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HAN AUTOMOTIVE RESEARCH_

Work Package 5: Analysis

Presentation of project datalogging, processing and analysis

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Contents

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- Summary
- Social impact
- E-trucks data analysis
- FAUN/Enginius data analysis
- Conclusion

Project data – data used – up to 2023/07

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Data provider	City	Country	Analysis time (days)	Data access	Data start	Analysis period
E-Trucks	Arnhem	NL	33	Yes	2022/06/21	2023/08/01
E-Trucks	Herten	DE	80	Yes	2022/09/12	2023/08/01
E-Trucks	Groningen	NL	-	No	-	-
Enginius	Duisburg	DE	108	Yes	2021/04/23	2023/08/01
Enginius	Brussels	BE	-	No	2023/11/01	-
Enginius	Indre-et-Loire	FR	-	Yes	2023/08/01	-
Holthausen	Aberdeen	UK	-	No	-	-

Project data

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- E-Trucks
  - Daily aggregated values
  - Vehicle data such as speed and distance
  - H2 use and fuel cell energy
- FAUN/Enginius
  - High frequency vehicle sensor values
  - Vehicle data such as axle loads, compactor activation, and distance
  - Driveline data such as motor speed, torque and temperature
  - Powertrain data such as H2 level, battery SOC, fuel cell current and voltage

Social impact

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Research of drivers' opinions and experiences

- Questionnaire
- Few results (5 replies)
  - ca. 75% Support for Reduce the emissions of the fleet
  - ca. 75% wants to contribute to reduce emissions
  - 100% enjoys driving
  - 100% feel control over the truck
  - ca. 50% is often concerned about the driving range

Arnhem, Netherlands

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Data was used from the time period 2022/07/20 to 2023/06/30

Distance

58.04km
- Average daily

1857km
- Total

Speed

36.93 km/h
- Average overall

H2 Use

6.15kg
- Average daily

196.92kg
- Total

H2 Consumption

11.82 kg/ 100km
- Average overall

H2 Refuel

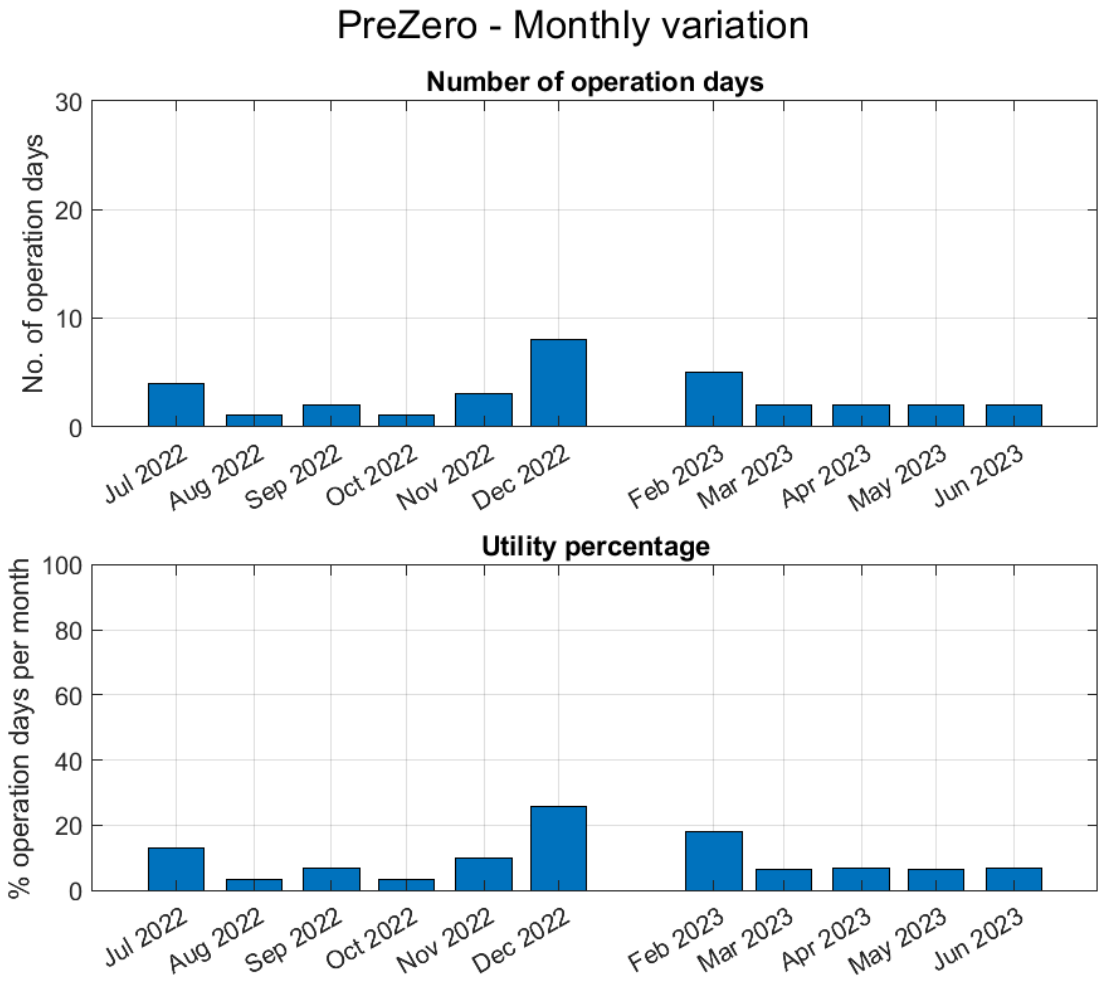
6 kg
- Average per refuel

54 kg
- Total

Arnhem Netherlands– Operability

- Fairly limited operation

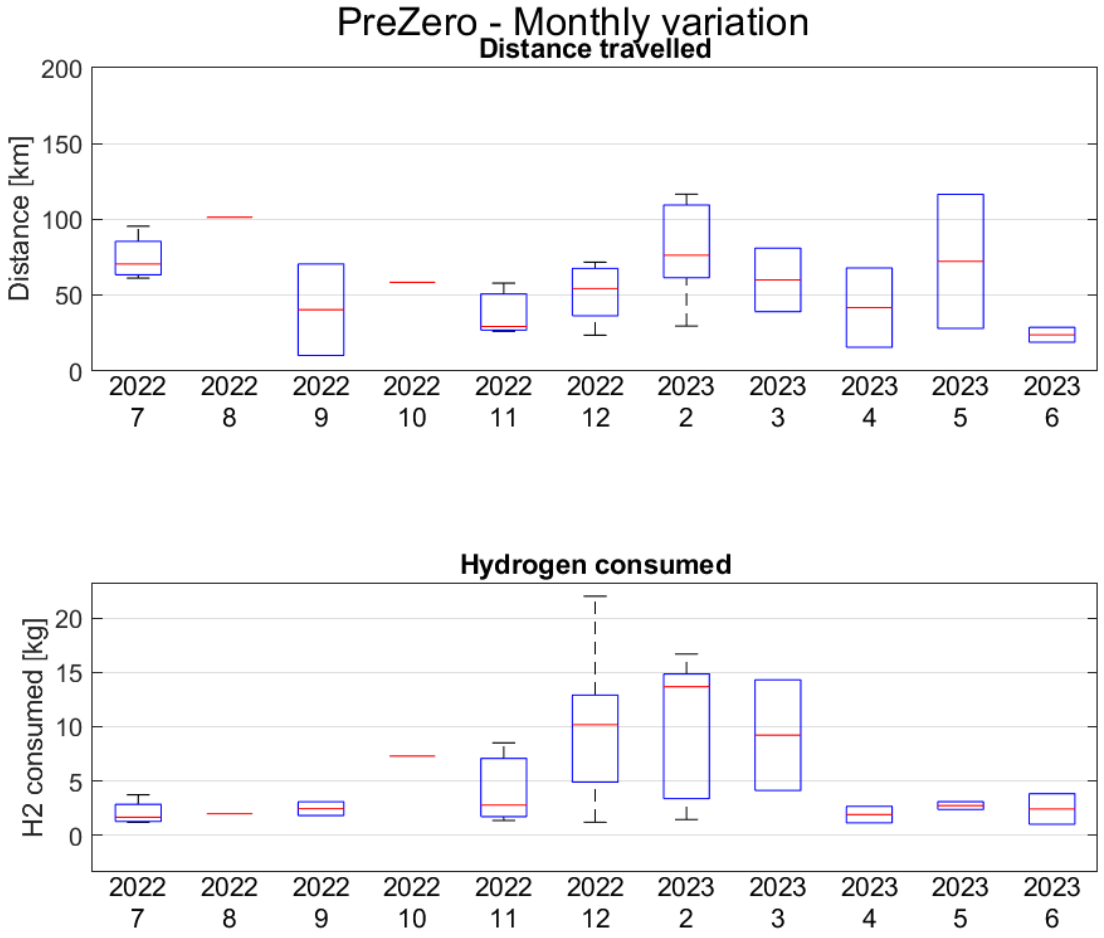
- except for a couple of months (Jul 2022, Dec 2022, Feb 2023) operation days are less than 4



Arnhem, Netherlands – Driving data

Vehicle distance travelled and hydrogen consumed

No refuse weight information on dashboards



Herten, Germany – Summary statistics

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Data was used from the time period 2022/09/12 to 2023/08/01

Distance

81.73 km
- Average daily

8010 km
- Total

Speed

28.68 km/h
- Average daily

H2 Use

11.22kg
- Average daily

1099.62kg
- Total

H2 Consumption

13.62 kg/ 100km
- Average daily

H2 Refuel

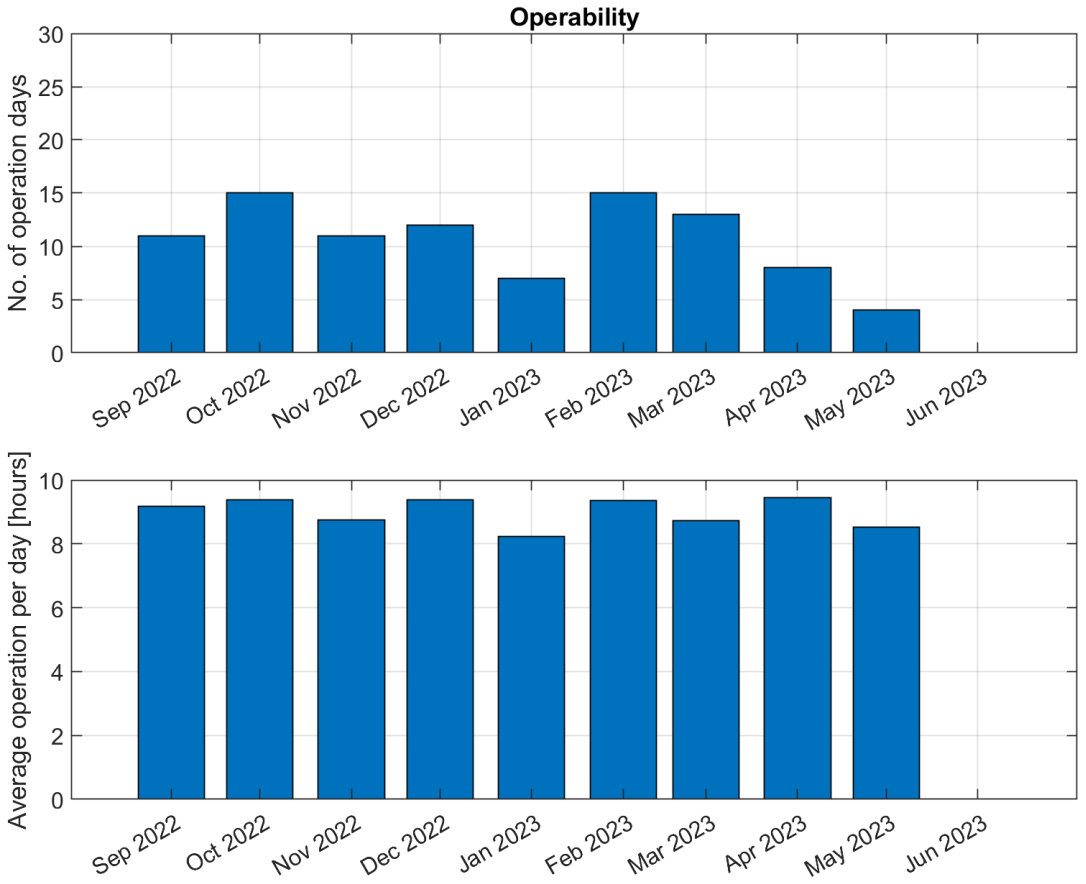
12.22 kg
- Average per Refuel

671.84 kg
- Total

Operability comparison – Herten and Arnhem

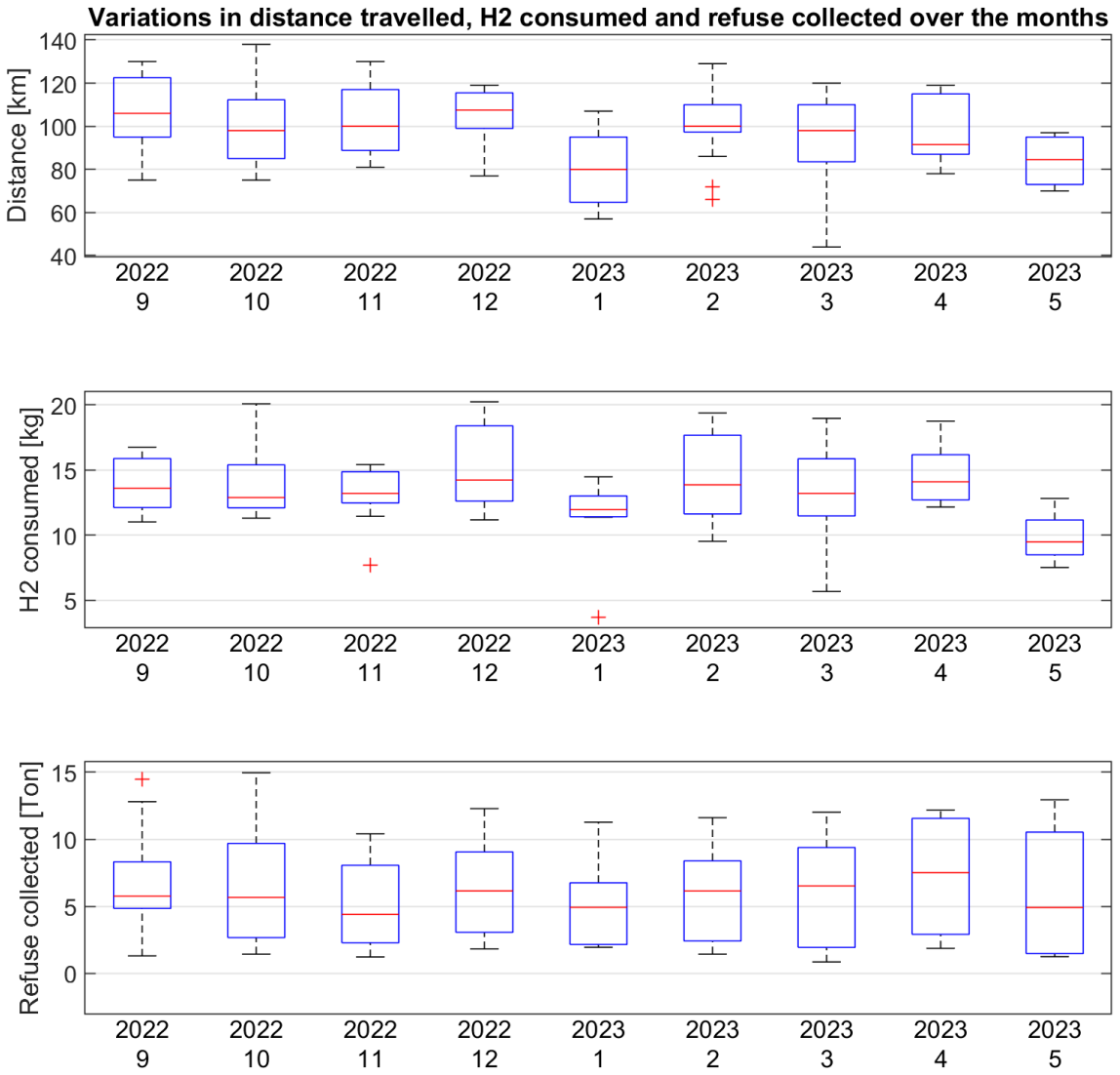
- In general, the RCV remains operational only upto 50% during the observed months
- Maximum no. of operation days (15) are observed in October 2022 and February 2023
- No operation days are recorded in June 2023

On the operation days, RCV performs more than 8 hours of operation on average



Herten, Germany – Driving data

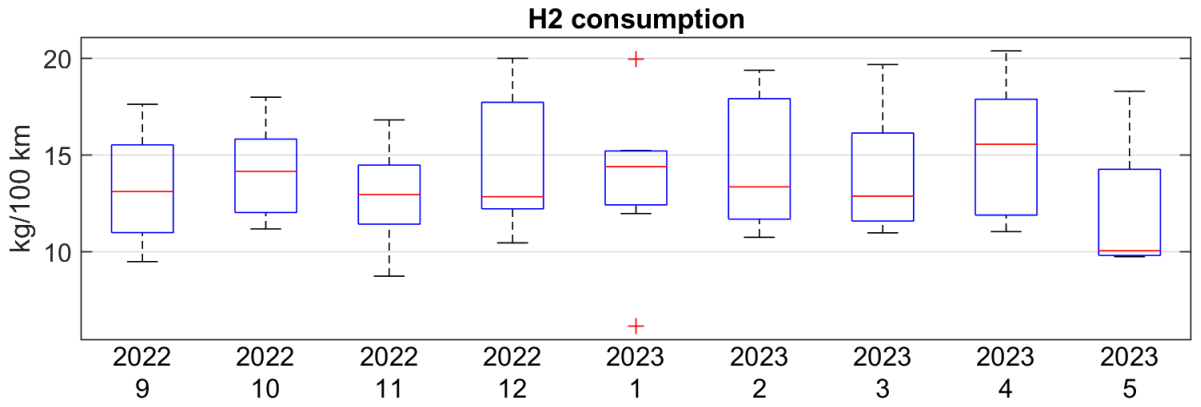
- Average distance traveled by the RCV remains close to 100 km, except for January and May 2023 (around 80 km)
  - Least no. of operation days in the two months
- Average H2 consumption remains close to 14 kg, except for May 2023 (around 10 kg)
- Average refuse collected remains close to 5 tons; steadily increasing in the beginning of 2023;

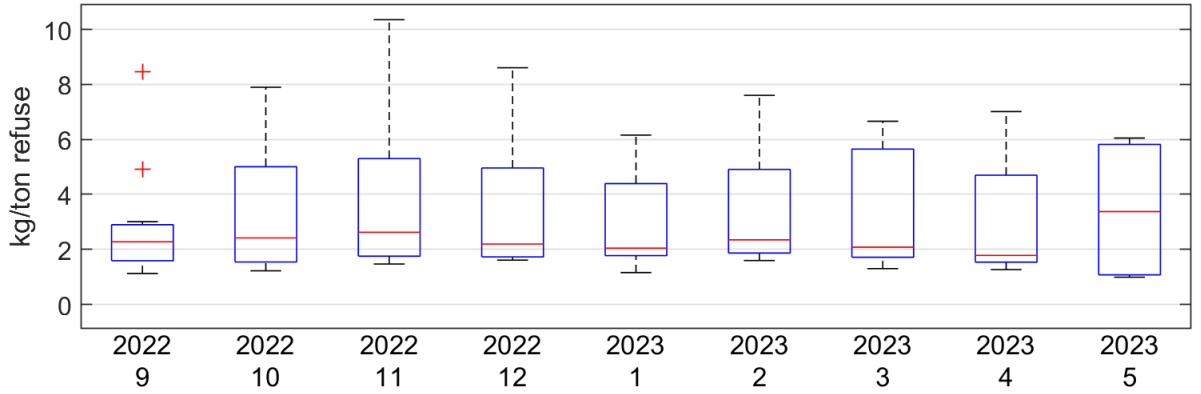


Herten, Germany – Driving data

- Average H2 consumption per 100 km, varies between around 13 and 15 kg, except for May 2023, viz.
  - Having the less average traveled distance and H2 consumed per day

- Average H2 consumption per ton of refuse collection remains close to 2 kg, except for May 2023 (around 3,5 kg)

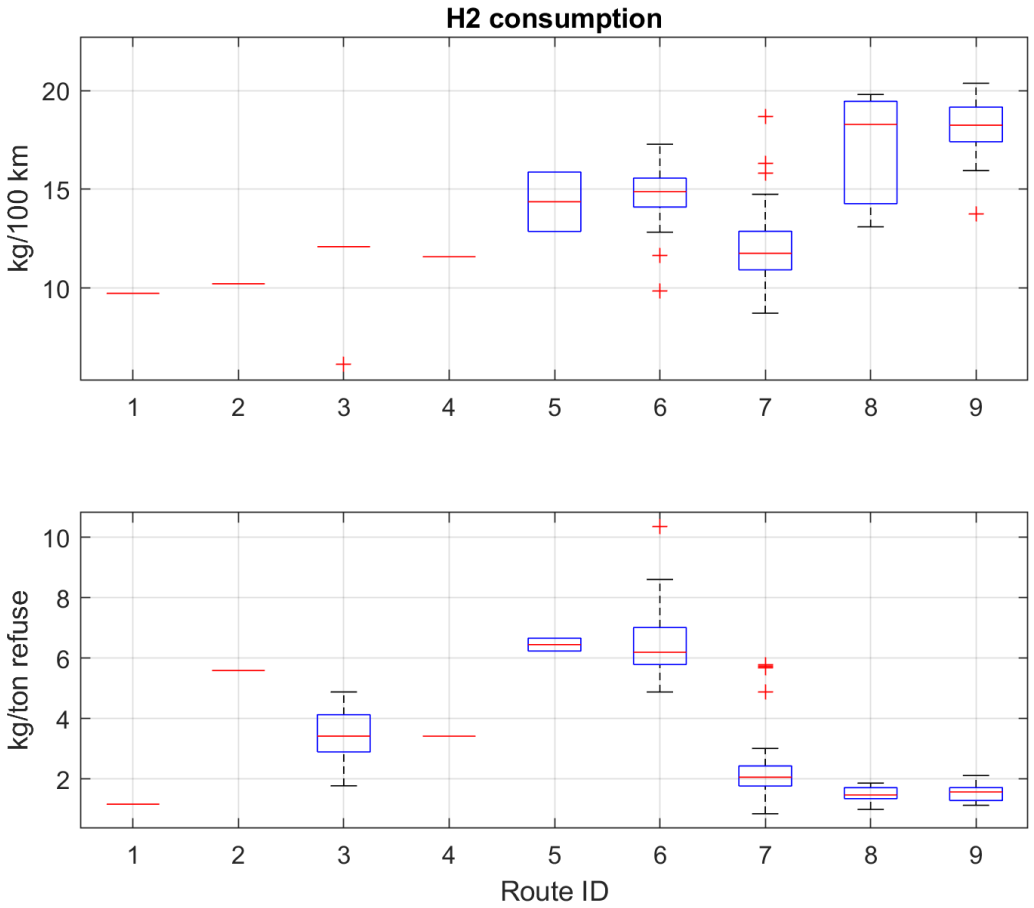




Herten, Germany – Driving data

- Routes 3 and 6 are both low-density refuse collection routes, with comparable densities, and average refuse amount.
  - Route 6 is comparatively longer than 3 and consumed more H2 thus higher consumption for Route 6 compared to 3

- Routes 1, 7, 8, and 9 are associated with high-density refuse, thus their consumption per ton of refuse is smaller than the other routes



Duisburg, Germany

Data was used from the time period 2022/08/01 to 2023/08/01

Distance

47km
- Average daily

21km
- Total

Speed

34 km/h
- Average overall

H2 Use

3kg
- Average daily

1kg
- Total

H2 Consumption

4 kg/ 100km
- Average overall

H2 Refuel

7 kg
- Average per refuel

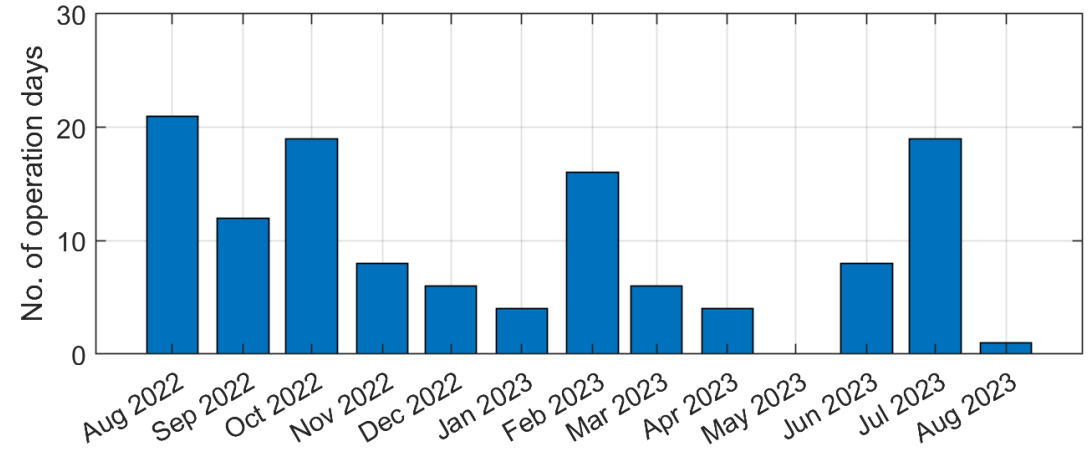
185 kg
- Total

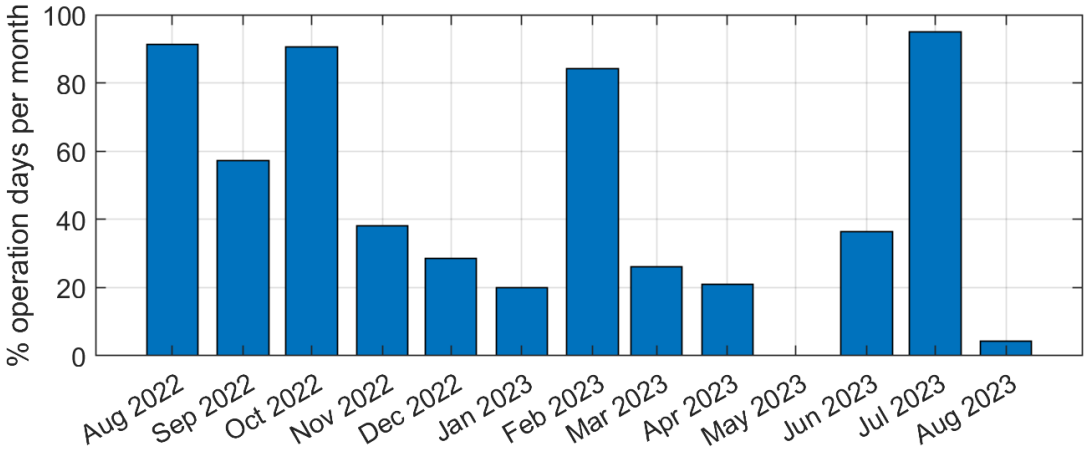
Duisburg, Germany – Utility

Analysis period: 2022/08/01 to 2023/08/01

- No operation in May 2023

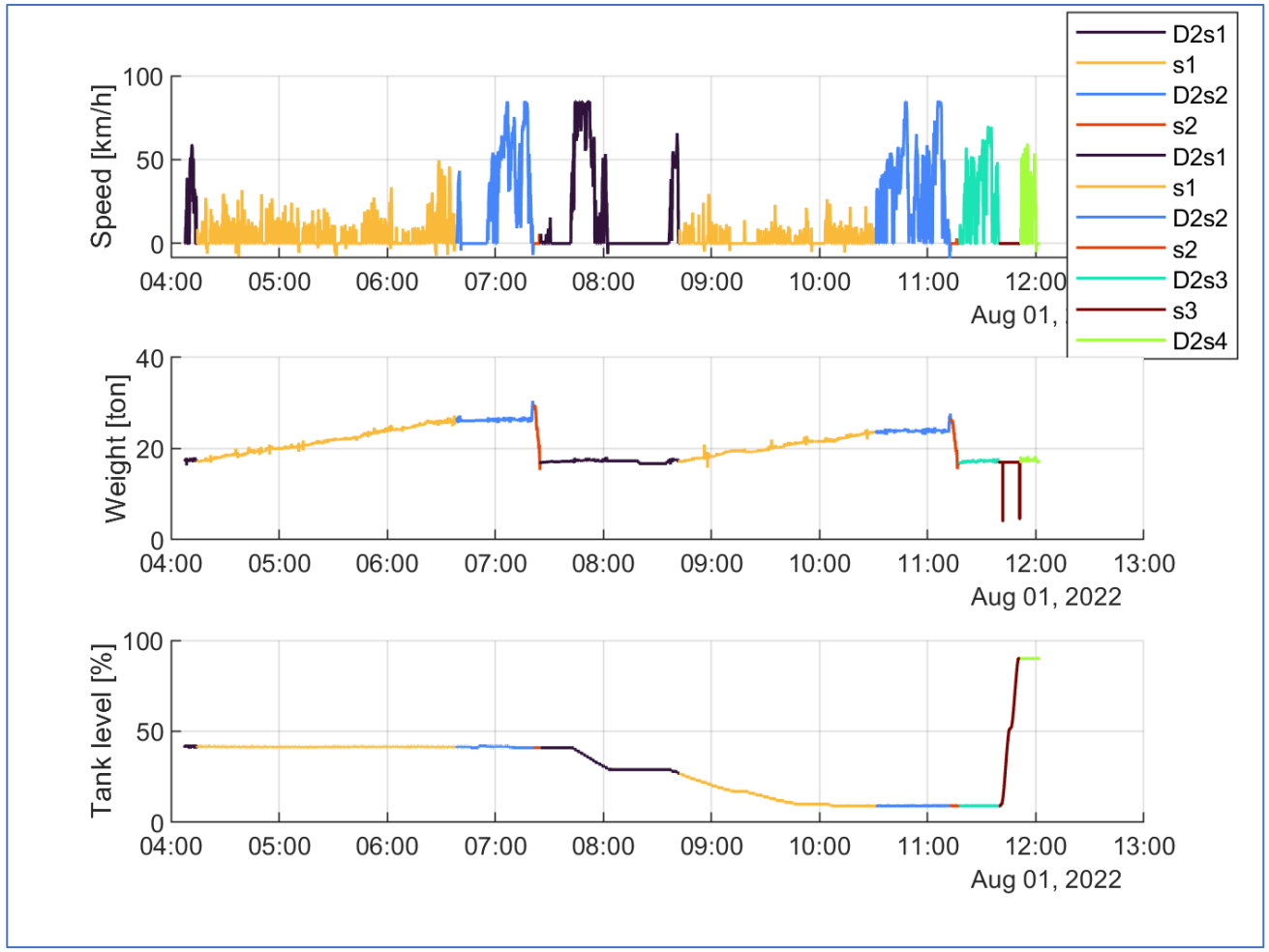
- Bottom figure shows the utility percentage per month excl. weekends
    - 4 months above 80%
    - 5 months above 50%



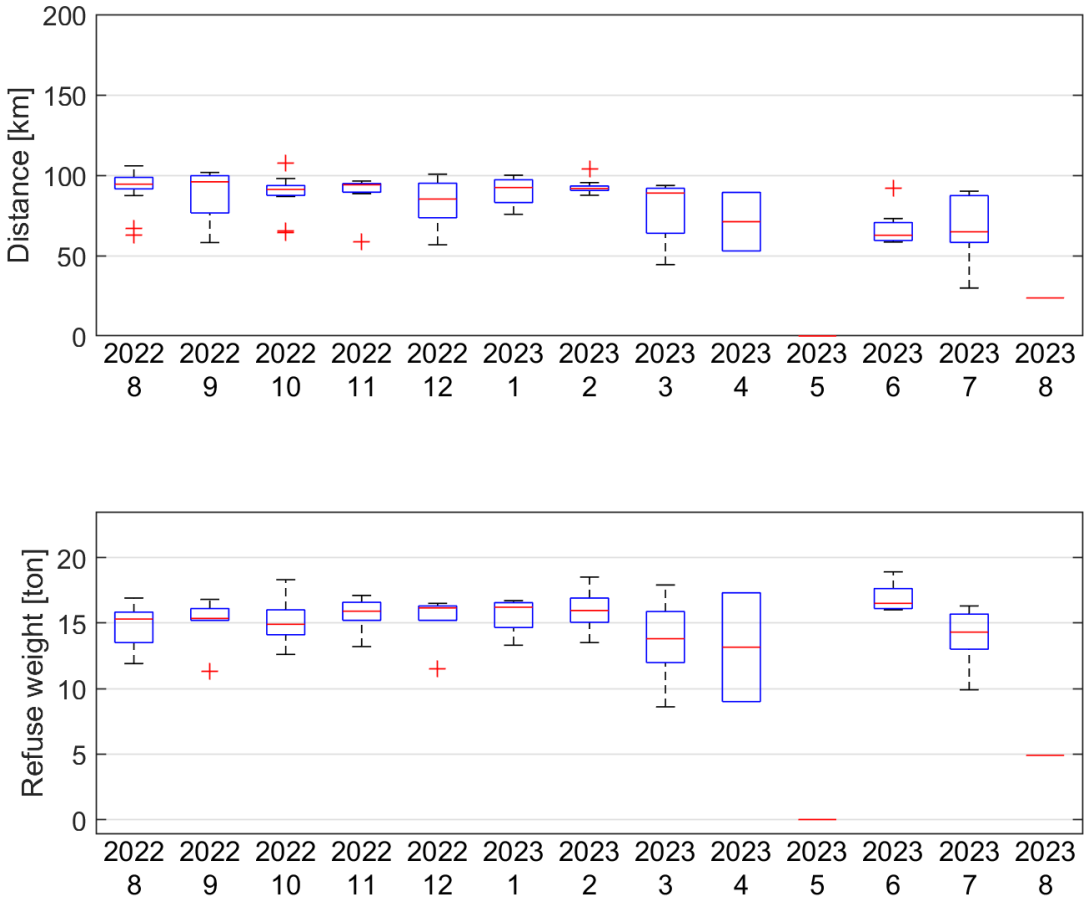


Duisburg, Germany

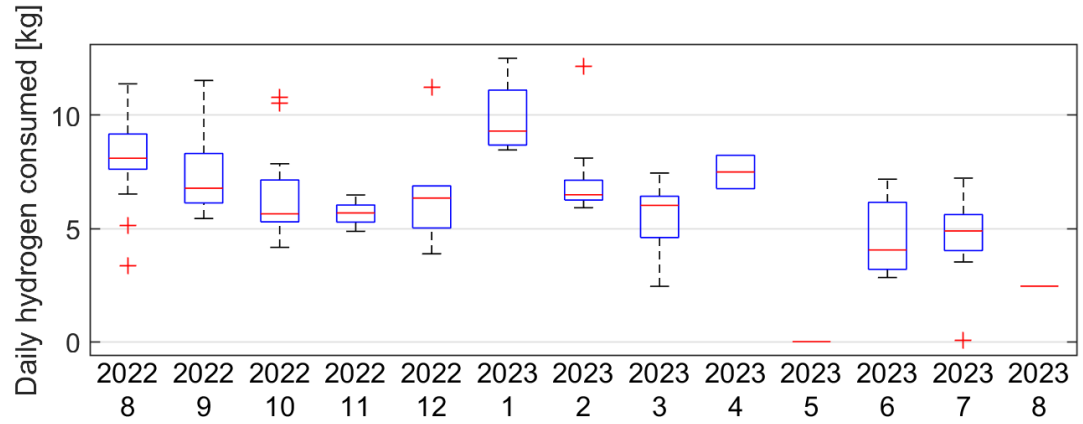
- Partial dataset used as input to analysis: 2022/08/01 to 2023/06/30
- Selecting a single day for analysis: 2022/08/01
- D2s# - Driving to segment
- s1 – Refuse collection
- s2 – Refuse disposal
- s3 – Refuelling
- D2s4 – Driving to depot

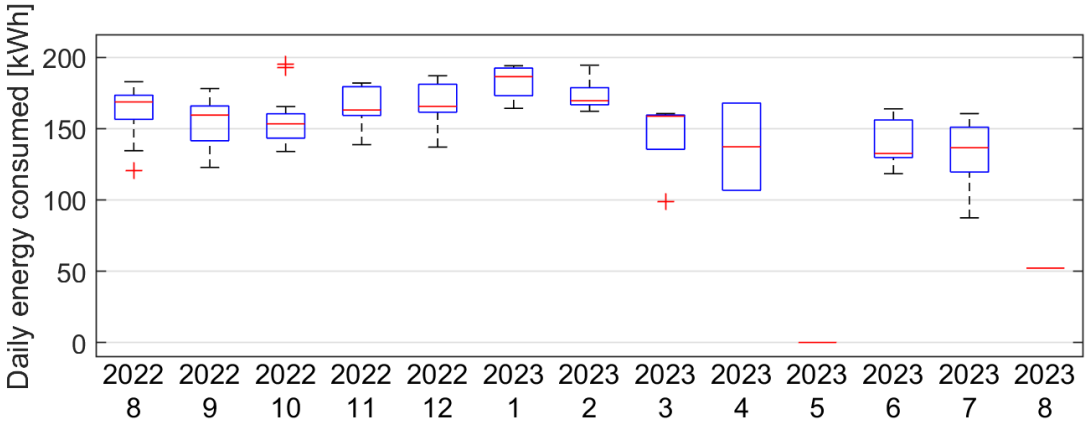


Duisburg, Germany – Operation

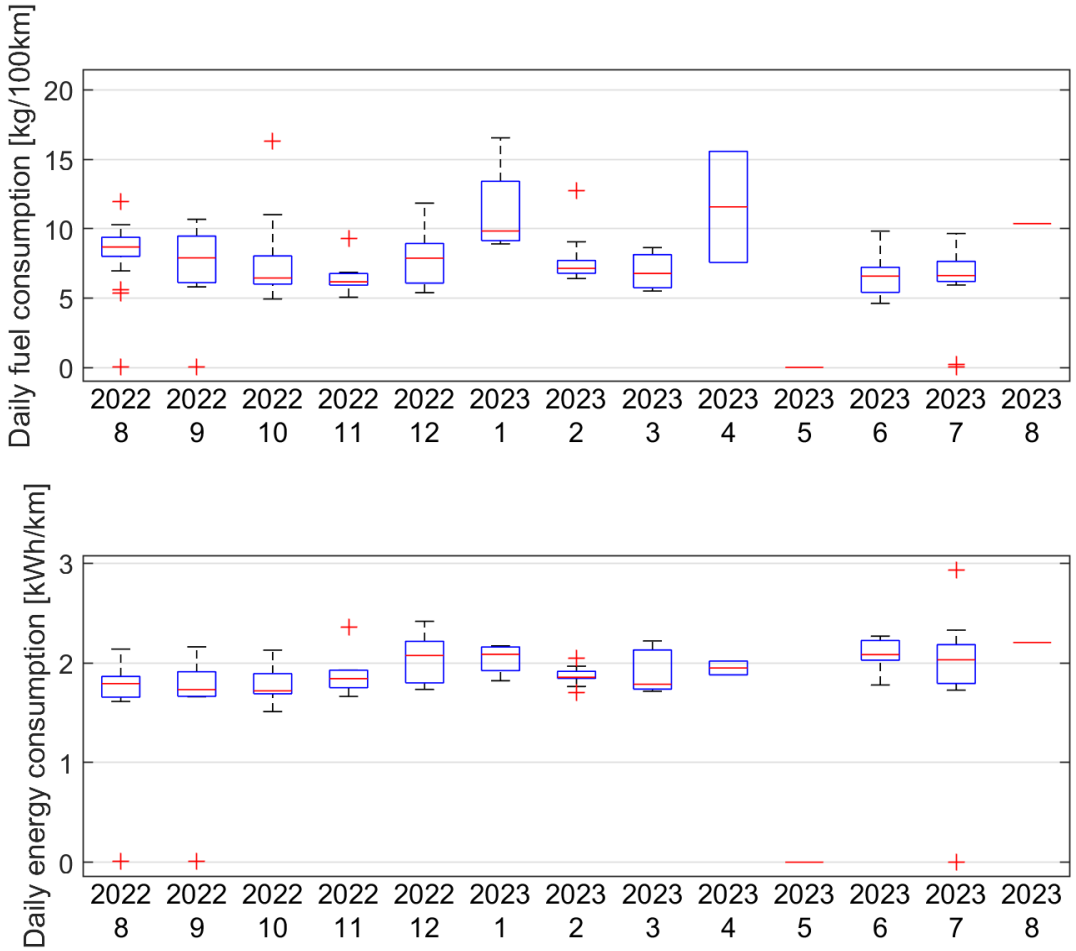


Duisburg, Germany – Operation





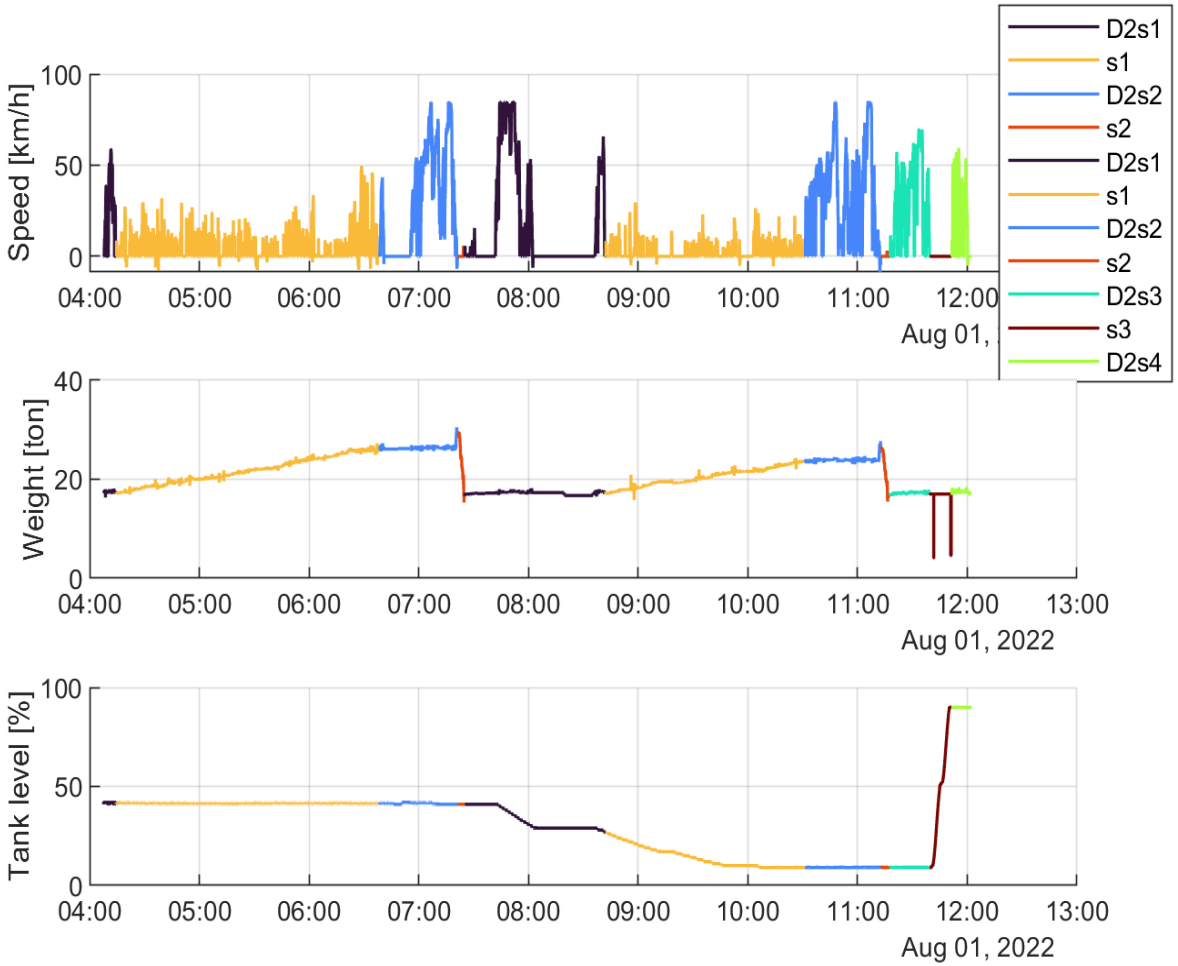
Duisburg, Germany – Operation



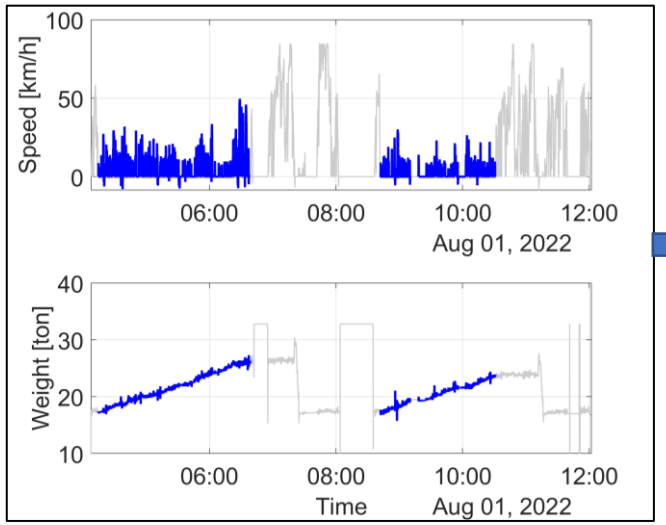
Duisburg, Germany – Operation segmentation

Example day: 2022/08/01

- s1 – Refuse collection
- s2 – Refuse disposal
- s3 – Refuelling
- D2s1 - Drive to refuse collection
- D2s2 – Drive to refuse disposal
- D2s3 – Drive to refueling
- D2s4 – Drive to base location/depot

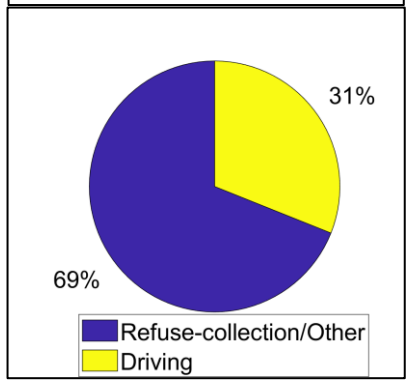


Duisburg, Germany – Refuse collection (s1)

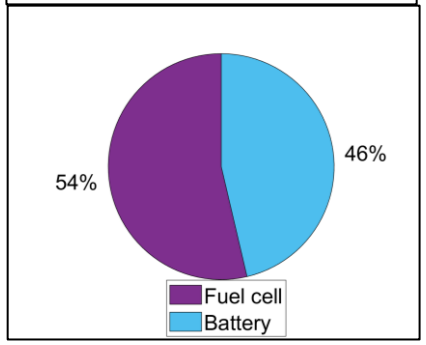


No. of collections, [-]	261
Average speed, [km/h]	2,14
Time duration, [h]	4,09
Collected refuse weight, [ton]	15,40
Collection distance [km]	11,11
Energy consumed [kWh]	70,6
Hydrogen consumed [kg]	2,73

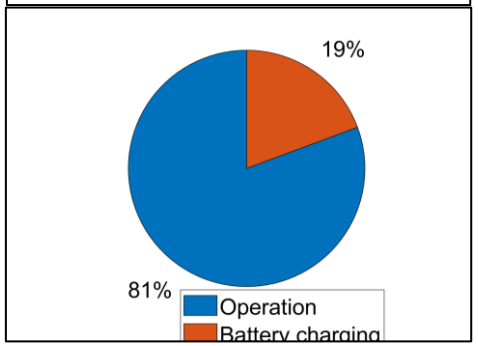
Energy consumed



Energy supplied



Hydrogen consumed

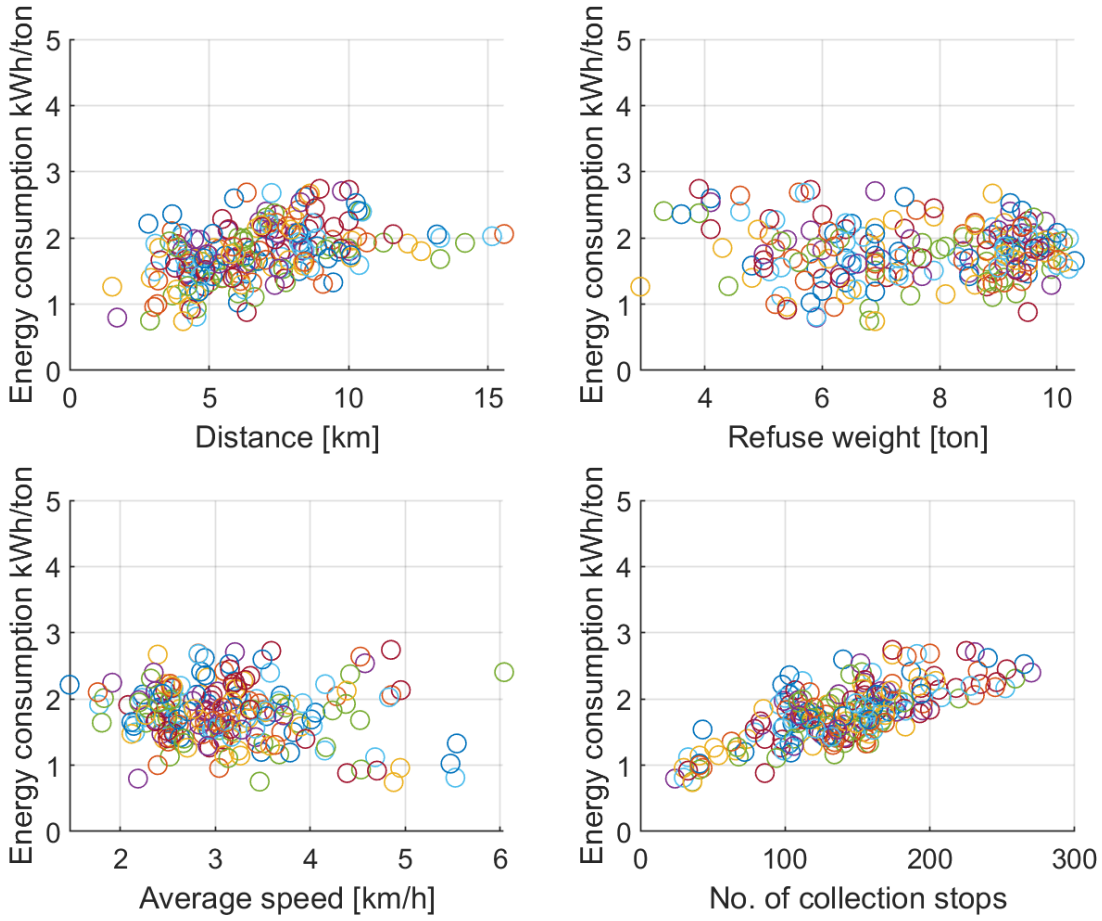


Duisburg, Germany – Operation: Refuse collection (s1)

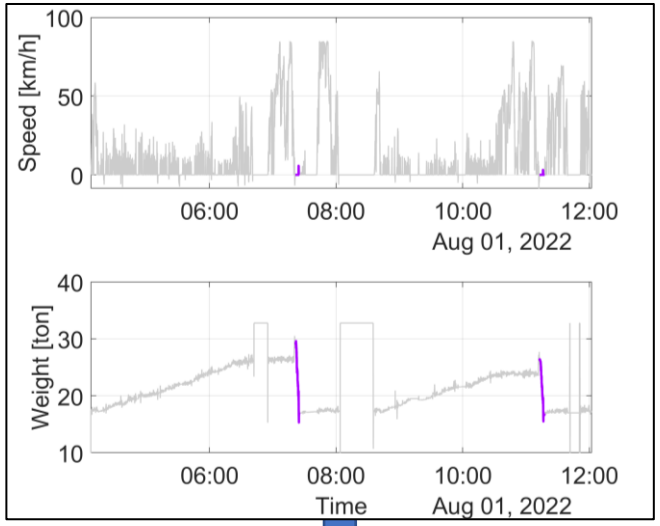
Energy consumption related to driving discussed in Drive2Refueling example

- Energy demand per ton positively varies with no. of collection stops and with the distance

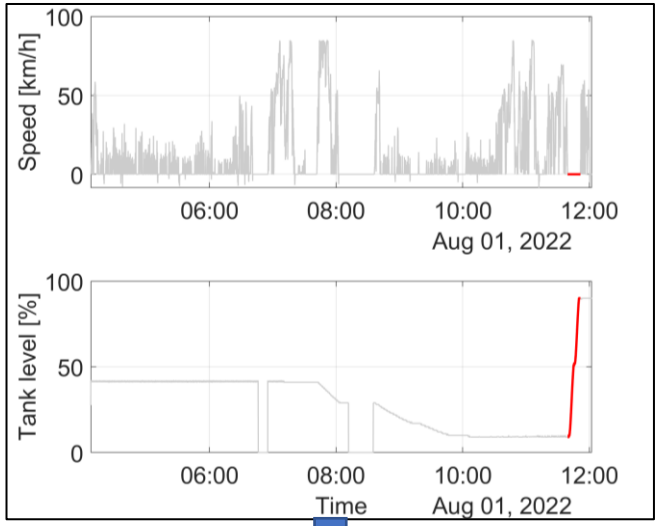
- Route should be classified as
  - Collections per km
  - Collections per ton



Duisburg, Germany – s2, s3

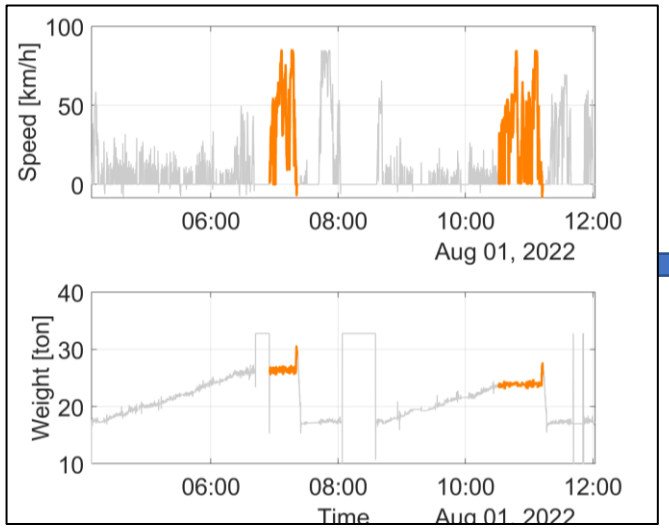


No. of disposals, [-]	2
Time duration, [h]	0,13
Disposed refuse weight, [ton]	15,40
Energy consumed, [kWh]	1,94
Hydrogen consumed, [kg]	0

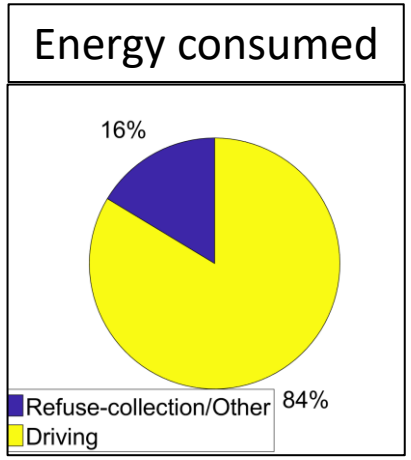


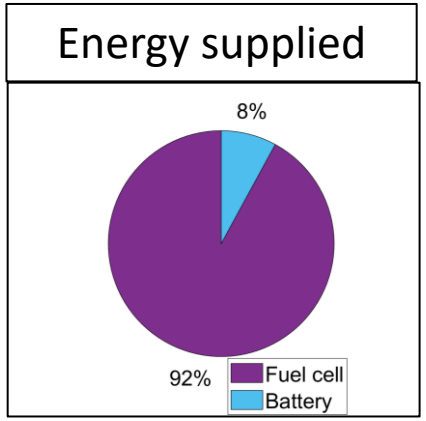
No. of refuels, [-]	1
Time duration, [h]	0,2
Hydrogen refueled, [kg]	12,84

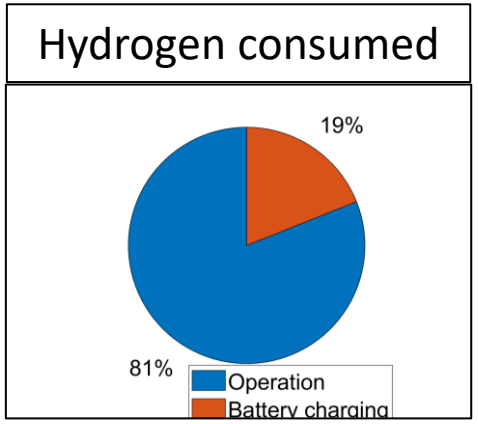
Duisburg, Germany –Drive to refueling (D2s3)



Average speed, [km/h]	29,96
Time duration, [h]	2,52
Average weight, [ton]	20,45
Distance travelled, [km]	80,97
Energy consumed, [kWh]	94,77
Hydrogen consumed, [kg]	2,28





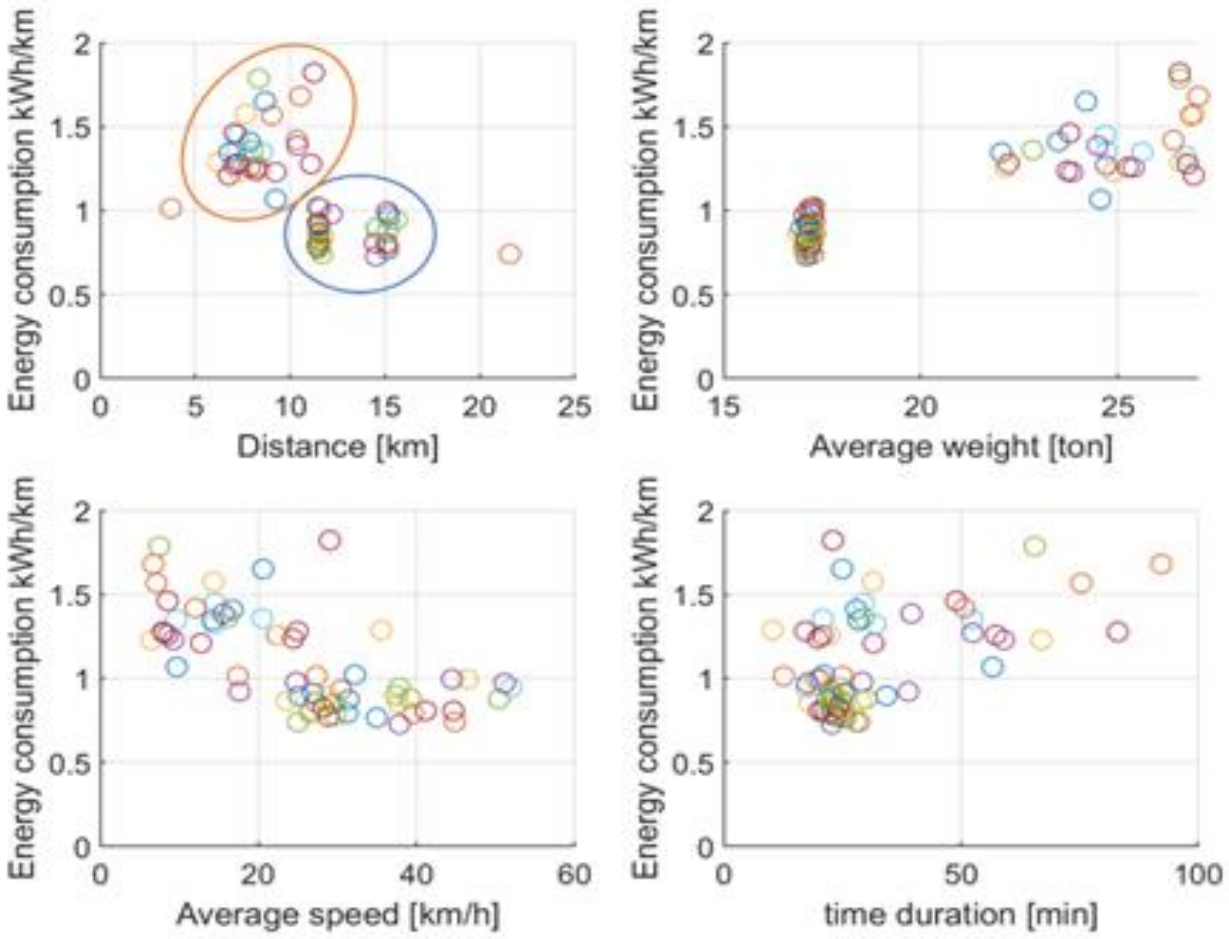


Duisburg, Germany – Operation: Drive to refueling (D2s3)

2 distinctive types can be seen:

- Blue eclipse: After refuse-disposal (lower average weight)
    - Two distinctive route from disposal area to refueling -> see different distances

- Orange eclipse: After refuse-collection (varying average weight) and higher energy consumption than the previous one



Duisburg, Germany – Segments

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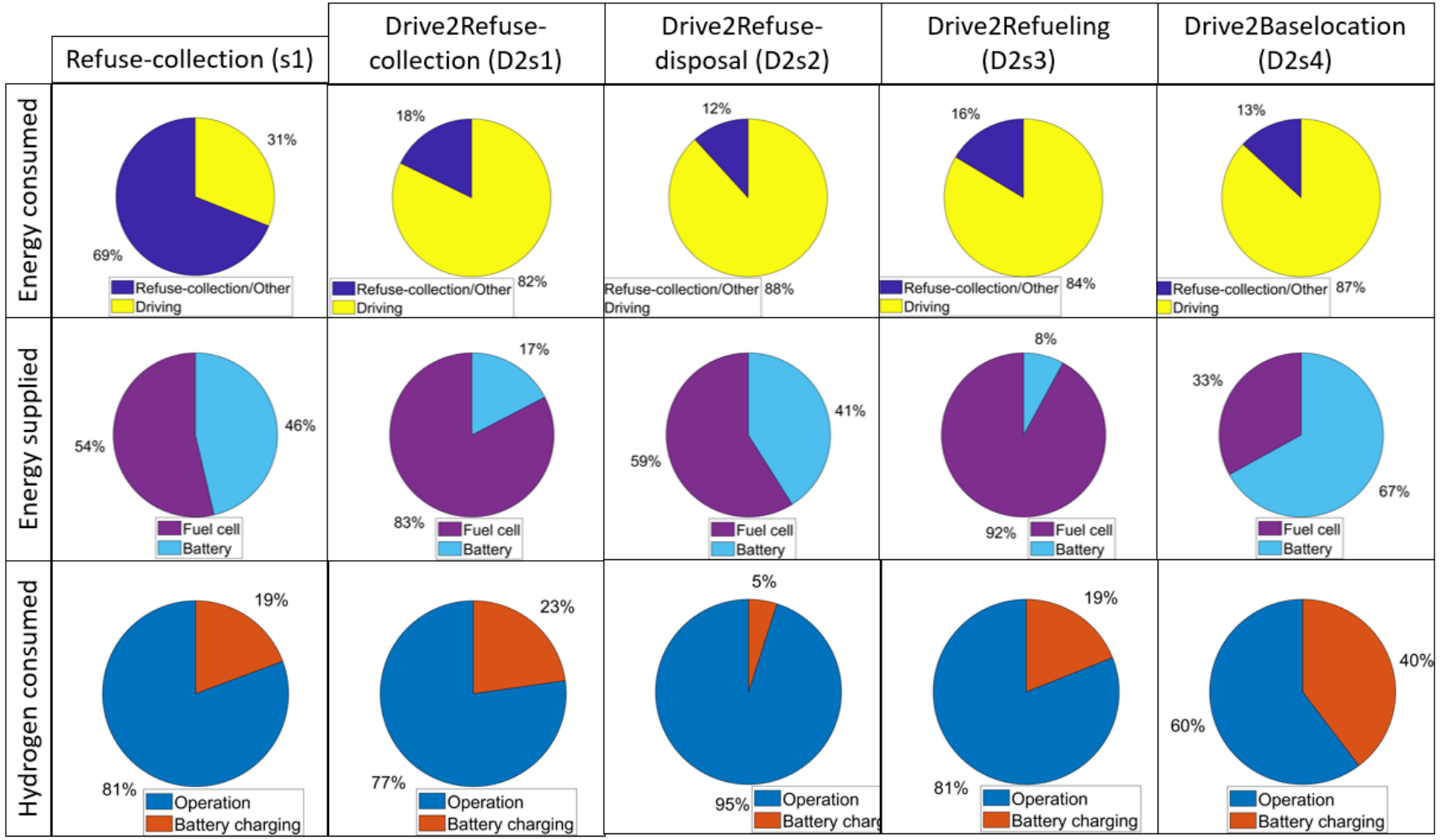
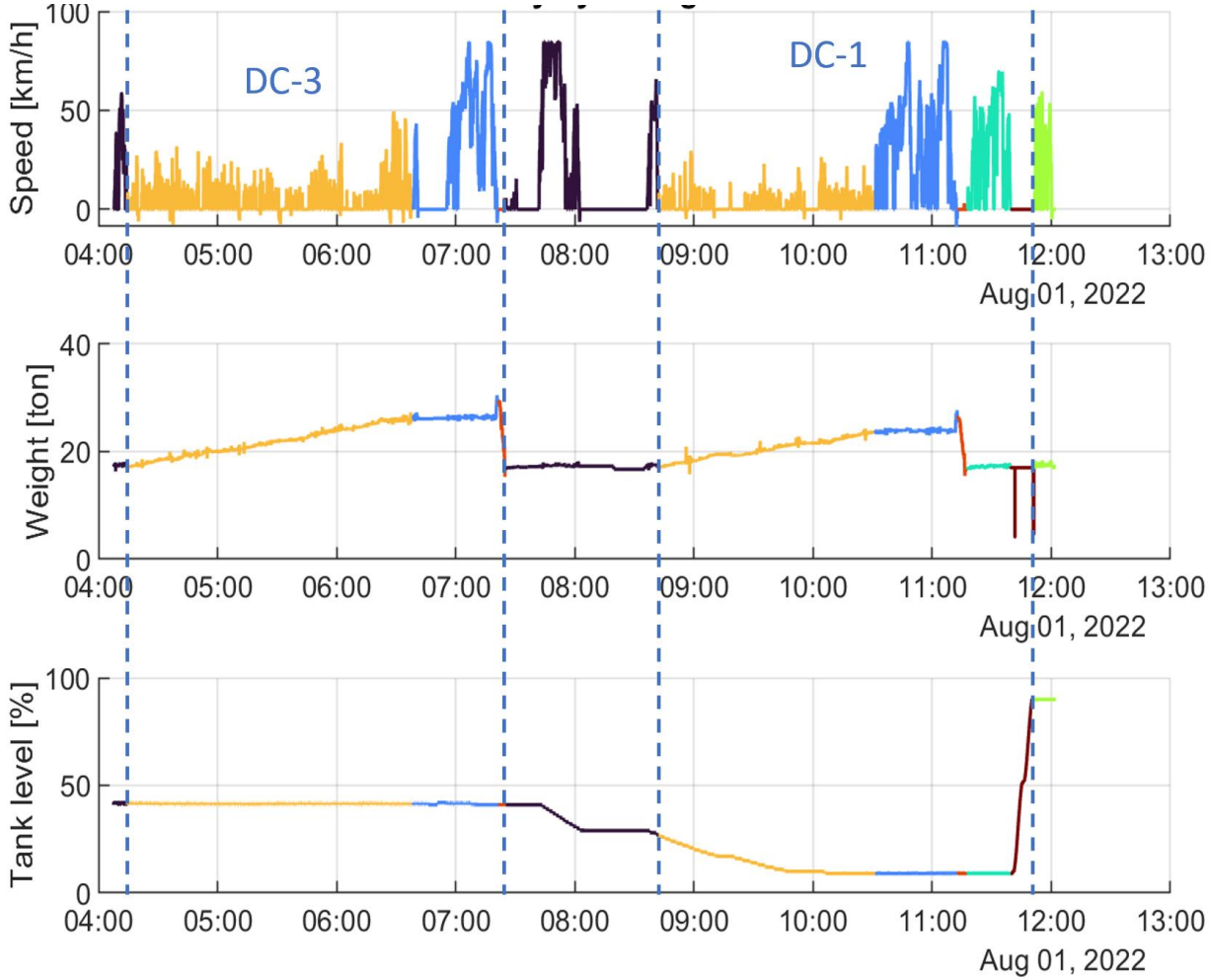


Duisburg, Germany – Operation duty cycles

- Segments are combined into duty cycles

DC-1	Refuse-collection (s1)	D2s2 →	Refuse-disposal (s2)	D2s3 →	Refueling (s3)
DC-2	Refuse-collection (s1)	D2s3 →	Refueling (s3)	D2s2 →	Refuse-disposal (s2)
DC-3	Refuse-collection (s1)	D2s2 →	Refuse-disposal (s2)		
DC-4	Refuse-collection (s1)	D2s3 →	Refueling (s3)		
DC-5	Refuse-collection (s1)				

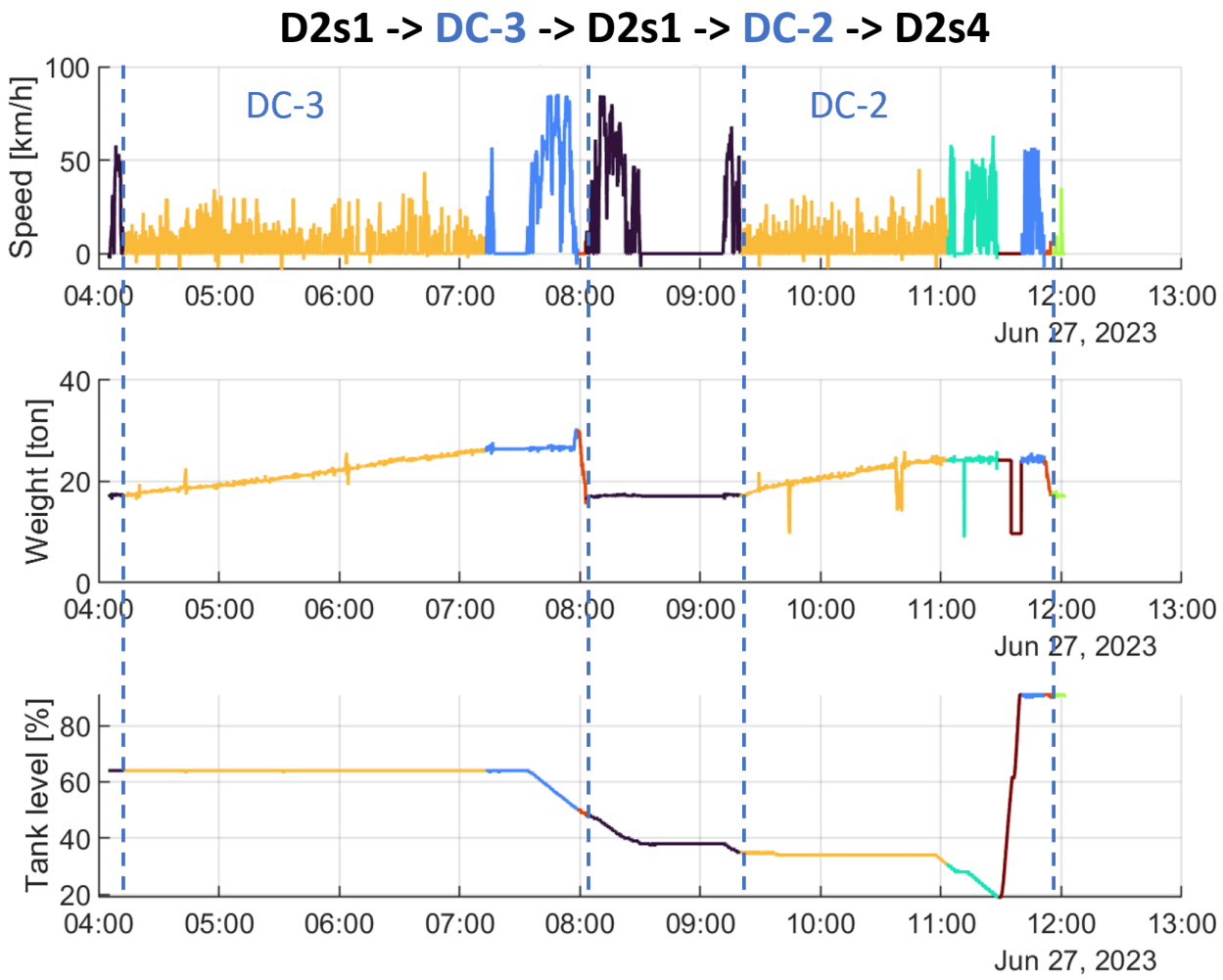
D2s1 -> DC-3 -> D2s1 -> DC-1 -> D2s4



Duisburg, Germany – Operation duty cycles

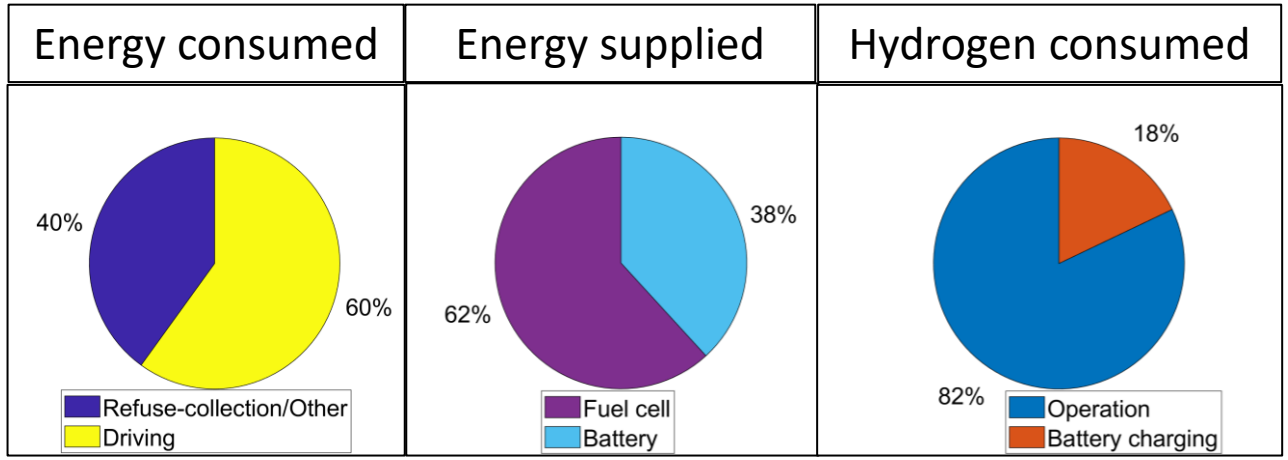
- Segments are combined into duty cycles

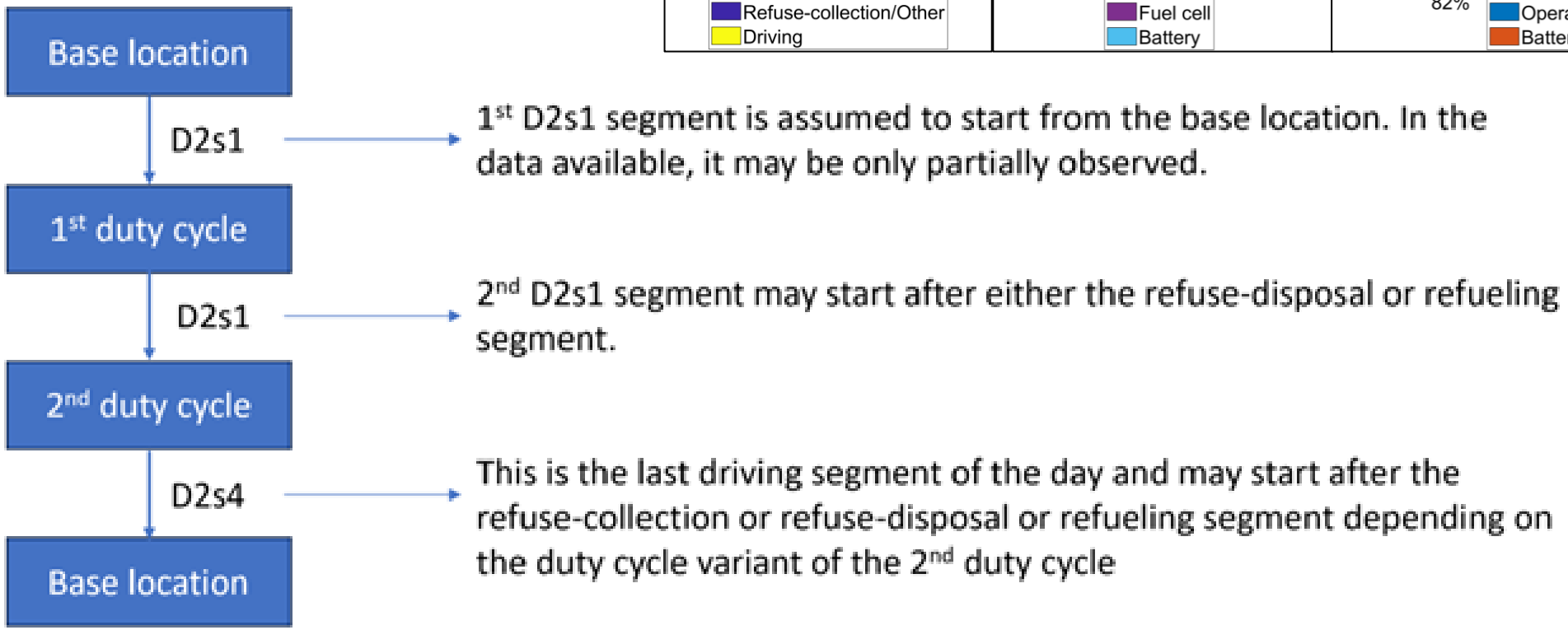
DC-1	Refuse-collection (s1)	D2s2 →	Refuse-disposal (s2)	D2s3 →	Refueling (s3)
DC-2	Refuse-collection (s1)	D2s3 →	Refueling (s3)	D2s2 →	Refuse-disposal (s2)
DC-3	Refuse-collection (s1)	D2s2 →	Refuse-disposal (s2)		
DC-4	Refuse-collection (s1)	D2s3 →	Refueling (s3)		
DC-5	Refuse-collection (s1)				



Duisburg, Germany – Operation day

- Generic day representation using duty cycles





Comparison of Vehicles

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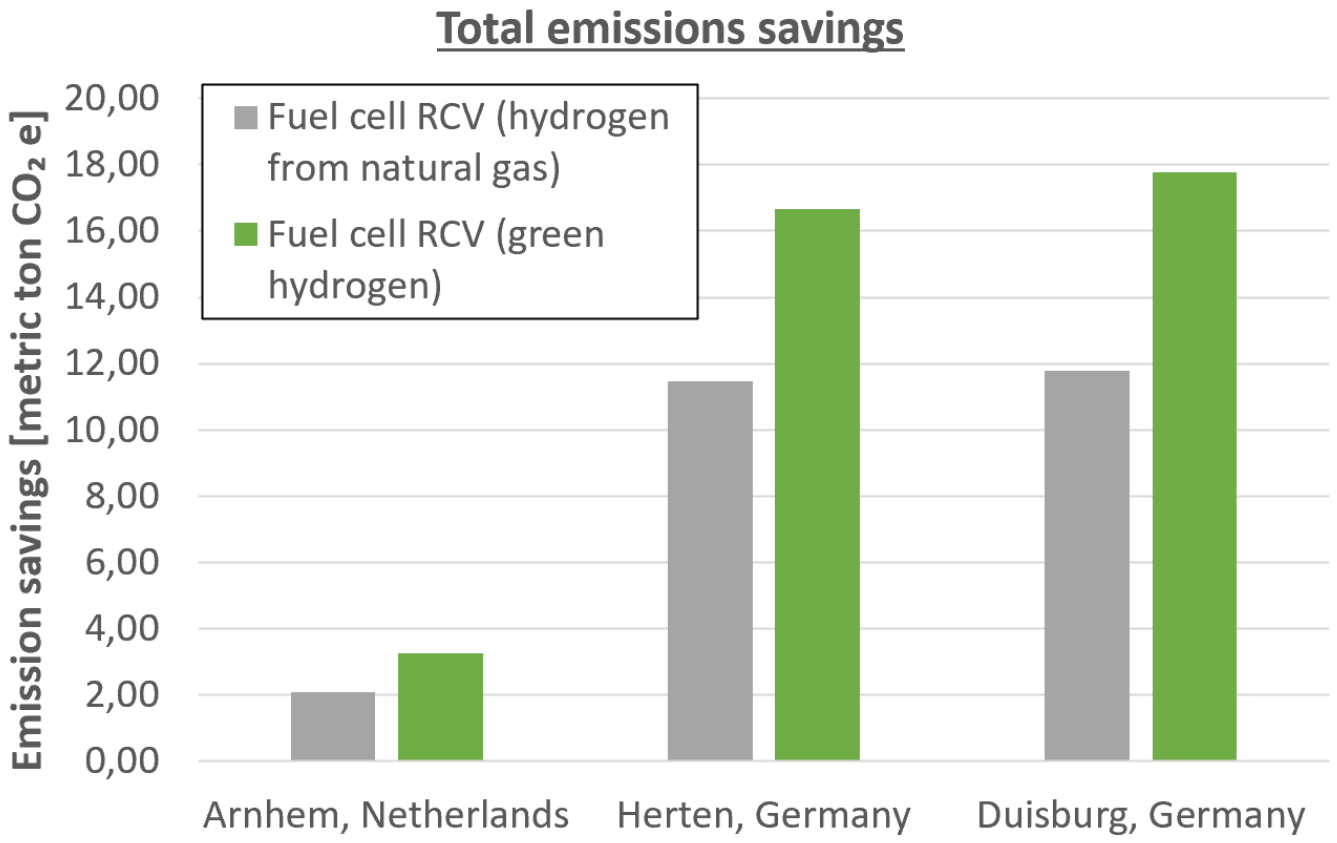
Category	Metric	Arnhem, NL	Duisburg, DE	Herten, DE
Distance [km]	Daily average	58.04	82.51	81.73
	Total	1857.4	8663.5	8010
H2 Use [kg]	Daily average	6.15	6.49	11.22
	Total	196.92	700.5	1099.62
H2 Consumption [kg/100km]	Daily average	11.82	7.58	13.62
Energy Consumption [kWh/km]	Daily average	1.71	1.86	1.75
H2 Refuel	Average per [kg]	6	11.33	12.22
	Number	9	65	55
	Average time [min]	17.44	12.65	10.84
Operation	Total days	32	108	80

Estimated emission savings within the analysis period

In comparison to diesel RCV



Learnings from project/conclusion

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- Include manufacturers in project to incentivise sharing of data
- Ensure good pipeline with clean and consistent data organised before vehicle contract signed

Future research – Data utility

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- Data-based modelling:
  - Predict/forecast a sequence of duty-cycle segments **optimized for fuel/energy consumption** using the following high-level inputs:
    1. Refuse-collection route optimization
    2. H2 level at the start of the daily operation
    3. Battery SoC at the start of the daily operation
  - **Route optimization**, refuse-collection authorities:
    1. Plan refuse-collection operation for an area optimized for fuel/energy consumption and operational (refuse-collection) requirements
    2. Assess the feasibility of operating H2-fueled refuse-collection vehicles on unknown routes

Future research - Data utility

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- Grey-box modeling approach based on the current analysis
  - further optimization at low-level, e.g., energy management strategy
  - From segment-based prediction to real-time (time-series) based prediction

- Adoption of performance-based standards for RCVs
  - Acceleration capability
  - Startability and gradability for operation on hilly routes