Can diesel-hydrogen dual fuel vehicles and hydrogen internal combustion engine vehicles play a stopgap role in decarbonising road freight transport?

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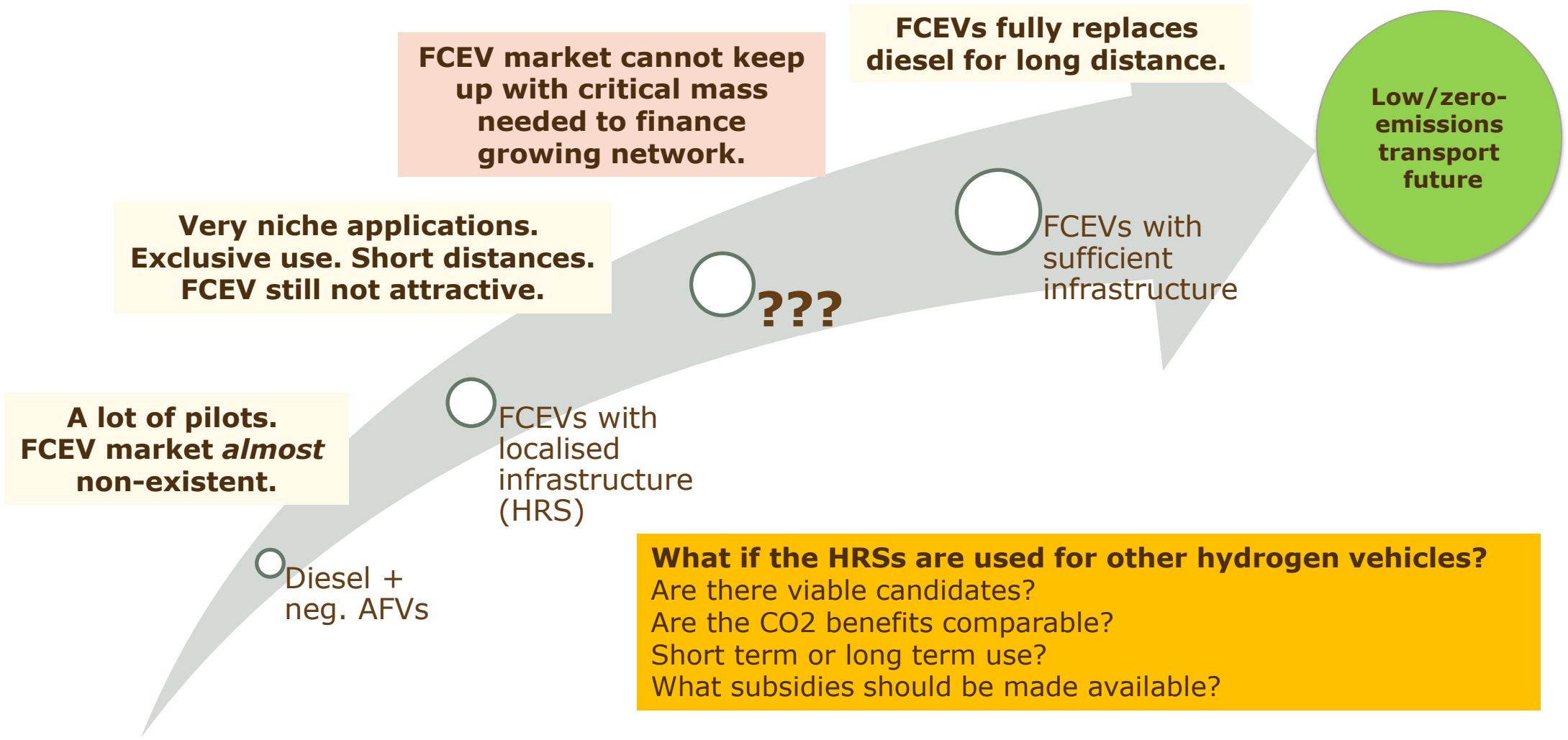
Context of the study: Roadmap to Zero-Emissions Road Transport



What if the HRSs are used for other hydrogen vehicles?
Are there viable candidates?
Are the CO2 benefits comparable?
Short term or long term use?
What subsidies should be made available?

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Outline

Study objective:

The evaluation compares the total cost of ownership (TCO) and CO2 emissions of the diesel-hydrogen dual fuel vehicle (DFV) and hydrogen internal combustion engine (H2ICE) with the diesel vehicle (DV), battery electric (BEV) and fuel cell electric vehicle (FCEV).

Approach

- TCO approach, based on Panteia's TCO tool developed for Dutch Topsector Logistics (https://www.topsectorlogistiek.nl/download/tco-vracht/)
- Well-to-wheels CO2 calculation (also calculates PM, NOx)

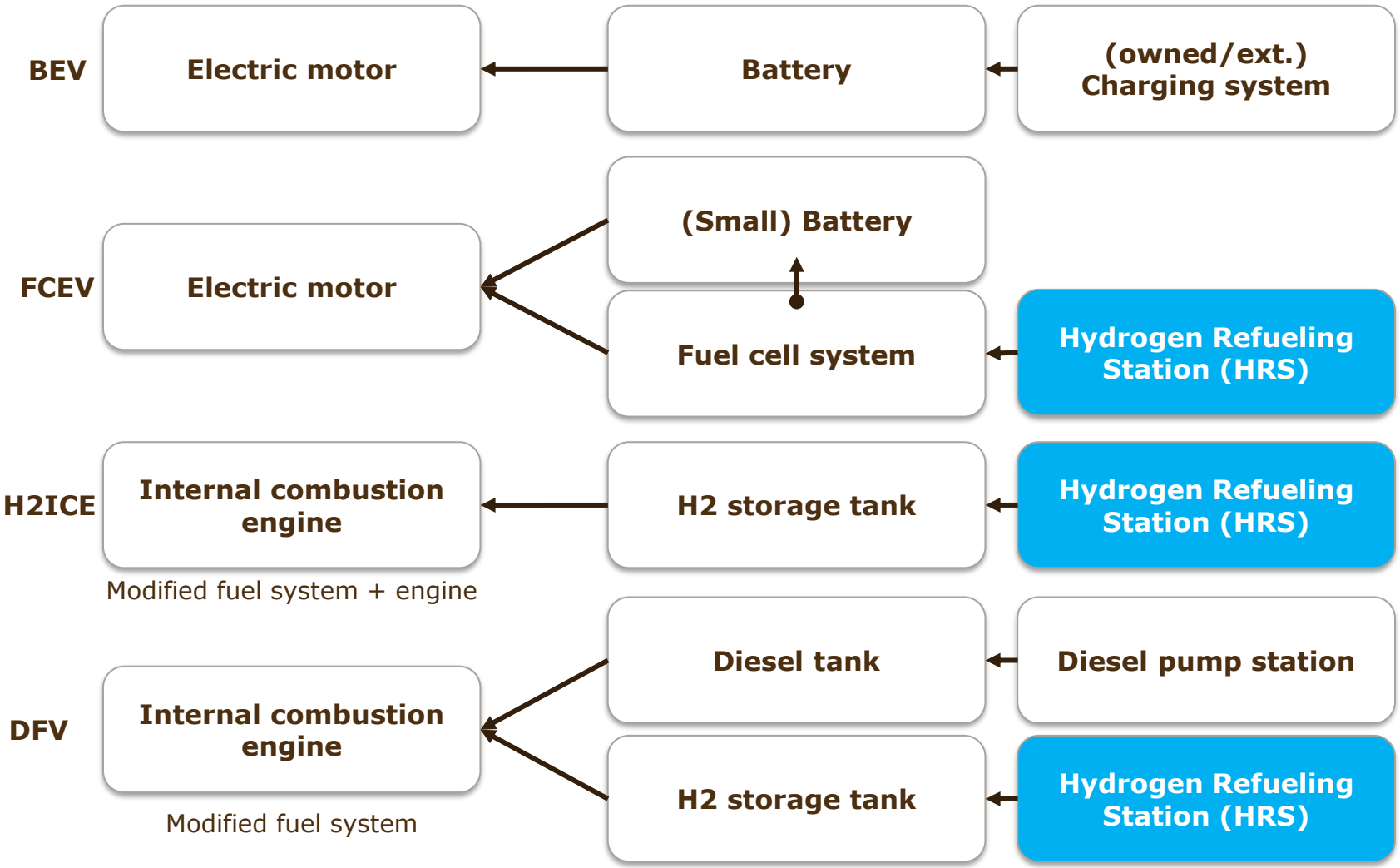
Results and discussion

- Three mission profiles for a tractor-trailer vehicle
- Subsidy analysis

Conclusions

- Viability for short/long term, CO2 benefits, subsidy

Vehicle technology



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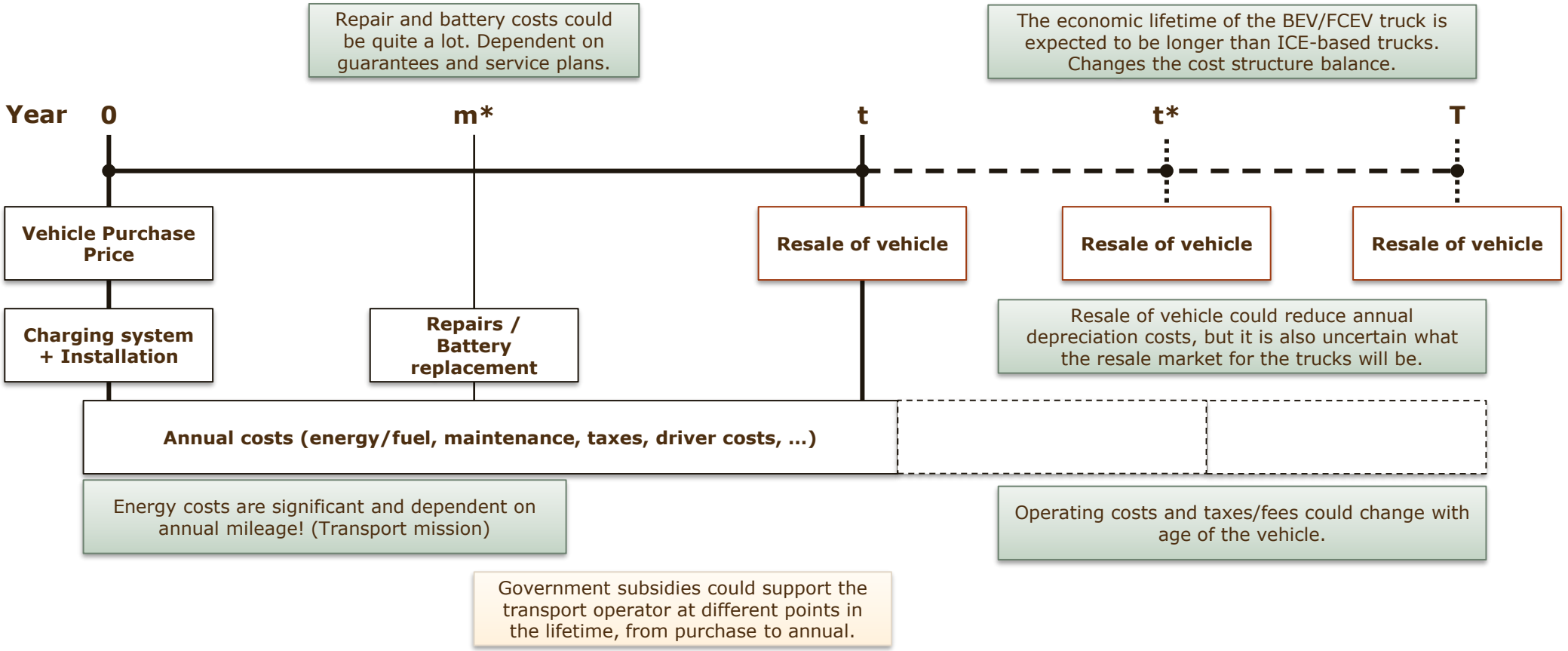
Total cost of ownership approach

TCO approach considers all costs (see fig.) over the service lifetime of the vehicle.
Useful for balancing out the importance of the initial investment costs and the usage costs.



m is the time for major repairs or battery replacement*

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Excel tool – input and summary results

TRANSPORT OPERATION CONTEXT

Vehicle type	Trekker-oplegger	
Refrigeration	niet gekoeld	
Expected kilometrage	100.000	km/year
Grey/green electricity	Groen	
Environmental level of hydrogen	Electrolysis RE	

Start nieuwe berekening

VEHICLE SYSTEM DATA

	Diesel vehicle	Electric vehicle	Fuel cell electric vehicle	Dual fuel vehicle	H2-ICE vehicle
Economic lifetime	7 Years	10 Years	10 Years	7 Years	7 Years
Resale value					
Productive hours per year	2.600	2.600	2.600	2.600	2.600
Cost for repairs	€ 1.500	€ 5.000	€ 10.000	€ 1.500	€ 1.500
Downtime days per year					
Charging power (kW)					
Battery capacity (kWh)					
Hydrogen storage tank (kg)				16,8	84
H2ICE-variant					H2ICE-SI

BASIC PRICE ASSUMPTIONS

SYSTEM PURCHASE

	Electric vehicle	Fuel cell electric vehicle	Dual fuel vehicle	H2-ICE vehicle
Vehicle	Trekker-oplegger 440 kWh	Trekker-oplegger 300 kW	Trekker-oplegger DF 17 kg	Trekker-oplegger H2ICE-SI 84 kg
Gross price				
Subsidy				
Net price	€ 370.416	€ 464.216	€ 164.000	€ 198.660

alle bedragen excl. BTW

	Private charging system
Gross purchase price	
Gross installation price	
Subsidy	
Net price	€ 29.000

ENERGY PRICE

	Diesel: euro/litre	Charging price: euro/kWh	Hydrogen: euro/kg
Energy price			

RESULTS

Scenario Scenario technically possible	Diesel Scenario valid	EV Optimale mix Scenario valid	Waterstof voertuig Scenario valid	Dual fuel vehicle Scenario valid	H2-ICE vehicle Scenario valid
Vehicle	Trekker-oplegger	Trekker-oplegger 440 kWh	Trekker-oplegger 300 kW	Trekker-oplegger DF 17 kg	Trekker-oplegger H2ICE-SI 84 kg
Private energy supply	nvt	FC50	nvt	nvt	nvt
Public energy supply	nvt	HPC150	nvt	nvt	nvt
Reliance on private energy supply	nvt	54%	nvt	nvt	nvt
Reliance on public energy supply	nvt	46%	nvt	nvt	nvt
Total cost per year	€ 176.707	€ 216.308	€ 335.079	€ 203.718	€ 337.027
Total cost per km	€ 1,77	€ 2,16	€ 3,35	€ 2,04	€ 3,37
Total cost per hour	€ 67,96	€ 83,20	€ 128,88	€ 78,35	€ 129,63
Emissions per year					
CO2 emissions (tonne per year, Well-to-Wheel)	102,85	-	-	68,57	-
PM exhaust and tires (kg per year, Tank-to-Wheel)	8,32	6,82	6,82	7,82	6,82
NOx (kg per year, Tank-to-Wheel)	146,06	-	-	146,06	146,06

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Excel tool - Detailed breakdown of costs

COST BREAKDOWN												
Fixed vehicle costs per year												
Road tax		€	840	€	-	€	-	€	840	€	-
Eurovignette		€	1.250	€	1.250	€	1.250	€	1.250	€	1.250
Vehicle financing Interest		€	3.714	€	8.534	€	12.787	€	4.104	€	5.106
Insurance		€	4.624	€	11.853	€	17.761	€	5.248	€	6.357
ZE vehicle tax		€	-	€	-	€	-	€	-	€	-
Miscellaneous costs		€	69	€	69	€	69	€	69	€	69
a: Total fixed vehicle costs per year		€	10.497	€	21.706	€	31.866	€	11.511	€	12.782
Variable vehicle costs per year												
Vehicle depreciation		€	14.759	€	31.414	€	47.069	€	17.545	€	20.291
Vehicle fuel costs		€	38.102	€	-	€	-	€	25.401	€	-
Charging costs		€	-	€	24.403	€	-	€	-	€	-
H2 costs		€	-	€	-	€	114.413	€	31.212	€	165.490
Adblue costs		€	667	€	-	€	-	€	560	€	667
Tires		€	3.920	€	3.920	€	3.920	€	3.920	€	3.920
Maintenance		€	8.010	€	3.044	€	19.412	€	9.091	€	11.012
Repair		€	1.500	€	5.000	€	10.000	€	1.500	€	1.500
Repair/maintenance for refrigeration unit		€	-	€	-	€	-	€	-	€	-
ZE road-based charge		€	-	€	-	€	-	€	-	€	-
CO2 tax		€	-	€	-	€	-	€	-	€	-
Specific transport costs		€	935	€	935	€	935	€	935	€	935
b: Total variable vehicle costs per year		€	67.893	€	68.716	€	195.749	€	90.164	€	203.815
Cost for charging system per year												
Purchase and installation		€	-	€	16.800	€	-	€	-	€	-
Operational costs		€	-	€	8.400	€	-	€	-	€	-
c: Total cost charging system per year		€	-	€	25.200	€	-	€	-	€	-
Total vehicle and charging system costs per year (a+b+c)		€	78.390	€	115.622	€	227.615	€	101.675	€	216.596
Total vehicle and charging system costs per km		€	0,78	€	1,16	€	2,28	€	1,02	€	2,17
Total vehicle and charging system costs per hour		€	30,15	€	44,47	€	87,54	€	39,11	€	83,31
Driver costs												
Salary inc. social obligations	27,13	€	70.538	€	83.120	€	70.538	€	70.538	€	70.538
Accomodation allowance	0,85	€	2.210	€	2.604	€	2.210	€	2.210	€	2.210
Miscellaneous costs	0,46	€	1.196	€	1.409	€	1.196	€	1.196	€	1.196
d: Total driver costs per year		€	73.944	€	87.134	€	73.944	€	73.944	€	73.944
Total direct costs per year (a+b+c+d)		€	152.334	€	202.756	€	301.559	€	175.619	€	290.540
Total direct costs per km		€	1,52	€	2,03	€	3,02	€	2,89	€	2,89
Total direct costs per hour		€	58,59	€	77,98	€	115,98	€	67,55	€	111,75
General overhead costs												
Salary inc. social obligations	8,4%	€	12.796	€	17.032	€	25.331	€	14.752	€	24.405
Facility	2,6%	€	3.961	€	5.272	€	7.841	€	4.566	€	7.554
Miscellaneous	5,0%	€	7.617	€	10.138	€	15.078	€	8.781	€	14.527
e: Total overhead per year		€	24.373	€	32.441	€	48.249	€	28.099	€	46.486
Total cost per year (a+b+c+d+e)		€	176.707	€	235.197	€	349.809	€	203.718	€	337.027
Total cost per km		€	1,77	€	2,35	€	3,50	€	2,04	€	3,37
Total cost per hour		€	67,96	€	90,46	€	134,54	€	78,35	€	129,63

Summary of key differences in TCO

Categories	DV	BEV	FCEV	DFV	H2ICE
Purchase price	DV price: €145k	DV price Battery: €400/kWh	DV price Battery Fuel cell system: €210/kW H2 storage tank €908/kg	DV price Fuel control system: €3.5k H2 storage tank: €833/kg	DV price Fuel control system H2 storage tank: €908/kg
Additional infrastructure cost	-	Private charging system	-	-	-
Energy price	Diesel: €1.20	Private: € 0.08 Public: € 0.30	H2: €11.56 (Green) or €7.56 (Grey)	*Diesel *H2	H2
Energy efficiency	40%	85%	45%	42%	31%
CO2 emissions	Diesel: 3.24 kg/L	Grid average: 0.37 kg/kWh Renewable: 0	Grey: 11 kg/kg H2 Green: 0	*Diesel *Grey or Green H2	Grey or Green H2

*DFV: ratio of energy H2 to Diesel is 30:70.

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Transport mission 1: Short trips (25 km), low annual mileage (50k)

Vehicle system:

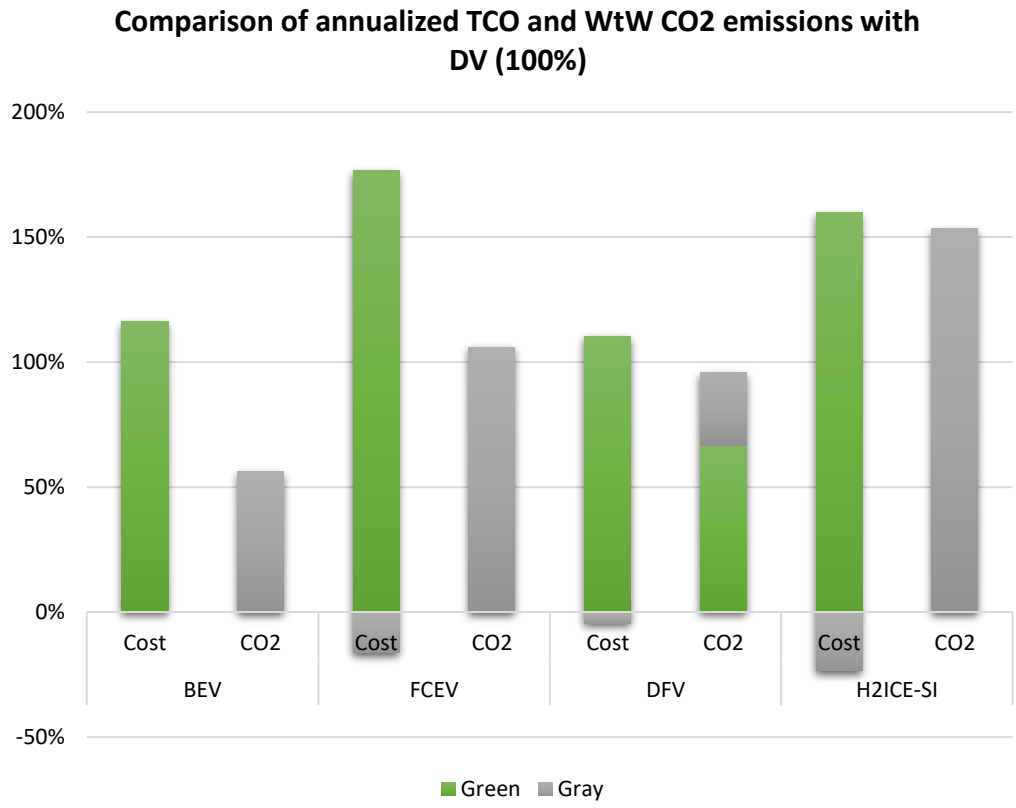
- BEV - 320 kWh & 150 kW charger
- FCEV – 100 kg H2 storage
- DFV – 12.6 kg H2 storage
- H2ICE – 67.2 kg H2 storage

TCO:

- DFV lowest TCO, followed by BEV (116%)
- Investment cost (inc. charger) of BEV and FCEV are 2.7 and 3.2 times higher, but for DFV and H2ICE, 1.1 and 1.3 times
- Energy cost of DFV, H2ICE and FCEV increase by 47%, 195% and 330% -> explains high TCO cost of H2ICE, FCEV
- Grey hydrogen reduces cost by up to 24% (H2ICE)

CO2 emissions

- FCEV, H2ICE benefit from 100% green hydrogen
- No benefits from grey hydrogen.



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Transport mission 2: Long daily trips (500 km), high annual mileage (130k)

Vehicle system:

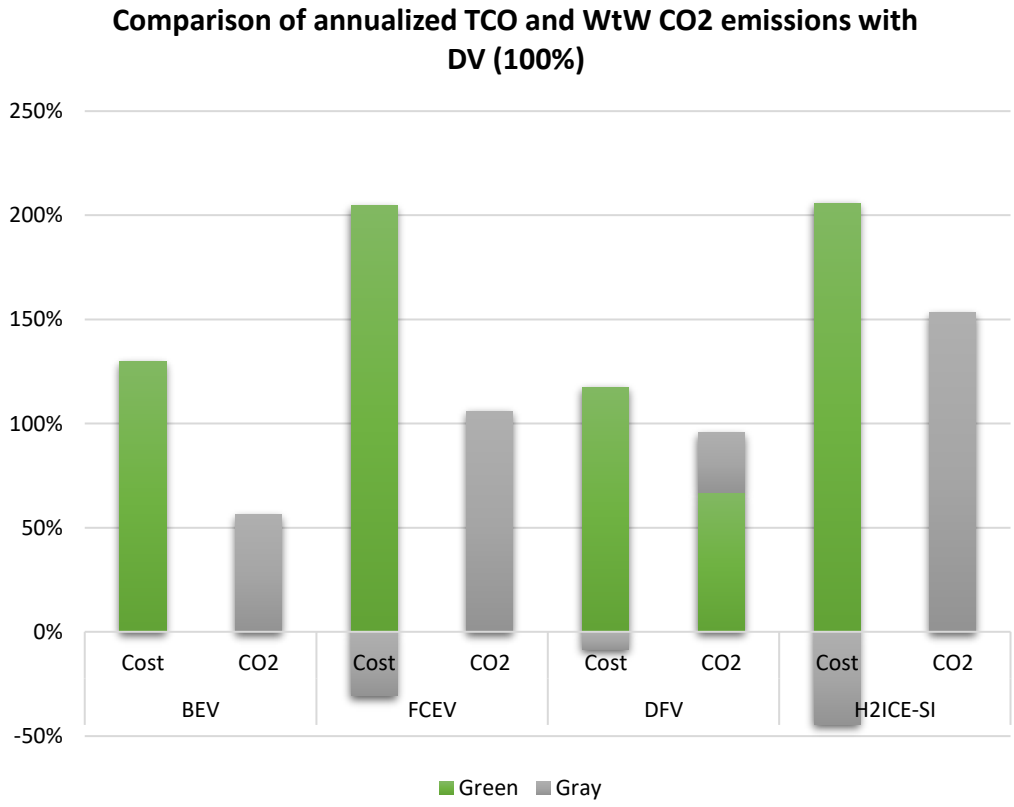
- BEV - 440 kWh & 350 kW charger
- FCEV – 200 kg H2 storage
- DFV – 16.8 kg H2 storage
- H2ICE – 84 kg H2 storage

TCO:

- DFV lowest TCO, followed by BEV (130%)
- Investment cost (inc. charger) of BEV and FCEV are 3.7 and 3.8 times higher, but for DFV and H2ICE, 1.1 and 1.4 times
- Sensitivity to hydrogen cost - Grey hydrogen reduces cost by up to 44% (H2ICE)
- BEV higher increase of external charging cost (40:60)

CO2 emissions

- No difference from previous
- BEV still lowest WTW



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Transport mission 3: Mixed length of daily trips (ave: 385km), average annual mileage (100k)

Vehicle system:

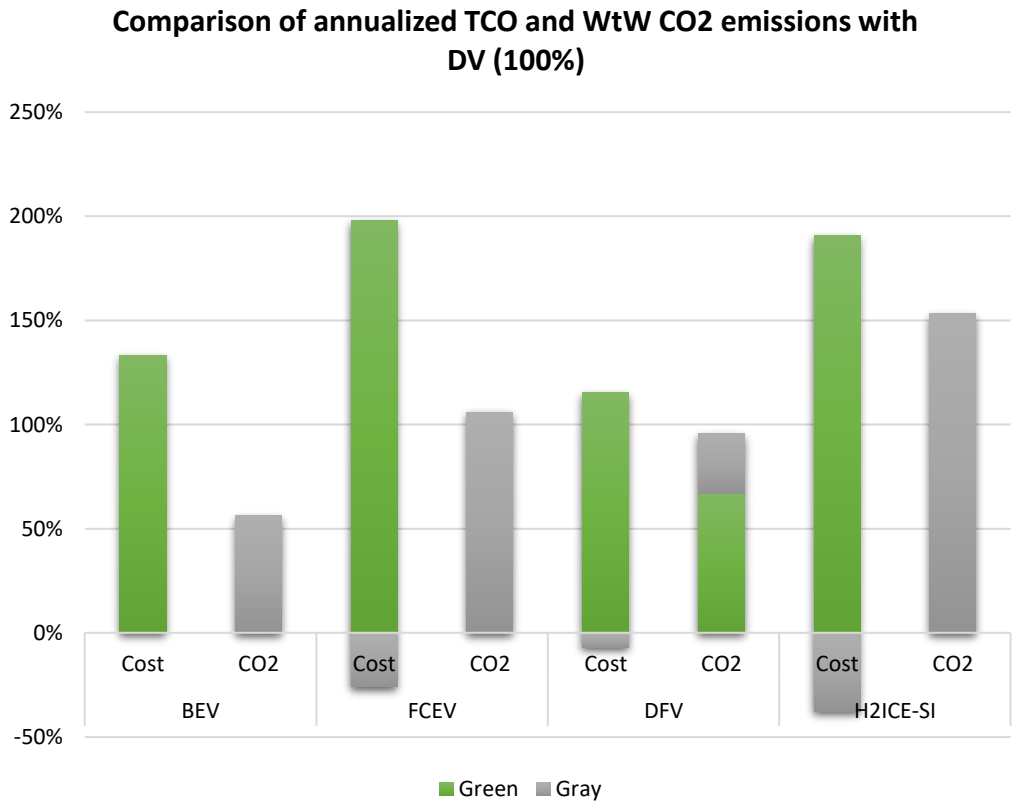
- BEV - 440 kWh & 350 kW charger
- FCEV – 200 kg H2 storage
- DFV – 16.8 kg H2 storage
- H2ICE – 84 kg H2 storage

TCO:

- Slightly lower than previous.
- Same investment cost (inc. charger)
- BEV higher increase of external charging cost (50:50)

CO2 emissions

- BEV still lowest WTW even with grey energy
- DFV reduction with green is 33% (3 DFVs produce as much as 2 DVs)



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Subsidy analysis – using Transport Mission 3 (100k mileage), green energy

Vehicle subsidies to even out investment cost

- FCEV: €410,500 -> TCO 169% (c. DV), which compared to 198% in base scenario
- DFV: €19,500 -> TCO 113% (c. DV), which compared to 115%
- H2ICE: €54,160 -> TCO 186% (c. DV), which compared to 191%

More DFVs can be subsidised compared to (21:1) FCEV; (3:1) H2ICE, with better TCO results.

Fuel price reduction from €12 to even out energy cost

- FCEV: Price = €3.90 (reduction of 8.10/kg H2) -> €760k /10y -> TCO 148% (c. DV)
- DFV: Price = €4.75 (reduction of 7.25/kg H2) -> €128k /7y -> TCO 103% (c. DV)
- H2ICE: Price = €2.65 (reduction of 9.35/kg H2) -> €890k /7y -> TCO 127% (c. DV)

More DFVs can be subsidised compared to (6:1) FCEV; (7:1) H2ICE, with better TCO results.

CO2 efficiency of subsidy to even out TCO

- FCEV: €2.3mil/10y: 100% reduction
- DFV: €190k/7y: 33% reduction -> €570k/7y for 3 vehicles
- H2ICE: €1.1mil/7y: 100% reduction

More efficient to subsidise DFVs | (4:1) FCEV; (2:1) H2ICE for same abs. CO2 reduction.

Conclusions

Viability

The TCO of the DFV is comparable to DV (10 to 17% higher) and can be considered a stopgap.

Unless cost of FCEVs and hydrogen fuel reduce significantly, the DFV will remain more financially viable.

In the long term, H2ICE might be more viable than FCEV, due to lower investment cost.

CO2 benefits

DFVs can reduce CO2 by 33% (based on assumed fuel proportion).

Grey hydrogen should not be considered as a stopgap fuel to reduce CO2.

Subsidy

DFVs are more efficient to subsidise in the interim than H2ICE.