced requirements on the charging network)
- Main cost: fixed implementation cost

Vehicle equipment *vs* infra equipment



Research questions

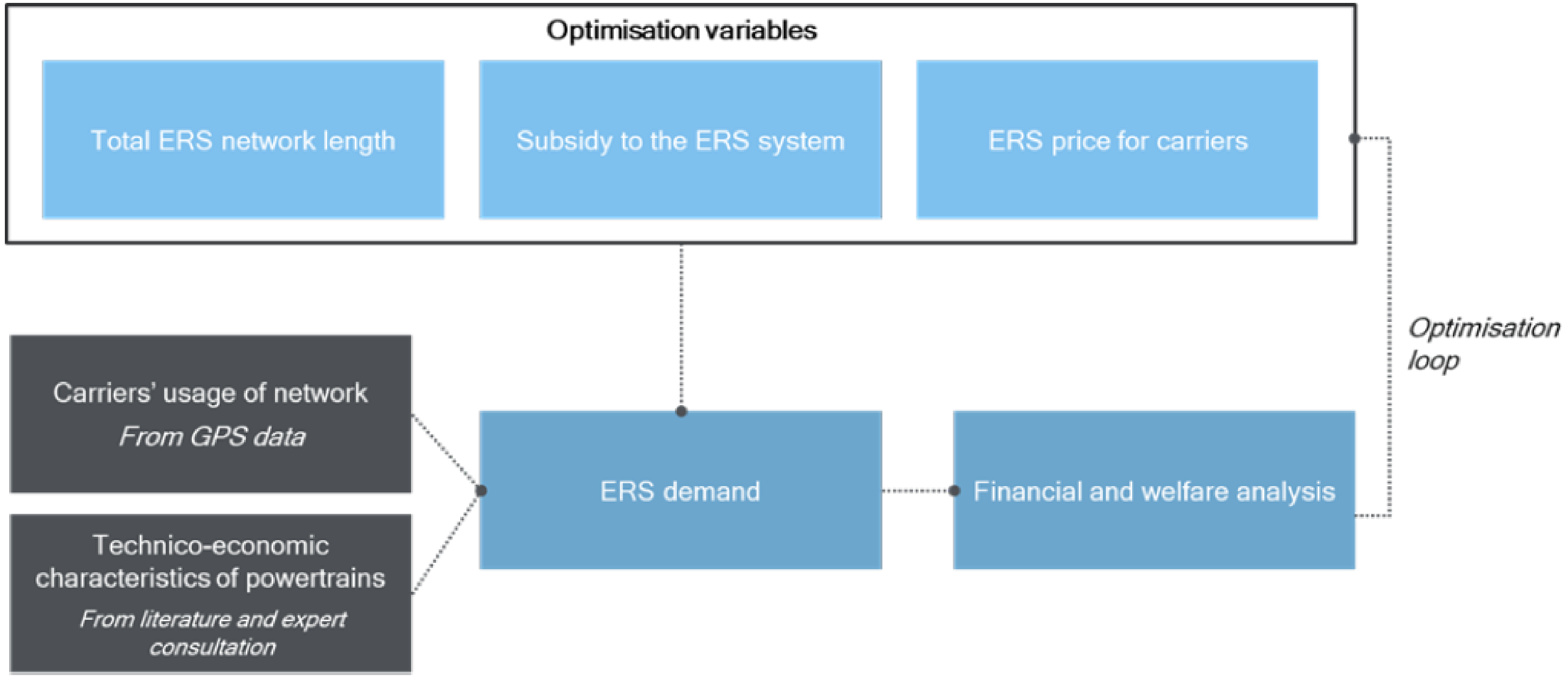
- Identify the economic and environmental relevance of the ERS solution in a market with ICE and BEV options
- Identify the optimal ERS network length and the optimal subsidy level

Current literature gaps

- ICE/BEV/ERS vehicle type choice based on vehicle operation patterns
- Endogenous relationship between ERS network length and market uptake
- Relationship between tax policy, subsidy, ERS pricing and ERS market uptake

Approach

- The vehicle type choice is based on a modified TCO approach
- The relationship between the TCO of an ERS truck and the ERS equipped network is calibrated with long term GPS truck data
- The overall architecture is classically built to find market equilibria and social welfare optima under a variety of policy and economic sets of assumptions



Vehicle type choice

- Each truck is characterised by:
  - D : the distance traveled yearly
  - ρ : the part of that distance on the ERS equipped highway network

- The TCO of the three options are:
  - $G_{ICE} = k_{ICE} + c_{ICE} D$
  - $G_{FBEV} = k_{FBEV} + c_{FBEV} D$
  - $G_{ERS} = k_{ERS} + \rho D c_{ERS} + \widetilde{D} \tilde{c}_{ERS}$

with $\widetilde{D} = \max\{0, D(1 - \rho\delta)\}$

and $\tilde{c}_{ERS} = c_{FBEV} + \frac{\alpha}{R_{FBEV}} \left(\frac{R_{FBEV}}{R_{ERS}} - 1 \right)$

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Corrected distance: accounts for the possibility to recharge on the ERS network

with $\widetilde{D} = \max\{0, D(1 - \rho\delta)\}$

and $\tilde{c}_{ERS} = c_{FBEV} + \frac{\alpha}{R_{FBEV}}\left(\frac{R_{FBEV}}{R_{ERS}} - 1\right)$

Variable cost on the ERS network

Variable cost off the ERS network

Unit variable cost off the ERS network: FBEV + detours and time loss

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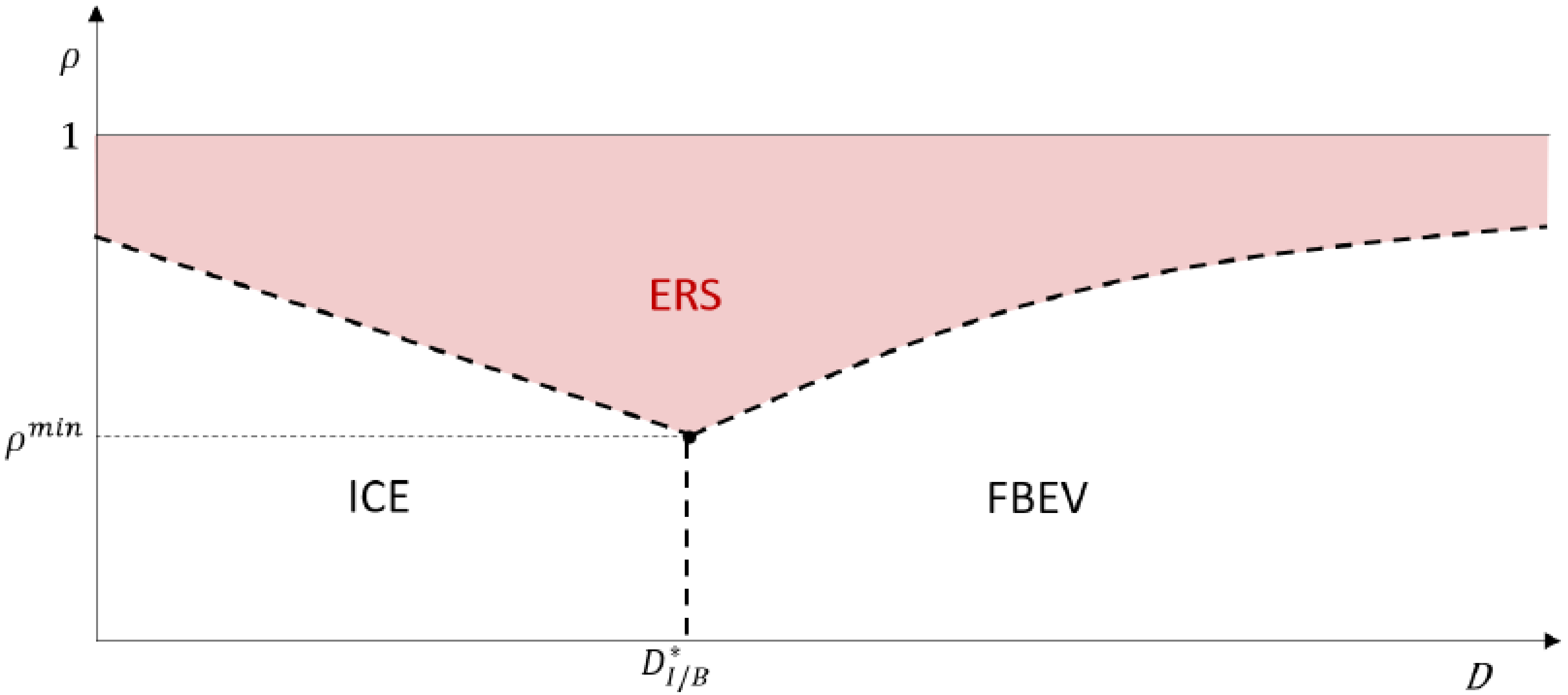
and $\tilde{c}_{ERS} = c_{FBEV} + \frac{\alpha}{R_{FBEV}}\left(\frac{R_{FBEV}}{R_{ERS}} - 1\right)$

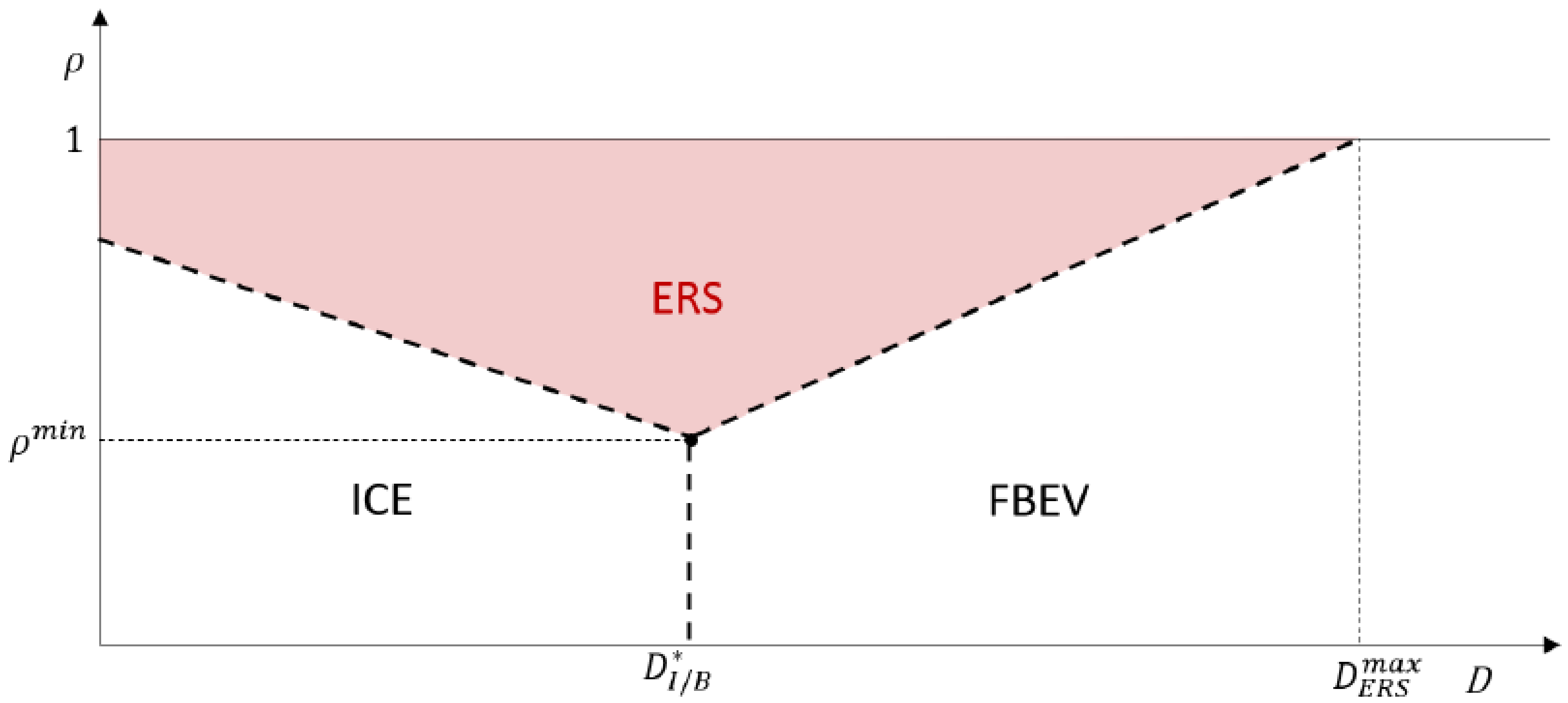
The demand is entirely described by the $(\boldsymbol{D}, \boldsymbol{\rho})$ distribution

Domains of relevance of the three options



Indicative shape of the relevance domains of ICE, FBEV and ERS when $c_{ERS} < c_{FBEV}$

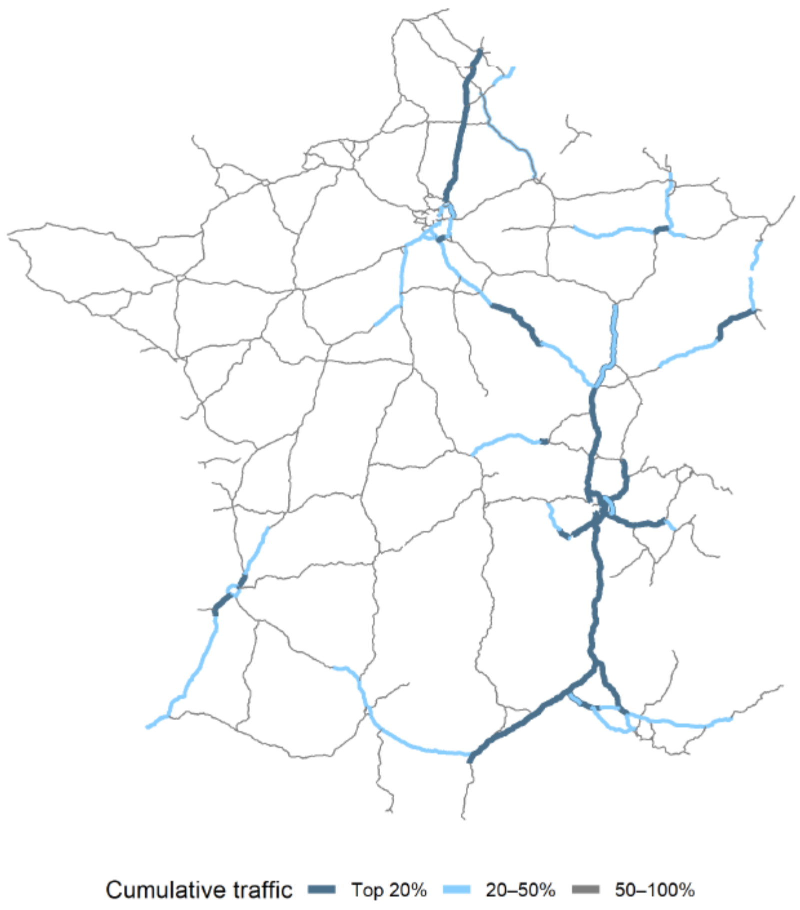
Domains of relevance of the three options



Indicative shape of the relevance domains of ICE, FBEV and ERS when $c_{ERS} > c_{FBEV}$

Dataset

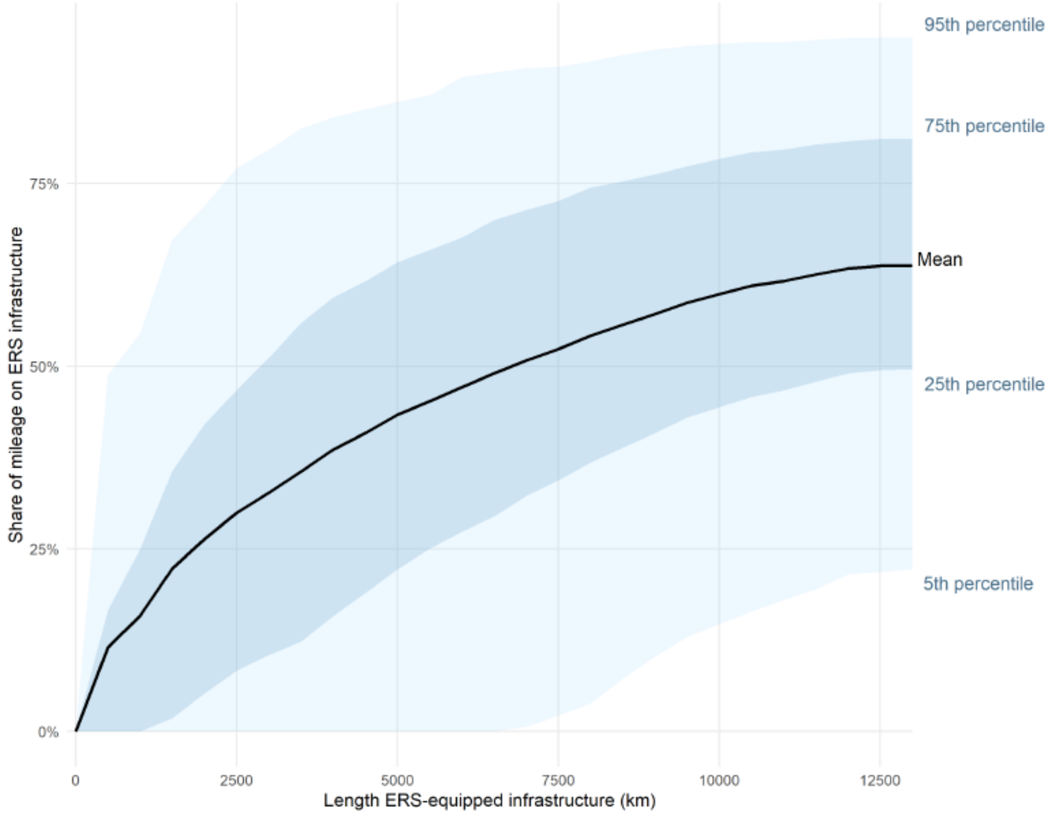
- We estimate the (D, ρ) joint distribution from two datasets:
  - A standard yearly distance distribution from French national statistics
  - A set of 80000 time stamped GPS traces of HDV collected during October 2024, with identifier continuity
- The GPS traces are pre-processed by matching them with the main road network in France, which was divided into 120 segments
- The distribution $\rho|D$ is assumed to be Beta shaped and calibrated so as to fit the GPS dataset for each value of D



HDV traffic distribution from the GPS dataset

ERS equipped network length and demand characteristics

- The (D, ρ) distribution depends on the ERS network length and position
- In this paper we opt for a greedy algorithm: the first equipped road is that one with the most HDV traffic, etc.
- The ρ distribution shifts upwards when the ERS network increases, but with diminishing returns
- Even with 100% of the highway network equipped, half of the trucks travel less than 60% of their distance on the ERS network



Distribution of ρ as a function of the equipped ERS network length

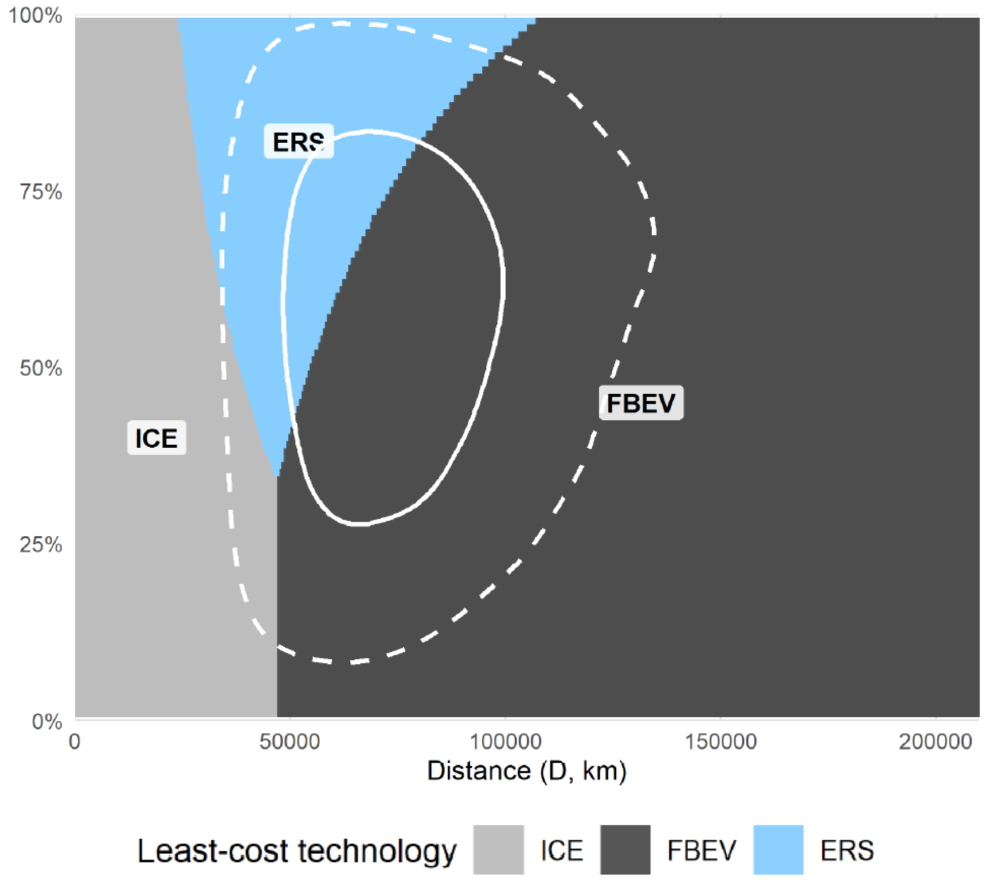
Market shares: mapping the demand distribution on the relevance domains of the alternatives

- For a given ERS equipped network length L_{tot} and price c_{ERS}, compute the (D, ρ) distribution
  - Example on the right graph: the plain (resp. dotted) line represents where 50% (resp. 90%) of the distribution's mass is located
- Draw the domains of relevance of each alternative
- The market share of the ERS is:

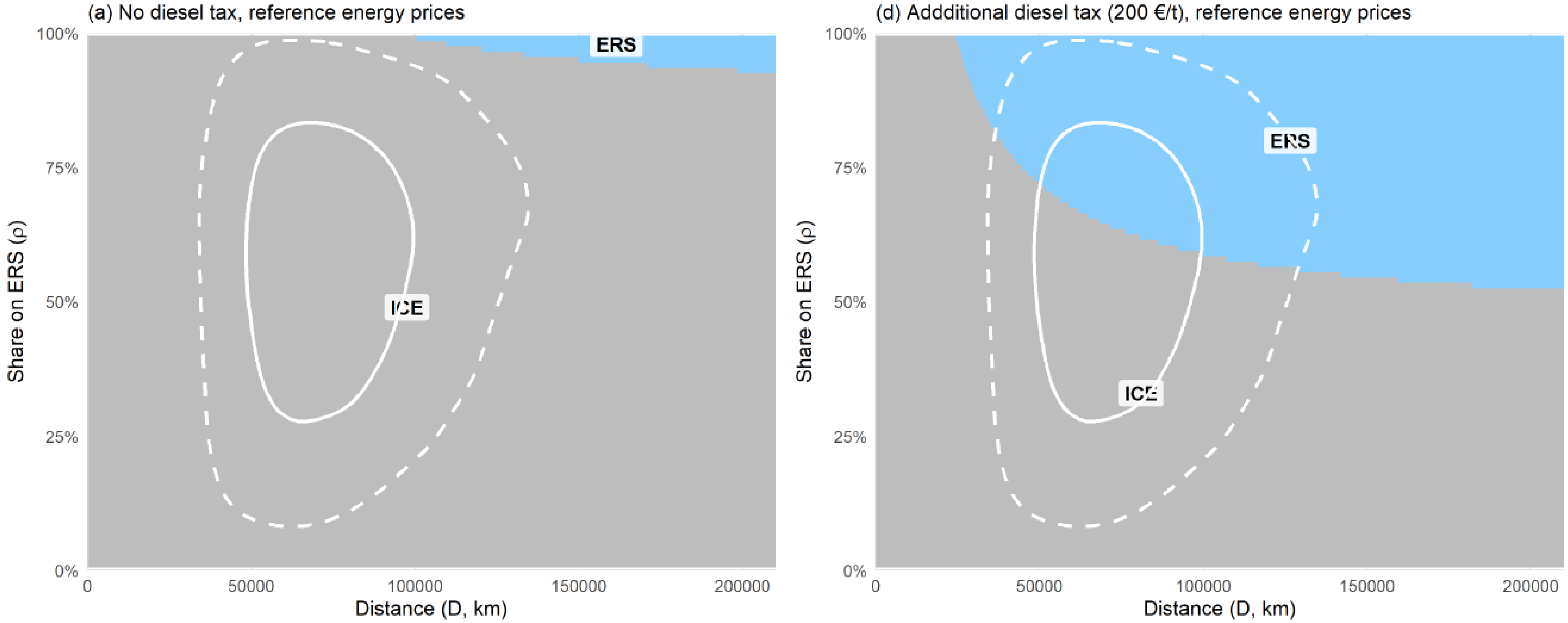
$$\pi_{\text{ERS}} = \iint_{\{(D,\rho):\, G_{\text{ERS}} \leq \min(G_{\text{ICE}}, G_{\text{FBEV}})\}} \phi_{D,\rho}$$

- The ERS travelled distance is:

$$Q_{\text{ERS}} = \iint_{\{(D,\rho):\, G_{\text{ERS}} \leq \min(G_{\text{ICE}}, G_{\text{FBEV}})\}} D\rho\phi_{D,\rho}$$

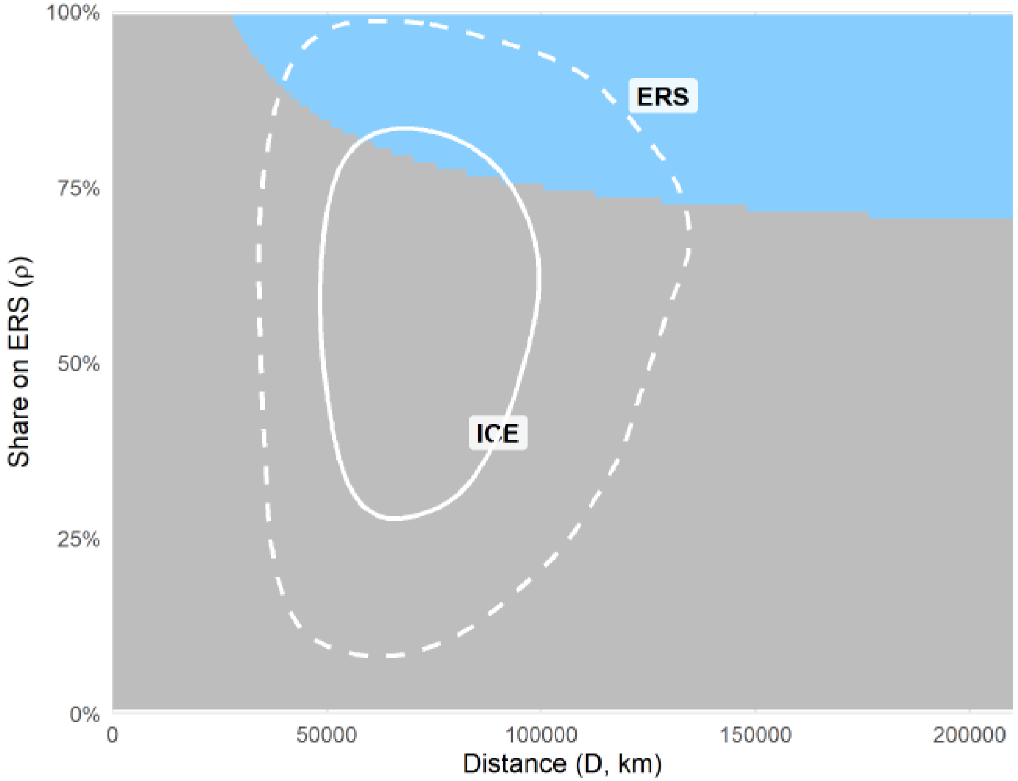


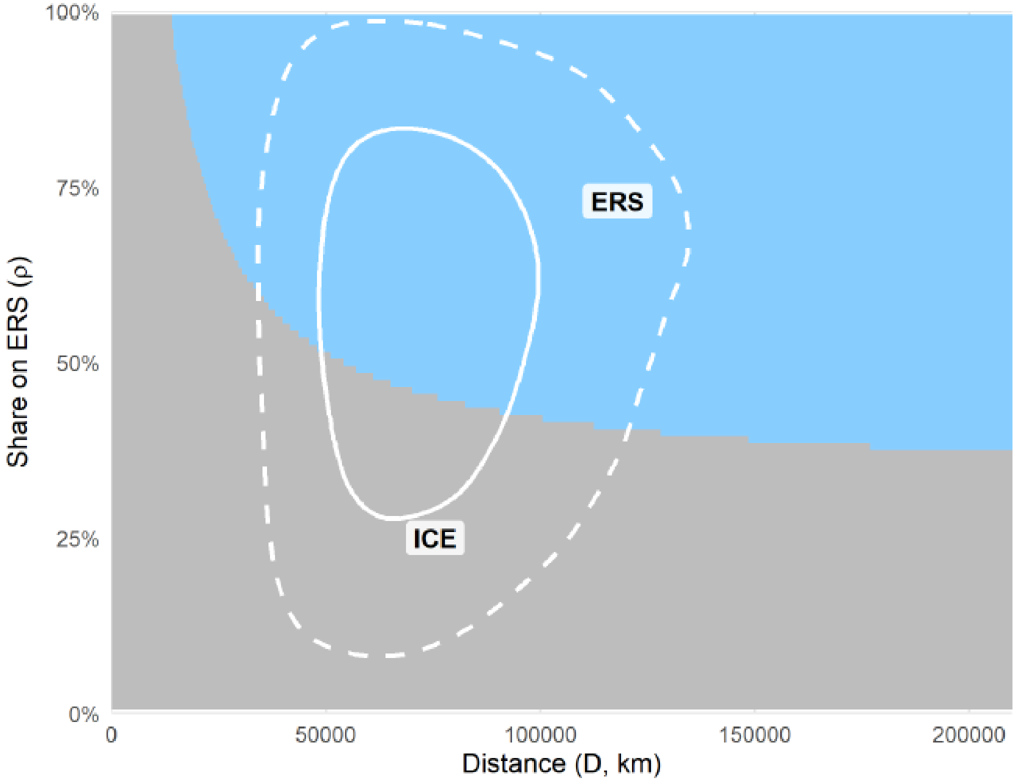
Market shares (L_{tot} = 8000km)



Base case: FBEV are out of the market, ERS is almost not competitive
With additional diesel tax: ERS covers half the market

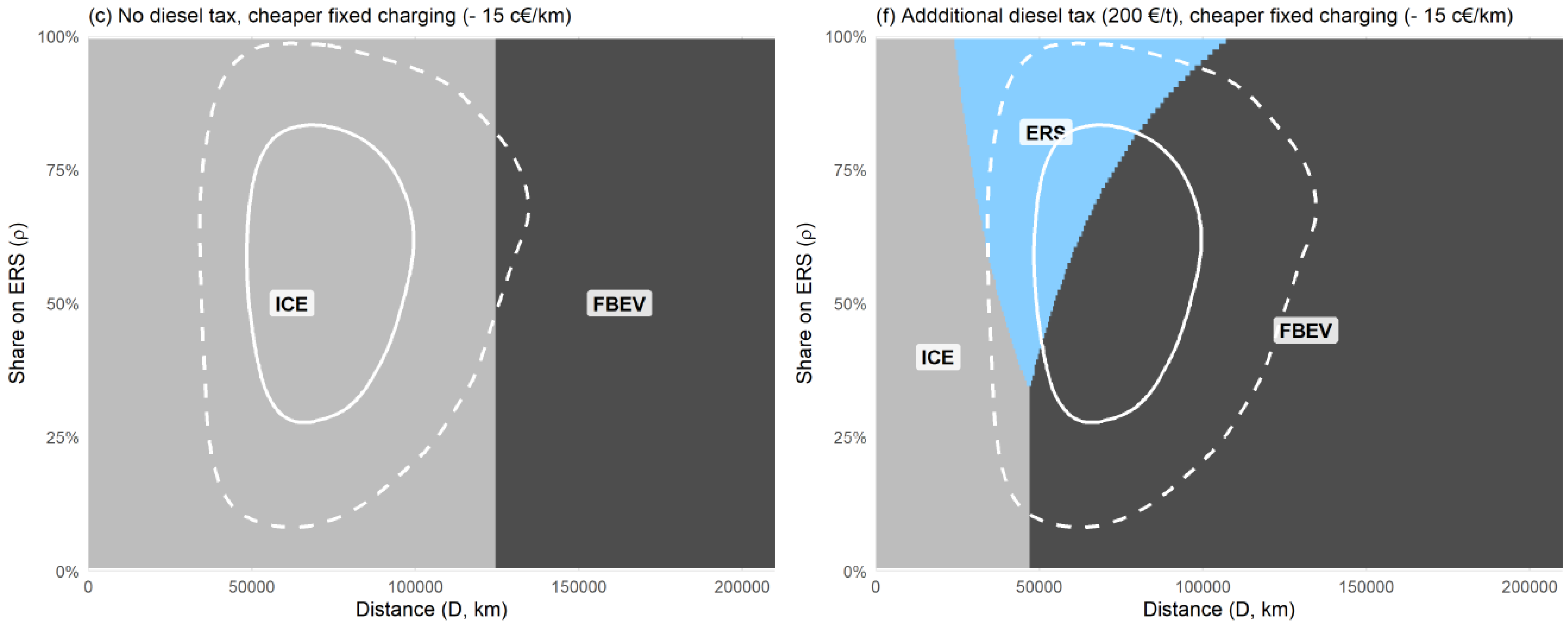
Market shares (L_{tot} = 8000km), cheaper ERS





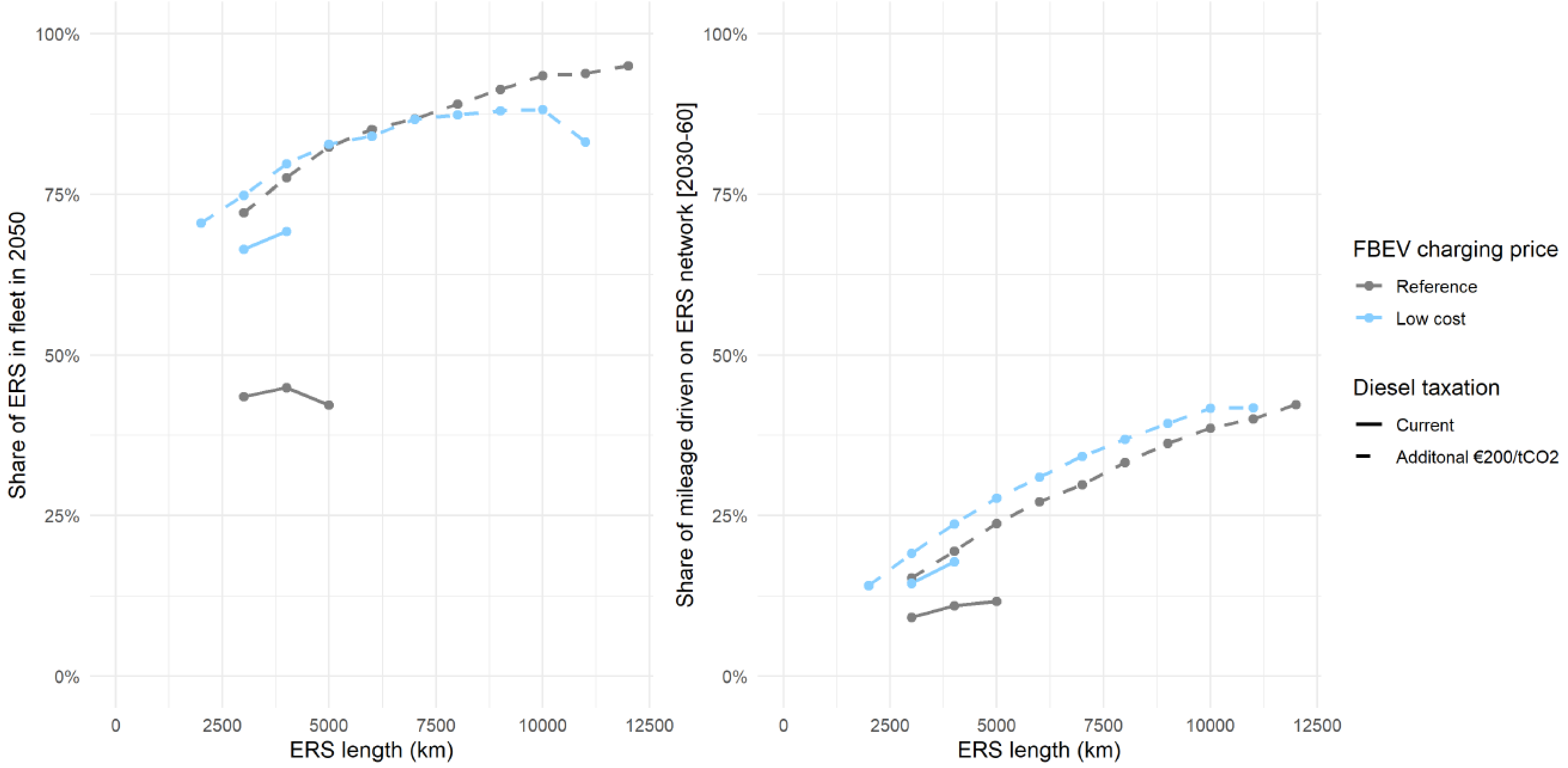
The ERS market share is improved and becomes significant, even at current prices and taxes

Market shares (L_{tot} = 8000km), cheaper FBEV



The ERS market share shifts partially to the FBEV

Network length, ERS vehicle market share, mileage on the ERS network



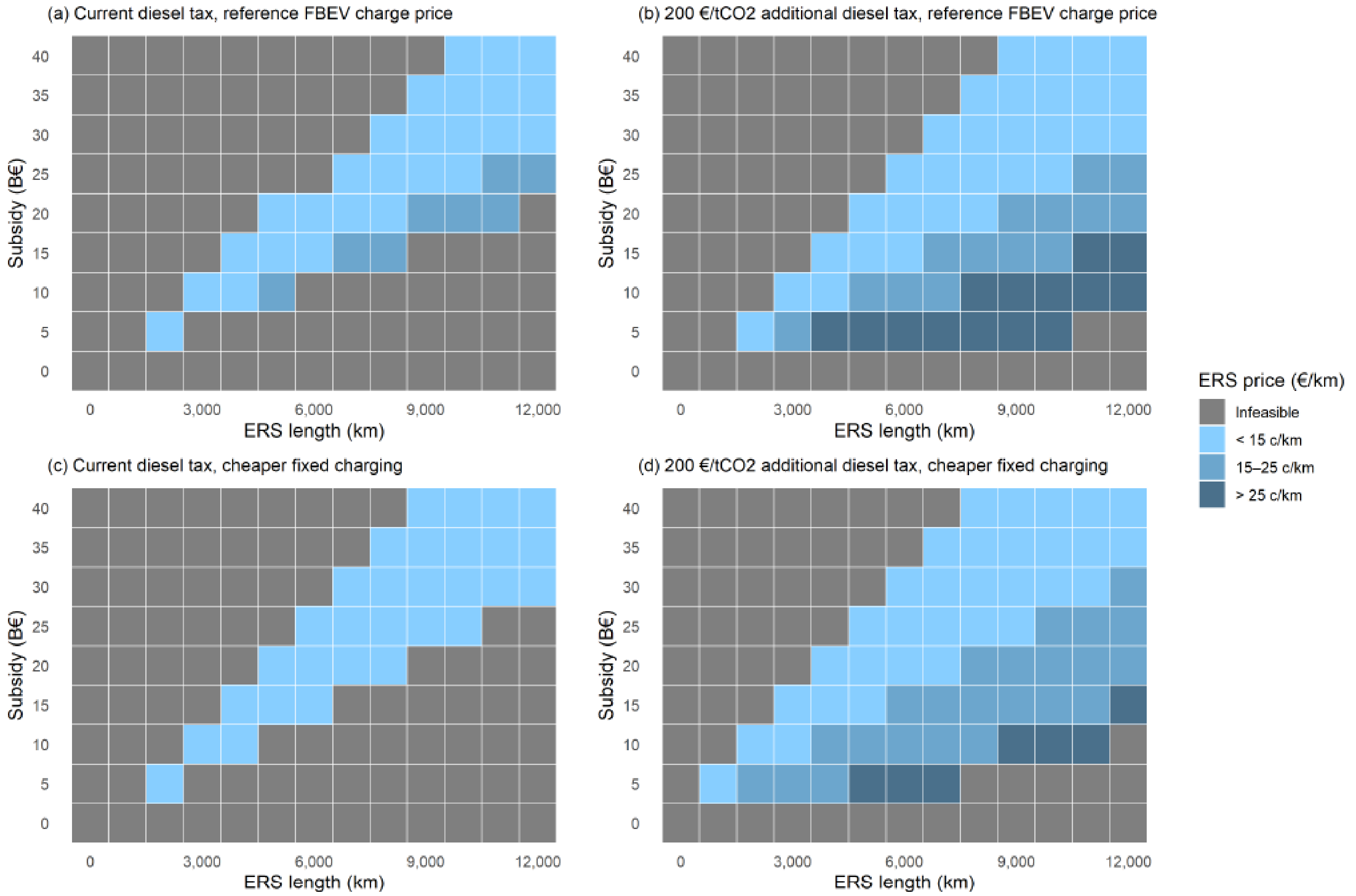
Assessment process

- For each scenario, we optimize simultaneously
  - The **total ERS network length** L_{tot}
  - The **upfront investment subsidy** S to the ERS operator's capital
  - The **ERS usage price** c_{ERS}
- The objective function is the social welfare. It consists of:
  - The carriers costs
  - The ERS operator's profit
  - The balance of state finances, with the opportunity cost of public funds
  - Externalities : GHG emissions, local pollutants emissions, including vehicle manufacturing and infrastructure construction (exact application depends on ETS2 assumptions)
- The ERS operator is assumed to be regulated so as to operate at zero profit
- Scenarios combine assumptions on: ERS costs, FBEV costs, tax policy, ETS2 implementation, etc.

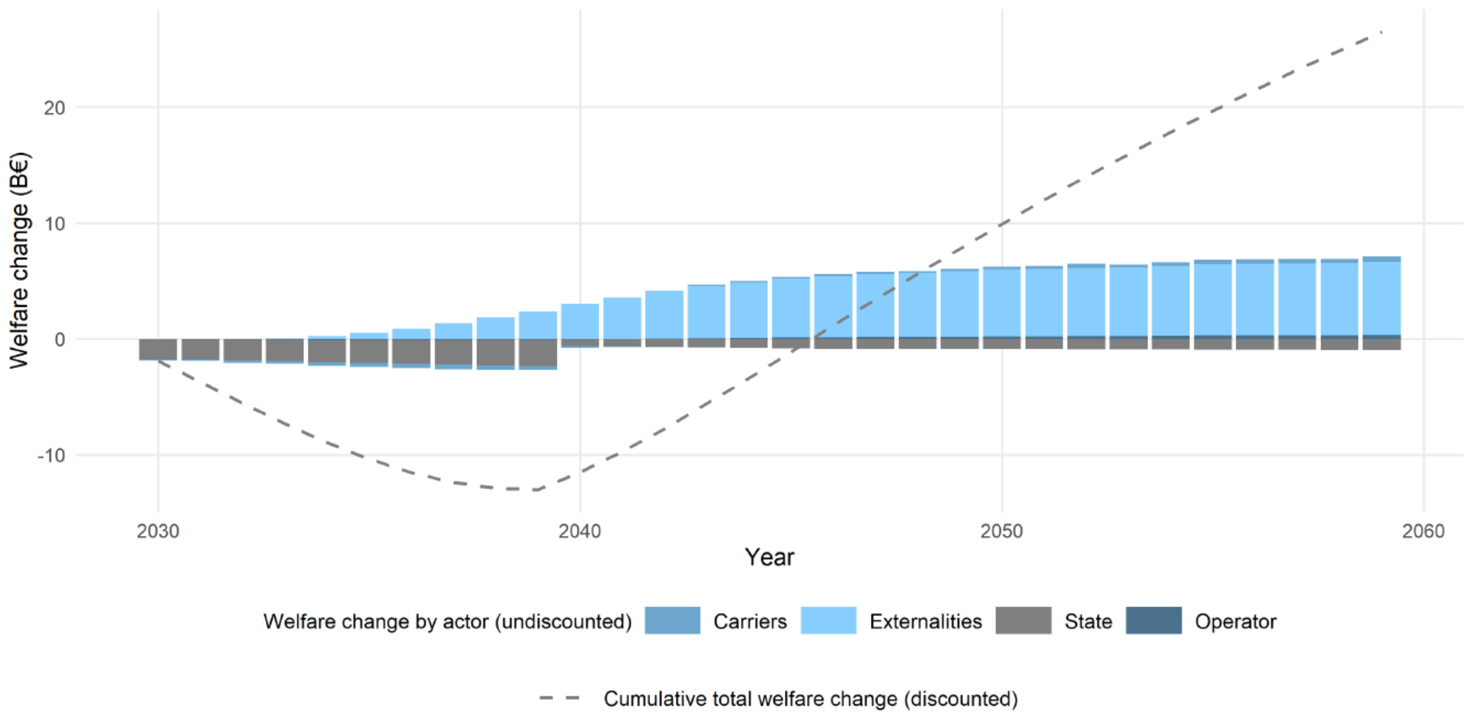
ERS pricing

The ERS operator is assumed to be regulated so as to operate at zero profit

Subsidies are only allowed to cover capital costs



Dynamics of the social welfare cost components (without ETS2)



- Assumptions
  - Infrastructure investments are spread on several years
  - Fleet renewal is not instant
  - ERS operator, truck buyers and social welfare are each computed with their own discount rates

Social welfare optima

Scenario	S (B€)	L_{tot} (km)	π_{ERS} (%)	π_{FBEV} (%)	c_{ERS} (c€/km)	ΔW (M€)	ΔCO_2 (Mt)
S_0	0	– No solution –					
	5	– No solution –					
	10	5,000	44	0	22	16,936	−145
	15	7,500	58	0	24	26,707	−198
	20	10,000	72	0	21	36,952	−247
S_{ETS}	0	10,000	92	8	41	25,605	−110
	5	10,000	96	4	34	27,887	−128
	10	12,000	98	2	32	28,323	−137
	15	12,000	99	1	27	28,431	−143
	20	11,500	99	1	22	27,942	−146
S_{FBEV}	– No solution for any subsidy level –						
$S_{FBEV+ETS}$	0	– No solution –					
	5	6,000	76	24	28	13,042	−12
	10	9,500	88	12	27	16,166	−13
	15	9,500	93	7	22	16,681	−14
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In the base scenario, a wide ERS network is welfare improving, but at a huge cost for public funds

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With ETS2, the ERS network is financially viable without public funds

Social welfare optima

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In that scenario, the optimal subsidy is lower, at 15G€

Social welfare optima

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With cheaper FBEV, the ERS option loses its financial viability even with very high subsidies (we only allow CAPEX subsidies)

Social welfare optima

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With cheaper FBEV and ETS2, ERS can be welfare improving but not as much as in the first ETS scenario

Conclusions

- The model shows the interdependency between
  - Vehicle operation patterns and the competitiveness of ICE, FBEV and ERS options
  - The equipped network geometry and the ERS pricing and market share
- The paper concludes (to date) that the ERS technology can be welfare improving, but will not appear spontaneously without strong and coherent public policies (subsidy and tax policy)
- It also concludes that the results are sensitive to price assumptions (in particular FBEV prices)

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