WHICH COMBINATION OF BATTERY CAPACITY AND CHARGING POWER FOR BATTERY ELECTRIC VEHICLES: URBAN VS. RURAL FRENCH CASE STUDIES

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SUMMARY

- Introduction
- Literature review
- Methodology
- Results:
  - Investments comparison between bigger battery capacities and charging infrastructure
  - BEV customer Business Model
  - Charging Point Operator Business Model
  - The Win-Win situation
- Robustness checks
- Conclusion

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STELLANTIS

Climate change

- The transport sector accounts for **30%** for greenhouse gas emissions, **44%** of which are emitted by **normal vehicles** (EEA, 2018).
- Public interventions for CO_2 limitations:
  - 2009: Directive 2009/29/EC of the European Union
  - 2016: Signature The Paris Agreement

CAFE engagement

- This engagement is called CAFÉ (CAFE standard : Corporate Average Fuel Economy)
- Emissions target of automotive manufacturers :
  - 2020: 95 gCO_2/km
  - 2050: 20 gCO_2/km
- Penalty for non-respect of the emissions: **€ 95/car/exceeded gCO_2/km → hundred billion euros per vehicles manufacturer**
- Stellantis is committed in the CAFE engagement

Technology

- Increase the sales of Electric

independent (if charged using RES)

- Barriers:
  - Charging infrastructure
  - High investments
  - Limited autonomy
  - Battery technology

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LITERATURE REVIEW

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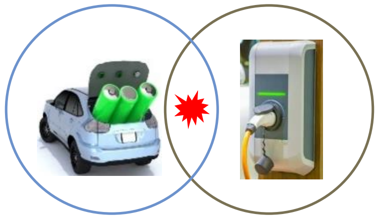
The question "Which combination of battery capacity and charging power" is rarely studied the literature



Paper	Country	Stream	Used data / Methodology	Daily/long trips	Conclusions
Jabbari and Mackenzie (2017)	-	3	A simulation of cost comparison to deploy more fast charging points	-	High reliability of access and high utilization rate of charging stations could be achieved by installing a large number of chargers
Wood et al. (2015)		3	A simulation of the driving behavior after increasing the battery capacity and installing fast charging points	-	It is more costly to add 100-km to the BEV autonomy than to increase the charging network
Funke et al. (2019)		3	400 real-world driver data from German commercial vehicles/ Cost model	Long trips	Cost comparison of the investments in bigger battery and in more charging stations: 50 kWh battery is the optimal solution Invest in fast charging infrastructure rather than batteries

Conclusion: Invest in fast chargers than in bigger batteries for long trips needs (in the case of the USA and Germany)

New questions remain: Research Gaps

1. What about daily trips needs (home-work)?
2. What about 7, 22, 50 kW chargers?
3. Which trade-off between battery capacity and types of chargers when no at-home sockets?

Research Question: For people who **cannot install a charger** at home: where should we invest? In **bigger batteries** or in more **available charging points**? And which **power** of charging?

SUMMARY

Hypotheses:

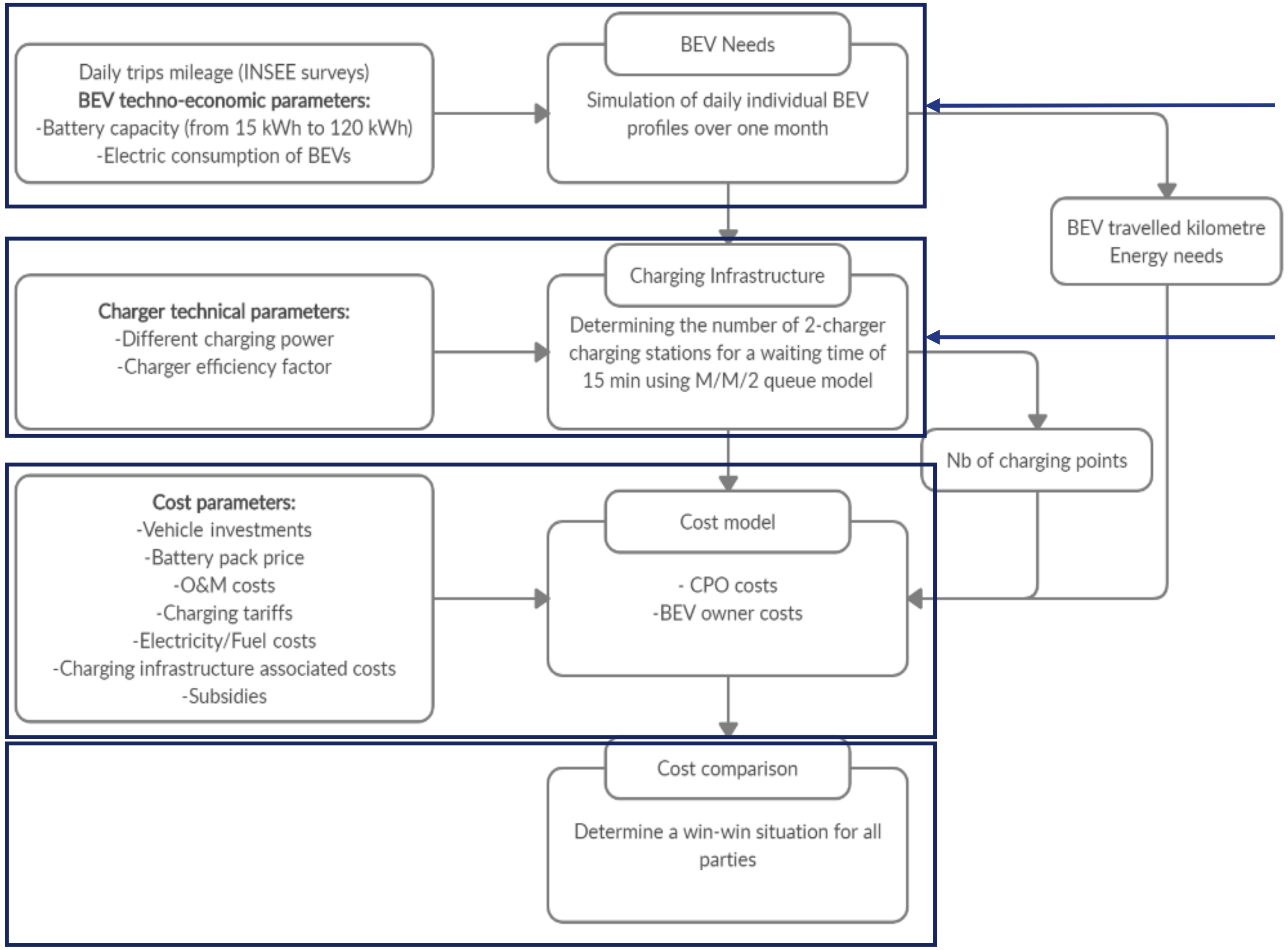
People who will use the infrastructure, cannot install a private charger at-home → The installation of private chargers differs with degree of urbanity

The driver will charge **from 20% to 80%** (if he cannot drive the next day)

We consider a trip: home-work and work-home

Annual Vehicle travelled kilometers in WLTP:

- Urban area: 6420 km/year
- Rural area: 37860 km/year



Methodology

We consider 3 types of vehicles:

- Small BEV with battery capacity [15 kWh; 20 kWh]
- Medium BEV with battery capacity [25 kWh; 45 kWh],
- Large BEV with battery capacity [50 kWh; 120 kWh]

We consider that every vehicle size could charge using a well-defined charger

- Small BEV using 7 kW charger,
- Medium BEV using 22 kW charger,
- Large BEV using 50 kW charger

METHODOLOGY

For this study, the ecosystem of the EV industry groups: the BEV owner and the Charging Point Operator

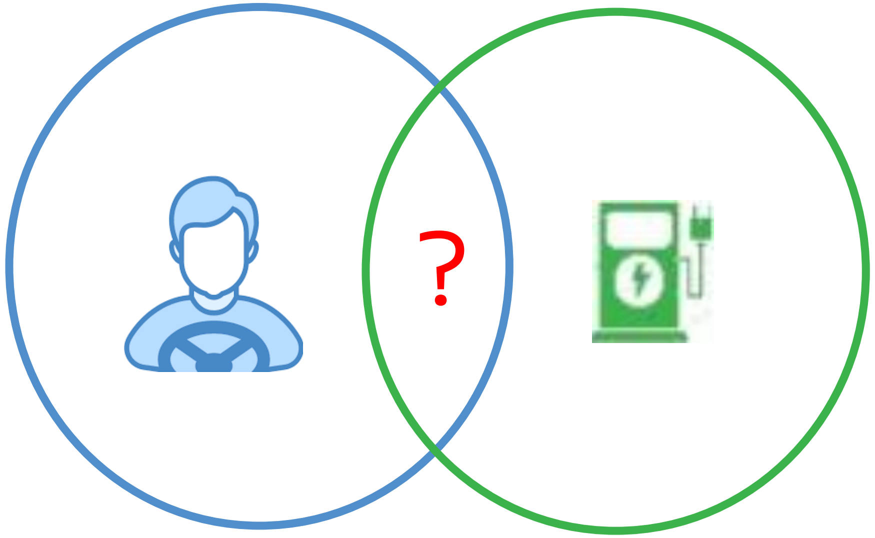
Equivalent Annual Cost (EAC) is the annual cost of owning, operating, and maintaining an asset over its entire life (Total Cost of Ownership without the residual value + OPEX and other yearly expenses).

BEV driver

Minimizing the investments and the costs

$$\boldsymbol{min(\Delta EAC_i) = min(EAC_{BEV,i} - EAC_{ICEV,i})}$$

The difference in annual costs between purchasing a BEV and an ICEV



Charging Point Operator (CPO)

Minimizing the costs

$$\boldsymbol{min(EAC_{CPO})}$$

$$\boldsymbol{min(Costs - Revenues)}$$

Vehicle Customer Business Model

$$EAC_{VEH,i} = \boxed{\frac{(1+r_{VEH})^{T_{VEH}} * r_{VEH}}{(1+r_{VEH})^{T_{VEH}} - 1}\left(I_{VEH,z} + c_{batt,i} * p_{1kWh} - c_{BEV,subsidies}\right)} + \boxed{aVKT_i * \left(c_{VEH,O\&M,z} + c_{VEH,charging}\right) + c_{BEV,card} + LCA_{ICEV,z} * p_{CO2}}$$

The amortized investments — Yearly charged expenses

Where: $c_{VEH,charging} = \begin{cases} c_{f,el} * \frac{cons_{VEH,z}}{P_z * \eta}; if\ VEH = BEV \\ c_{f,el} * cons_{VEH,z}; if\ VEH = ICEV \end{cases}$

- $i = 1, \dots, N$ is the driving profile

$$z = \begin{cases} Small\ ; if\ c_{batt} \leq 20\ kWh \\ Medium; if\ 20\ kWh < c_{batt} < 65\ kWh \\ Large\ ; if\ c_{batt} \geq 65\ kWh \end{cases}$$

$EAC_{VEH,i}$	**Equivalent Annual Cost of the driving profile 'i'**	**[€/Year]**
r_{VEH}	Interest rate	[-]
T_{VEH}	Lifetime	[Years]
$I_{VEH,z}$	Vehicle investment of Type z (w/o battery)	[€]
$c_{batt,i}$	Battery capacity	[kWh]
p_{1kWh}	Price of 1 kWh	[€/kWh]
$c_{BEV,subsidies}$	Subsidies	[€]
$aVKT_i$	Annual Vehicle Km Travelled	[km/Year]
$c_{VEH,O\&M,z}$	Operation and Maintenance cost of a vehicle Type 'z'	[€/km]
$c_{VEH,charging}$	Charging fees	[€/Year]
$c_{f,el}$	Fuel/Electricity cost	[€/l] or [€/min]
$cons_{VEH,z}$	Fuel/Electricity consumption	[l/km] or [kWh/km]
P_z	Associated charging power	[kW]
η	The efficiency of the charging point	[-]
$c_{BEV,card}$	Access card for charging stations	[€/year]
$LCA_{ICEV,z}$	Life Cycle Assessment of ICEV Type 'z'	[tCO2/Year]
p_{CO2}	Price of 1 tonne of CO2	[€/tCO2]

This formula (EAC) could be applicable on both BEV or ICEV study cases by changing the different techno-economic parameters.

We compare the costs of purchasing a BEV to an ICEV (of the same type):

$$\boxed{\Delta EAC_i = EAC_{BEV,i} - EAC_{ICEV,i}}$$

Charging Point Operator Business Model

$$EAC_{CPO} = \boxed{N\left(\frac{(1+r_{CPO})^{T_{CPO}} * r_{CPO}}{(1+r_{CPO})^{T_{CPO}}-1}\left(I_{CP,z}+I_{CPO,Civil\,works,z}+I_{CPO,Installation,z}+I_{CPO,Grid\,connections,z}-c_{CPO,subsidies}\right)\right.} + \boxed{\left.c_{CPO,O\&M}+c_{CPO,MB}+c_{CPO,com}\right)} - \boxed{\sum_{k=1}^{\#BEV}\left(c_{CPO,charging,k}+c_{CPO,card,k}-c_{CPO,elec} * YCE_k\right)}$$

The amortized investments — Yearly charged expenses — Revenues

$EAC_{CPO,j}$	**Equivalent Annual Cost of a charger ‘j’**	**[€/Year]**
r_{CPO}	Interest rate	[-]
T_{CPO}	Lifetime	[Years]
$I_{CP,z}$	Charging point investment of Type ‘z’	[€]
$I_{CPO,Civil\,works,z}$	Civil works investment of Type ‘z’	[€]
$I_{CSO,Installation,z}$	Installation investment of Type ‘z’	[€]
$I_{CPO,Grid\,connections,z}$	Grid connections investment of Type ‘z’	[€]
$c_{CPO,subsidies,z}$	Subsidies of Type ‘z’	[€]
$c_{CPO,O\&M,z}$	Operation and Maintenance cost of Type ‘z’	[€]
$c_{CPO,MB}$	Metering and billing cost	[€]
$c_{CPO,com}$	Communication cost	[€]
r	The number of BEV that use one charger	[-]
$c_{CPO,charging,k}$	Charging cost for the driver of the vehicle ‘k’ (=$c_{BEV,charging,k}$)	[€]
$c_{CPO,card,k}$	Subscription fee to access the charging infrastructure ‘k’ (=$c_{BEV,card}$)	[€/Year]
$c_{CPO,elec}$	Electricity cost for the CPO	[€/kWh]
YCE_k	Yearly Charged Energy of BEV ‘k’	[kWh/Year]

Charging Point Operator techno-economic parameters

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Investments comparison between bigger battery capacities and charging infrastructure

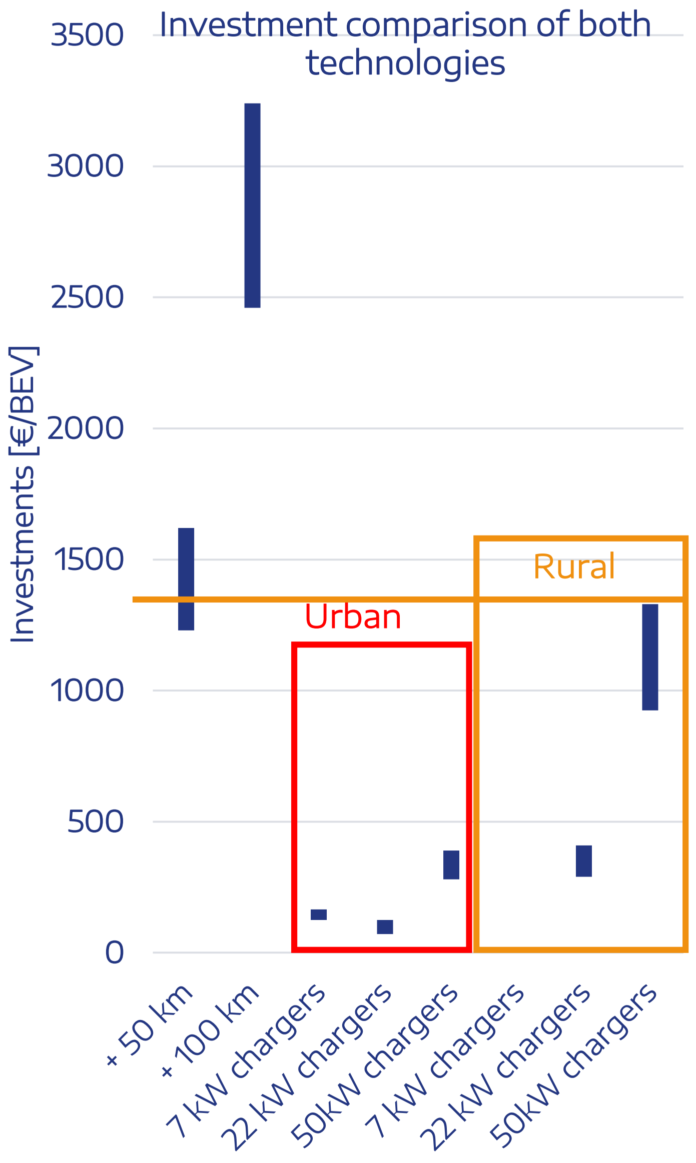
We compared the investments increasing the autonomy of the vehicle and the deployment of more charging infrastructure (easier to understand and communicate):

$$I = \frac{I_{CI}}{\#BEVs}$$

Where:
- I_{CI} price of 1 charger
- $\#BEVs$ nb of BEVs that will use this charger

- Investing in bigger batteries could vary from 1200 to 3200 €/BEV (Price of 1 kWh = 150 €)
- For Urban needs:
  - Installing more available charging infrastructure is cheaper than in bigger battery sizes
- For Rural needs:
  - Installing more 22 kW available charging infrastructure is cheaper than in bigger battery sizes
  - Increasing the autonomy by 5 km comes with lower cost than deploying more 50 kW chargers.

Investing in 22kW chargers come with the lowest investment, for all cases, compared to other charger speeds and to bigger batteries.



STELLANTIS

BEV customer Business Model

For urban areas:

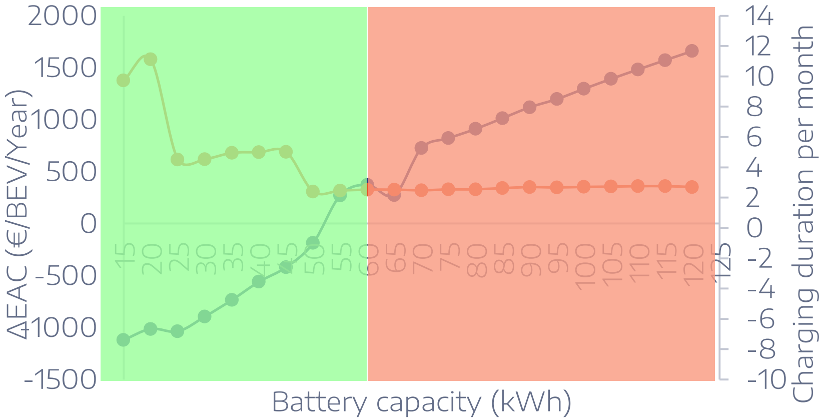
- ΔEAC < 0 for 15 → 50 kWh BEV
- The **most cost-efficient** solution:
    - 15 kWh BEV
    - **High** charging duration (12 hrs/month)

For rural needs: The choice will depend on the driver's daily travelled kilometres

- Small BEVs are excluded
- The **most cost-efficient** solution:
    - 50 kWh BEV (ΔEAC < 0)
    - **High** charging duration (15 hrs/month)
    - **Risky** for some drivers
- The cost-efficient solution:
    - 65 kWh BEV (ΔEAC > 0)
    - **Reasonable** charging duration (10 hrs/month)
    - **Not risky** for some drivers

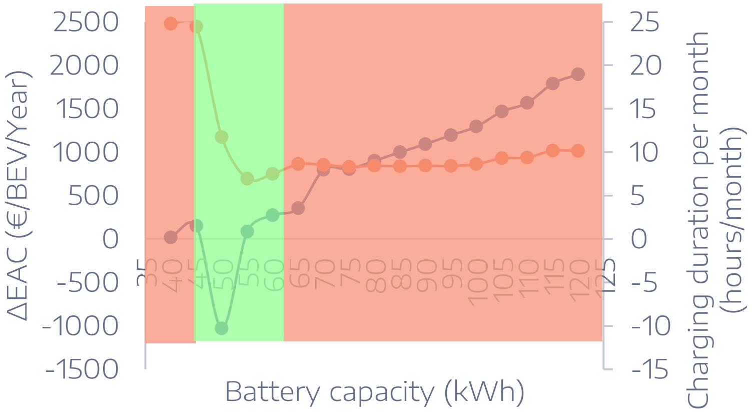
The graphs represent $\boldsymbol{\Delta EAC}$ (difference between purchasing a BEV and an ICEV of the same type) for both urban and rural needs

URBAN case study



Urban: [15 kWh; 50 kWh]

RURAL case study

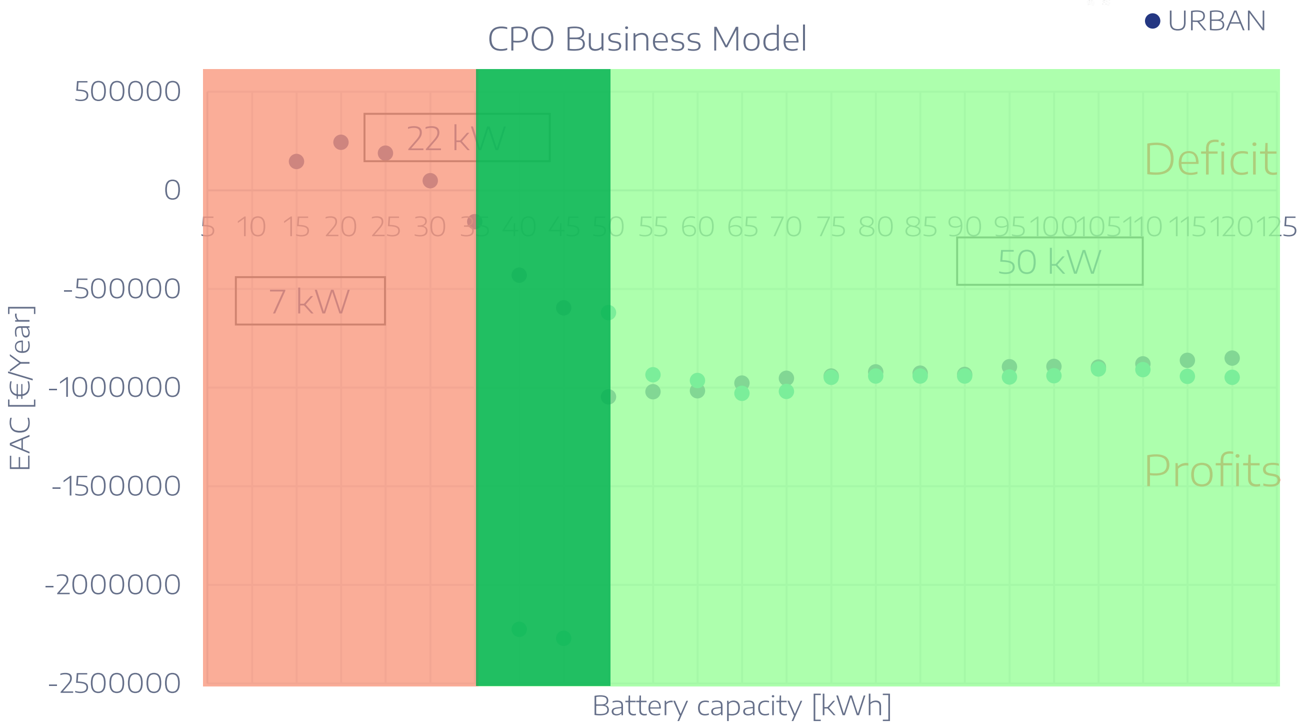


Rural: [50 kWh; 65 kWh]

For the BEV customer: there is a **trade-off** between lower costs and high charging durations
For urban needs: $\boldsymbol{\Delta EAC}$ **< 0 for** [15 kWh; 50 kWh]
For rural needs: it depends on the driver's travelled kilometres: (1) $\boldsymbol{\Delta EAC}$ **< 0 for** [50 kWh]; (2) $\boldsymbol{\Delta EAC}$ **> 0 for** [55 kWh; 65 kWh]

Charging Operator Business Model

- A **positive EAC** means that a **deficit** is recorded Costs>Revenues
- Profits could be generated especially with **variable** pricing method, rather than **fixed** pricing one → a profitable business under certain conditions.
- For **small** BEV: Fixed pricing method
  - **No** profits due to the charging price → recommended to change the charging price **> 1€/hour**
- For **medium** BEV: Variable pricing method
  - 25 kWh and 30 kWh: **no profits** → recommended to change the charging price > 1,5€ for the first hour
  - 35 kWh to 60 kWh: **profits** → bigger the battery → more profits (because of the exceeded minute charging price)
- For **large** BEV: Fixed pricing method
  - The profits are slightly decreasing with bigger batteries
- The maximum of profits is recorded for **50 kWh** for urban and **45 kWh** rural needs



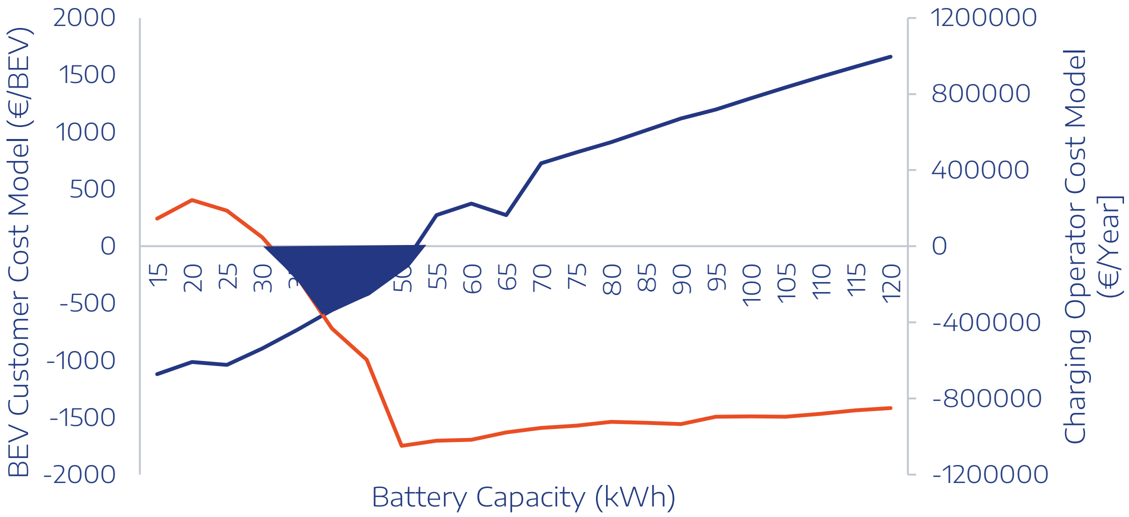
Urban: [35 kWh; 120 kWh] - 22 kW and 50 kW chargers
Rural: [50 kWh; 120 kWh] - 22 kW and 50 kW chargers

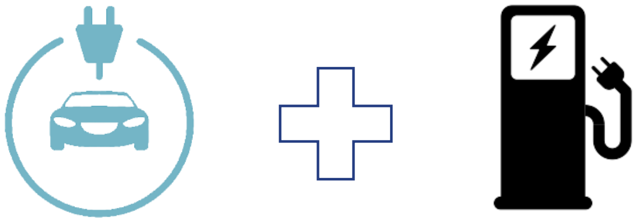
Different pricing levels are used: (Source: Chargemap)
- For 7 kW charger: 1€/hour (**Fixed** pricing level)
- For 22 kW charger: 1,5€ for the 1st hour and 0,2€/exceeded min (**Variable** pricing level)
- For 50 kW charger: 2€ for the access and 0,247 €/min (**Fixed** pricing level)

Every BEV owners pay 5€/month as subscription

COMPARISON

Win-win situations for urban areas

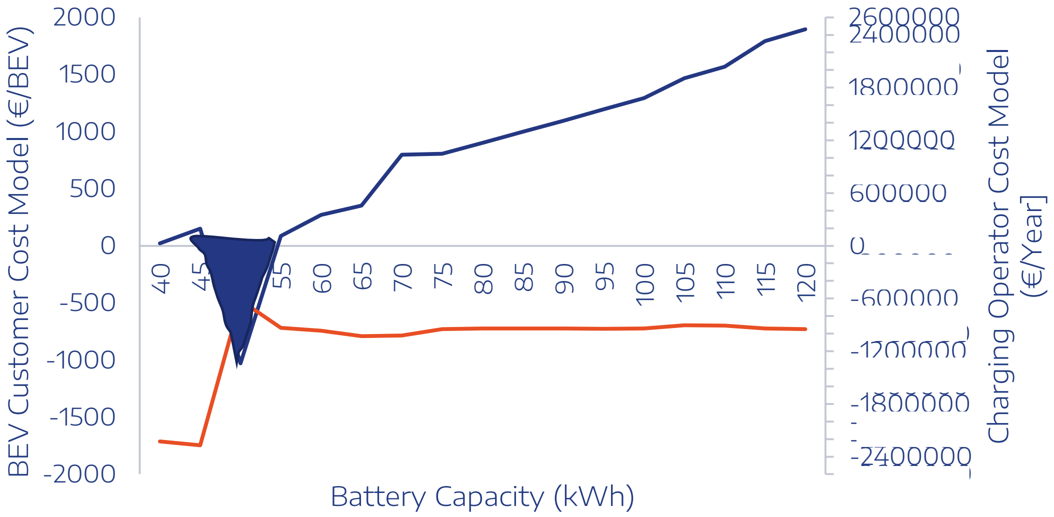


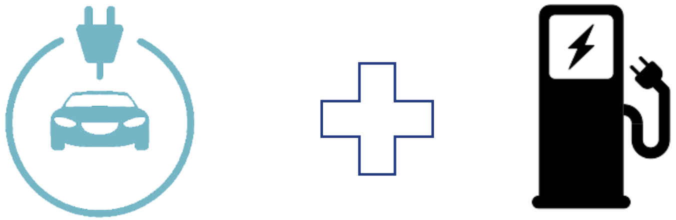


[35 kWh; 50 kWh] BEVs

22 kW and 50 kW chargers

Win-win situations for rural areas





Solution is highly individual:

- 50 kWh BEVs BUT limited autonomy
- 55-65 kWh BEVs for good autonomy

50 kW chargers

SUMMARY

ROBUSTNESS CHECKS

ROBUSTNESS CHECK 1

Mixing the usage between BEV sizes and charging powers: all BEVs could charge using all powers.

Using **slow** charger → **long** charging duration

For urban area:
- 35-45 kWh BEVs + 22 kW chargers
- 50 kWh BEVs + 50 kW chargers

For rural area:
- 40-45 kWh BEVs + 22 kW chargers
- 50-65 kWh BEVs + 50 kW chargers
- 65 kWh BEV is the best choice for BEV driver (autonomy)

Similar to our results

ROBUSTNESS CHECK 2

Changing the charging pricing method

Results are antagonists.

For urban area:

- 35-45 kWh BEVs + 22 kW chargers (+per **exceeded minute** pricing method – **after one hour**)
- 50 kWh BEVs + 50 kW chargers (+**per minute** pricing method – **access fee**)

For rural area:

- No conclusions → future studies

Similar to our results for urban area

ROBUSTNESS CHECK 3

Increasing the charging tariffs by 50%

We measured the elasticity

For urban area:
- **Low** elasticity for Small-battery and large-battery BEVs ($-1<\varepsilon<0$)
- **High** elasticity for Medium-battery BEVs ($\varepsilon<-1$)

For rural area:
- **High** elasticity for all BEVs ($\varepsilon<-1$)

Recommendations for revising the charging tariffs

The results of the robustness checks are similar to our results

Future studies: Investigate for a **win-win solution** for the **pricing** method variation for **rural** area

Policy recommendation: The **impact** of **increasing the charging tariffs** on the drivers' behaviours

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CONCLUSION

- This study answers the Research Question: « *which combination of battery capacity and charging power for battery electric vehicles: urban vs. rural French case studies* ».

- We used **the Equivalent Annual Cost**, by analyzing the business models of the charging point operator and the BEV customer.

- **12 scenarios of identical privately-purchased BEVs** were simulated, by increasing their battery capacity of 5 kWh.

- **Hypotheses and assumptions:**
    - BEVs are divided into 3 sizes based on their battery capacity.
    - Small BEVs use 7 kW chargers, Medium BEVs use 22 kW chargers, Large BEVs use 50 kW chargers.
    - Customers, who do not have a private charger at home, will use the public charging infrastructure.
    - The needs are calculated based on their daily trips needs (Work-Home, Home-Work) for both urban and rural areas.
    - Charging from 20% to 80%.

- Results show that it is cheaper to invest in **22 kW chargers** rather than increasing the autonomy by **50 and 100 km** for both urban and rural areas.

- **For urban area:**
    - 35-45 kWh BEVs + 22 kW chargers
    - 50 kWh BEVs + 50 kW chargers

- **For rural area:**
    - 40-45 kWh BEVs + 22 kW chargers
    - 50-65 kWh BEVs + 50 kW chargers
    - 65 kWh BEV is the best choice for BEV driver (autonomy)

- The results of the robustness checks are similar to our results:
    - **Future studies**: Investigate for a **win-win solution** for the **pricing** method variation for **rural** area
    - **Policy recommendation**: The **impact** of **increasing the charging tariffs** on the drivers' behaviours

THANK YOU FOR YOUR ATTENTION
QUESTIONS?

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