Energy and Emissions for Transportation Systems

Feasibility Study of **Alternative Energy Solutions for a Railway Line in France: Clermont-Ferrand ⟶ Brioude**

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AGENDA

1 INTRODUCTION

- Case study
- Motivations & project objectives

2 ALTERNATIVE ENERGY SOLUTIONS

- Technical and environmental analysis
- Financial results

3 CONCLUSIONS

- Operational Considerations
- Limitations

CASE STUDY

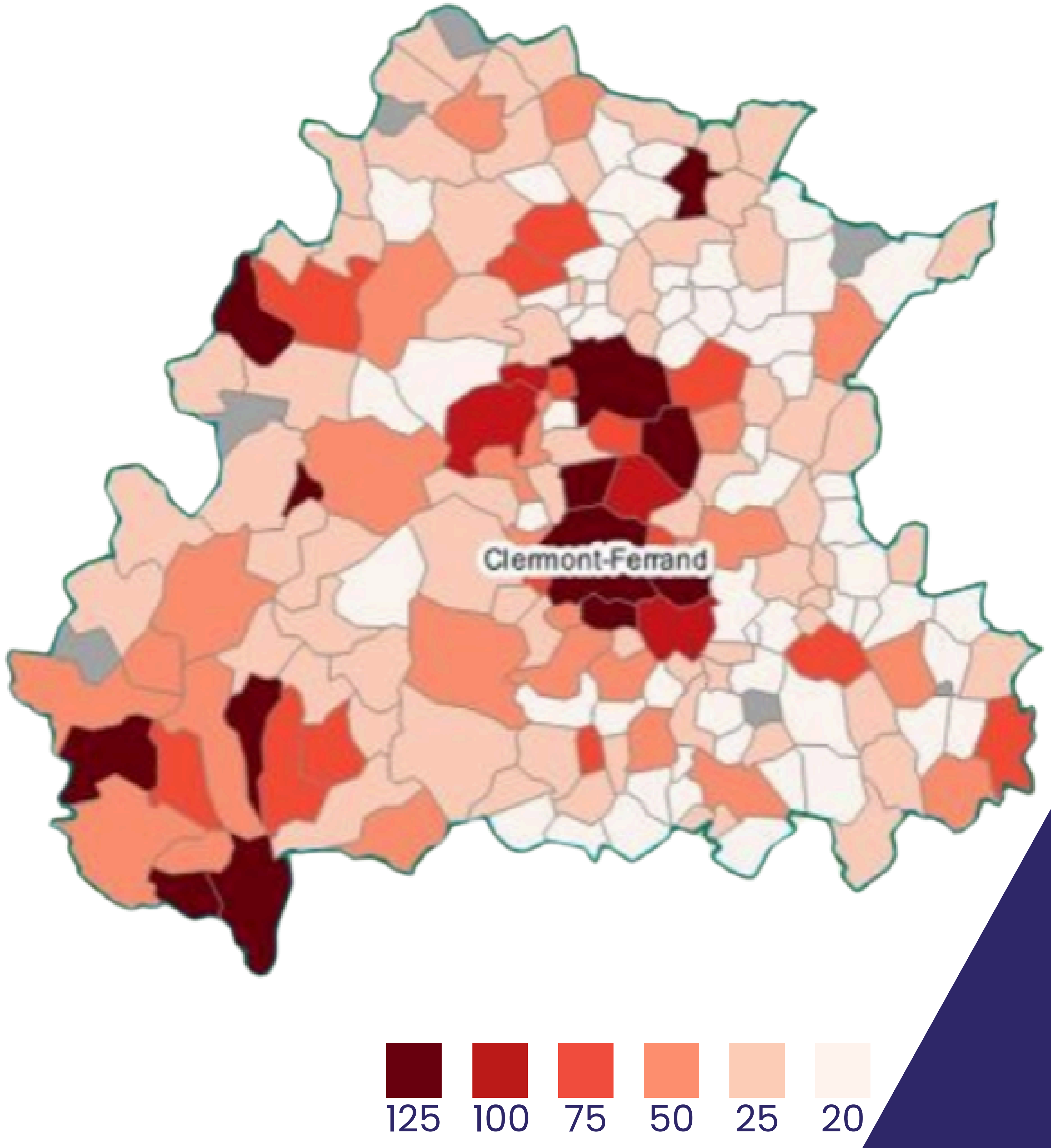
Why This Line? - Strategic Relevance

Territorial Context
Rural area of central France
High **use of private cars** for moving

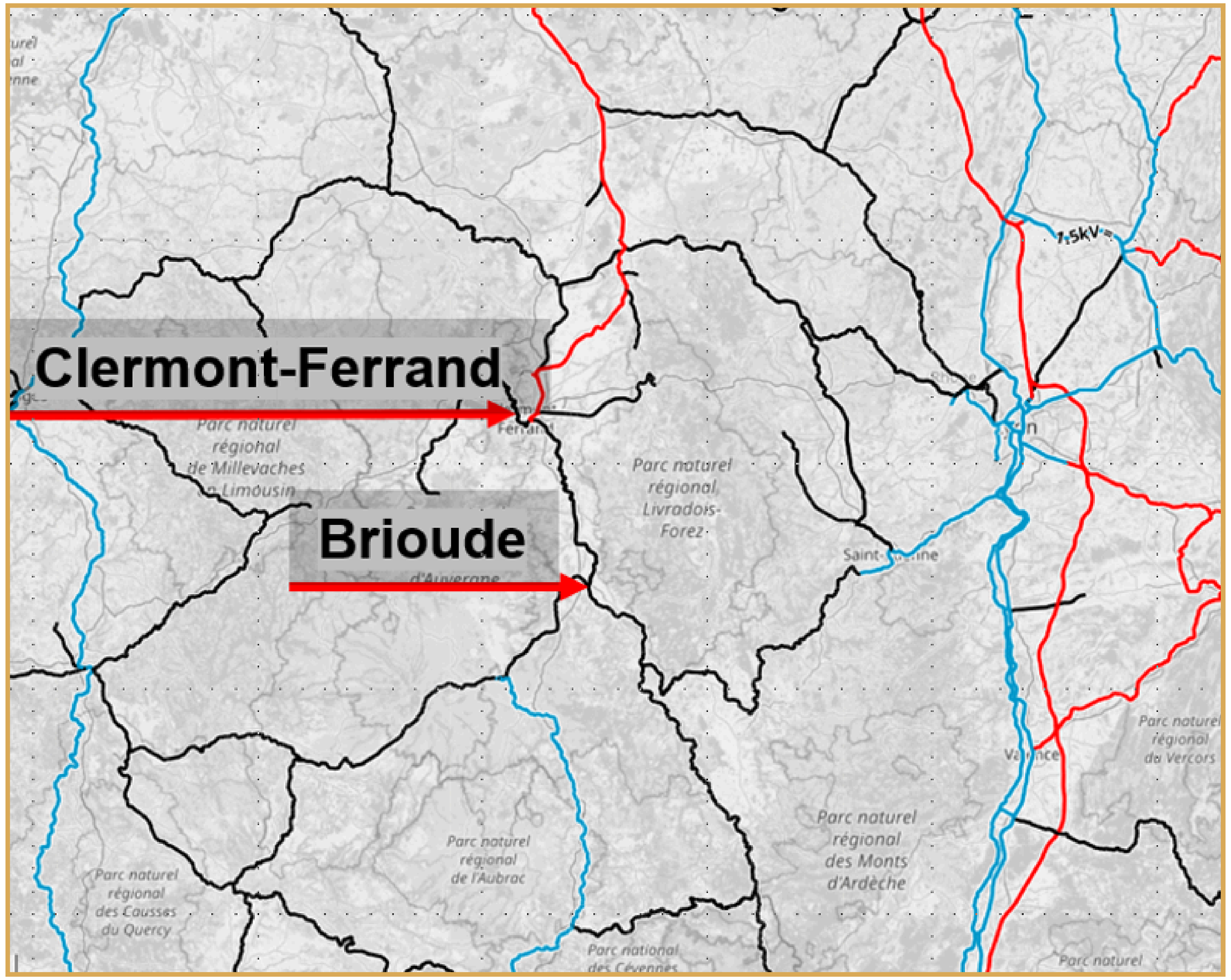
95% of **employees living in countryside** → Important **commuting challenge**

Actual Railway Service
- **70 km** – 1h 06min travel time
- 3 **intermediate stops**
- **12 round trips/day**
- still operate with **Diesel Train**

Employment to inhabitants concentration map



MOTIVATIONS & GOALS



— non electrified railway — electrified railway

Low Electrification Rate

Only ~**55%** of French railway **lines are electrified**
→ **Below EU average**

Opportunity of the Area:

- **Competitive French energetic mix** (mainly nuclear, wind and hydro resources)
- **H2 production** already existing/under development in the area (HYmpulsion)
- **Biomasses**: highly dense agricultural activity in the «Diagonale du vide»

ALTERNATIVE ENERGY SOLUTIONS

The project aims to assess sustainable alternatives to diesel traction on a railway line

AS - IS : Diesel

- **Standard Diesel-power B7**
  Refinery: Feyzin
- **B100 rapeseed-based Diesel**
  (aligned to SCNF goals)

TO - BE : Battery

- **Grid Powered Scenario**
  Electric recharging through the national electricity grid
- **PV + Grid Supply Scenario**
  Battery recharging powered by local PV plants integrated with grid backup

TO - BE : Hydrogen

- **Grid-Fed Electrolysis**
  On-site H2 production powered by electricity grid
- **PV + Grid Electrolysis**
  Local H2 production partially powered by PV supported by the grid

AS - IS SITUATION: DIESEL TRAIN

Crude Oil → Feyzin Refinery: FAME & CCS → 175 km Truck → Transport / Distribution → Storage (underground tanks) → Refilling Station → Train

External Production

Station

Line served by Alstom Regiolis B84500

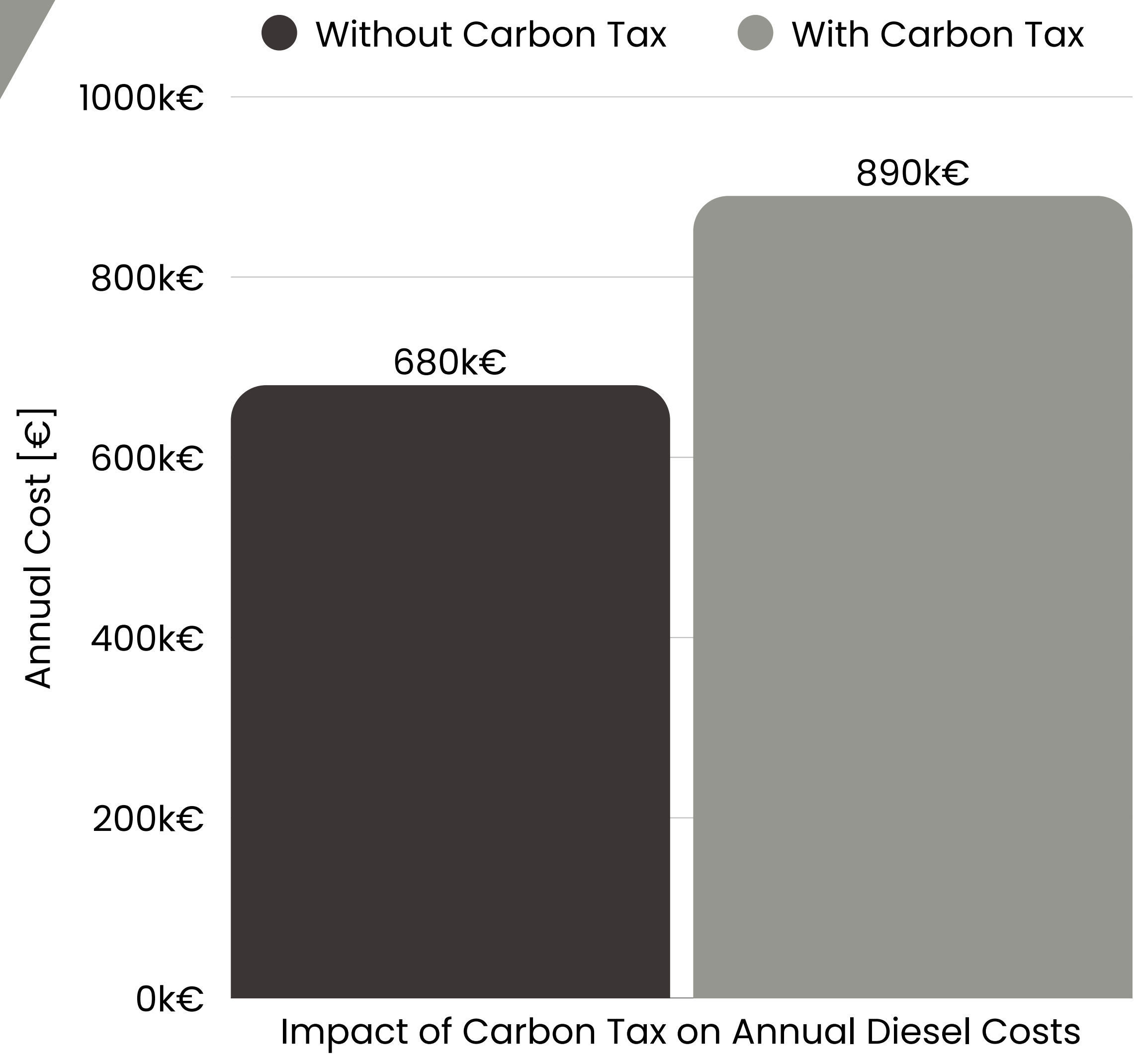
12 round trips per day between Brioude and Clermont-Ferrand

Fuel supplied from **Feyzin refinery** (~175 km distance)

Refueling centralized **in Clermont-Ferrand**

Trains consume **2.000 liters/day of B7** diesel (~753.000 L/year)
~75 refueling trips/year by **tanker truck**

COST & ENVIROMENTAL IMPACT



EMISSIONS BREAKDOWN:

- **Well-To-Tank** (fuel production/refining): **130 gCO_2e/MJe**
- **Tank-To-Wheel** (combustion): **~90 gCO_2e/MJe**
- Total **daily emissions: ~6 tCO_2e/day**
- Annual total: **2.100 $tCO_2e/year$**

LEVELIZED COST OF FUEL

- Without carbon tax:

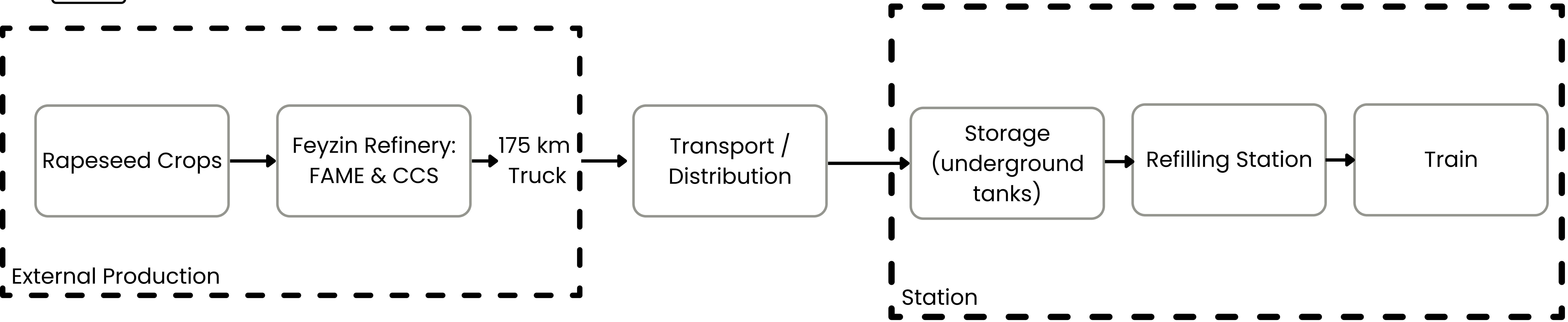
  LCOF = 0,9 €/L → based solely on fuel and transport costs
- With carbon tax (100 €/ton CO_2):

  LCOF = 1,2 €/L → includes additional costs due to emissions

Highly exposed to carbon tax impact → +€200.000/year
Key Issue: **High emissions and long-term cost vulnerability due to fossil fuel dependency**

BIODIESEL TRAIN SCENARIO

The B100 train solution is already being tested and scaled by SNCF, with successful operations on the Paris–Granville line, with biodiesel made from 100% French rapeseed

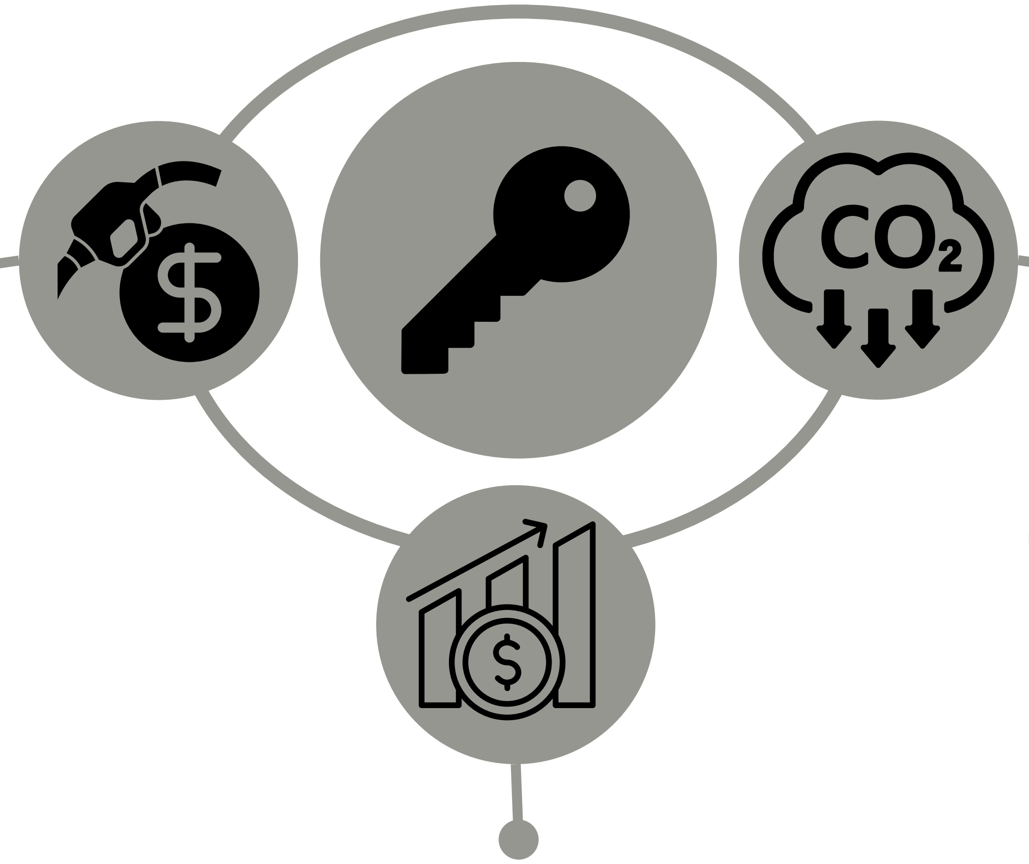


Same trains and infrastructure as diesel scenario ⟶ **no fleet replacement needed**

Fuel from **rapeseed by-products**, FAME type, refined at Feyzin refinery
2.200 liters/day of B100 needed (more consumption due to lower energy density)

~81 refueling trips/year by **tanker truck**

COST & ENVIROMENTAL IMPACT



LEVELIZED COST OF FUEL

- **Without Carbon tax**:
  LCOF: **1,25 €/L** or 0,15 €/kWh
- **Carbon tax impact (100 €/ton CO_2)**:
  LCOF: **1,5 €/L** or 0,20 €/kWh

GLOBAL EMISSIONS:

~**5 tCO_2/day** → 1.840 tCO_2/year

12% less than diesel, thanks to renewable origin of the fuel

OPEX (refining, distribution, electricity) → **total annual cost: €990,000**

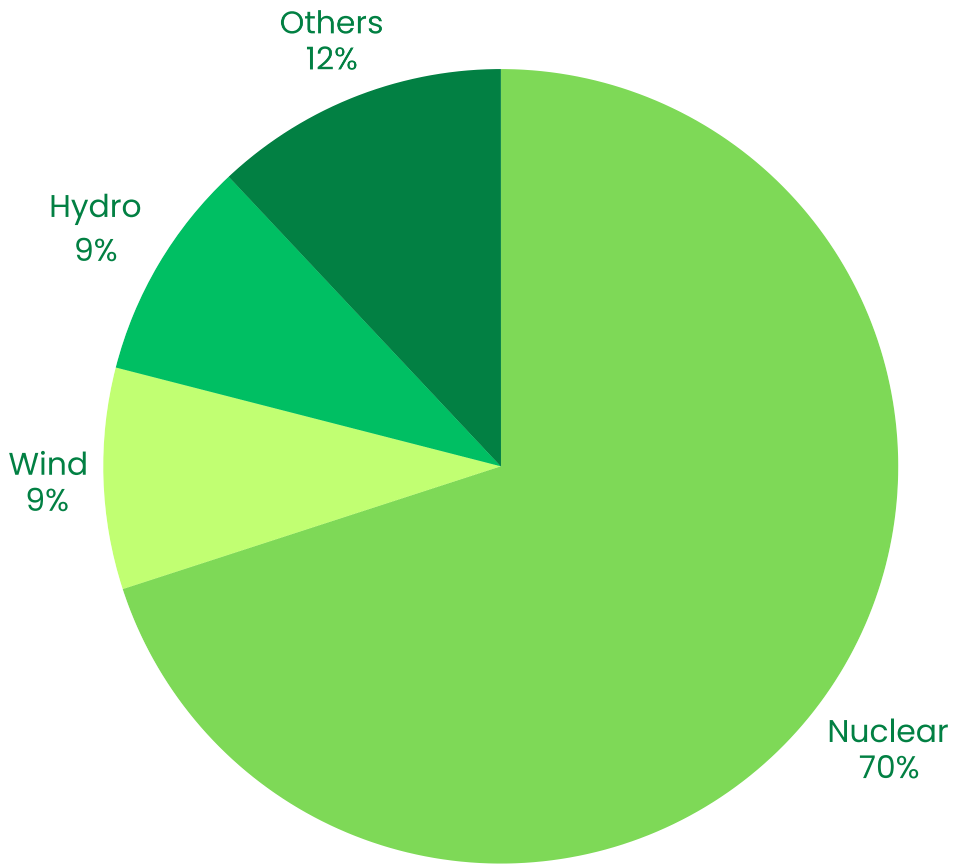
New **total costs with Carbon tax impact: €1.100.000/year**

!

- Despite lower emissions, **cost remains higher than conventional diesel and subject to EU RED II regulatory limits** on biofuels.
- **250 hectares** would need to be cultivated **to supply one year of fuel demand**

BATTERY TRAIN

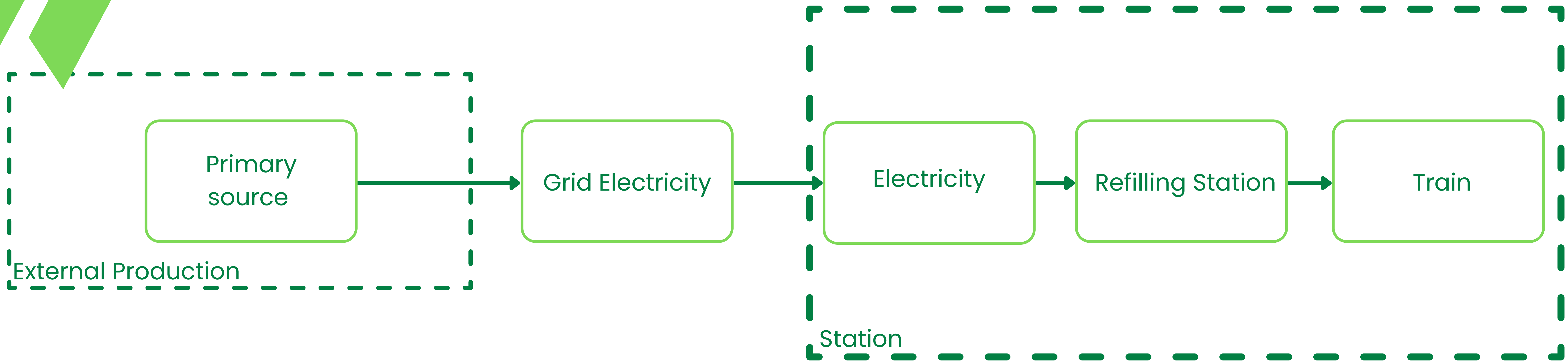
French Energy Mix



21,000 kWh/day of electricity consumed

Charging via **pantograph** at terminal stations
(range < 1 roundtrip)
→ no infra electrification needed, no BESS

BATTERY TRAIN: GRID SUPPLY

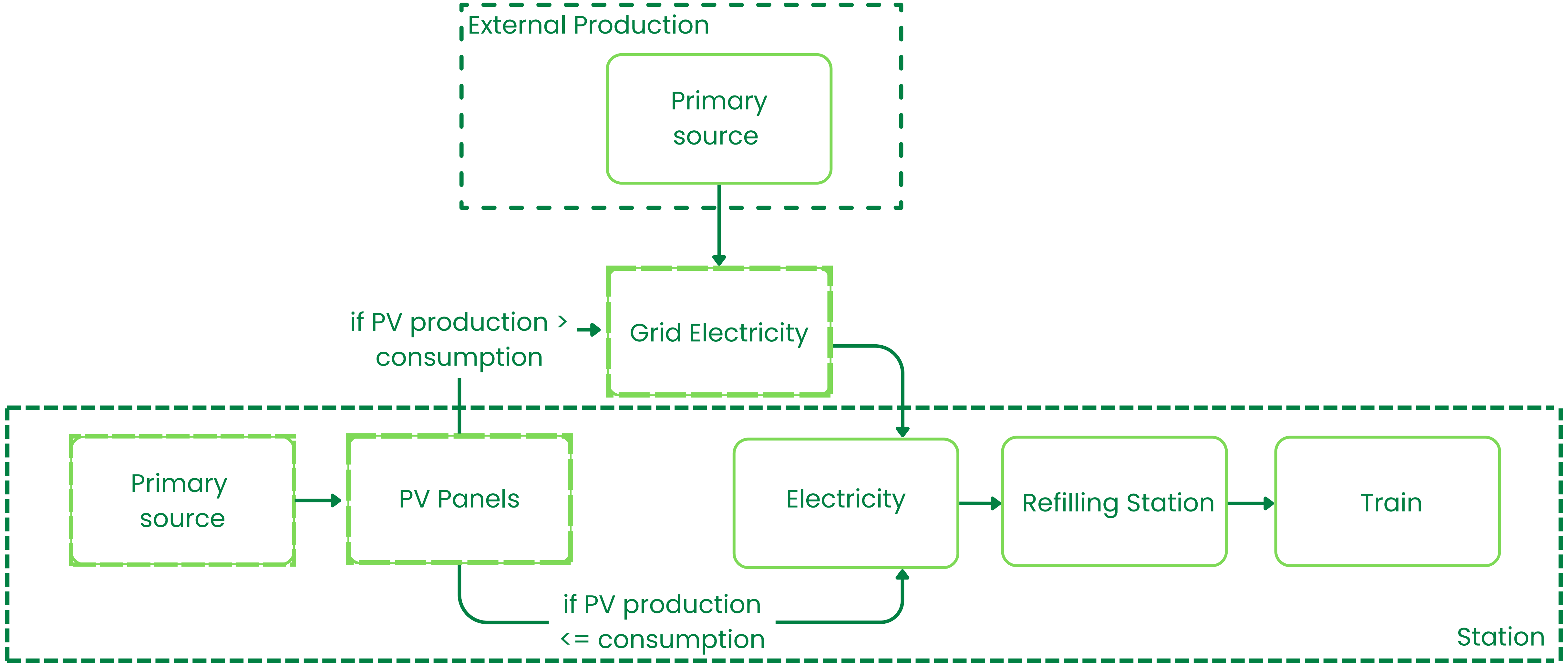


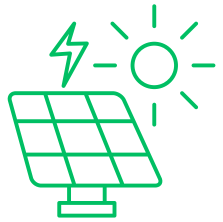
French energetic mix has low carbon impact

Any infrastructure needed, only train replacement, **100% from national grid**

Highly **dependant** on grid (prices and incidents)

BATTERY TRAIN: PV + GRID SUPPLY

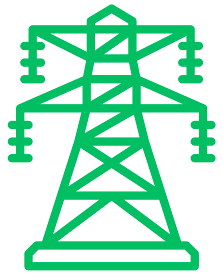




PV system:

- Optimised cost : 49% supplied by PV
- Installed capacity: **7.6 MWp**
- Surface required: ~**2.5 hectares**

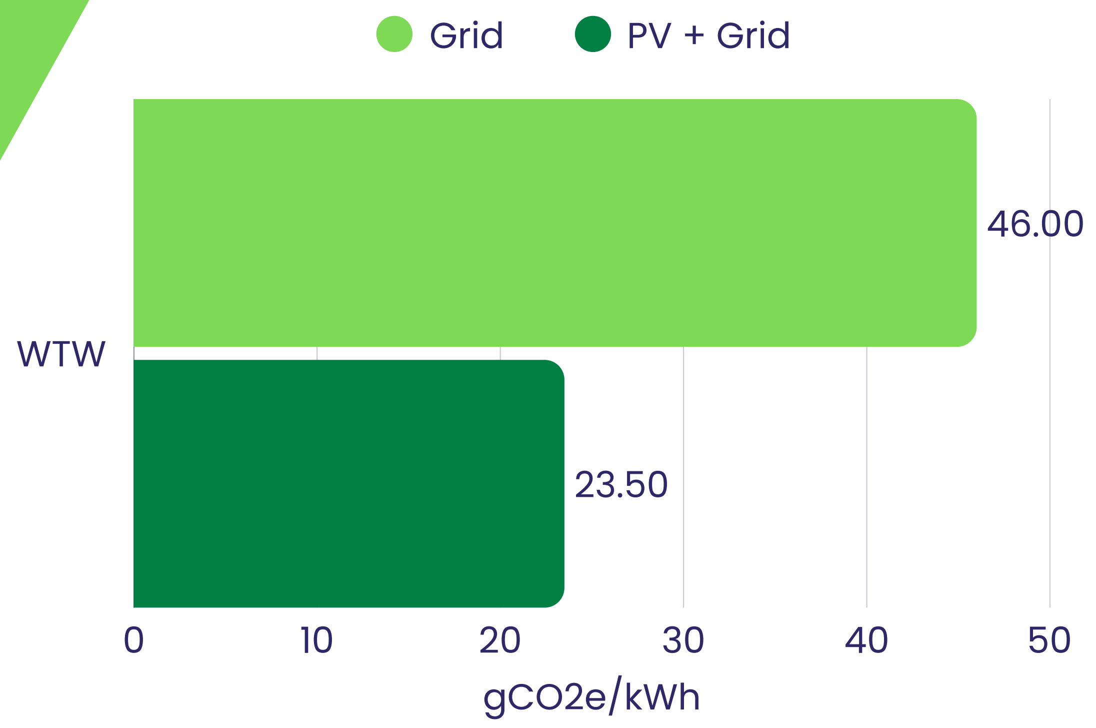
Investment and construction for PV,
Land to find and exploit

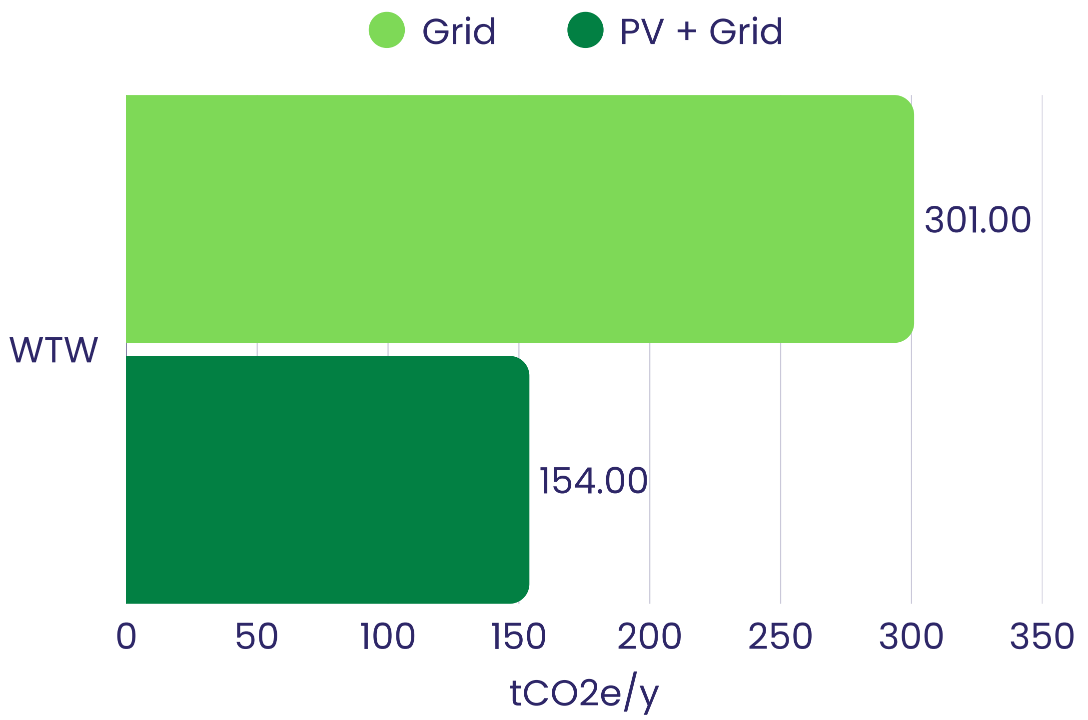


Less dependant on grid,
more renewable

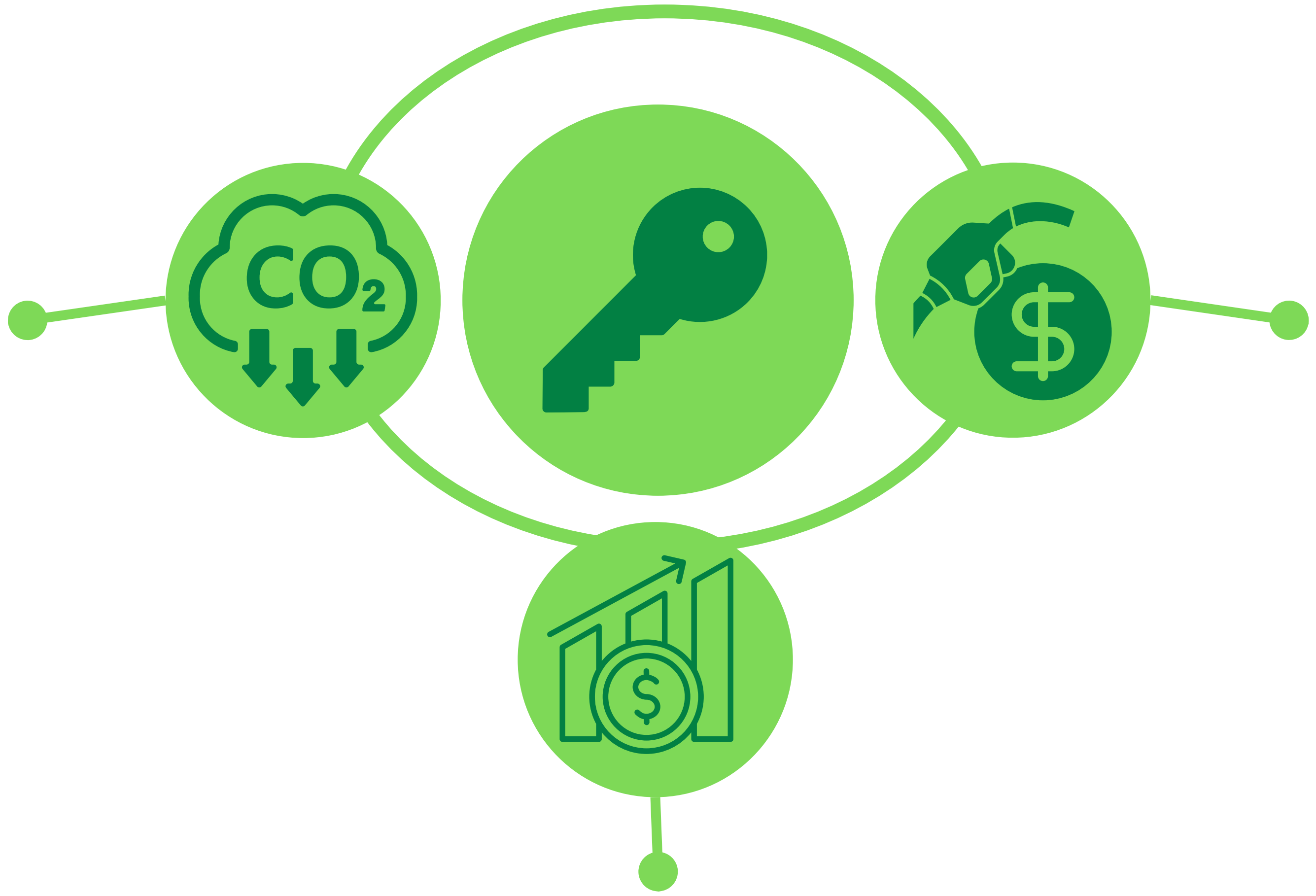
COST & ENVIRONMENTAL IMPACT

Reference : actual energy from dynamic model





PV emissions not accounted



Costs when 100% Grid:
CAPEX = 0€
OPEX EE = 1.3 m€/y

↓

Cost with PV integration:
CAPEX PV = 0.93 m€/y
OPEX PV = 0.12 m€/y ← O&M costs
OPEX EE = -81 k€/y ← Buy/Sell

Cost of EE when 100% Grid:
0.20 €/kWh

↓

Cost of EE with PV integration:
0.17 €/kWh
(assessing sold energy and PV investment)

H2 TRAIN: GRID FED ELECTROLYSIS

Zero Emission Valley and HYmpulsion programs as examples of how H2-powered mobility is already a strategic priority in the region.

External Production: Primary source → Grid Electricity → Station: EE to electrolyzing station → Electrolysis (30 bar)+ compression → Refilling Station (385 bar) → Train tanks (350 bar)

Hydrogen is **produced locally** in Brioude through an **on-site electrolysis plant: daily demand 1140 kg H_2/day**

↓

Prevent transporting H_2 over long distances (Lhyfe facilities)

No storage: H_2 produced and consumed daily, **avoiding compression/cooling**

Evaluation of 2 **different scenario assumptions** for the electolyzer sizing:

1. 188 kg H_2/tank (full refill scenario)
   - Electrolyzer power: 40,5 MW
   - Electrolyzing efficiency ~61.9%

2. 95 kg H_2/roundtrip (realistic consumption)
   - Electrolyzer power: 19,1 MW
   - Electrolyzing efficiency ~66.4%

COST & ENVIROMENTAL IMPACT

1 Full Tank Refill (188kgH_2) 2 Realistic Consumption (95kgH_2/roundtrip)

CAPEX cost: €6.7 million

Carbon tax impact: +€94,000

CAPEX cost: €2.9 million (-72%)

Carbon tax impact: +€88,000

WITHOUT CARBON TAX:

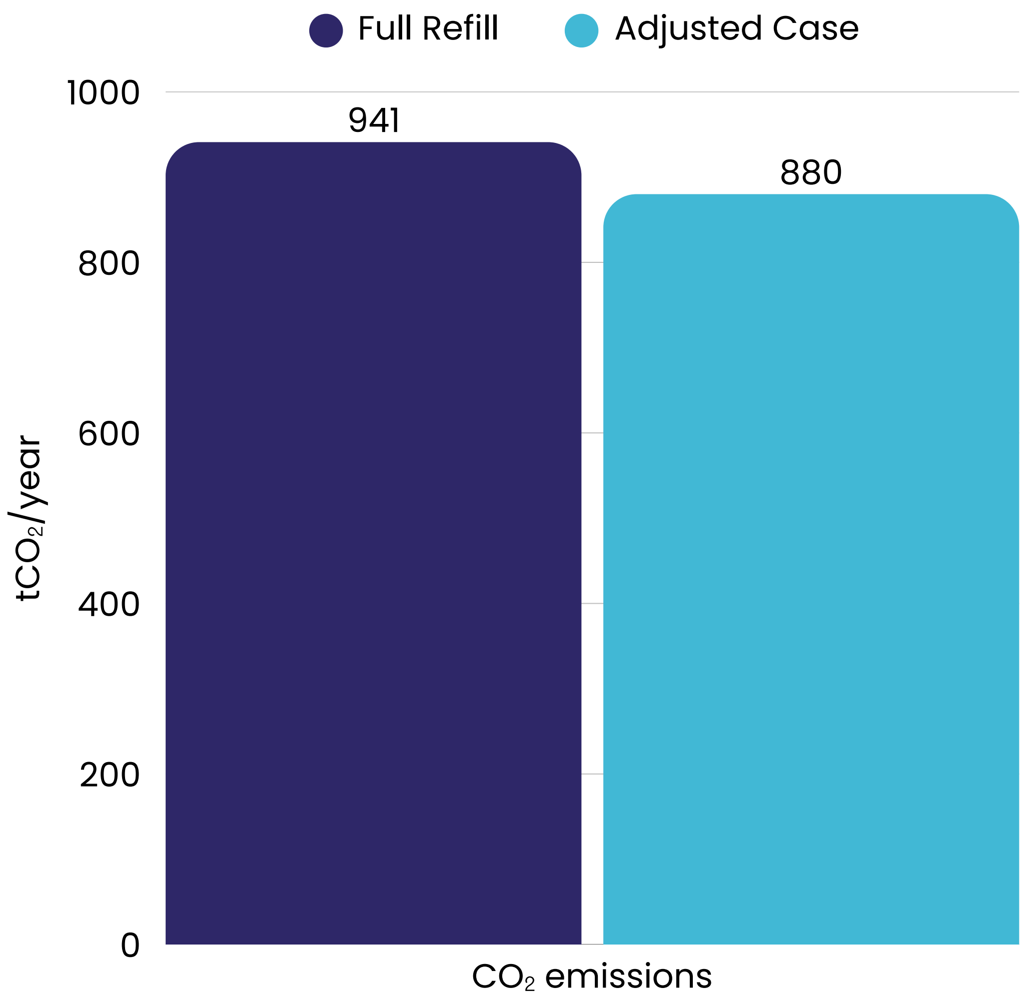
LCOH: 24.65€/kg H_2

LCOH: 16.14€/kg H_2 (-34%)

WITH CARBON TAX:

LCOH: €24.8€/kg H_2

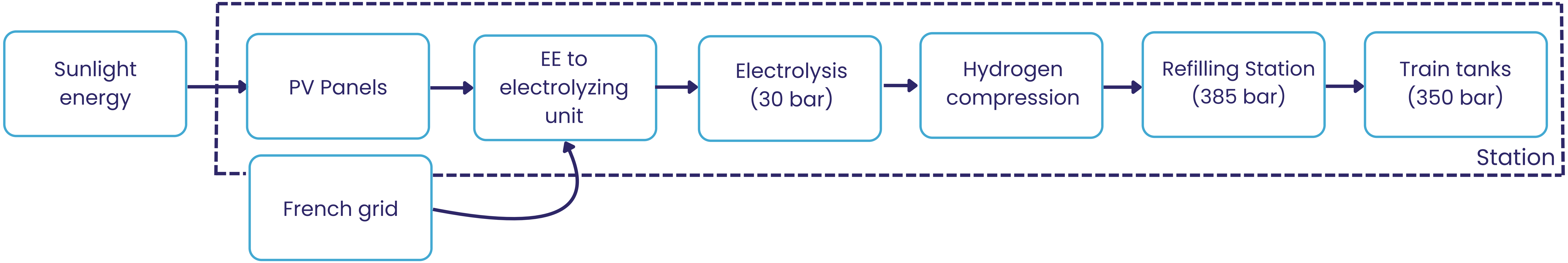
LCOH: €16.35€/kg H_2



The quantity of hydrogen needed to run the service is still the same for both scenario (only a different ELC sizing was assessed), and with it also the overall energy needed for it, its cost and its impact.

This is the reason why the global impact on the environment remains important

H2 TRAIN: PV + GRID SUPPLY



- Same procedure of PV Power optimization used in Battery case
- ~4.5 ha needed to install PV panels

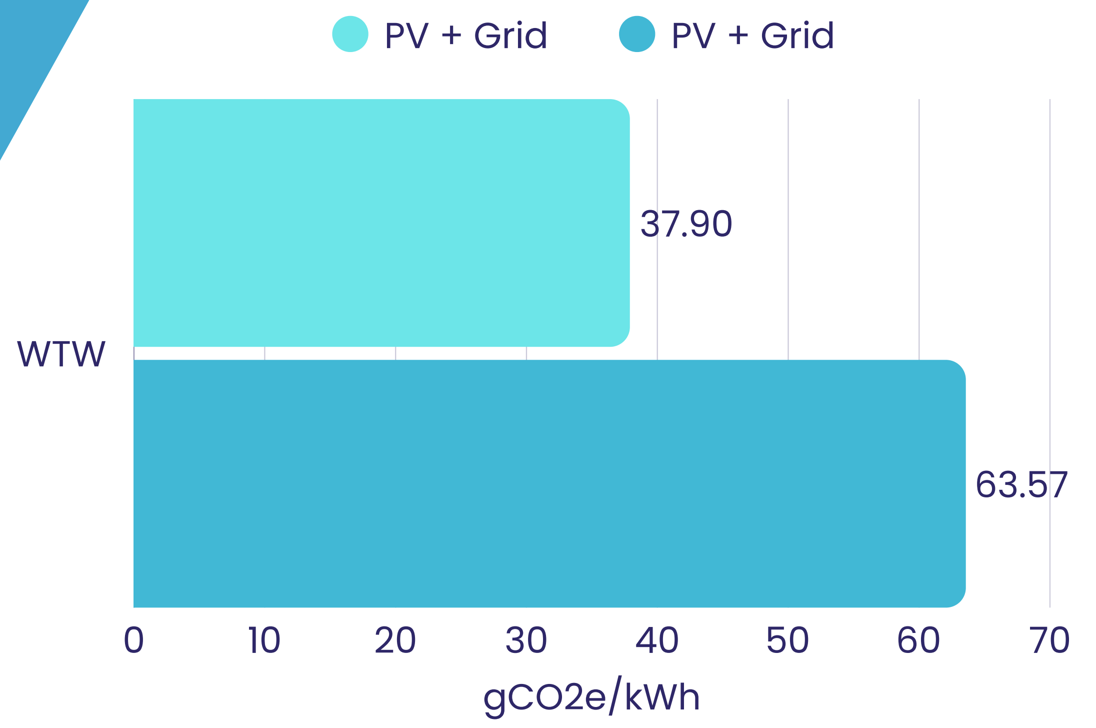
Fuel: **Hydrogen produced** on-site at Brioude station

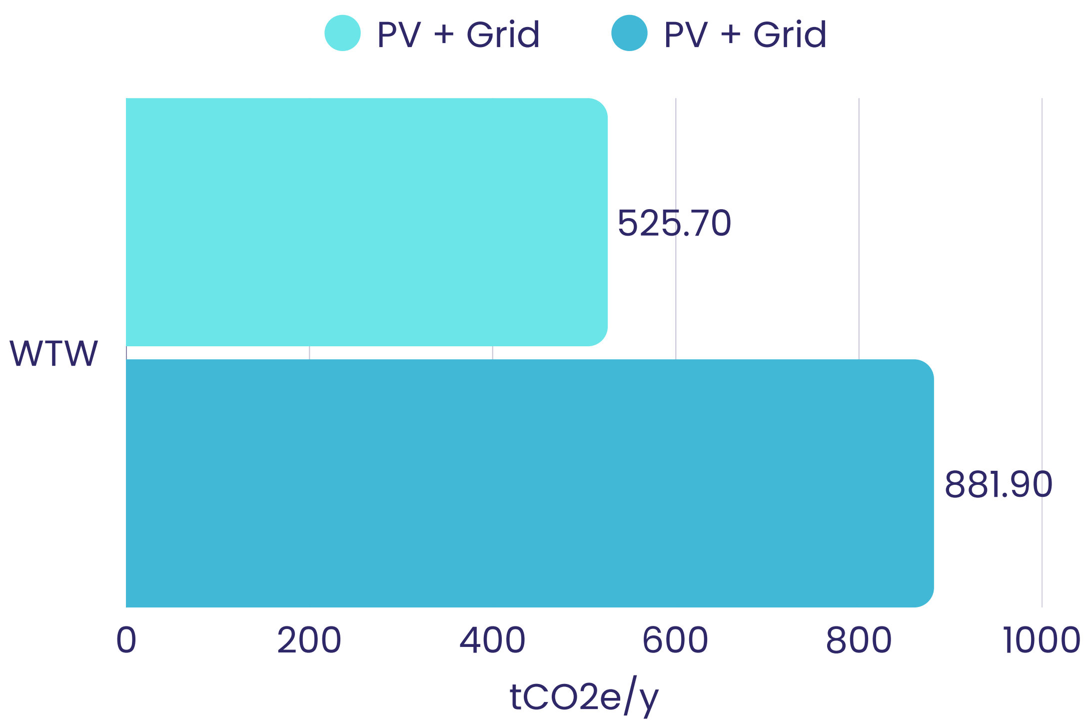
Electrolyzer sized to meet daily peak production
Sizing compliant to the results emerged after **95kg production scenario.**

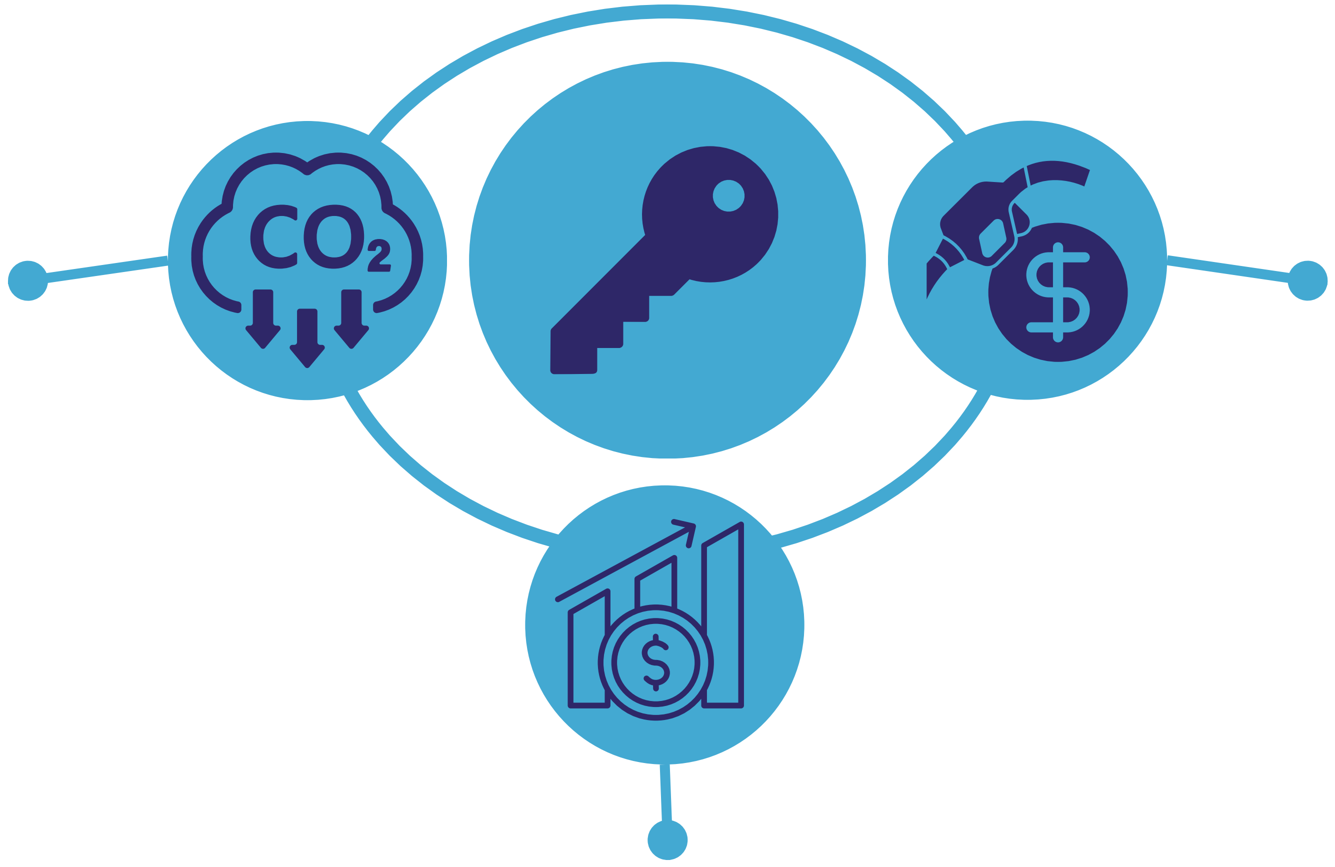
Dual energy source:

- **PV plant** (27,500 panels – 13.75 MWp) ⟶ System covers ~40% of annual H_2 energy demand
- **French grid** during peak demand (parallel operation) ⟶ electricity sold when in excess

COST & ENVIROMENTAL IMPACT







CAPEX (electrolyzer): **€2.92 million/year**
OPEX (EE, free of C-taxes): **€1.04 million/year**
Carbon tax impact (100 €/tCO_2)
→ ~€52,700/year

Cost of Energy reduction reflects also in a strong reduction of LCOH

LCOH when 100% Grid:
16.14 €/kgH2

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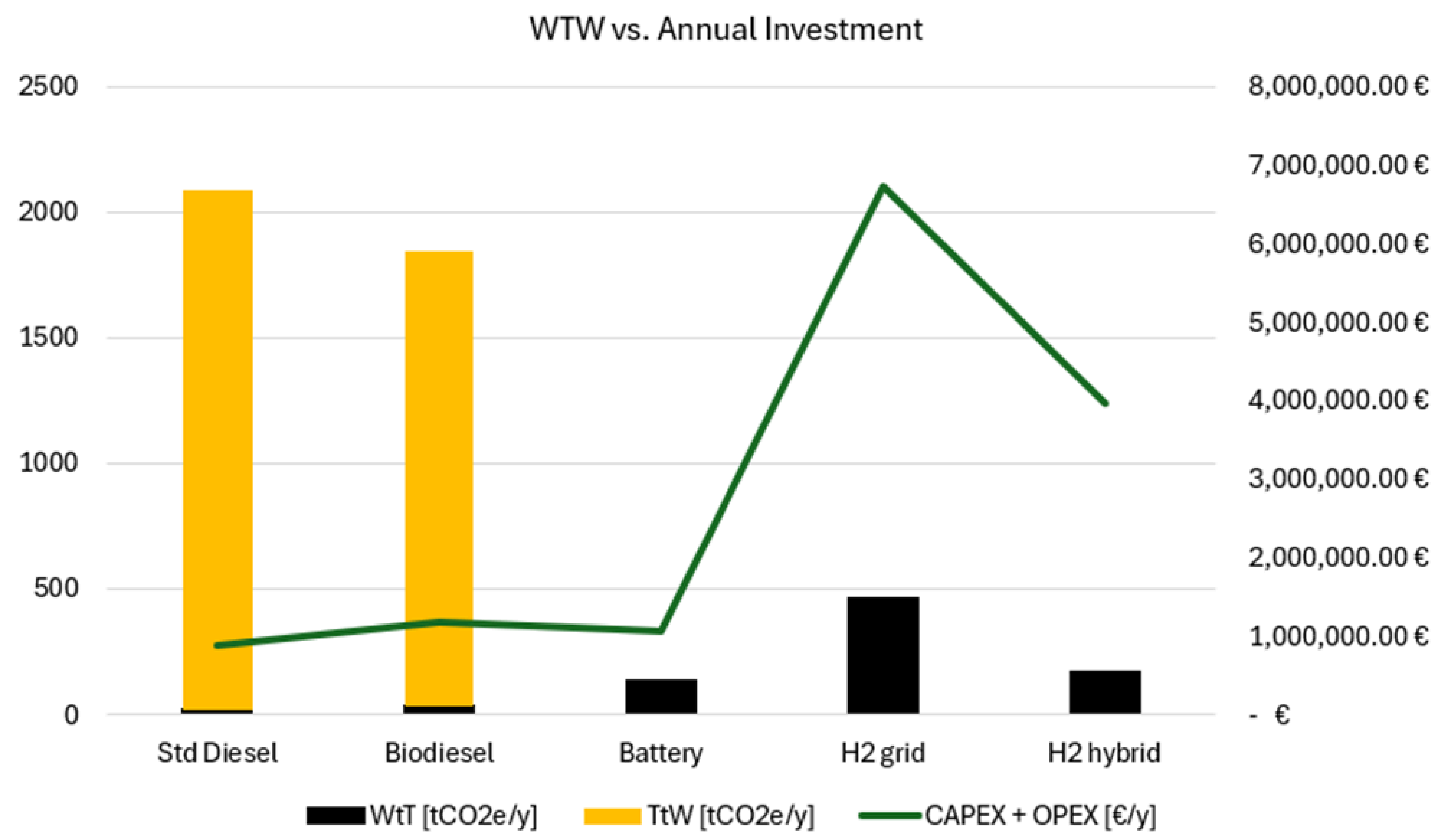
LCOH with PV integration:
9.52 €/kgH2

OPERATIONAL CONSIDERATIONS



Diesel & Biodiesel:

- Lowest operating costs, but **very high TTW emissions**
- Biodiesel reduces TTW emissions slightly, but **still high WTT emissions due to the agricultural and refining cycle**

Battery:

- It has the most balanced profile, with **drastically reduced emissions and low annual costs**
- Effective solution, but with **operational autonomy limits** (train must be recharged every round trip)

Hydrogen (PV + Grid):

- Significant **emissions and costs reduction**
- It is the **best long-term option** and can be integrated **with existing regional infrastructure**

Hydrogen (Grid only):

- **Worst combination** in terms of costs and emissions
- Very **high investment required** (over €6 M/y) with **considerable annual emissions**

CONCLUSIONS

01

Oversized installations
Photovoltaics (up to 13.75 MWp) and **electrolyzer** (up to 40 MW) **are very ambitious** for a single railway line

↓

only **feasible with strong economies** of scale and co-financing.

02

Impulsive production of H_2
The assumption of **production only during refuelling** implies energy peaks that are not compatible with local railway logic

↓

constant production + storage systems could be necessary.

03

Rolling stock costs not included
The analysis does **not consider rolling stock investments** in cases of transition to batteries or hydrogen

↓

underestimated impact on total **CAPEX.**

04

Exclusion of grid-only scenarios
The battery-powered grid-only train was excluded:

- **No environmental benefit** compared to PV + grid mix
- Similar energy cost, **higher grid dependency**

Thank You

For Your Attention