Green Hydrogen vs Electrification in Bus Fleets

A presentation of the Enabling Support Tool (EST)

Tadgh Cummins, Tim Williamson, Branca Arthur Delmonte

Background

- Public transport sector accounts for approx. 6% of global GHG emissions and can be hard to electrify – Potential for green hydrogen

- Acquisition of new diesel vehicles to be banned in 2035 (EU) and 2030 (Ireland)

- 92% of buses in the EU are still running on diesel

- We need to decarbonise – two prominent technologies:

  - Battery electric bus (BEB)

  - Fuel cell electric bus (FCEB)

Green Hydrogen vs Electrification in Bus Fleets

Why use hydrogen when I could electrify?

BEBs are generally cheaper than FCEBs,
BUT:

BEB = Battery electric bus
FCEB = Fuel cell electric bus
ICEB = Internal combustion engine bus

H_2

H_2

BEBs suffer from range limitations

Additional BEBs and/or more expensive infrastructure required

FCEBs have comparable range to ICEBs: can deal with more energy intensive routes

Mixed Fleet

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What does the Enabling Support Tool do?

Enables bus fleet operators & transport authorities to plan & scope best fleet decarbonisation mix

Assumes first decarbonisation approach will be battery electrification

Portion of the fleet unsuited to battery electrification is identified*

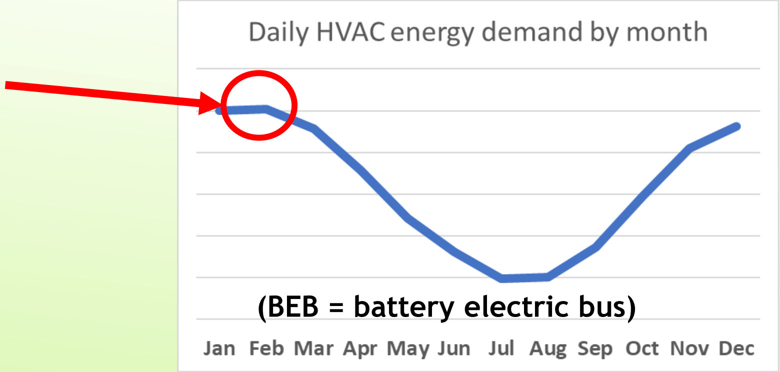
** Due to HVAC loads, utilization rates, passenger & battery weight, steep gradients*

The EST calculates Total Cost of Ownership and Total Cost of Abatement for different decarbonisation options

EST Input process

1
- Select location from list
- Input average operational hours per day

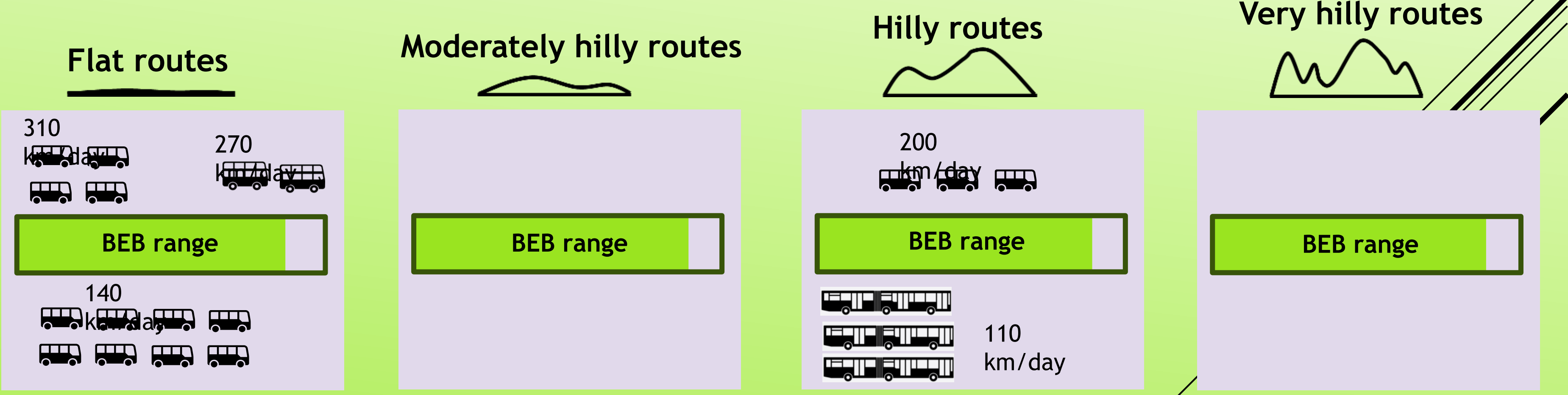
Model estimates worst-day energy demand of HVAC systems



2 ***Buses can be input into four 'hilliness' categories:***

- Three bus sizes can be input:

- Input **number of buses** below BEB range, and an **average daily distance.**
- Repeat for buses below range of BEB



3
- Other inputs: price of electricity, diesel, hydrogen

This input process circumvents the need for complex drive cycle inputs, while still capturing the essential fleet data required to compare & combine BEBs & FCEBs in a mixed fleet

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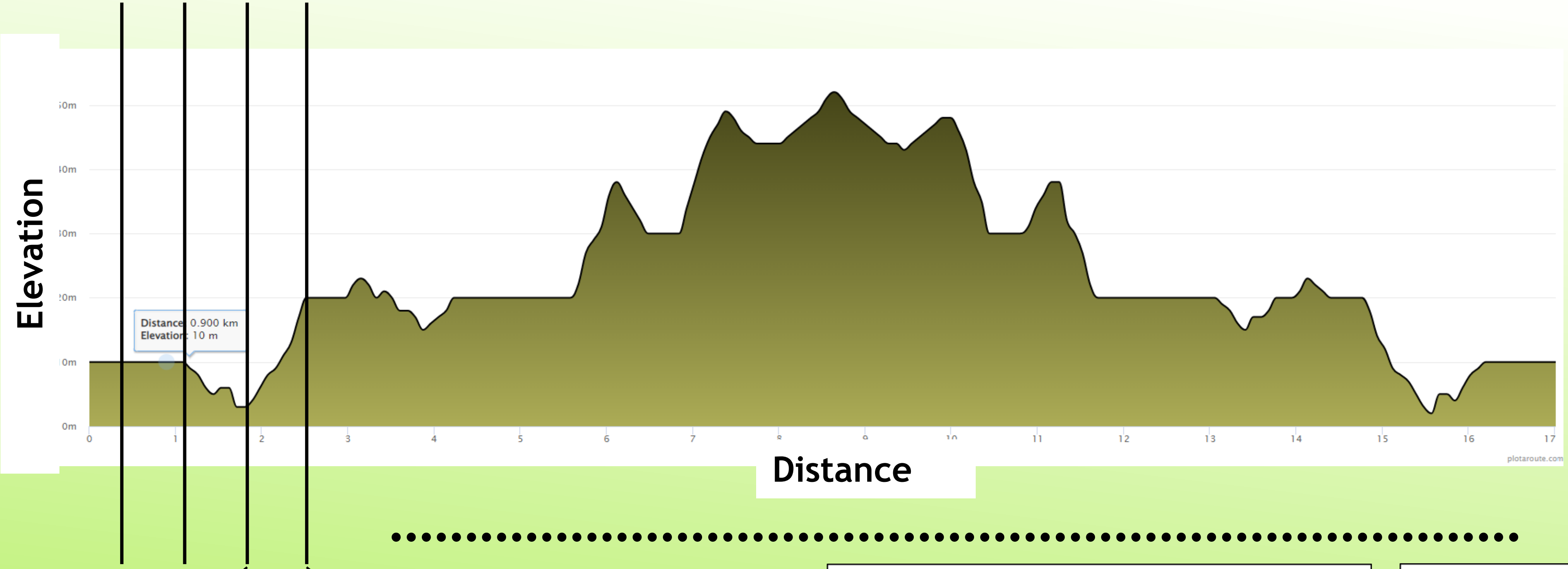
Categorising route hilliness



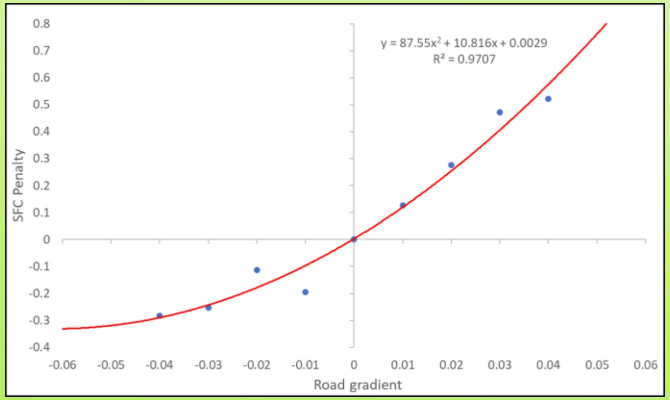
p_{ICEB}

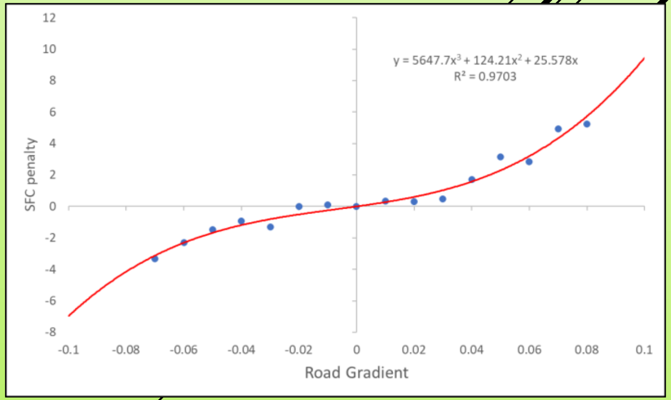
p_{BEB}

p_{FCEB}

…

- Calculate fuel consumption penalty for each bus type using correlations:





- Calculate **average fuel consumption penalty** for the route profile for each bus type

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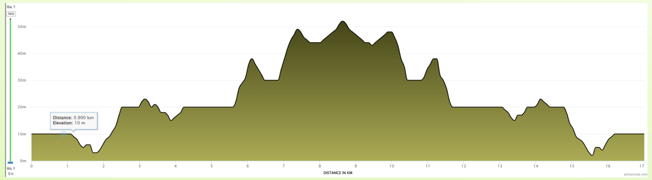
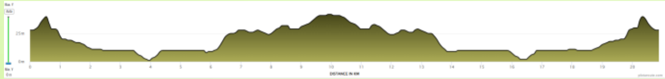
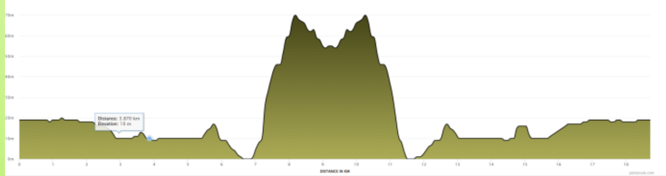
Categorising route hilliness

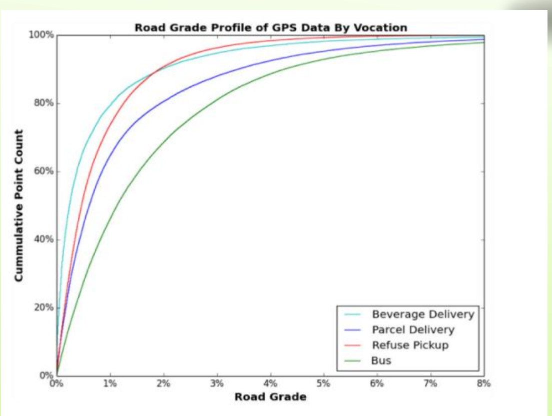






- **Repeat for several route profiles across a range of different gradients (within reason) ->**

  - **Based on the analysis, four categories of hilliness were chosen based on the SFC penalty experienced by a BEB**



'Evaluating the Impact of Road Grade on Simulated Commercial Vehicle Fuel Economy Using Real-World Drive Cycles' (Lopp, Wood et al. 2015).

Hilliness category definitions

Hilliness Category	BEB SFC penalty range	p_{BEB}	p_{ICEB}	p_{FCEB}	BEB range
H_1 – Flat	$0 \leq p < 0.02$	0	0	0	X_1
H_2 – Moderately hilly	$0.02 \leq p < 0.1$	0.055	0.04	0.0176	X_2
H_3 – Hilly	$0.1 \leq p < 0.2$	0.15	0.1	0.048	X_3
H_4 – Very hilly	$0.2 \leq p < 0.4$	0.3	0.23	0.096	X_4

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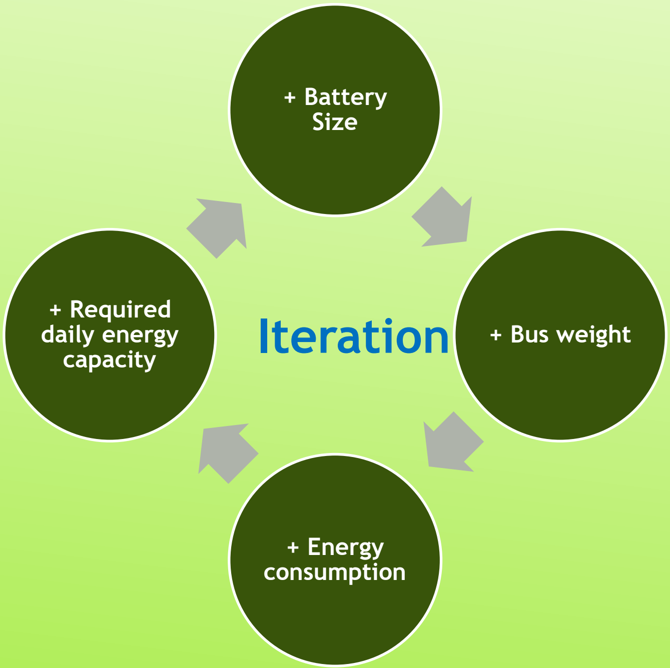
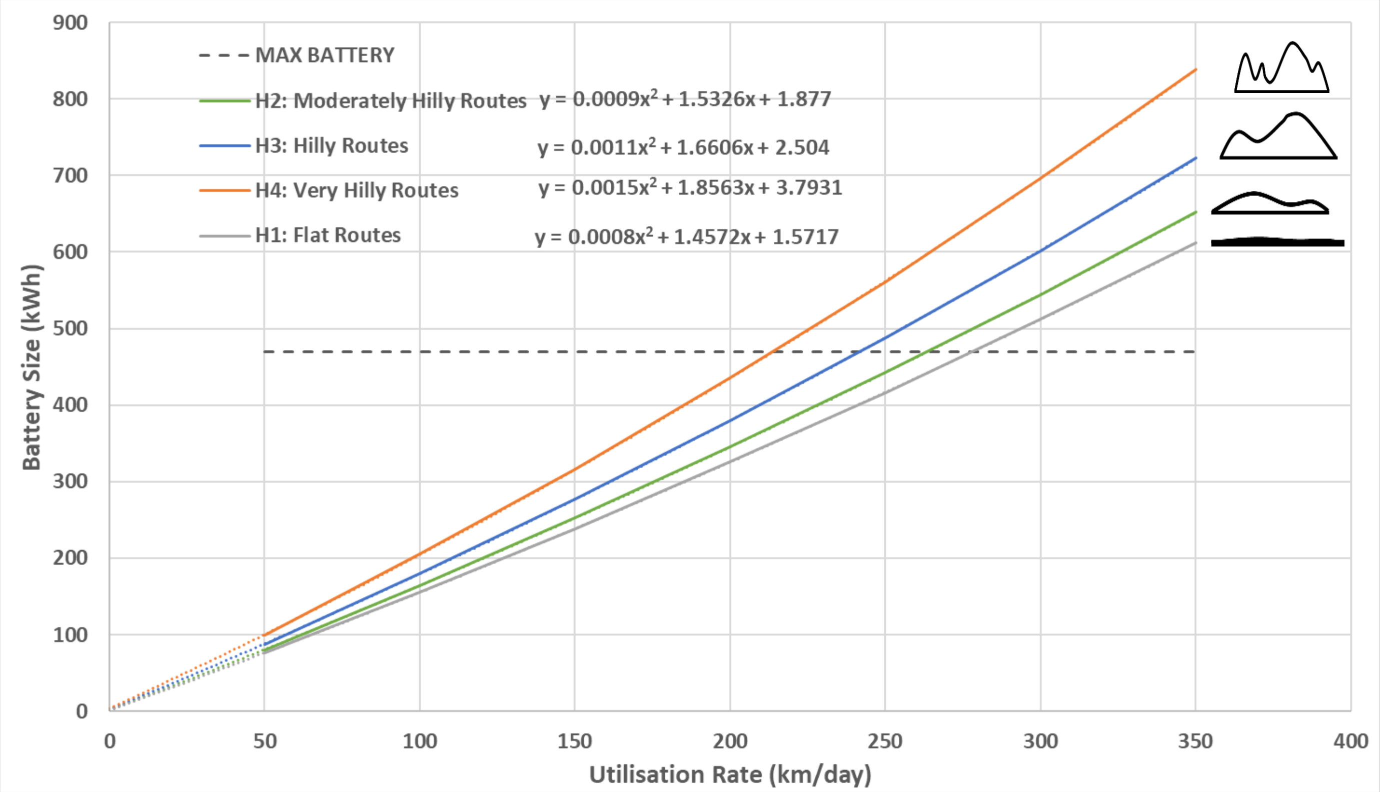
Battery sizing

- Batteries are sized using polynomial correlations
- These were developed based on iterative calculations for battery size for a range of utilisation rates





- - - MAX BATTERY

➢ This determines when an extra electric bus is needed

Galway city fleet

1

- Select location from list
- Input average operational hours per day

Model estimates worst-day energy demand of HVAC systems

Maximum range of BEB is reduced

BEB range (km/day) -29km

2

Buses can be input into four 'hilliness' categories:

Flat routes

BEB range: 245 km

Moderately hilly routes

×15 268 km/day

BEB range: 233 km

×16 166 km/day

Hilly routes

BEB range

Very hilly routes

BEB range

3

- Economic inputs: price of electricity, diesel, hydrogen

H2	2 – 12€/kg
Diesel	1.66€/litre
Electricity	0.23€/kWh

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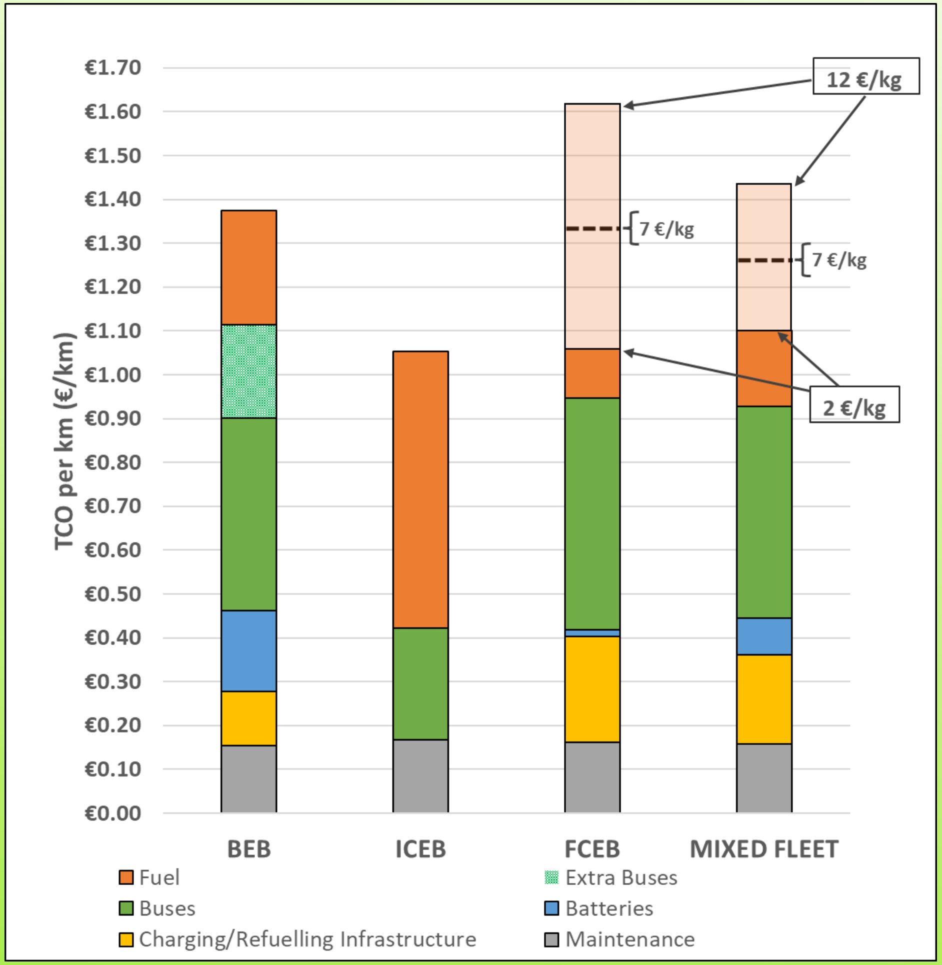
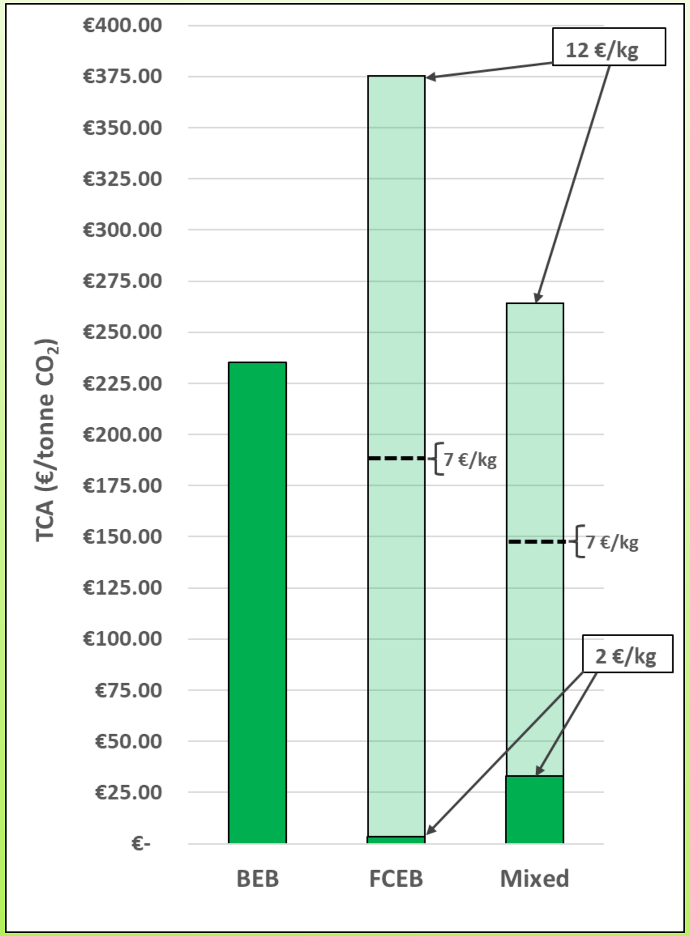
Galway city fleet

Total Cost of Ownership



Total Cost of Abatement



- BEB fleet requires **+15 additional buses** due to short range of double-deck BEBs
- BEB fleet charging station peak power draw: **1.8 MW**, requiring a ~€350k substation upgrade

- FCEB cost parity with:
  - BEB at **7.70 €/kg**
  - ICEB at **1.90 €/kg**

- The **mixed fleet becomes the cheapest option** after diesel at a hydrogen price of **~10 €/kg***

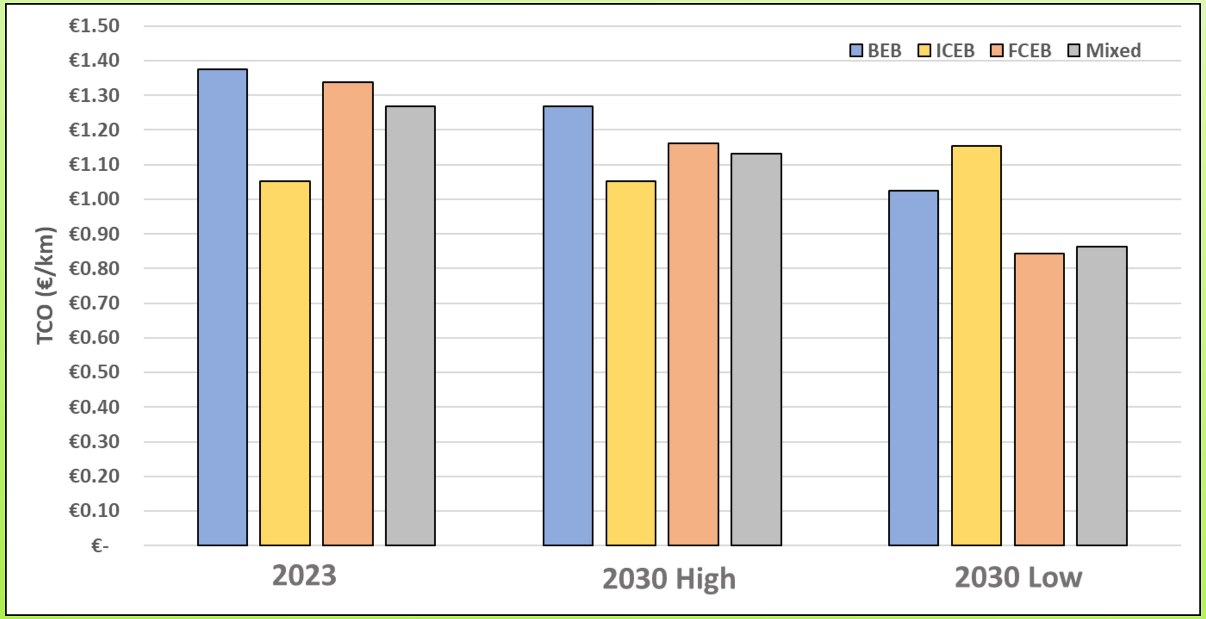
**** These are unpublished results***

Galway city 2030

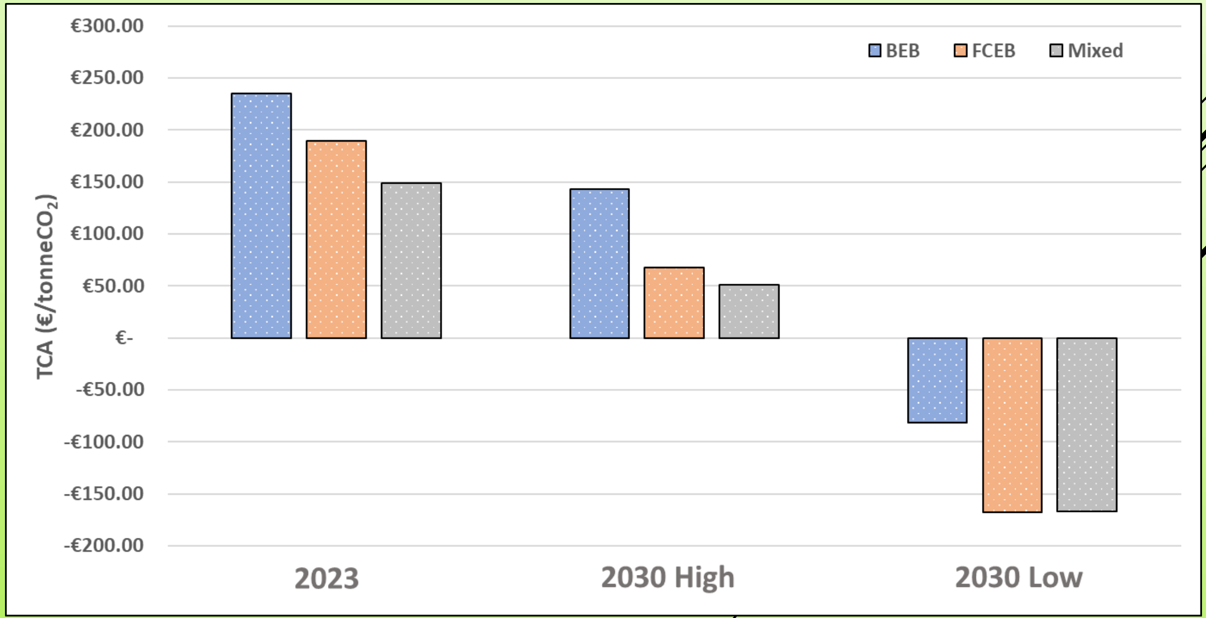
- FCEB & BEB technology & infrastructure costs are declining, ICEB technology has matured
- Two scenarios were developed to investigate possible 2030 costs:

2030-High (pessimistic), **2030-Low** (optimistic)

Total Cost of Ownership



Total Cost of Abatement



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** These are unpublished results*

Summary

- The transition to **zero-emission bus fleets** is accelerating
- The Enabling Support Tool was developed to **aid decision-making** in this transition
- **Electrification** is currently the cheaper option on a bus-by-bus basis (in most cases)
- **Green hydrogen** is currently more expensive, but has many potential benefits on the fleet-level
- **Double-deck** FCEBs are particularly suited to green hydrogen and can be cheaper than double-deck BEBs on the fleet-level
- Fleet operators and transport authorities should consider a **mix of electrification and green hydrogen** when planning zero-emission fleets

The online Enabling Support Tool

A simplified* version of the EST techno-economic model is available on the CH2F website:

https://communityh2.eu/

*No substation costs, fixed bus-to-charger ratio, same surface area for all bus sizes