

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

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*Séminaire SPLOTT 15/12/25*

# 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

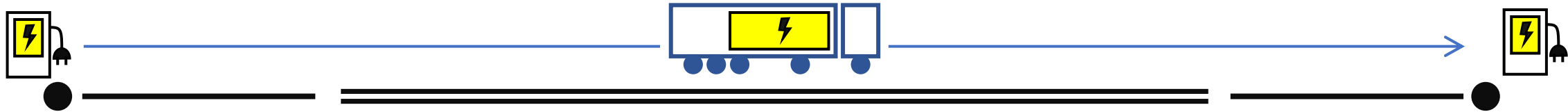
## PROJET PIA 4 CHARGE AS YOU DRIVE

Conductive  
rail

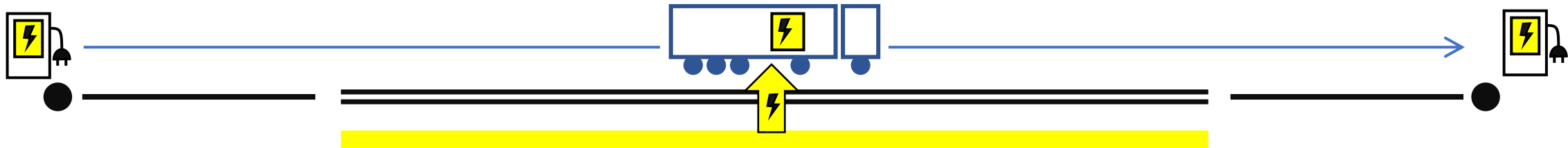


Contact-less  
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# The Electric Road System

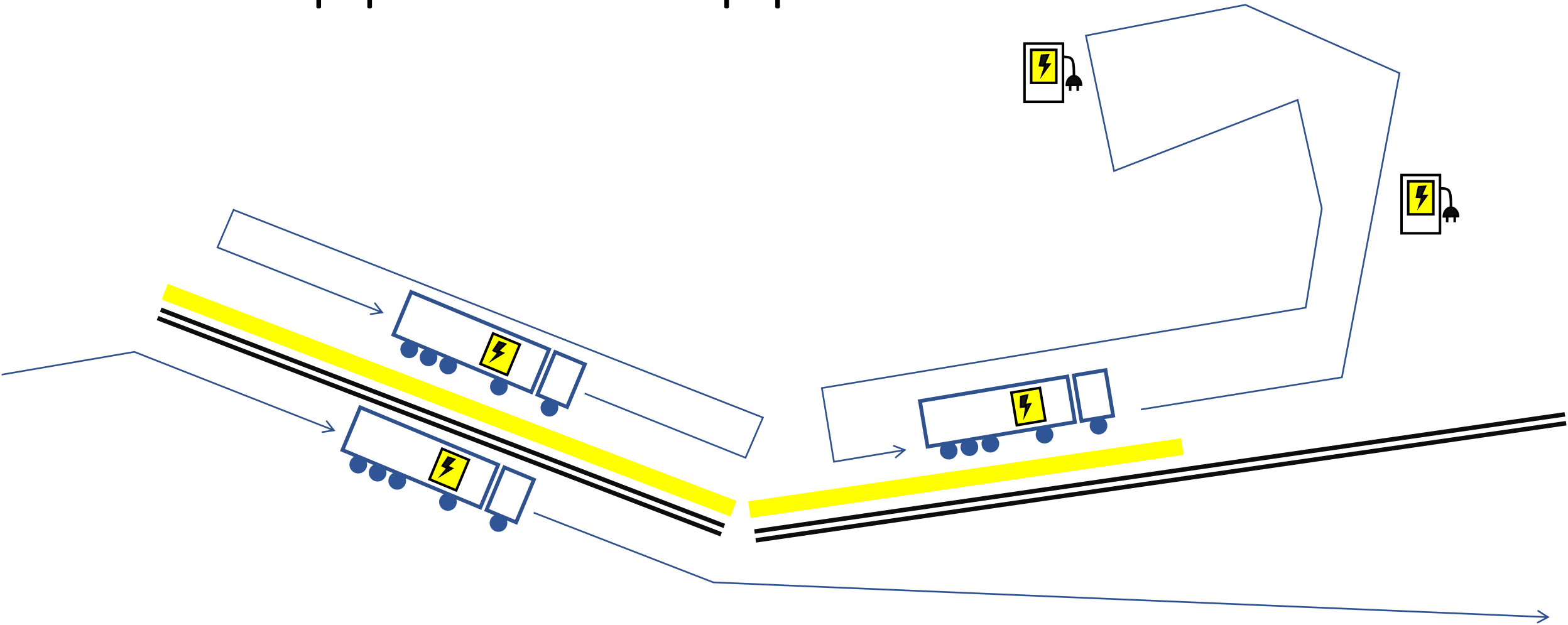


BEV Option



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

# Vehicle equipment vs infra equipment



## Research questions

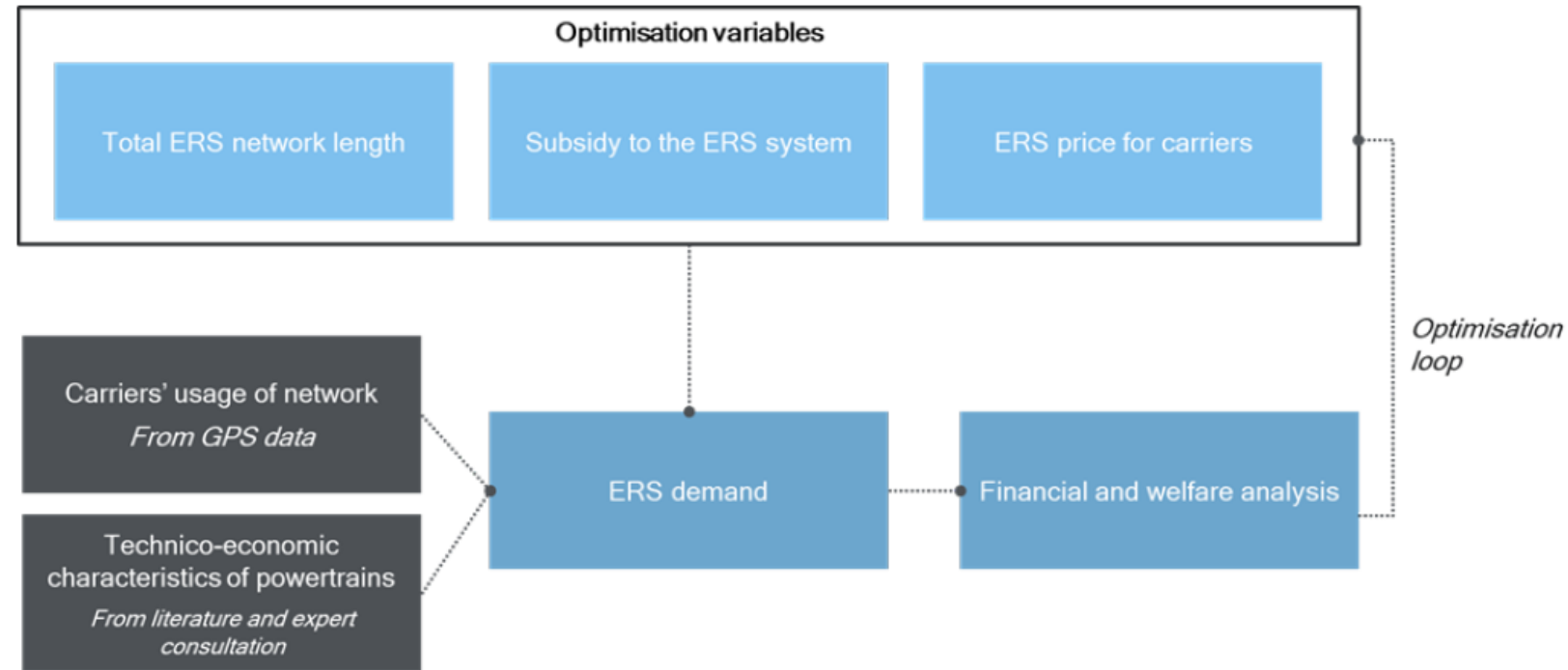
- Identify the economic and environmental relevance of the ERS solution in a market with ICE and BEV options
- Identify the optimal ERS network length and the optimal subsidy level

## 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
  - $\rho$  : the part of that distance on the ERS equipped highway network

- The TCO of the three options are:

- $G_{ICE} = k_{ICE} + c_{ICE}D$
- $G_{FBEV} = k_{FBEV} + c_{FBEV}D$
- $G_{ERS} = k_{ERS} + \rho D c_{ERS} + \tilde{D} \tilde{c}_{ERS}$

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

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

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- $G_{ERS} = k_{ERS} + \underbrace{\rho D c_{ERS}}_{\text{Variable cost on the ERS network}} + \underbrace{\tilde{D} \tilde{c}_{ERS}}_{\text{Variable cost off the ERS network}}$

Variable cost on the ERS network

Variable cost off the ERS network

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

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

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

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

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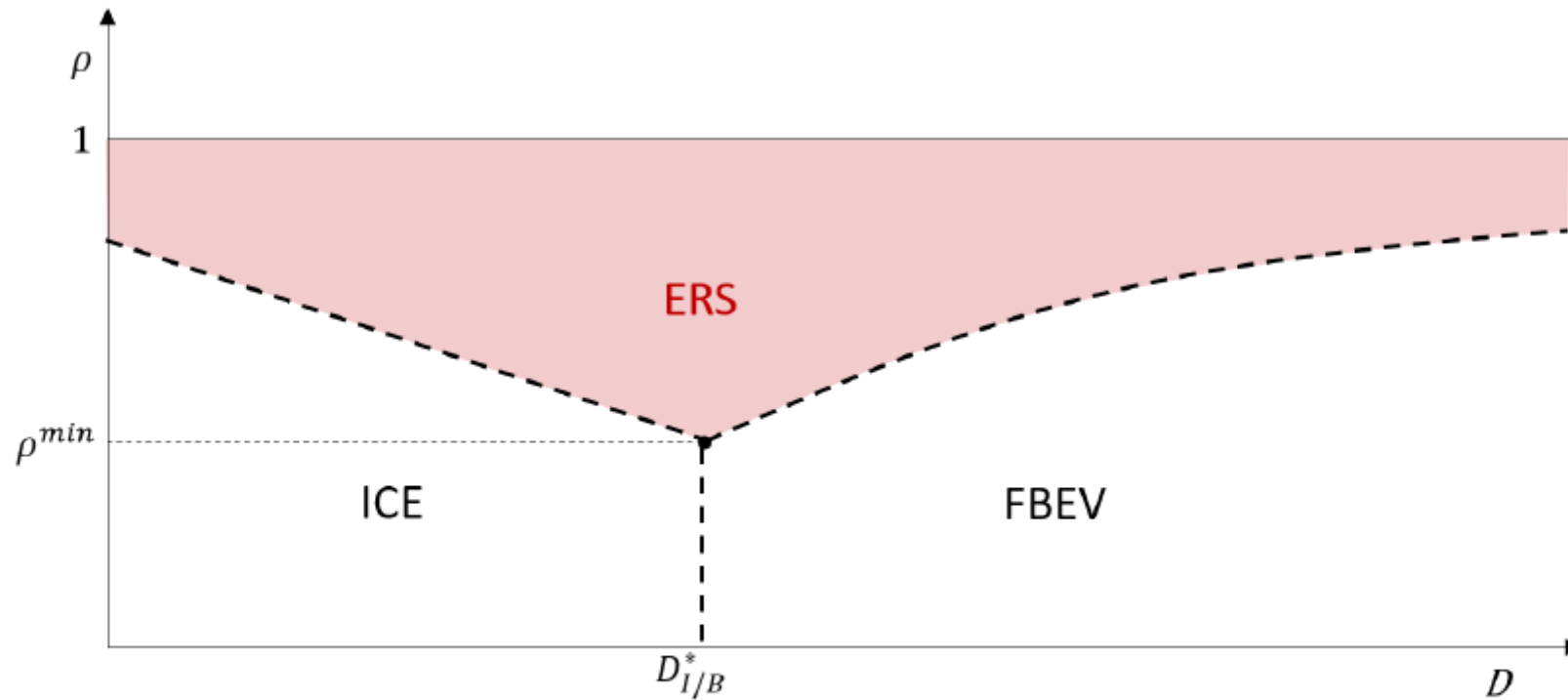
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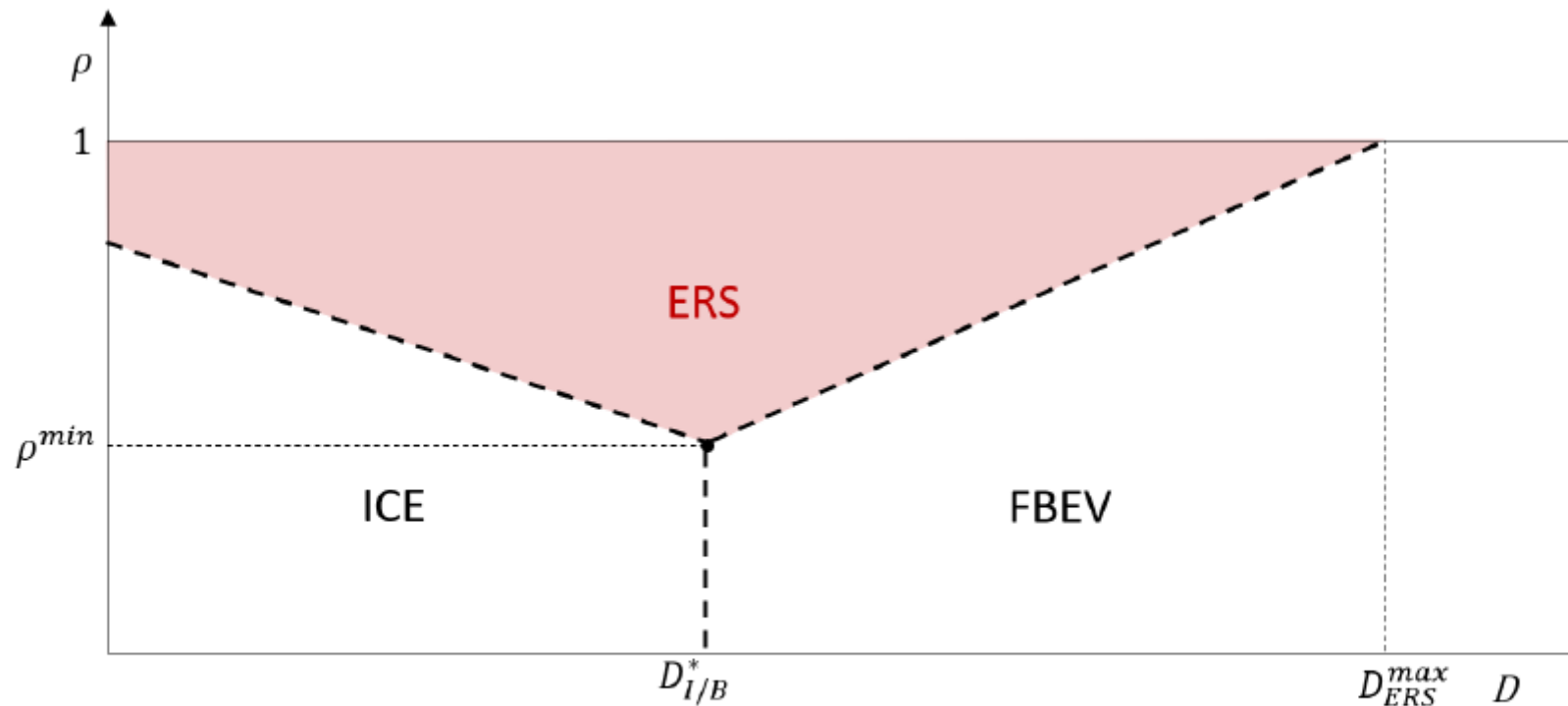
**The demand is entirely described by the  $(D, \rho)$  distribution**

# Domains of relevance of the three options



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

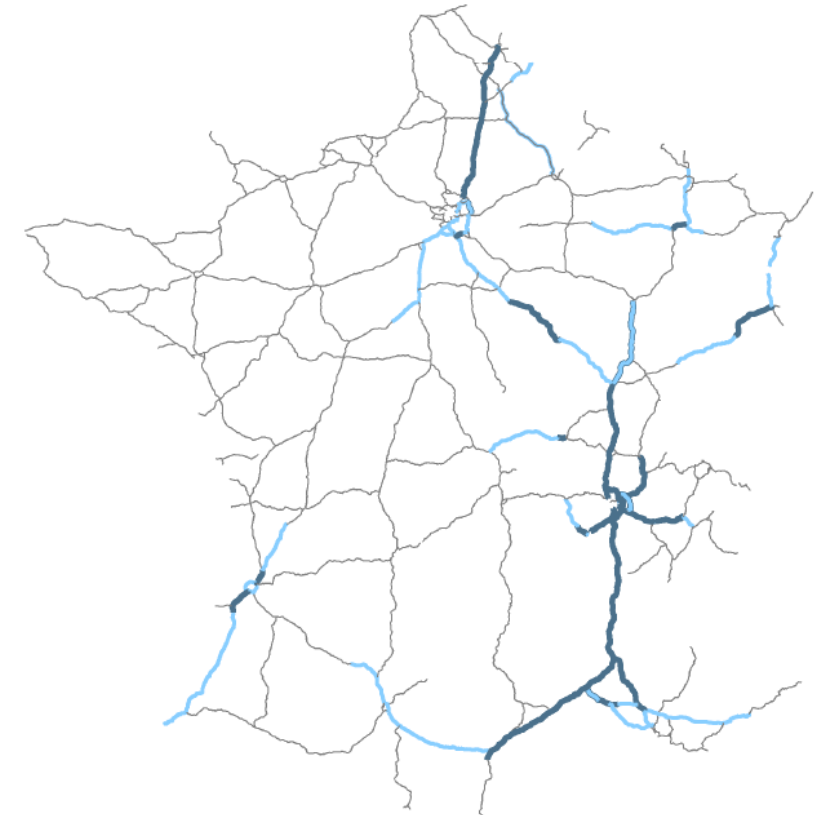
# Domains of relevance of the three options



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

# Dataset

- We estimate the  $(D, \rho)$  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  $D$

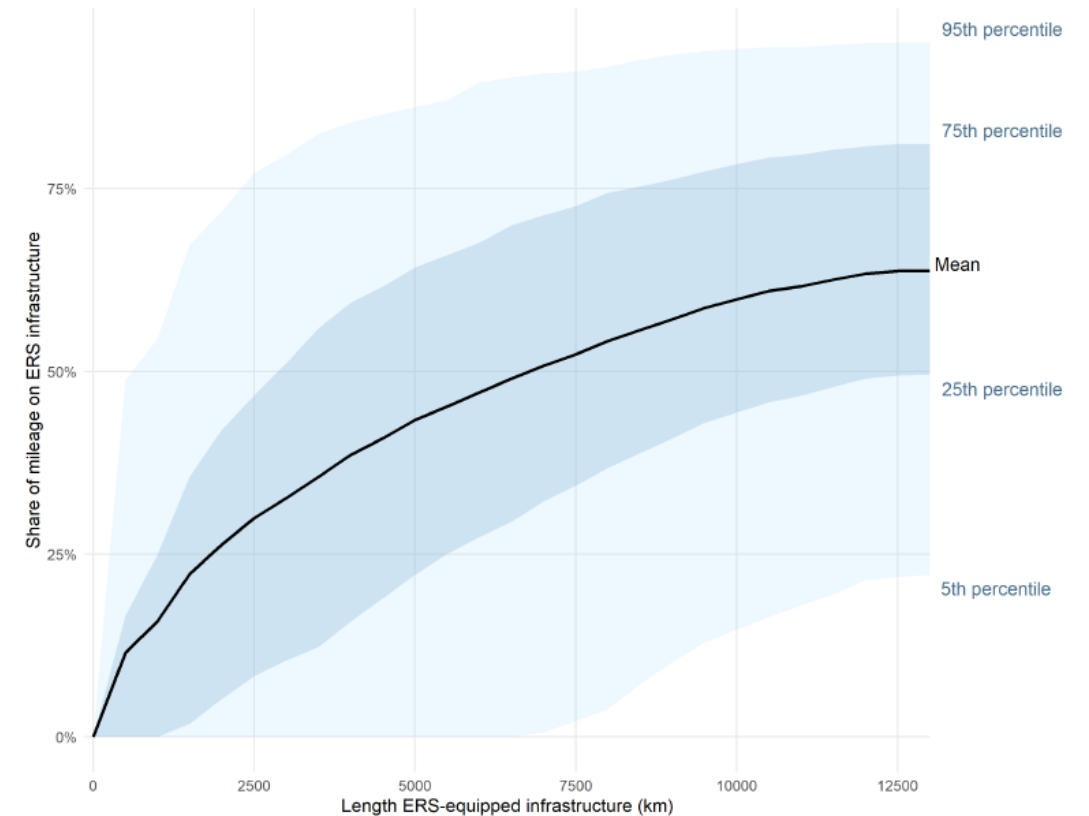


Cumulative traffic — Top 20% — 20–50% — 50–100%

*HDV traffic distribution from the GPS dataset*

# ERS equipped network length and demand characteristics

- The  $(D, \rho)$  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  $\rho$  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  $\rho$  as a function of the equipped ERS network length*

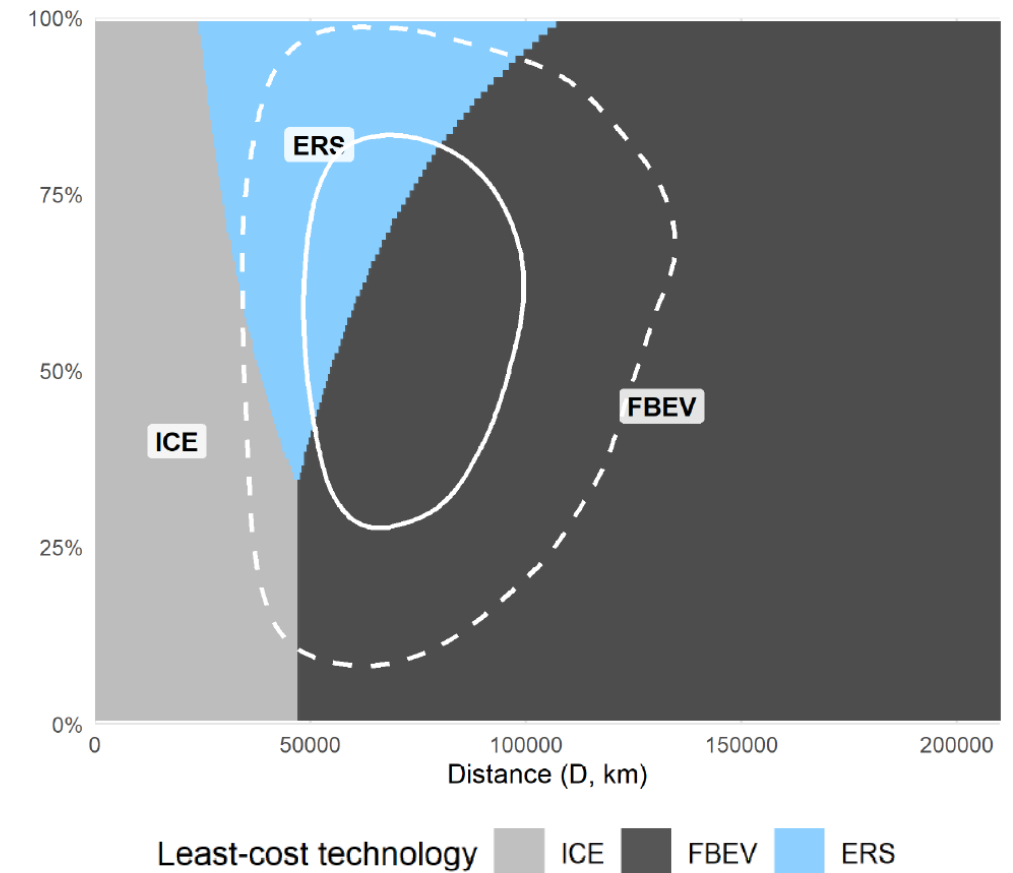
# Market shares: mapping the demand distribution on the relevance domains of the alternatives

- For a given ERS equipped network length  $L_{tot}$  and price  $c_{ERS}$ , compute the  $(D, \rho)$  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:

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

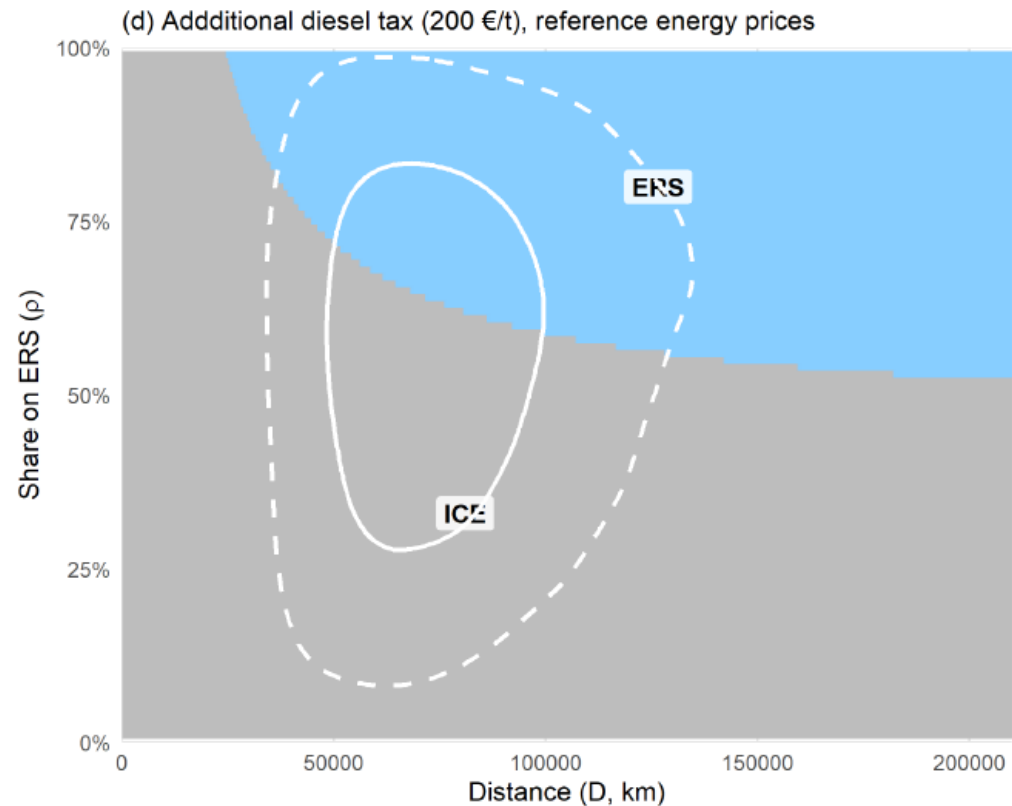
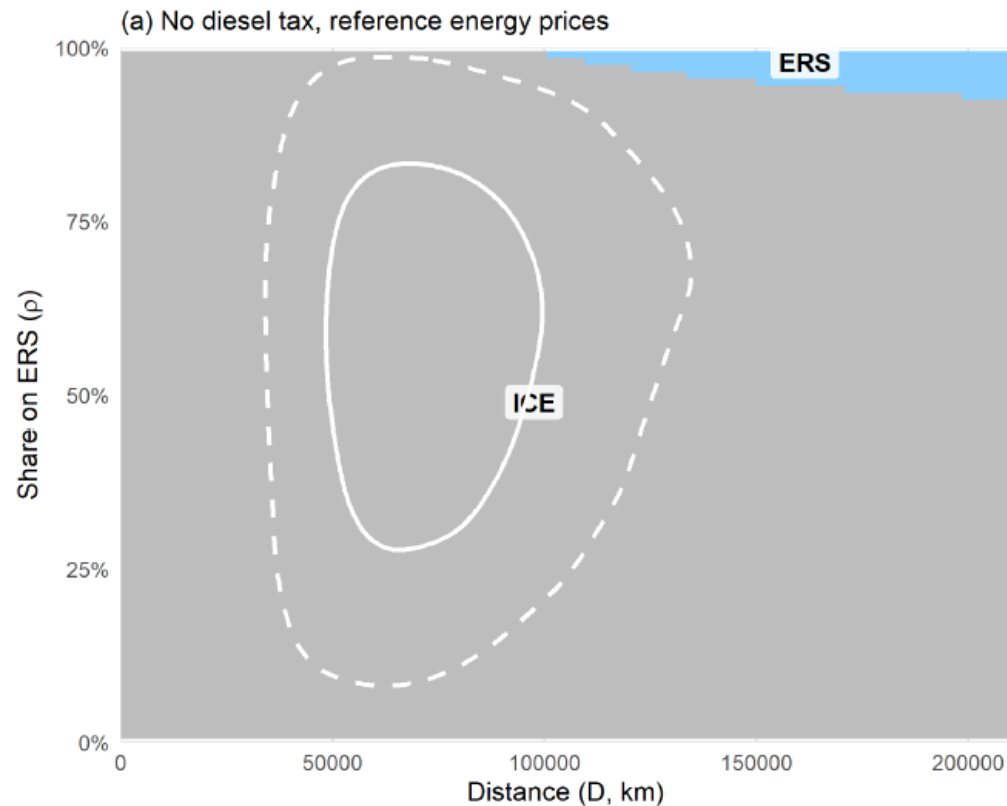
- The ERS travelled distance is:

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



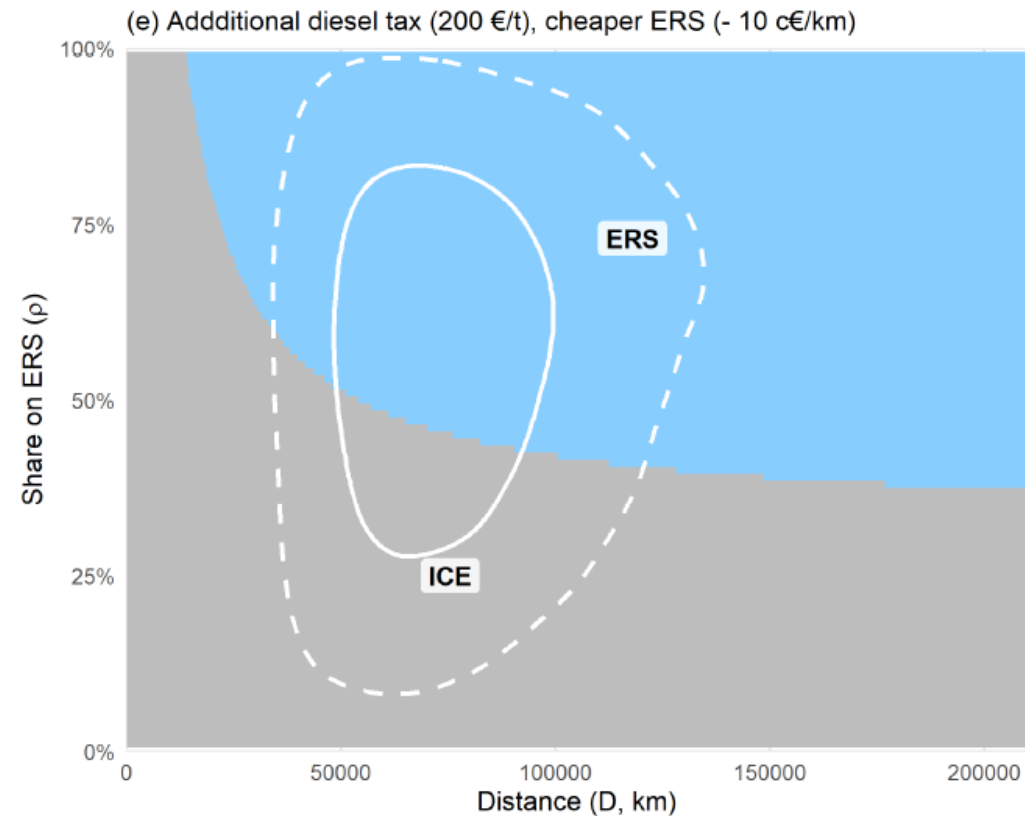
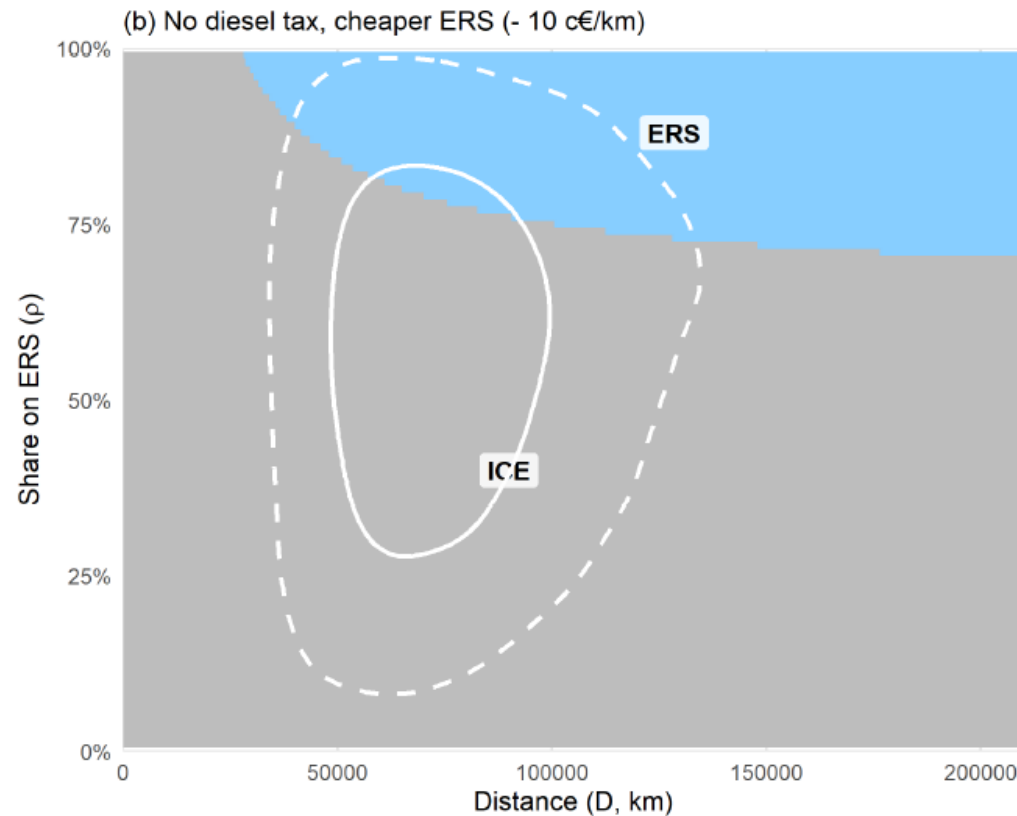


# Market shares ( $L_{tot} = 80000\text{km}$ )



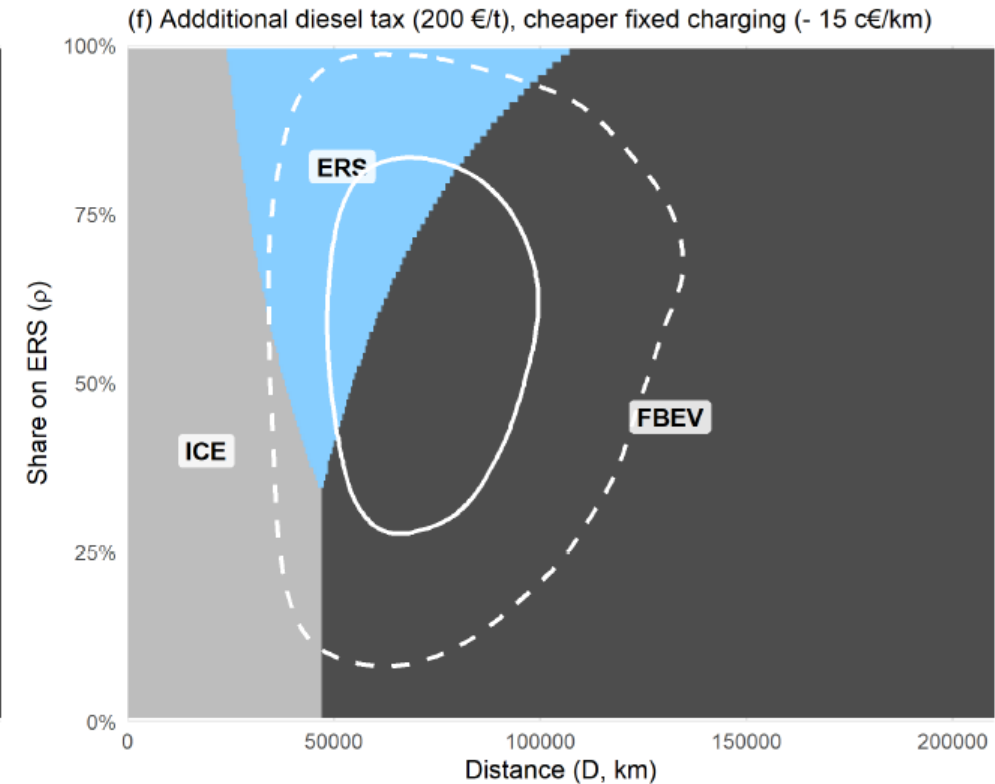
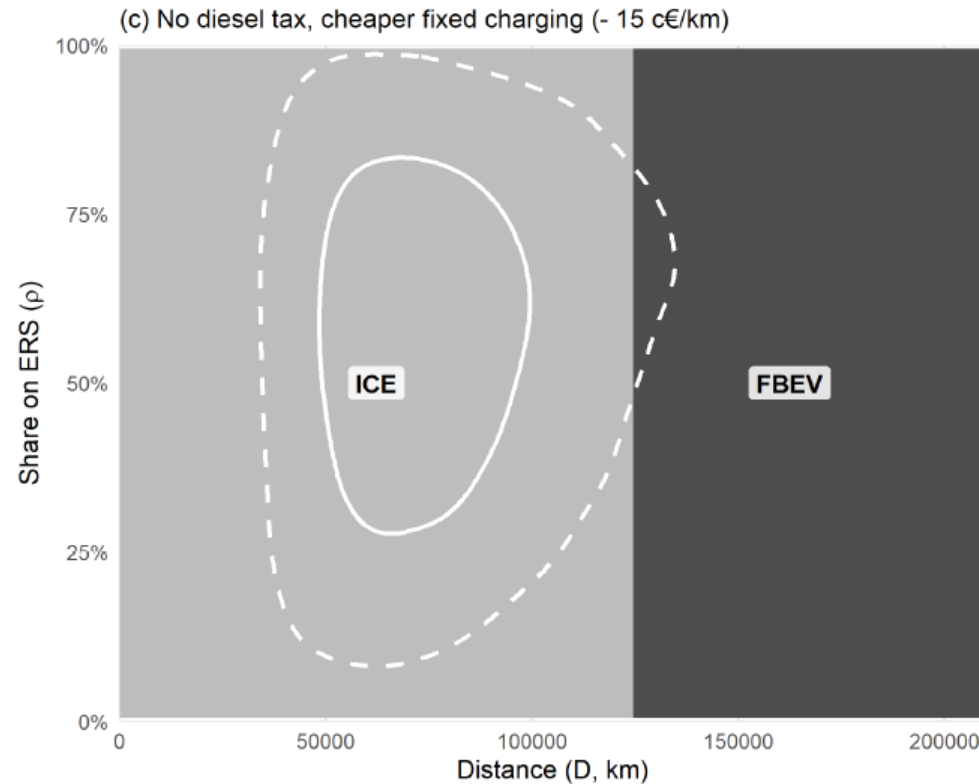
Base case: FBEV are out of the market, ERS is almost not competitive  
 With additional diesel tax: ERS covers half the market

# Market shares ( $L_{tot} = 8000\text{km}$ ), cheaper ERS



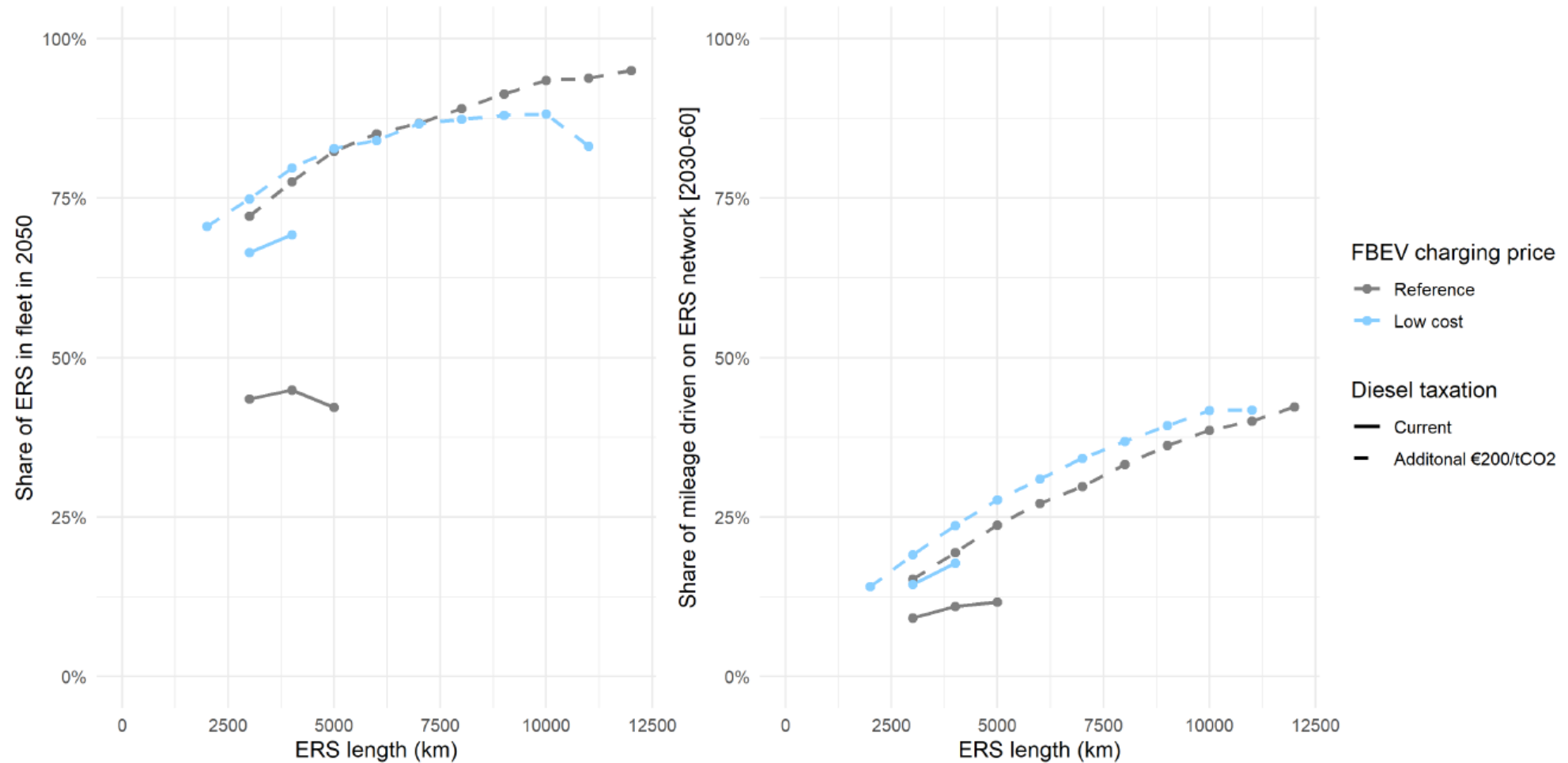
The ERS market share is improved and becomes significant, even at current prices and taxes

# Market shares ( $L_{tot} = 80000\text{km}$ ), cheaper FBEV



The ERS market share shifts partially to the FBEV

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



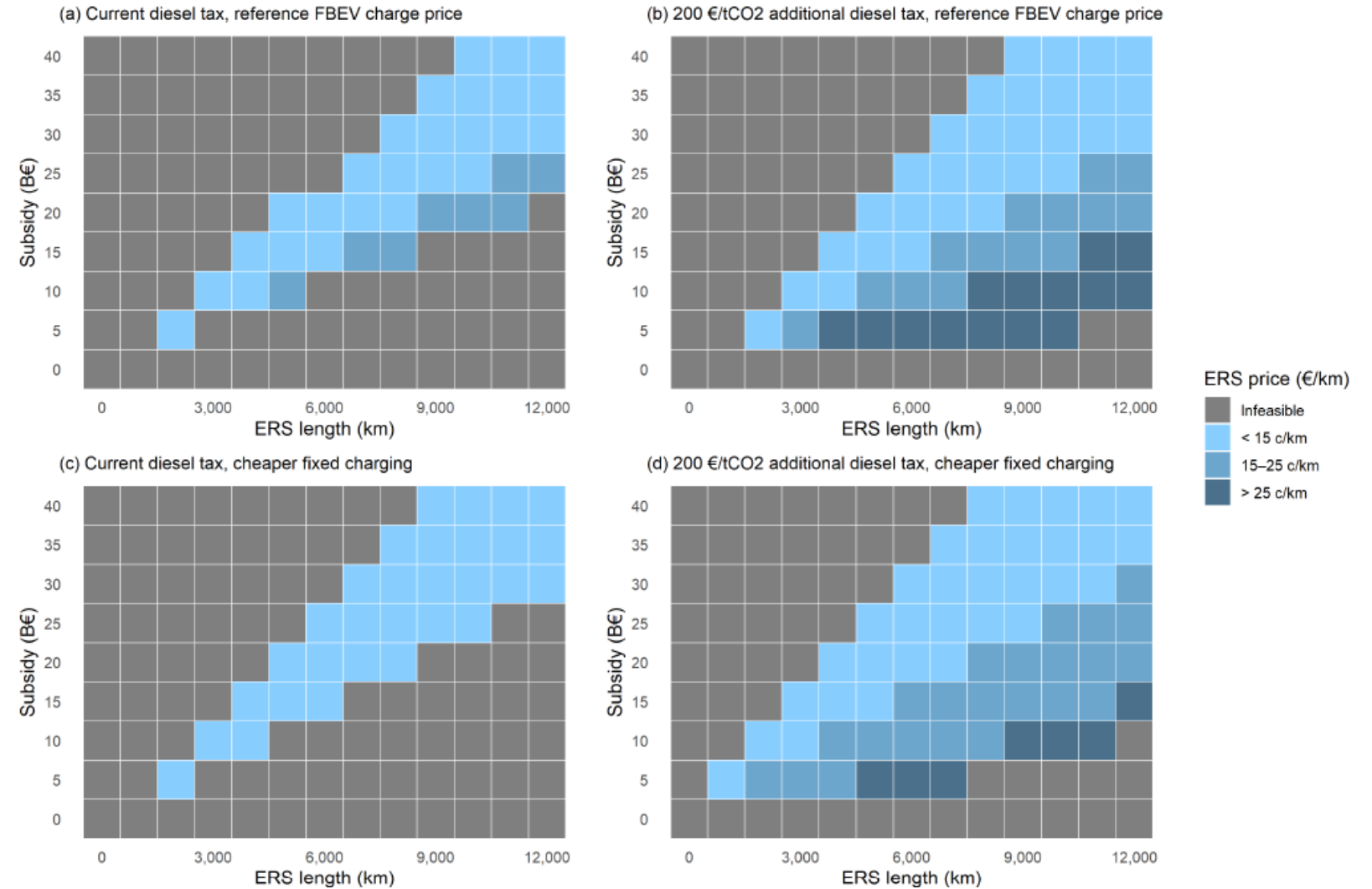
# Assessment process

- 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.

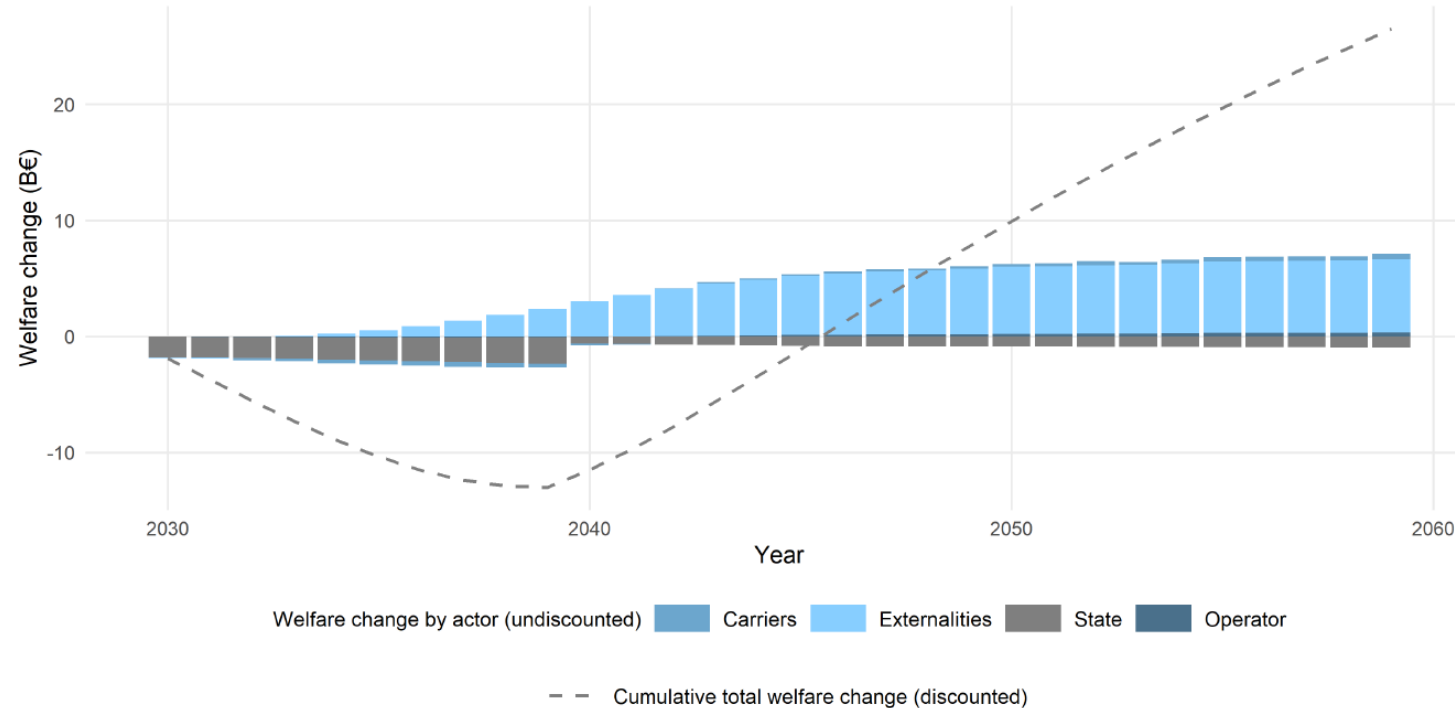
# ERS pricing

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€)	$L_{\text{tot}}$ (km)	$\pi_{\text{ERS}}$ (%)	$\pi_{\text{FBEV}}$ (%)	$c_{\text{ERS}}$ (c€/km)	$\Delta W$ (M€)	$\Delta \text{CO}_2$ (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
$S_{\text{ETS}}$	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
$S_{\text{FBEV}}$	– No solution for any subsidy level –						
$S_{\text{FBEV+ETS}}$	0			– No solution –			
	5	6,000	76	24	28	13,042	–12
	10	9,500	88	12	27	16,166	–13
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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)

The research is part of project Charge As You Drive (CAYD) funded by BPI France.