HAN University of Applied Sciences

HAN Automotive Research & Model-based Information Systems

Hyundai ix35 FCEV

Fuel Efficiency and Driver Experience

FINAL REPORT

2018

Hyundai IX35 FCEV

Colophon

Client	Rijkswaterstaat / The Ministry of I&M and Municipality of Arnhem

Project

Research done by	HAN University of Applied Sciences ➢ HAN Automotive Research (HAN-AR) ➢ Model-based Information Systems (M-BIZ)
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Report

Title	Fuel Efficiency and Driver Experience of the Hyundai ix35 FCEV
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Project Factsheet

Energy consumption

As can be seen in the table herunder, the average fuel efficiency of the three Hyundai ix35 FCEV vehicles: Helmond: 5-XLH-61, Rhoon: 9-XKB-49, and Arnhem: 4-ZTB-51, is 83km/kgH_2, in total 62.356km has been driven, using a 786kg of hydrogen, during 2385 trips. For each vehicle individualy this result in:

VehicleID	#Trips	Σ(Trip time)	Σ(Distance)	ΣH_2 mass	Mean values		
					Trip distance	Speed	Fuel Efficiency
	-	hr	km	kg	km	km/hr	km/kgH_2
Helmond	**681**	**477**	**32084**	**358,6**	**47**	**67**	**89,5**
Arnhem	**596**	**213**	**10205**	**124,8**	**17**	**47**	**81,8**
Rhoon	**1108**	**353**	**20067**	**257,8**	**18**	**57**	**77,9**
All	**2385**	**1043**	**62356**	**741,1**	**-**	**-**	**83,0**

The impact on fuel efficiency is analysed with respect road type driven, gearbox usage (Driivng Mode) and use of the Air Conditioner (AC). The results for the three vehicles – Helmond, Rhoon and Arnhem – are shown in the table below.

Vehicle / Influence	Helmond	Arnhem	Rhoon
Road Type	**km/kgH_2**	**km/kgH_2**	**km/kgH_2**
City	85,9	79,4	79,6
National	91,1	81,8	82,4
High Way	89,1	81,5	79,6
Driving Mode	**km/kgH_2**	**km/kgH_2**	**km/kgH_2**
D-Mode	88,8	81,6	80,6
E-Mode	90,0	80,0	81,1
Air Conditioning	**km/kgH_2**	**km/kgH_2**	**km/kgH_2**
On/Off	88,5/89,6	79,7/81,3	79,0/80,5

Well to wheel - CO_2-equivalence

The ***fuel tank capacity*** of Hyundai ix35 FCEV is **5.63** kg.

For ***electrolysis*** used in Helmond (Waterstofnet), this leads to **8.5 kg** CO_{2EQ} (GHG-emission) per full tank, using Wind energy for hydrogen production (1,5kg/CO_{2EQ}/kgH_2), based on information from Waterstofnet.

The refuelling station at Rhoon, uses **chlorine electrolysis, with green certificates**. This leads to **0 kg** CO_{2EQ} (GHG-emission) per full tank.

For ***Steam Methane Reforming*** (SMR) used Arnhem (HyGear) this leads to **72.6 – 86.1 kg** CO_{2EQ} (GHG-emission) per full tank, using fosil fuels for hydrogen production (12.9 – 15.3kg/CO_{2EQ}/kgH_2), based on European Joint Research Center (JRC, Brussels) data.

User experiences of the drivers of the vehicle

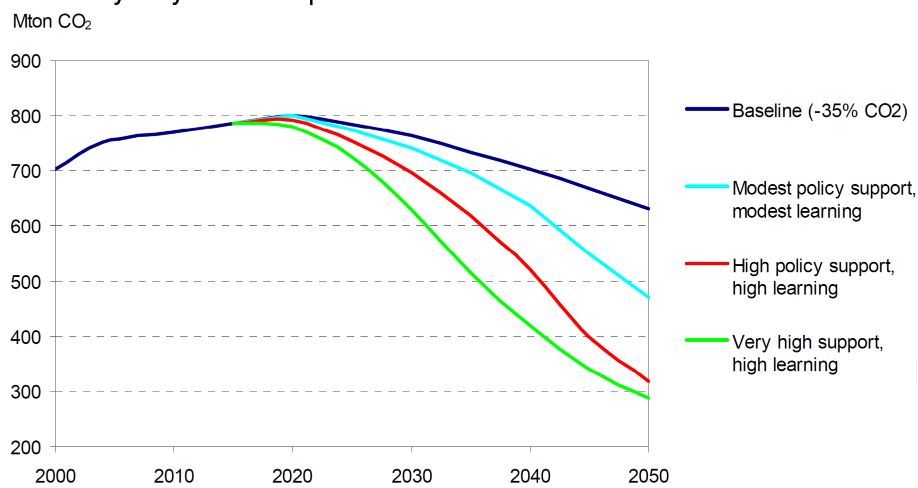
41 questionnaires were filled out, over the poject period 10.2015 – 12.2017. 17% of the questionnaires were filled out by participants outside the project group; 12% Toyota Mirai, 2% a City Bus and 2% an ix35 FCEV outside the test fleet.

On average drivers were satisfied about driving the Hyundai ix35 FCEV; operational comfort was appreciated by approx. 80% of the participants, by "8", on a scale from 1 to 10. Though 27% of the trips were longer than 500km, only 19% of the drivers claimed: little ("enigszins") range anxiety (2% claimed: strong ("Sterk tot zeer sterk")). Whilst the range was evaluated with <6, on a scale from 1 to 10.

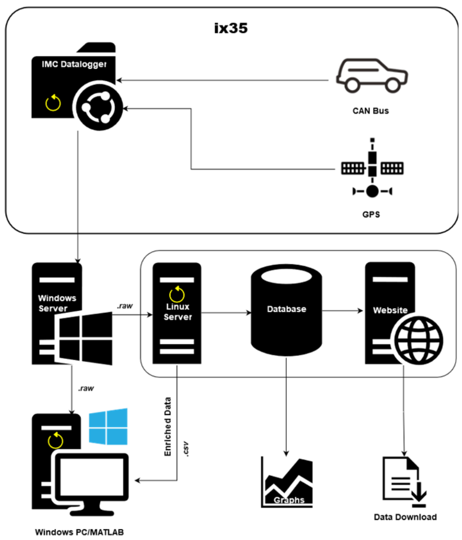
The most negatively judged aspect of hydrogen propelled vehicles is the limited availability of fuelling stations. This is according expectations, since there are only three fuelling stations in the Netherlands.

Summary

Accoring to Hoen, v. d. Brink and Annema the reduction of CO_2 emissions is increasingly important in achieving sustainable transportation. In spite of increasing reduction efforts, the traffic induced CO_2 emission level will show a 2% rise in 2020 w.r.t 2006 level in the Netherlands. CO_2 emissions of the road transport sector in the Netherlands is 16% of the overall CO_2 emissions. As shown in the figure below (high learning scenario) 50% of the demand in road transport in 2050 is according to Borthwick covered by hydrogen transport (high learning scenario, leading to approx. 60% CO_2-reduction, compared to the baseline), according the EU HyWays roadmap of 2008.



Therefore, one of the choices to reduce CO_2 reduction, is the use of hydrogen in drivelines, more specifically: FCEVs, being electric vehicles, using fuel cell technology for energy storage.
To assess the potential of hydrogen in transport to mitigate the trend in CO_2 reduction and develop knowledge and gain insight in effects of the usage of hydrogen in transport, both the Ministry of I&M and the Municipality of Arnhem set up a research project into the environmental aspects of a hydrogen propelled vehicle. In this project, running from April 2015, until December 2017, the CO_2-equivalent of hydrogen as a fuel has been assessed, as well as the fuel efficiency and the user experience, of the three Hyundai ix35 FCEV vehicles: Helmond: 5-XLH-61, Rhoon: 9-XKB-49, and Arnhem: 4-ZTB-51.



To assess the fuel efficiency of the vehicle, over 60 parameters were collected while driving. This data was send offline to a central database at HAN University Research, using the GPRS network. There data post processing evaluated fuel efficiency while driving in inner-cities, national roads and high ways, the impact of driving in economy mode and the air conditioning usage. In the picture on the right the data system has been depicted.

Next to the real life data acquisition, an online survey was used to assess the user experience, e.g. vehicle driving experience, range anxiety, and others.

Aggregated Results – Fuel Efficiency, and Mileage Driven

The mean aggregated fuel efficiency for the three vehicles in the Netherlands vehicles is: **83 km/kgH_2** (see Table 1). The distance driven per vehicles, differs significantly; the Helmond vehicle drove 3 times more and the Rhoon vehicle 2 times more than the Arnhem vehicle. The fuel efficiency of the Helmond vehicle shows the best value, positively affected by the longer mean trip length (longer trips leading to) and higher mean speed (higher power demand leading to a better fuel cell efficiency).

VehicleID	#Trips	Σ(Trip time)	Σ(Distance)	ΣH_2 mass	Mean values		
					Trip distance	Speed	Fuel Efficiency
	-	hr	km	kg	km	km/hr	km/kgH_2
Helmond	**681**	**477**	**32084**	**358,6**	**47**	**67**	**89,5**
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All	**2385**	**1043**	**62356**	**741,1**	**-**	**-**	**83,0**

Table 1 Overall results over three vehicles

In Figure 1 the number of refuelling's for all three vehicles are shown; a 264 refuelling's have been registered. The results, given per quarter over the project period, show a decreasing tendency. The peak in the 1^{ST} quarter of 2016, coincides with the moment that all three vehicles became fully operational.

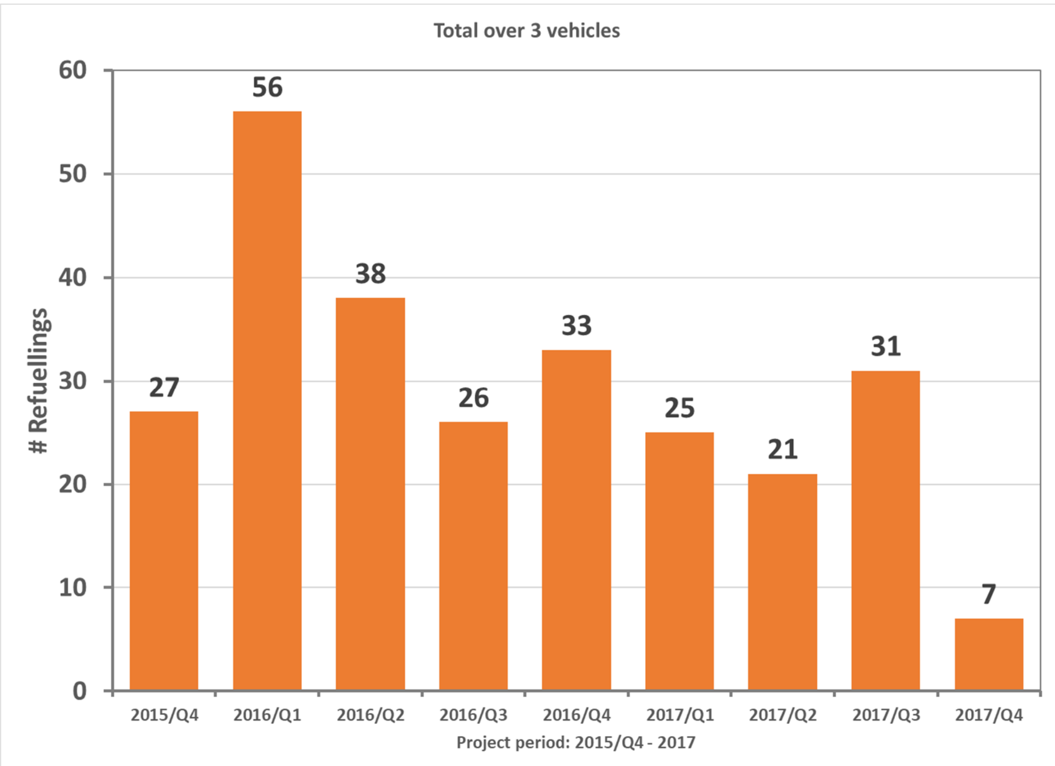

Figure 1 Total (3 vehicles) number of refuelling's (vehicle data)

The **Helmond** vehicle has an mean quarterly fuel efficiency of: **89,2 km/kgH_2** (min. 83,9 km/kgH_2, max. 93,9 km/kgH_2). Figure 2 shows the fuel efficiency (H_2 Efficiency), per quarter over the project period.

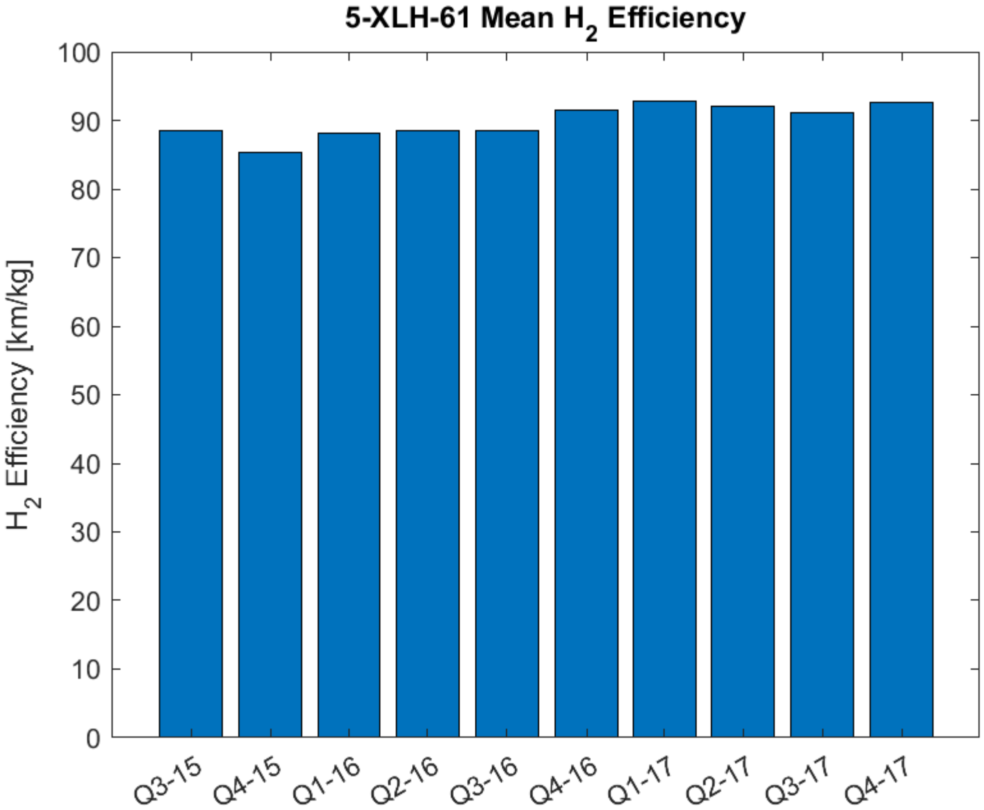

Figure 2 Aggregated results Helmond vehicle: Fuel Efficiency

Figure 3 shows the number of refuelling's for the Helmond vehicle; a 137 refuelling's have been registered. Clearly a peak value can be seen in the beginning (2016/Q1) of the project. At the end of 2017, the Helmond refuelling station was not operational, and thus the vehicle hasn't hardly been used in this quarter.

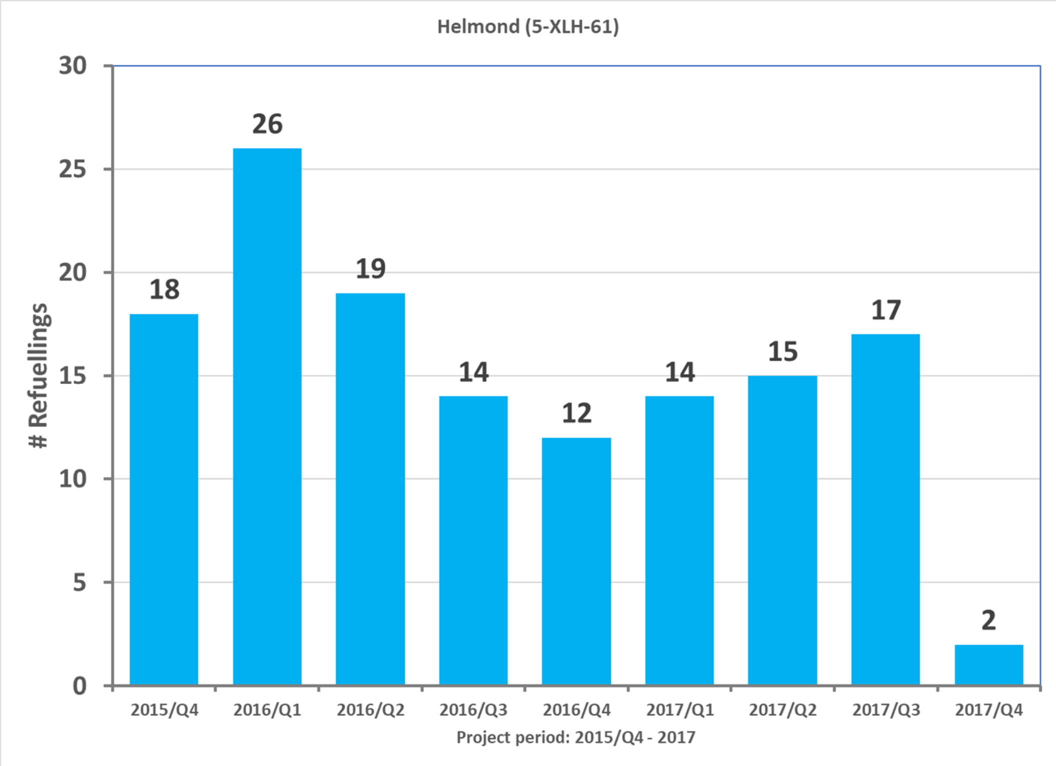

Figure 3 Helmond vehicle - Quarterly refuelling's (vehicle data)

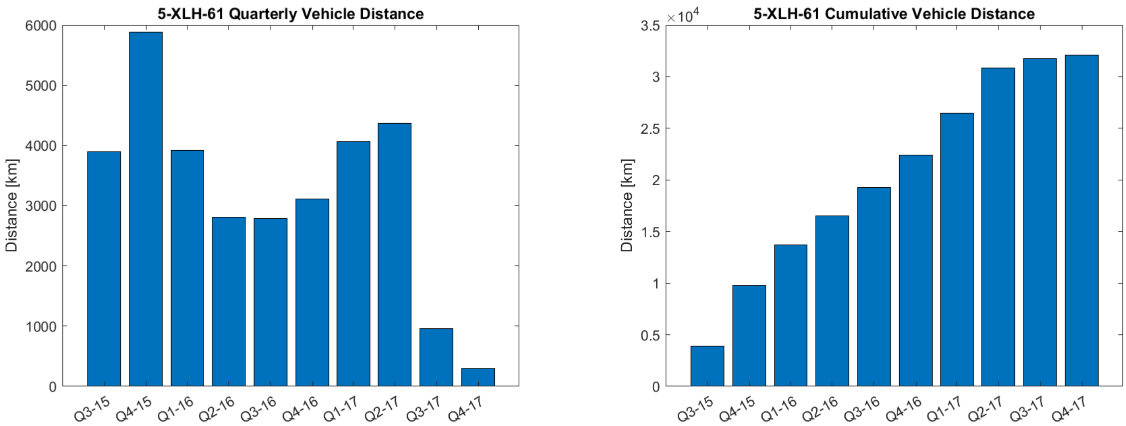

Figure 4 Aggregated results Helmond vehicle: Distance driven

Figure 4 shows the distance driven per quarter (left graph) and accumulative (right graph). Clearly a peak of approx. 6000km can be seen in the first quarter of 2016. Due to not being operational of the refuelling station, the distance travelled in the last part of 2017 shows a significant lower value.

The **Rhoon** vehicle mean quarterly fuel efficiency of: **80,1 km/kgH_2** (min. 75,9 km/kgH_2, max. 82,5 km/kgH_2). Figure 5, shows the fuel efficiency (H_2 Efficiency), per quarter over the project period. The data acquisition of the Rhoon vehicle has been out of operation in the Q1 and Q2 of 2017, which can be clearly seen in Figure 5, and Figure 7.

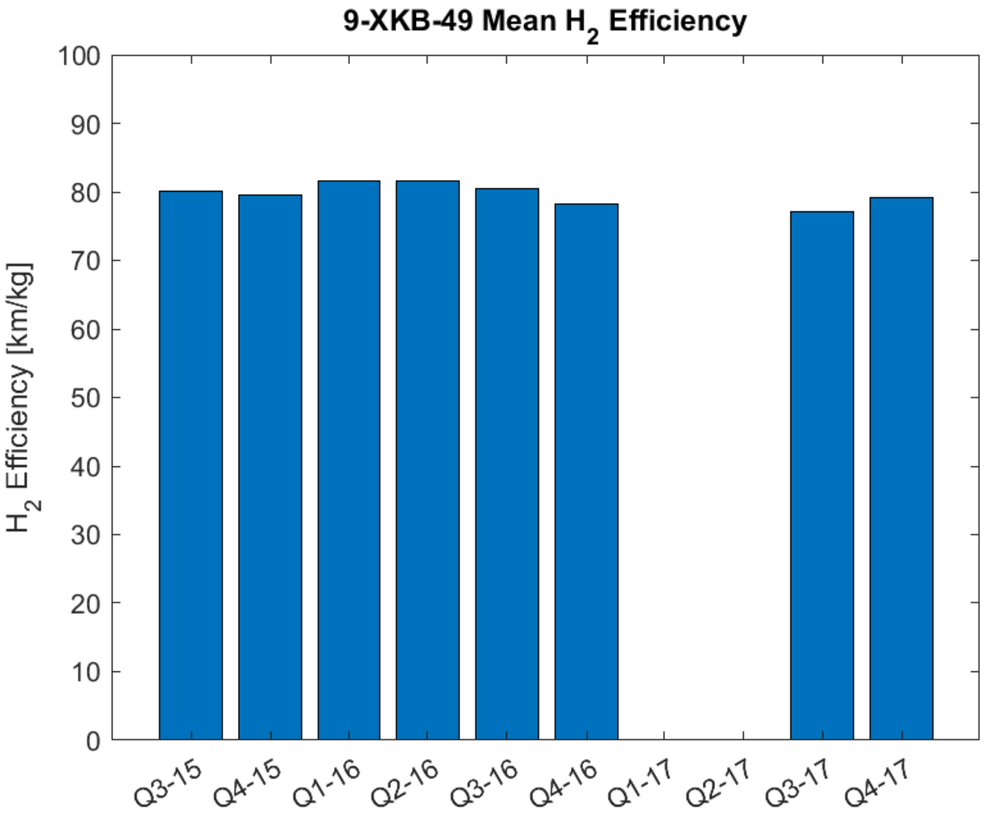

Figure 5 Aggregated results Rhoon vehicle: Fuel Efficiency

Nevertheless, the Rhoon vehicle has been driving as can be seen in Figure 6; 6 refilling's occurred, out of a total of 82 refuelling's have been registered.

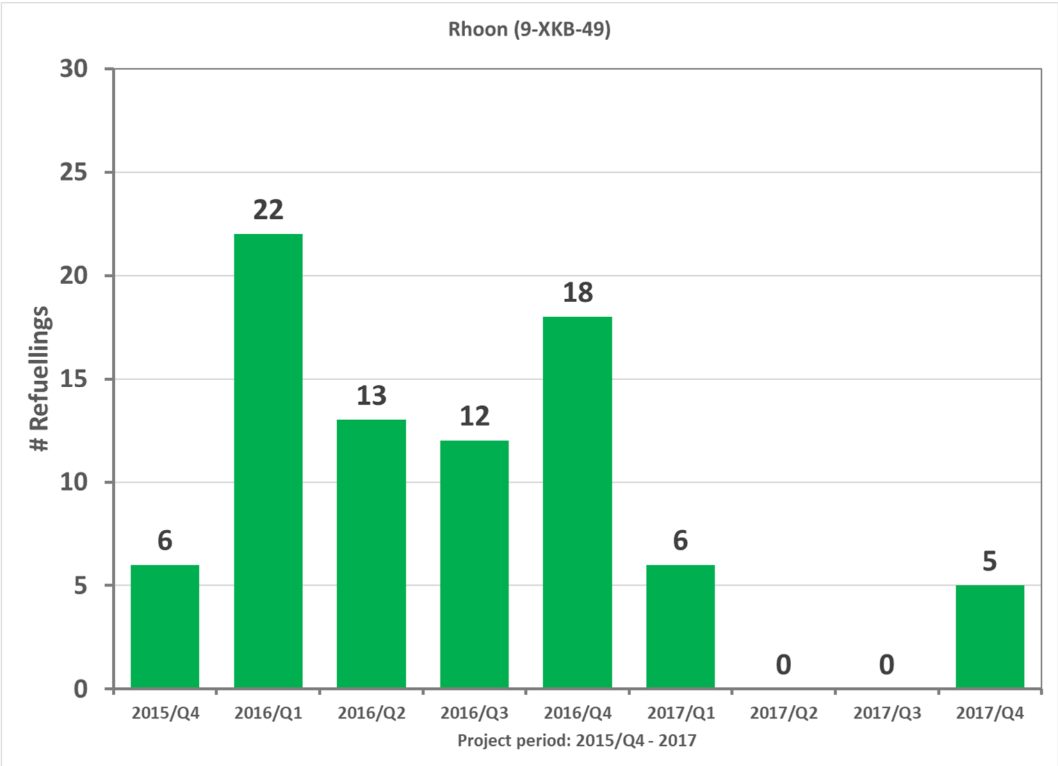

Figure 6 Rhoon vehicle - Quarterly refuelling's (vehicle data)

Figure 6 and Figure 7 show both peak values in 2016/Q1 and 2016/Q4. In 2016/Q1 over a 5000km has been driven, using 63,3kg of hydrogen. In 2016/Q4, approx.63,6kg of hydrogen has been used for approx. 4000km.

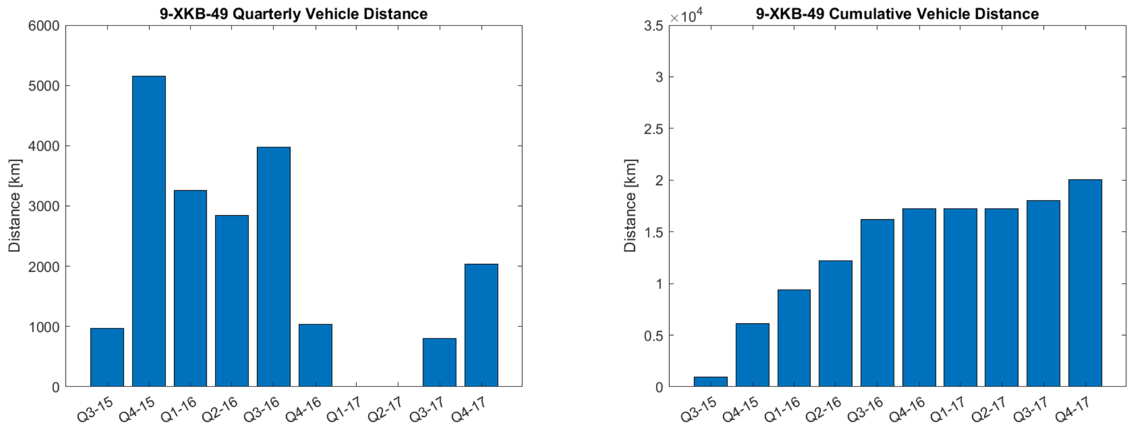

Figure 7 Aggregated results Rhoon vehicle: Distance driven

The **Arnhem** vehicle has a mean fuel efficiency (see Figure 8) of: **80,4 km/kgH_2** (min. 73,6 km/kgH_2, max. 85,8 km/kgH_2).

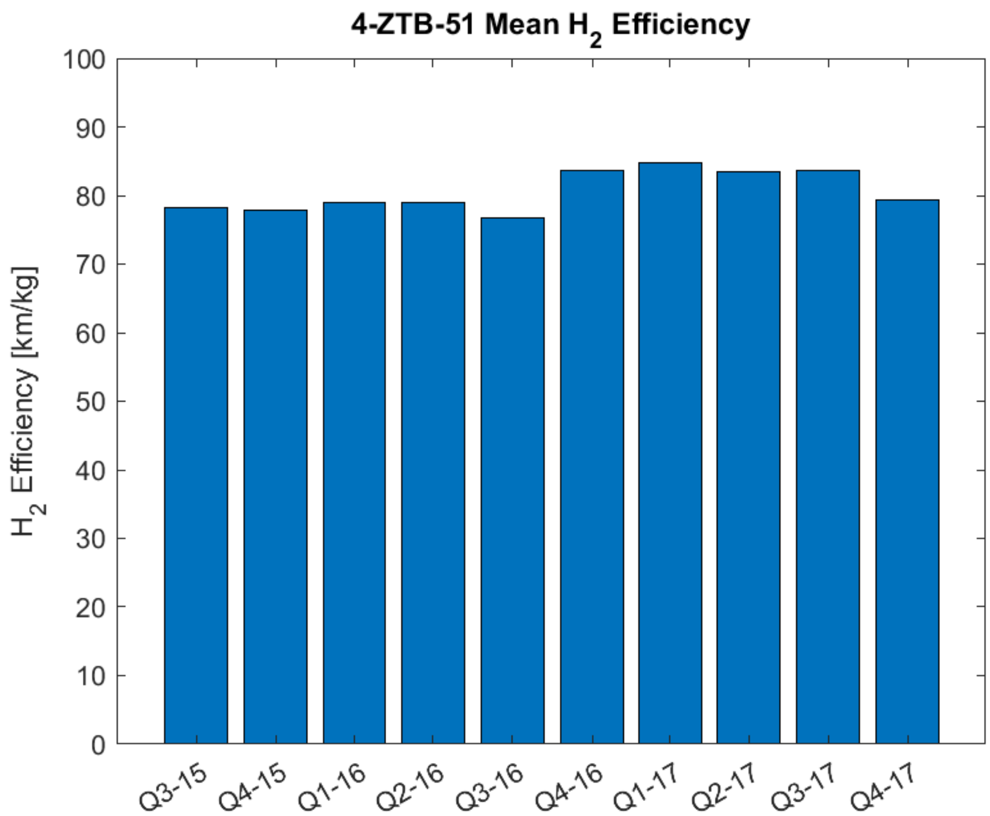

Figure 8 Aggregated results Arnhem vehicle: Fuel Efficiency

In mid-2016, the Arnhem vehicle has been out of operation for some time, due to an minor accident. However, the delivery of a crucial part caused the vehicle to be out of operation for quite some time (2016/Q3). Figure 9; show a 45 refuelling's that have been registered over the monitoring period.

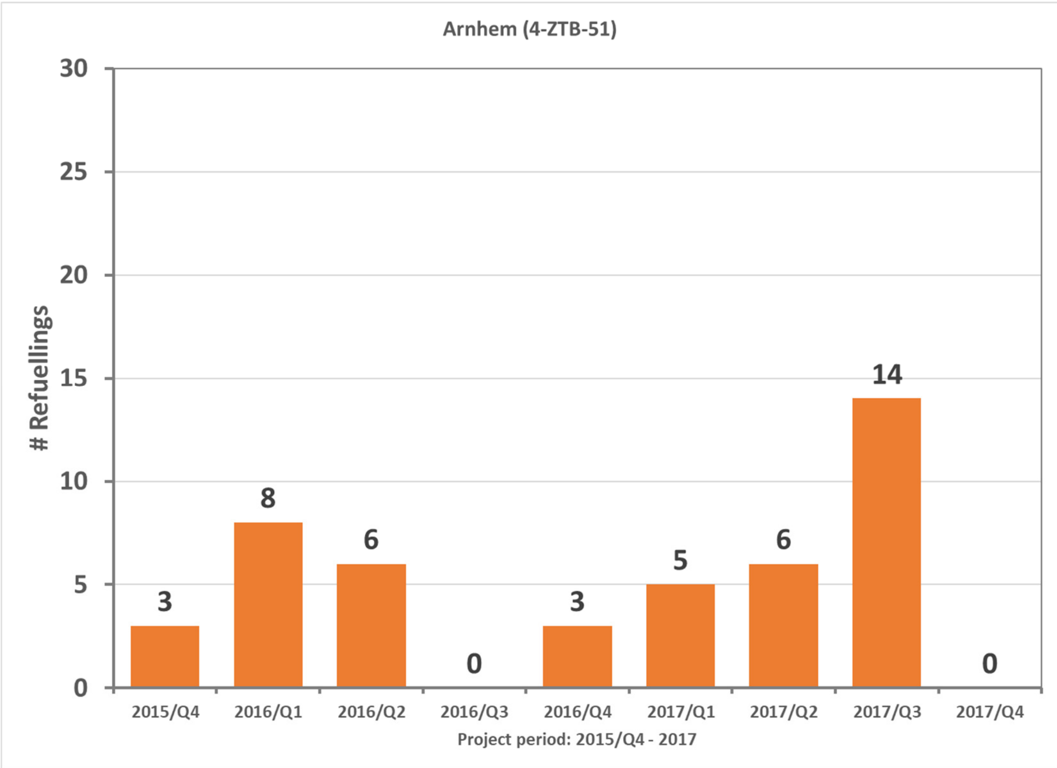

Figure 9 Arnhem vehicle - Quarterly refuelling's (vehicle data)

In 2017/Q4, the refuelling station in Arnhem opened officially.

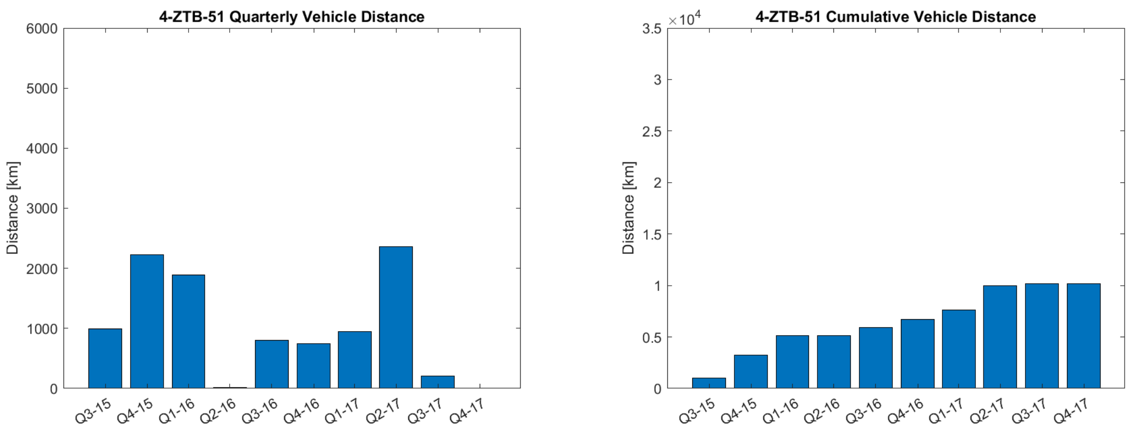

Figure 10 Aggregated results Arnhem vehicle: Distance driven

Aggregated Results – Road type, Drive Mode and AC-usage

Driving the vehicle in the city, of on the high way is expected to result in an different fuel efficiency. In Table 2, the mean shows the impact of driving the vehicle in 1) a city – typical speed limit: 50km/h, 2) on highway's – typical speed limit: 100 – 120km/h, 3) national road, i.e. "provincial wegen", typical speed limit: 80km/h.

GPS_road	Mean Speed km/hr	Mean Fuel Efficiency km/kgH2
City	**17,7**	**81,6**
Highway	**88,7**	**83,4**
National	**41,7**	**85,1**
No Id	**40,7**	**81,2**

Table 2 Impact of road type on fuel efficiency

On average the national road shows a better fuel efficiency, than on high way's. This can be due to the higher maintained speeds

Additionally the group: "No Id", is given. These are roads are undefined, due to: exit- and entrance roads to highways and (undefined) national roads, GPS inaccuracy, etc.

Driving in a given gearbox mode (Drive Mode) affects the fuel efficiency. The Hyundai ix35 FCEV, has an automatic gearbox, with D(rive), E(conomy)-modes and L(ow gear). In Table 3, the mean of the fuel efficiency shows the impact of the Shift Lever position (D, E, or L-mode).

Drive Mode	Mean Acelerator Pedal position %	Mean Vehicle Speed km/hr	Mean Fuel Efficiency km/kgH_2
D	**18,7 (σ:17,6)**	**60,3**	**83,7**
E	**27,4 (σ:23,7)**	**65,3**	**84,0**
L	**15,3 (σ:17,2)**	**45,0**	**85,2**

Table 3 Impact of the drive mode on fuel efficiency

Though E-mode is expected to be the most fuel efficient driving mode, the driver using the accelerator pedal defines the actual fuel efficiency. During driving in E-Mode, the accelerator pedal is pushed deeper (27,4%) and operated with higer spread (±23,7%). Most presumably, this is due to maintaining speed according traffic flow, instead of driving with a constant pedal position (which will lead to significant lower acceleratioon values). Driving in the L-Mode induces a significantly higher energy regeneration, leading to a better fuel efficiency.

AC	Mean Total Power kW	Mean Fuel Efficiency km/kgH2	StDev km/kgH2
Off	**11,7**	**82,4**	**19,5**
On	**14,3**	**83,8**	**20,2**

Table 4 AC usage and Fuel Efficiency

Using the air conditioner (AC), can lead to less fuel efficiency. In Table 4, the mean value is used to show of the effect of AC usage. Though a clear difference is observed in power taken from the fuel cell – 11,7kW at AC off, versus 14,3kW at AC on – this isn't be translated to fuel efficiency. The AC-system uses max 2.5kW, which is a) not used constantly and b) is low compared to the 100kW power availablein the drive line. Environmental impact, like: traffic circumstances, road type, driver behaviour, etc.) will supress, cover, the impact on fuel efficiency.

Fuel efficiency FCEV, compared to BEV

Basically, the Hyundai ix35FCEV, is an electric vehicle, having a fuel cell available as a electric power generator. Thus, comparing the fuel economy, expressed in energy per distance driven (Wh/km), to a pure battery driven vehicle will show the efficiency of the ix35FCEV drive line.
The energy consumption of the ix35FCEV (empty vehicle weight: 1921 kg) is 220 Wh/km, rated to weight: 115 Wh/ton.km. Whereas a modern battery Electric Vehicles (BEVs) achieve

an energy consumption of e.g. 110 Wh/km for the BMW i3 (weight 1440 kg, 92 Wh/ton.km) or 252 Wh/km for the Tesla Model S (weight: 2188 kg, 115 Wh/ton.km).

Results - CO_2-Equivalence (GHG-Emissions)

The vehicle used in this monitoring project, the Hyundai ix35 FCEV, has a fuel tank capacity of 144ℓ, at a fuel tank pressure of 70MPa. This leads to 5.63 kg hydrogen per full tank.

In the Helmond refuelling facility, hydrogen is produced by Waterstofnet, using ***electrolysis*** as production method. Waterstofned claims a GHG-emission of 1.5kg CO_{2EQ}/kgH_2, which leads to **8.5 kg CO_{2EQ}** (GHG-emission) per full tank, when refuelled in Helmond.

In the Rhoon refuelling facility, hydrogen is produced by Air Liquide, using ***chlorine electrolysis, with green certificates*** as production method. The refuelling station at Rhoon claims a GHG-emission of 0kg CO_{2EQ}/kgH_2, which leads to **0 kg CO_{2EQ}** (GHG-emission) per full tank, when refuelled in Rhoon.
Additionaly, Air Liquide produces hydrogen based on ***Steam Methane Reforming*** as well. Joint Research Center (Brussels) data shows a GHG-emission of 12.9 – 15.3kg CO_{2EQ}/kgH_2, using natural gas distributed by pipeline.

In the Arnhem refuelling facility, hydrogen is produced by HyGear, using ***Steam Methane Reforming*** as production method on location. Joint Research Center (Brussels) data shows a GHG-emission of 12.9kg CO_{2EQ}/kgH_2. This leads to **72.6 kg** CO_{2EQ} (GHG-emission) per full tank, using natural gas distributed by pipeline for hydrogen production.

Throughout the monitoring period the three vehicles refuelled basically at every available fuelling station (Arnhem, Helmond and Rhoon). Therefore in Table 5, the consequences for the GHG-emission is shown, based on production technology.

Referring to a ix35 class vehicle, having an class average CO_2-emission of 160gr/km, the ix35 FCEV is a "Label A" vehicle when running on hydrogen originating from electrolysis. The Rhoon vehicle, using hydrogen originating from SMR using natural gas, are either "Label C or D", identified (±10% variation with respect to the class average).

Refuelling station		**Helmond**	**Rhoon**			**Arnhem**
		electrolysis	chlorine electrolysis, with green certificates	Steam Methane Reforming: natural gas piped over 7,000km	Steam Methane Reforming: natural gas piped over 4,000km	Steam Methane Reforming
GHG emissions in kg CO_{2EQ}/kgH_2		1.5	0	15.3	12.9	12.9
Vehicle	km/kgH_2	gr/km	gr/km	gr/km	gr/km	gr/km
Helmond	89.5	17	0	171	144	144
Arnhem	81.8	18	0	187	158	158
Rhoon	77.9	19	0	196	166	166

Table 5 GHG emissions in gr/km for different hydrogen production methods and the 3 vehicles

Results - Driver Experience

The drivers (NN) filled out 41 questionnaires during the project period, including users of the Toyota Mirai (12%), a City Bus (2%) and third parties Hyundai ix35 FCEV users (2%). On average drives were satisfied about driving the Hyundai ix35 FCEV; operational comfort was appreciated by approx. 80% of the participants, by “8”, on a scale from 1 to 10. Though 27% of the trips were longer than 500km, only 19% of the drivers claimed: little range anxiety (2% claimed: strong). Whilst the range was evaluated with <6, on a scale from 1 to 10. The most negatively judged aspect of hydrogen propelled vehicles are the availability of fuelling stations. This is according expectations, since there are only three fuelling stations in the Netherlands.

Contents

Abbreviations

AC	AirCo; heating/cooling system of the vehicle	
AL	Air Liquide	
AP_M	Accelerator pedal position; mean value	[mm]
CAN	Controller Area Network	
CCS	Carbon Capture and Storage	
CNG	Compressed Natural Gas	
CSD	H_2-station - compression, storage, and dispensing costs	
CH_4	Natural gas (Carbon-Hydrogen)	
CO	Carbon Monoxide	
CO_2	Carbon Dioxide	
D(-Mode)	D-Mode, selector position of the gear box; normal driving position	
DOE	Department of Energy of the United States	
E	Energy	[(k)Wh]
EC	Energy Consumption	[kWh.100km^{-1}
E_{H2}	Energy to produce hydrogen	[kWh/kg]
E(-Mode)	E-Mode, selector position of the gear box; energy saving position	
ECN	Energy research Centre of the Netherlands	
EU	European Union	
EV	Electrical Vehicle -	
$E_{REF.}$	Energy; amount of energy used over a 100km reference trajectory	[MJ.100km^{-1}]
EOBD	Extended On Board Diagnostic system	
FC	Fuel Cells	
FCEV	Fuel Cell Electric Vehicle	
FE	Fuel Efficiency (see glossary)	
FE_M	Mean value of the fuel efficiency	
FE_{Q1}	25%-quartile value of the fuel efficiency	
FE_{Q3}	75%-quartile value of the fuel efficiency	
FTP	Federal Test Procedure	
GC	Green Certificates	
GC_P	Green Certificates on production, pipe line transport (NOT included in GC)	
GHG	Green House Gases[1]	
GPS	Global Positioning System	
GWP	Global Warming Potential	
HRS	Hydrogen Refuelling Station	
HAN	Hogeschool van Arnhem en Nijmegen (HAN University of Applied Sciences)	
HANAR	HAN Automotive Research	
H_2	Hydrogen	

[1] The primary greenhouse gases in Earth's atmosphere are: carbon dioxide, methane, nitrous oxide and Emissions of Fluorinated Gases. (https://www.epa.gov/ghgemissions/overview-greenhouse-gases). Water vapor and ozone are also considered to be a GHG (https://www.ncdc.noaa.gov/monitoring- references/faq/greenhouse-gases.php?section=watervapor)

$H_{0,D}$	Lower calorific value: Diesel	[MJ/kg]
$H_{0,H}$	Lower calorific value: Hydrogen	[MJ/kg]
$H_{0,P}$	Lower calorific value: Petrol	[MJ/kg]
I	Current	[A]
ICE	Internal Combustion Engine	
IPCC	Intergovernmental Panel on Climate Change	
JRC	Joint Research Centre of the European Commission	
$L_{PARTIAL}$	Partial load of the Hyundai ix35FCEV, during simulation	1970 kg
L_{GROSS}	Gross weight of the Hyundai ix35FCEV, during simulation	2290 kg
LHV	Lower heating value	[MJ/kg]
LNG	Liquefied Natural Gas	
MPI	Multi Point Injection (engine fuel input system)	
MS	Mobile Sources	
MySQL	User oriented (My) System Query Language - computer language to query a database	
NEDC	New European Drive Cycle	
NG	Natural Gas	
OEM	Original Equipment Manufacturer (e.q. Hyundai, Tesla, BMW, …)	
O&M	Operations and Maintenance	
P	Power	[kW]
P(-Mode)	P-Mode, selector position of the gear box; parking position	
PEMFC	Proton exchange membrane fuel cell	
PSA	Pressure Swing Adsorption (PSA), to used to recover and purify hydrogen	
PV	Photo Voltaic	
R(-Mode)	R-Mode, selector position of the gear box; reversed driving position	
SMR	Steam methane reforming	
SS	Stationary Sources	
U or V	Voltage	[V]
TTW	Tank-to-wheel analysis	
WLTP	Worldwide harmonized Light vehicles Test Procedure	
WN	Waterstofnet	
WTT	Well-to-Tank	
WTP	Well-to-pump	
WTW	Well-to-wheel analysis	

Symbols

δ	Ratio: (Measured value – Simulated Value) over Measured value	
ϕ	Energy flow variable	
σ	Standard deviation	
ρ_D	Specific density: Diesel	[kg/m^3]
ρ_H	Specific density: Hydrogen	[kg/m^3]
ρ_P	Specific density: Petrol	[kg/m^3]
2-WD	Two wheel – 1 axle – drive line for vehicles	

Subscripts

AVG	Average value
D	Diesel
H	Hydrogen
M	Mean
P	Petrol
REF	Reference value

Glossary

Arnhem	Test vehicle, license plate: 4-ZTB-51 (Car 2), fuels basically in Helmond
Distance	Distance travelled with the vehicle
Fuel Efficiency	Distance travelled with the vehicle, using 1 kg of hydrogen ([km/kgH_2])
Fuel consumption	the volume of fossil fuel (here: petrol of diesel) used to drive a 100km ([ℓ/100km])
Helmond	Test vehicle, license plate: 5-XLH-61 (Car 1), fuels basically in Helmond
Rhoon	Test vehicle, license plate: 9-XKB-49 (Car 3), fuels basically in Rhoon
Tank stop	Fuelling moment of a test vehicle
Test Fleet	the three vehicles participating in this experiment; the Arnhem, the Helmond and the Rhoon
Test Vehicle	One of the three participating Hyundai ix35 FCEV vehicles, referred by as: “Arnhem”, Helmond”, or “Rhoon”
Trip	Period between the moment “Ignition On”, until “Ignition Off”
Trip time	Time span over a trip, in hours, minutes, second

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Hyundai ix35FCEV; Vehicle performance assessment

HyLights - Monitoring & Assessment Framework

{Part 1: summarizing report - Comply with: Monitoring & Assessment Framework (MAF)}

1. Monitoring & Assessment Framework – Introduction

To be able to compare different fleet test, the European Union (EU), defined the "Monitoring & Assessment Framework (MAF) Handbook I" [1], a framework within which the acquired data must be presented.
Three main groups are identified

1. Project Governance Indicators
   a. Project management
   b. Legal
   c. Socio-economics
2. Vehicle Performance Indicators
   a. Vehicle segments
   b. Technical specifications
   c. Cumulative performance data
3. Hydrogen Infrastructure Performance Indicators
   a. Technical specifications
   b. Cumulative operating performance

Ad 1 - since the ix35 monitoring project is part of an overall client project on the ix35, the project governance indicators are not registered within this document

Ad 2 - The vehicle performance indicators are part of the project: "Hyundai ix35 FCEV - Fuel Efficiency and Driver Experience", as reported in this document and is based on online monitoring of real life vehicle data, while driving.

Ad 3 - the hydrogen infrastructure performance indicators no part of the project: "Hyundai ix35 FCEV - Fuel Efficiency and Driver Experience". Data related to this project is acquired in cooperation with the client. In consequence of this, only RSD has been obtained in relation to the vehicles participating in this project.

Ad 2 and 3 - both, vehicle and fuelling station assessment, require incident reporting. This data has been gathered by questionnaires for the vehicle and for the fuelling stations by data coming from a "WhatsApp-group"

2. Vehicle Performance Indicators

2.1. Vehicle segments

The vehicle segment is defined in [1, pp. 21, Table 6]; accordingly the segment of the assessed vehicles is: “**Passenger Car**”. The sub-category, identified in [1, pp. 21, Table 6], is: “**MPV**”.

2.2. Technical specifications (V1-V8)

Three identical vehicles took part of the monitoring project: the Hyundai ix35 FCEV. For these vehicles the “General Vehicle Data”, and “Technical Vehicle Specifications”, are given.

In Table 6, the general vehicle data is given, according [1], Annex: Data tables – “Template for General Vehicle Data”.

GENERAL VEHICLE DATA		HYLIGHTS
Date:		
Name:		
ISSUE	UNIT	DATA/DESCRIPTION
General		
Vehicle operator	-	Rijkswaterstaat (RWS), Gemeente Arnhem (GA)
Vehicle identification number	-	RWS: 5-XLH-61 en D36 9-XKB-49, GA: 4-ZTB-51
Vehicle type (vehicle segment)	-	Stationwagen (AC)
Vehicle manufacturer	-	Hyunday
Model & variant name	-	ix35 , FCEV
Model year	-	2014
First time on the road (with road certification)	-	5-XLH-61: 23-09-2014 9-XKB-49: 02-09-2014 en 4-ZTB-51: 30-3-2015
Travelled km @ project beginning	-	0
Operating hours @ project beginning (if applicable)	-	-
Propulsion system (ICE, FC, with or without hybrid)	-	Fuel cell electric vehicle
Propulsion system manufacturer/integrator	-	Hyundai
Home base (depot/garage)	-	5-XLH-61: Helmond, 9-XKB-49: Rhoon, 4-ZTB-51: Arnhem:
Fuel		
Fuel type (CGH2 @ … MPa, LH2,…)	-	CGH2 @ 70MPa
Fuel standard	-	CGH2
Other fuel specifications	-	-
Vehicle dimensions		
Length	m	4,41
Width	m	1,66
Height	m	1,82
Wheel base	m	2,64
Number of seats	-	5
Empty weight	kg	1.821
Gross vehicle weight	kg	2.250
		HyLights is funded by the European Commission

Table 6 Overview of the general vehicle data according [1]

In Table 7 the technical vehicle specifications are given, according [1], Annex: Data tables – “Template for Technical Vehicle Specifications”.

VEHICLE PERFORMANCE INDICATORS - Technical Specifications			HYLIGHTS
Vehicle Identification: 5-XLH-61 (HELMOND), 4-ZTB-51 (ARNHM) & 9-XKB-49 (RHOON) Date: Name:			
(PI-#)	ISSUE	UNIT	DATA
Vehicle: HELMOND (5-XLH-61)			
(V-1)	Maximum constant speed km/h	km/h	160
(V-2)	Acceleration 0-50 km/hr (car)	s	4,8 (Road data)
	Acceleration 0-60 km/hr (bus)	s	-
	Acceleration 0-100 km/hr (car)	s	12.5 (OEM data), 15,1 (Road data)
	Elasticity 80-120 km/hr (car)	s	14,9 (Road data)
(V-3)	Driving range km	km	594 (OEM data), 502,0 (Road data)
Vehicle: RHOON (9-XKB-49)			
(V-1)	Maximum constant speed km/h	km/h	160
(V-2)	Acceleration 0-50 km/hr (car)	s	5,3 (Road data)
	Acceleration 0-60 km/hr (bus)	s	-
	Acceleration 0-100 km/hr (car)	s	12.5 (OEM data), 14,0 (Road data)
	Elasticity 80-120 km/hr (car)	s	12,0 (Road data)
(V-3)	Driving range km	km	594 (OEM data), 456,8 (Road data)
Vehicle: ARNHEM (4-ZTB-51)			
(V-1)	Maximum constant speed km/h	km/h	160
(V-2)	Acceleration 0-50 km/hr (car)	s	4,4 (Road data)
	Acceleration 0-60 km/hr (bus)	s	-
	Acceleration 0-100 km/hr (car)	s	12.5 (OEM data), 13,8 (Road data)
	Elasticity 80-120 km/hr (car)	s	0,0 (Road data)
(V-3)	Driving range km	km	594 (OEM data), 428,6 (Road data)
Drivetrain			
(V-4)	Volumentric power density	l per kW	
	Gravimentric power density	kg per kW	
(V-5)	Ambient temperature limits for vehicle operation	min°C	
		max °C	
Hydrogen storage			
(V-6)	Maximum hydrogen storage capacity of the vehicle	kg of H2	5.64
(V-7)	Energy density of the hydrogen storage system	w%	
		kg per litre	0.039167
(V-8)	LH2 storage autonomy time of the vehicle	days from 50% state of filling to remaining range of 20 km	
			HyLights is funded by the European Commission

Table 7 Overview of the general vehicle data according [1]

0to 0(p.: 119 - 127) show the measurement results of the acceleration and elasticity measurements.

2.3. Cumulative performance data (V9 – V16)

Table 8, shows the MAF parameter: (V-9): "Total distance travelled", up to (V16): "Approval and operational hurdles of the vehicle".

VEHICLE PERFORMANCE INDICATORS - Cumulative Performance Data				HYLIGHTS
		5-XLH-61	9-XKB-49	4-ZTB-51
MAF Handbook I - Vehicle Parameter	Unit	Helmond	Rhoon	Arnhem
(V-9) total travelled distance km vehicle				
@Start (01.10.2015)	km	119	298	0
@Stop (31.12.2017)	km	32203	20365	10205
(V-10) hydrogen refuelled and consumed	kg per refuelling	358,6	257,8	124,8
(V-11) vehicle availability % vehicle				
(V-12) safety incidents reporting - report for		See Table 8 - 10		
(V-13) vehicle efficiency	%			
MANUFACTURER (based on: NEDC)	kgH_2/100 km	0,9512		
USER (based on: Real life measurements)	kgH_2/100 km	1,12	1,23	1,32
(V-14) vehicle emissions – regulated emissions	g per km vehicle	None		
(V-15) customer satisfaction report subcontracted public				
(V-16) approval and operational hurdles of the vehicle				
HyLights is funded by the European Commission				

Table 8 Overview of the MAF-indicators V9 – V16

(V17): "Buses – number of passengers", is left out, since this category is not applicable.

Safety incidents reporting (V-12)

Category	Description
A	Stack or ICE
B	Periphery (mechanical components, e.g. compressor, valves,…)
C	Electrical components (i.e. electric motor, inverter,…)
D	H2 storage
E	High voltage battery
F	Stack or ICE

Table 9 Classification of failure categories

VEHICLE PERFORMANCE INDICATORS - Vehicle Incident Reporting HYLIGHTS

						Unscheduled event						Safety relevant					
Number of incident	Vehicle identification	Day, time out of operation	Day, time back to operation	km reading of the vehicle	operating hours of the vehicle	Yes, category A	Yes, category B	Yes, category C	Yes, category D	Yes, category E	Comments (GB)	Yes, category 1	Yes, category 2	Yes, category 3	Yes, category 4	Yes, category 5	Comments (NL)
1	5-XLH-61	01-12-14		3200			X				Damage botom plate				X		NL: Schade onderzijde
							X				Humidifier replaced				X		
2	5-XLH-61	23-01-15		9843			X				O-ring filler nipple mounted in hemond				X		O-ring vulnippel gemonteerd in Helmond
3	5-XLH-61	17-12-15		19478		X					20.000km maintenance and ECU upgrade				X		
4	9-XKB-49	11-09-15		20937		X					20.000km maintenance and ECU upgrade				X		
5	9-XKB-49	02-09-16		36693					X		Tank cleaned (poluted Hydrogen)				X		
6	9-XKB-49	26-06-17		45885				X			Error code P1DC4-PMC module isolation. Water sensor replaced				X		(Watertrapsensor vervangen)

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Table 10 VEHICLE PERFORMANCE INDICATORS - Vehicle Incident Reporting

Category	Vehicle incident	Description
This rating system is to be used to categorise Hydrogen Vehicle safety data potentially for statistical analysis.		
1	Vehicle incident/ injury/ H2 release	Hydrogen Vehicle accident that resulted in injury. H2 release has occurred.
2	Vehicle incident/ injury/ no H2 release	Hydrogen Vehicle accident that resulted in injury. No H2 release has occurred.
3	Vehicle incident/ without injury/ H_2 release	Hydrogen Vehicle incident that did not result in any injury but possible vehicle damage. H2 release has occurred.
4	Vehicle incident/without injury/ no H_2 release	Hydrogen Vehicle incident that did not result in any injury but possible vehicle damage. No H2 release has occurred.
5	Near miss	An event that under different circumstances could have become an incident specified in category 1-4

Table 11 Classification of safety incident categories related to H2 vehicles

3. Hydrogen Infrastructure Performance Indicators

This chapter gives the MAF data for fuelling stations, participating in the ix35FCEV project.

3.1. Technical specifications

3.1.1. Refuelling station Helmond - Waterstofnet

In Table 12 and Table 13, the generic fuelling station data is given for fuelling station of Waterstofnet in Helmond.

GENERAL HYDROGEN REFUELLING STATION DATA (1) - WATERSTOFNET			HYLIGHTS
Date:16/1/2018			
Name: Stefan Neis (WaterstofNet)			
ISSUE	UNIT		DATA/DESCRIPTION
General			
Fuelling station owner / operator	-		WaterstofNet vzw
Fuelling station location	-		Automotive Campus Helmond (NL)
Date of final construction / first operation	month/year		Tuesday, October 1, 2013
Total hydrogen onsite production capacity	$kg_{(H2)}$ per day		72 kg/day => 144 kg/day after upgrade febr '18
User interface / terminal	Description		Tokheim registration and PitPoint dispenser
Type of filling station (multiple choice)			
Stand alone, only hydrogen	MC	■	
Integrated hydrogen station (e.g. into conventional HRS)	MC		
Accessibility (multiple choice)			
public	MC	■	Public during working hours semi public during the night and weekends
limited / restricted	MC/description		*Example: only to project partners*
Opening hours (per week)	-		
Refuelling procedure (multiple choice)			
Self-service refuelling		■	
Assisted refuelling service, why?			
Automatic - robotic refuelling			
Dispensed fuels (multiple choice)			
CGH2 @ .... Bar	MC/description	■	*350 bar and 700 bar, cars and heavy duty*
LH2	MC		
Other fuels	MC/description		
Concept of the filling station (multiple choice)			
Booster concept	MC		
Cascade concept	MC	■	
Vapourisation of LH2	MC		
Other	MC/description		
Key components			
Dispenser supplier	-	■	PitPoint
Hydrogen storage supplier	-	■	Lincoln and Wystrach
Hydrogen storage type (LH2, CGH2,...)	Description	■	CGH2
Hydrogen storage capacity	kg (H2)	■	250 kg
Hydrogen storage volume	m³	■	combination
Hydrogen compressor / pump supplier	-	■	multiple, Idro Mechanicca and PDC
Hydrogen compressor / pump type	-	■	Membrane and piston
Hydrogen compressor capacity	Nm³/h	■	60Nm3/hr and variable for 700 bar
Pipeline pressure	bar		-
Distance	km		-

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Table 12 General fuelling station data (1) - Waterstofnet

GENERAL HYDROGEN REFUELLING STATION DATA (2) - WATERSTOFNET		HYLIGHTS
Date: 16/1/2018		
Name: Stefan Neis (WaterstofNet)		
ISSUE	UNIT	DATA/DESCRIPTION
Hydrogen supply (multiple choice)		
On-site fuel production - if yes…. Y/N		
….natural gas & reformer	MC	
...LPG & reformer	MC	
...other primary fuel & reformer	MC/description	
...electricity & electrolyser	[redacted]	30Nm3/hr Alcalyne elctrolyser Hydrogenics (upgrade to 60Nm3/hr in February 2018)
other	MC/description	
Central production - if yes…	Y/N	
description	-	
Hydrogen transportation - if yes…	Y/N	
… via pipeline	MC	
…via delivery truck	MC	
… other	MC/description	
Primary feedstock mix for H2 generation		
NG %		
Liquid hydrocarbons %		
coal %		
nuclear %		
national electricity grid mix %		
biomass %		50% Biomassa
hydro %		
wind %		50% Wind
solar %		
geothermal %		
others %		100% groene stroom van Greenchoice
Total:		100%

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Table 13 General fuelling station data (2) - Waterstofnet

3.1.2. Refuelling station Rhoon

In Table 14 and Table 15, the generic fuelling station data is given for fuelling station of AirLiquide (AL) in Rhoon.

GENERAL HYDROGEN REFUELLING STATION DATA (1)			HYLIGHTS
Date:			
Name:			
ISSUE	UNIT	DATA/DESCRIPTION	
General			
Fuelling station owner / operator		AL	
Fuelling station location		Rotterdam	
Date of final construction / first operation	month/year	11-2014	
Total hydrogen onsite production capacity	N/A		
User interface / terminal	Description	Payment terminal with instructions	
Type of filling station (multiple choice)			
Stand alone, only hydrogen	MC		
Integrated hydrogen station (e.g. into conventional HRS)	MC		
Accessibility (multiple choice)			
public	MC		
limited / restricted	MC/description	X	*to several customers*
Opening hours (per week)	-		
Refuelling procedure (multiple choice)			
Self-service refuelling			
Assisted refuelling service, why?			
Automatic - robotic refuelling			
Dispensed fuels (multiple choice)			
CGH2 @ .... Bar	MC/description		*700bar & 350 bar*
LH2	MC		N/A
	MC/description		
Concept of the filling station (multiple choice)			
Booster concept	MC		
Cascade concept	MC		Yes
Vapourisation of LH2	MC		N/A
Other	MC/description		
Key components			
Dispenser supplier			Confidential
Hydrogen storage supplier			Confidential
Hydrogen storage type (LH2, CGH2,...)			GH2
Hydrogen storage capacity	kg (H2)		95
Hydrogen storage volume	m³		2,8
Hydrogen compressor / pump supplier			Confidential
Hydrogen compressor / pump type			Confidential
Hydrogen compressor capacity	Nm³/h		81m3/h and 289m3/h
Pipeline pressure	bar		80-100 bar
Distance	km		
			HyLights is funded by the European Commission

Table 14 General fuelling station data (1) – AirLiquide (AL)

GENERAL HYDROGEN REFUELLING STATION DATA (2)			HYLIGHTS
Date:			
Name:			
ISSUE	UNIT		DATA/DESCRIPTION
Hydrogen supply (multiple choice)			
On-site fuel production - if yes…. Y/N		N	
….natural gas & reformer MC	MC		
...LPG & reformer MC	MC		
...other primary fuel & reformer	MC/description		
...electricity & electrolyser MC			
other	MC/description		
Central production - if yes…	Y/N		
description	-		
Hydrogen transportation - if yes…	Y/N		
… via pipeline	MC	Y	
…via delivery truck	MC	N	
… other	MC/description		
Primary feedstock mix for H2 generation			
NG %			
Liquid hydrocarbons %			
coal %			
nuclear %			
national electricity grid mix %			
biomass %			
hydro %			
wind %			
solar %			
geothermal %			
others %	100%		Chlorine electrolysis (green certificates)
Total:			100%
			HyLights is funded by the European Commission

Table 15 General fuelling station data (2) – AirLiquide (AL)

3.2. Cumulative performance data, I-4 and I-5

To evaluate the performance of the refuelling station, the refuelling quantity in [kg] for project internal and external vehicles is reported.

In Figure 11 the overall fuelled mass during the project period (2015/Q4 – 2017/Q4), is shown, as well as the period prior to the project (vehicles were available prior to the project start).

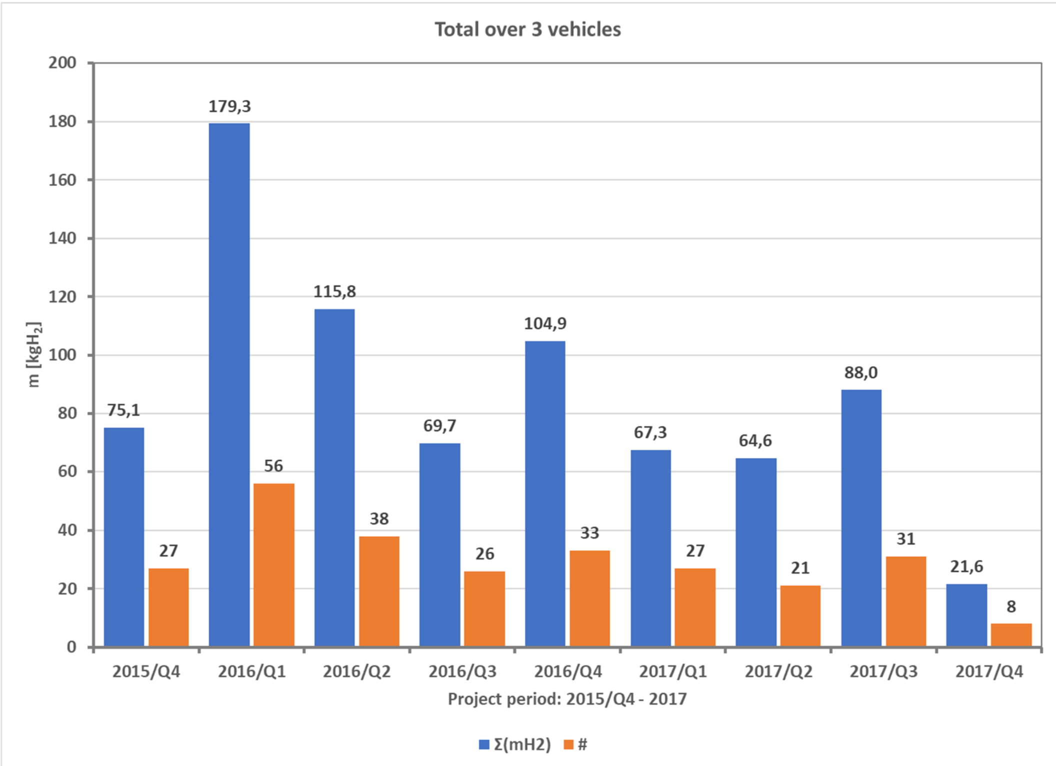

Figure 11 Overall fuelled mass Hydrogen during project period

VEHICLE REFUELLING DATA (HYDROGEN REFUELLING STATION) HYLIGHTS

Date, time	Vehicle ID	Refuelling station ID	Refuelling duration [min]	CGH_2 35 MPa	CGH_2 70 MPa	LH_2
03-10-2014, at 11:47	9-XKB-49	Helmond - Waterstofnet	4:07		3,90	
08-10-2014, at 21:23	9-XKB-49	Helmond - Waterstofnet	4:47		5,06	
…	…	…	…	…	…	…
08-09-2017, at 18:04	4-ZTB-51	Helmond - Waterstofnet	3:57		3,82	
20-09-2017, at 08:00	5-XLH-61	Helmond - Waterstofnet	2:23		2,20	

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Table 16, the refuelling's of the subsequent project vehicles are shown. In these tables only a sub-part is shown. In 0Appendix 11 Helmond - Vehicle Refuelling ; HRS-data, (p.109), the total overview of the refuelling data at Helmond is given. In 0Appendix 12 Rhoon - (p.115), the total overview of the refuelling data at Rhoon is given.

VEHICLE REFUELLING DATA (HYDROGEN REFUELLING STATION) HYLIGHTS						
Date, time	Vehicle ID	Refuelling station ID	Refuelling duration [min]	CGH_2 35 MPa	CGH_2 70 MPa	LH_2
03-10-2014, at 11:47	9-XKB-49	Helmond - Waterstofnet	4:07		3,90	
08-10-2014, at 21:23	9-XKB-49	Helmond - Waterstofnet	4:47		5,06	
…	…	…	…	…	…	…
08-09-2017, at 18:04	4-ZTB-51	Helmond - Waterstofnet	3:57		3,82	
20-09-2017, at 08:00	5-XLH-61	Helmond - Waterstofnet	2:23		2,20	
HyLights is funded by the European Commission						

Table 16 Overview of Refuelling data at Helmond (©WaterstofNet)

3.3. Cumulative performance data, I-6 and I-16

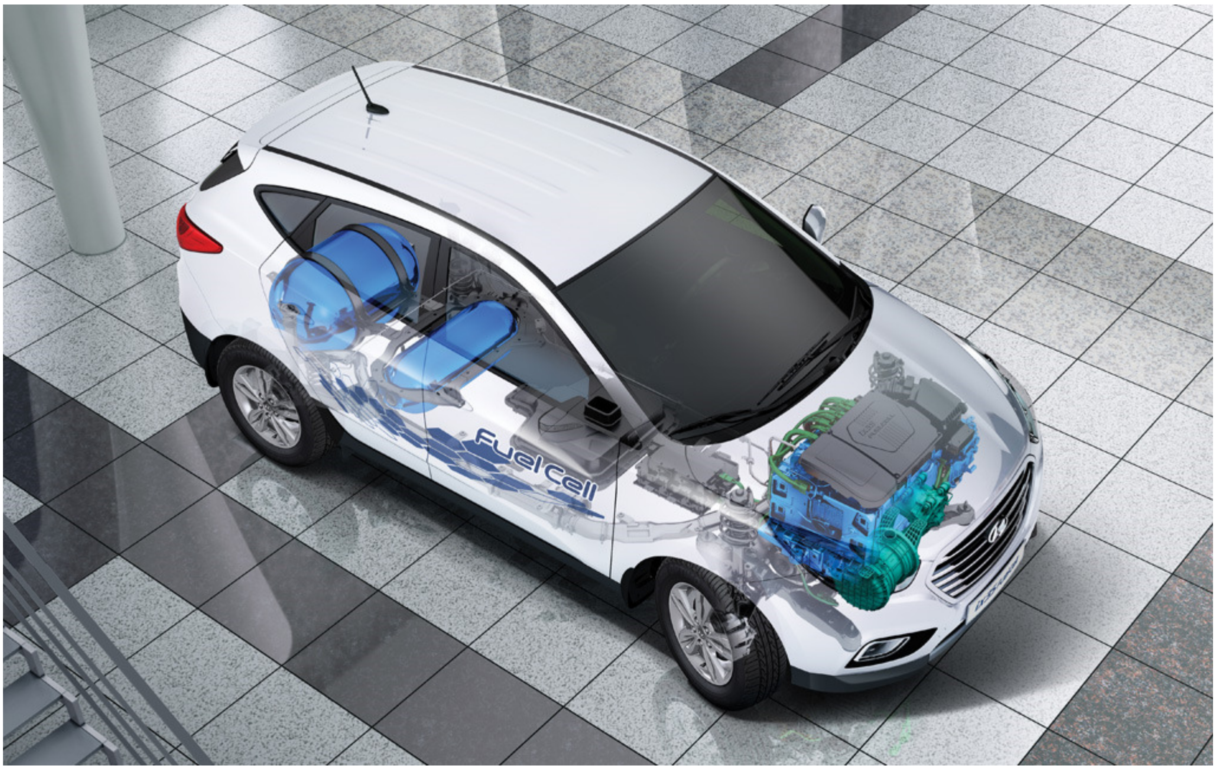
PI	Description	Remarks per Fuelling station
(I-6)	Utilisation rate of the refuelling station	Helmond Rhoon
(I-7)	Refuelling station availability	
(I-8)	Safety incidents reporting	
(I-9)	Fuel quality and composition	
(I-10)	Hydrogen losses	
(I-11)	Quantity of delivered H2 (central H2 production)	
(I-12)	Hydrogen produced (onsite H2 production)	
(I-13)	Utilisation rate of the fuel production unit (onsite H2 production)	
(I-14)	Specific energy demand at the hydrogen refuelling station	
(I-15)	Customer satisfaction	
(I-16)	Approval and operational hurdles of the HRS	

Table 17 Cumulative Performance Indicators refuelling stations

Hyundai ix35FCEV; Vehicle performance assessment

Vehicle Performance
Real Life Data and Driver assessment

{Part 2: summarizing report – using real life data from the vehicle and driver survey's}



4. Introduction

The project reported on in this document, includes monitoring 3 hydrogen ix35 FCEV [2], [3], [4], for 27 months: October 2015 – December 2017). Two vehicles are used by The Ministry of I&M (5-XLH-61 and 9-XKB-49) and one vehicle (4-ZTB-51) is used by the Municipality of Arnhem ('Clients', refer to both). In this document, the three vehicles together will be referred by as: "test fleet". The research is carried out by HAN Automotive Research, in cooperation with Model-based Information Systems, both part of the HAN University of Applied Sciences. The Hyundai ix35 is a fuel cell vehicle with high pressure gaseous storage (700 bar), a 100kW fuel cell and an electric motor, combined with a limited size battery-pack without external charging possibility. During the project, vehicle usage and vehicle fuel efficiency will be analysed based on real life collected data.

4.1. General

The reduction of CO_2 emissions is increasingly important in achieving sustainable transportation. In spite of increasing efforts, the traffic induced CO_2 emission level will show a 2% rise in 2020 w.r.t 2006 level in the Netherlands [5]. CO_2 emissions of the road transport sector in the Netherlands is 16% of the overall CO_2 emissions [6]. One of the chances, or perhaps: choices, to affect this is the usage of hydrogen in drivelines, more specifically: FCEVs, being electric vehicles, using fuel cell technology for energy storage.
In the HyWays study of 2008 amongst 10 member states[2] [7], the developed roadmap pointed out that 50% of the demand in road transport in 2050 is covered by hydrogen transport [7] (see figure 12; high learning scenario).

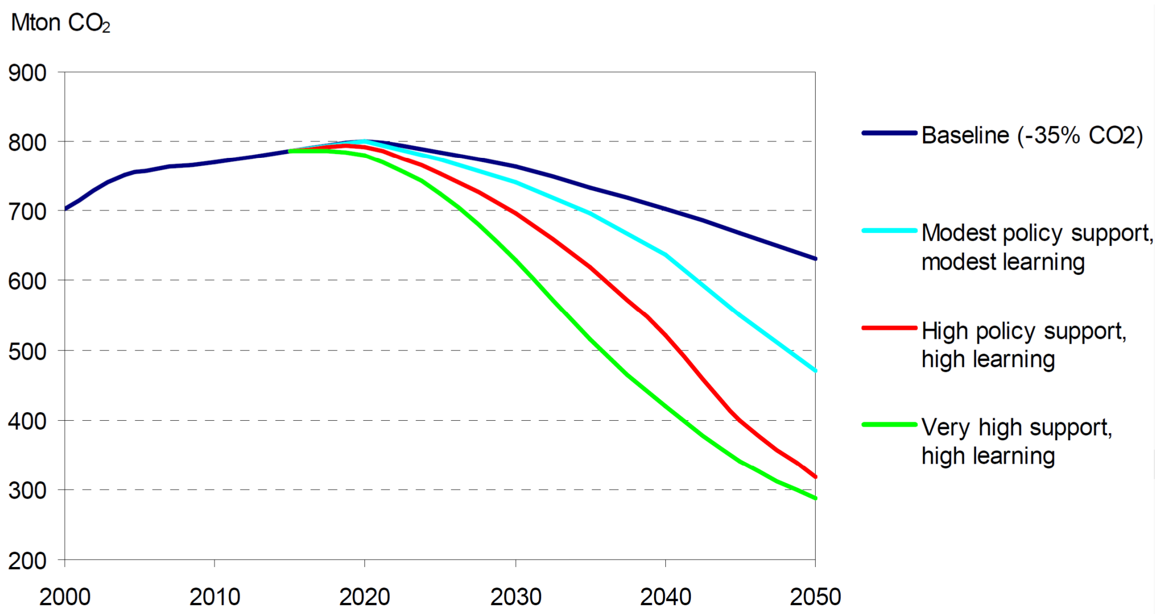


Figure 12 Development of total CO_2 emission for road transport for 10 member states [7, p. 34]

2 Participated by: Finland, France, Germany, Greece, Italy, Netherlands (ECN – H. Jeeninga), Norway, Poland, Spain and United Kingdom

The high learning scenario leads to a 55% – 60% reduction of CO_2-emissions compared to the baseline scenario[3]. However, development of the CO_2-emission in the baseline scenario strongly depends on oil price, CO_2-emissions reduction targets and targets for (minimum shares) of alternative motor fuels; these are key parameters.

The Ministry of I&M and the Municipality of Arnhem see great potential in the use of hydrogen vehicles to create a positive impact on CO_2 emission reduction in the road transport sector. To assess the potential of hydrogen to mitigate this trend and develop knowledge and gain insight in effects of the usage of hydrogen in transport both organizations set up a research project into the environmental aspects of a hydrogen driveline vehicle, by assessing the well-to-tank analysis in a general way and the tank-to-wheel analysis in more detail.

In assignment of the Ministry of I&Mm and the Municipality of Arnhem, HAN Automotive Research, part of the HAN University of Applied Sciences, carries out a program assessing the usage of three Hyundai's ix35's during their daily usage. This report covers a period of 9 quarters: 4[TH] quarter 2015, 2016 and 2017).

4.2. Project Goal

The goal of the project is to get a clear picture of the effects of using hydrogen vehicles, not only in terms of objective data, but as well the subjective experiences of drivers and users of the vehicle. To limit the scope of the project, three areas of has been defined:

1. Evaluate the fuel efficiency
2. Assessment of the well-to-wheel energy usage
3. Gain insight in the user experience of the vehicle

Regarding 1 and 2: The assessment of the well-to-wheel analysis is split in two trajectories: 1) the well-to-tank to analysis and 2) the tank-to-wheel analysis. The well-to-tank analysis will be done with a rather generic approach. No specific production analysis will be done and the focus will be on production of the hydrogen. In contradiction to this, the tank-to-wheel analysis will be considered in more detail. The fuel efficiency will be evaluated with respect to driving mode and usage of the air-conditioning unit. The latter can only be qualified in terms of: "on" and "off".

4.3. Problem definition

As has been mentioned in the previous section, the focus of this project will be the use of hydrogen as a fuel. In this perspective three hydrogen-powered Hyundai ix35FCEV vehicles, 2 of the Ministry of Infrastructure and Environment and 1 of the Municipality of Arnhem, are being monitored.

The usage of hydrogen in a vehicle is far from common. Surveys in literature show that a wide range of papers and reports are available, but only few based on real-world data. To be able to objectively evaluate the usage of the FCEV, with respect to fuel efficiency and driving

3 The baseline figures for road transport (light and heavy duty vehicles) are based on the EC-study Energy Trends 2030: *European Energy and Transport - Trends to 2030. Office for Official Publications of the European Communities, Luxembourg, 2003*

experience it is necessary to obtain data from vehicles driving during professional use, being not artificial, research focused trips in real-world traffic.

The focus of the project on fuel efficiency while driving, requires on line data acquisition of driveline and vehicle status related data. Data is gathered through CAN-bus[4] access on the freely accessible EOBD[5] port.

Driver experience is gathered by an internet survey, supported by monkey survey. 31 questions could be answered (see appendix 8). The answers to the questions will combined due to multiple driver experiences in driving the Hyundai ix35FCEV.

4.4. Project Focus and Research Questions

Based on the aforementioned, the following focus of the project has been defined: establish the real-world fuel efficiency of the Hyundai ix35 FCEV, gain insight in the user experiences during use of the vehicle, and research the well-to-wheel energy deployment.

From the aforementioned the following research questions are defined in cooperation with the clients:

1. What is the fuel efficiency of the participating vehicles[6]

2. Insights in the well-to-wheel fuel efficiency, related to different production methods and the subsequent CO_2 emissions[7]

3. What are the user experiences of the drivers of the vehicle[8]

4.5. Document Breakdown

4 CAN bus (Controller Area Network) is a vehicle bus standard designed to allow microcontrollers and devices to communicate with each other in applications without a host computer

5 Extended Onboard Diagnostics (EOBD)

6 Original question: Wat is het energieverbruik van de waterstofvoertuigen

7 Original question: Inzicht in het “Well-to-wheel” energiegebruik (§2.3), van de verschillende productiemethoden van waterstof en de daarbij behorende CO2-emissies

8 Original question: Wat zijn de rijervaringen van de gebruikers van deze voertuigen

5. Background

In this chapter back ground information will be given on both objective project focus and research questions (see §4.4): 1) Fuel Efficiency of the participating vehicles and 2) Insights in the well-to-wheel fuel efficiency.

The following topics will be addressed:

1. Reference values on fuel efficiency for comparison reasons of similar ix35 vehicles. Next to FCEVs, pure EVs, diesel and petrol fuelled vehicles are considered as well;
2. For the well to wheel analysis, GWP due to hydrogen production method is considered;
3. Hydrogen fuel costs and fuel cell degradation.

5.1. Project information

In 2015 on a national level, 22% of the CO_2 emissions were related to mobile sources, of which 72% is related to road traffic [6]. The CO_2 emissions of mobile sources increased by 21% relative to the level of 1990 [6], whereas the overall level of CO_2 emissions increased by 9% in that period. It is interesting to see that the legally restricted emission components: CO (-54%), NOX (-70%) and particle matter (PM, -73%), improved significantly [6]. In appendix 1, Table A1-1 to 3, an overview of this data is given.

Since 2010, carbon dioxide (CO_2) emissions for new passenger cars in European Union (EU) have decreased by more than 0.020 [kg/km] [8]. In 2015, the CO_2 emissions from new passenger cars was 0.1196 [kg/km] on average, 8% below the official EU target for this, set for 2015. However, in 2006, it became apparent that the European CO_2 emission reduction agreement with passenger cars manufacturers would (will) not be achieved [5]. The study reveals that road transport is the second biggest greenhouse gas (GHG) emission source in the EU.

Hydrogen fuel cell vehicles (FCEV) have zero harmful tail pipe emissions. FCEVs are driven with the use of electric motors, just as in full electric vehicles. The difference lies in the source of the electricity. Fuel cell vehicles generate their own electricity with a chemical process that combines hydrogen and oxygen to form water. The advantage of an FCEV is that hydrogen fuel can be produced using methods that have low environmental impacts.

Hydrogen vehicles have the potential to become a future and sustainable transportation solution, because it both reduces oil use and harmful emissions such as CO_2. However, as the GHG emissions of the vehicle whilst in use are zero, the tank-to-wheel section only indirectly effects the GHG, simply because a higher fuel consumption on the vehicle leads to more frequent refuel points, requiring more Hydrogen to be manufactured, and if this process causes GHGs, then the higher fuel consumption of the vehicle will result in higher GHG from the production process.

Electric powered vehicles (EVs), still today, have a limited range. Few EVs have a range of over 250km, regardless of the environmental (e.g. temperature) and geographical (e.g. hills) circumstances. The time to >80% SOC of batteries is significantly higher than the refuelling of a conventional vehicle. Using a fuel cell in the powertrain of the EVs, eliminates the time constrain when refuelling, and brings us range (>500km). However, the sparsely available refuelling point brings in another stressful issue: where to refuel and do I make it there? This phenomenon is called range anxiety.

Ministerie van Infrastructuur en Milieu (Ministry of Infrastructure and the Environment) of the Netherlands, along with Rijkswaterstaat (RWS), claims that the CO_2 reduction targets for the EU in 2050 cannot be reached with conventional techniques. The desired results must be achieved using alternative techniques. Thus, with great interest to discover potential of alternative energy sources, especially the use of hydrogen in mobility.

The project: "Hyundai ix35 FCEV; Fuel Efficiency and Driver Experience", analyses the fuel efficiency of three hydrogen vehicles (Hyundai ix35 FCEV), to understand the fuel economy of hydrogen fuel cell system.

Furthermore, the fuel efficiency gives us the possibility to support the well-to-wheel analysis of the fuel cell driven vehicles. And finally, the driver experience will give us insight in the acceptance of the vehicle by the driver.

5.2. Hyundai Test Vehicle - ix35 FCEV

Hyundai released their first generation of hydrogen vehicle models in 2001, the Santa Fe FCEV. After 11 years of development and 2 generations in between, in 2012 Hyundai presented the newest hydrogen fuel cell vehicle, the Hyundai ix35 FCEV, onto the market. The main elements of the Hyundai ix35 FCEV propulsion system are shown in Figure 13.

Figure 13 Hyundai ix35 FCEV Model [9]

The fuel tank (1) has a pressure of 700 [bar] combined with a high voltage lithium polymer battery pack (2) of 24 [kWh]. The battery is charged with a combination of energy produced by the fuel cell (3) and captured when braking. During hard acceleration, the battery pack provides an extra boost. The fuel cells, where electricity is produced by electrolysis between H_2 and O_2, generate water vapour as the only tailpipe emission. An inverter converts (4) direct current from the fuel cell to alternating current to the motor, and regulates engine speed and torque. The electronically controlled transmission (5) helps in seamless driving and recovers energy during braking.

Table 18shows the reference performance parameters.

Fuel Efficiency	Urban	0.8896

[$kgH_2.100km^{-1}$]	Highway	0.9868
	Combine	0.9512
Driving range [km]		594
CO_2 emission [$kg.km^{-1}$]		0
Fuel tank capacity [kg] [ℓ]		5.64 144

Table 18 Hyundai ix35 FCEV Specification [9]

In comparison with the previous generation, which only had a 300 [km] driving range, there is a big improvement in this generation. This is due to a greater space made for the hydrogen fuel tanks, and the compression to 700 [bar] possible with the new hydrogen tank. The newest ix35 has a powerful electric motor which provides 100kW of power, with a top speed of 160 [km/h].

5.3. Reference Vehicles

The performance of the three test vehicles Reference values on fuel efficiency for comparison reasons of similar ix35 vehicles. Next to FCEVs, pure EVs, diesel and petrol fuelled vehicles are considered as well;

5.3.1. Copenhagen Reference project

Many projects have been run over the years which are related to elaborating on hydrogen applied in the driveline (FCs) of vehicles. In cooperation with both clients, the Hyundai ix35FCEV [2], [3] have been used in the Copenhagen project [10, p. 5]. From the Copenhagen project, the following reference values are adopted [10]:

a. Operational average fuel efficiency over one (test) year: 75km/kgH_2 (06.2013 – 06.2014)
b. On road fuel efficiency
    a. 82km/kgH_2 (August 2013 - maximum)
    b. 68km/kgH_2 (January 2013 - minimum)
c. Distance driven in 1½ years: 180,490 km
d. Average distance travelled per vehicle day of operation is 41km
e. Range (NEDC): 594km
f. Documented fuel efficiency: 1.07 kgH_2/100km, (93km/kgH_2)

Figure 14, shows the average temperature over the test period (June 2013 - 2014) and the subsequent a. Maximum fuel efficiency 82km/kgH_2 (august 2013).

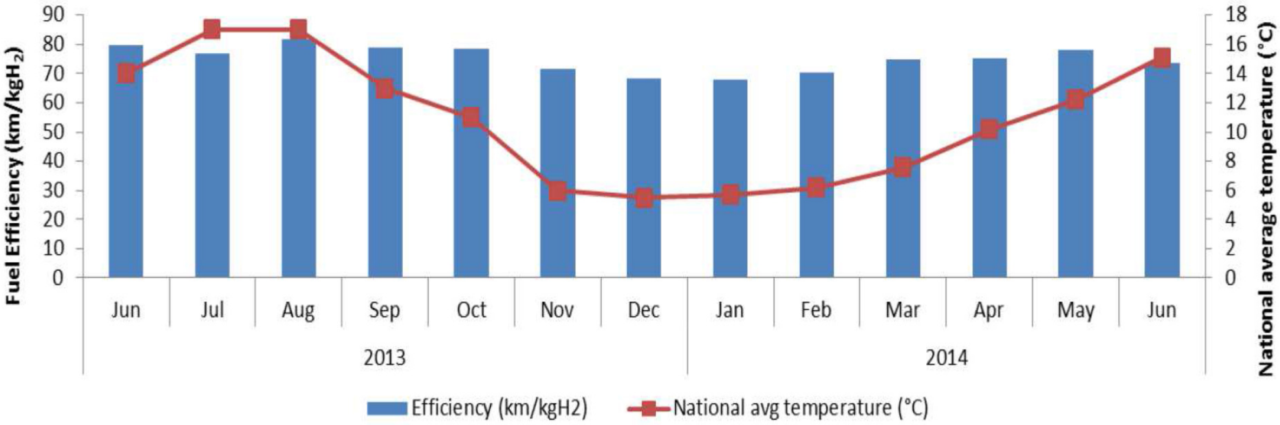


Figure 14 Average Temperature per month and fuel efficiency [10]

5.3.2. Hyundai Reference Vehicle - ix35 2WD and Tucson

There are not many comparable ICE models from Hyundai that can be used as a control group for the hydrogen vehicle. They are the Hyundai ix35 (Australian version) and the Hyundai Tucson (the updated model of the ix35 ICE version). Since the Hyundai ix35 FCEV is front wheel driven, with automatic transmission, only 2WD models with automotive transmission will be shown as references. The relevant specifications for these vehicles are presented in table 19 and table 20.

Fuel consumption [ℓ.100km^{-1}]	Urban	11.2
	Highway	6.8
	Combine	8.4
Driving range [km]		520 – 830km[9], typical (on road): 738km
CO_2 emission(Combine) [kg.km^{-1}]		0.2
Fuel tank capacity [ℓ]		58

Table 19 Hyundai ix35 2WD Specification [11]

Fuel consumption [ℓ.100km^{-1}]	Urban	10.9
	Highway	6.1
	Combine	7.9
Driving range [km]		570 – 1020km[10], typical (on road): 784km
CO_2 emission(Combine) [kg.km^{-1}]		0.182
Fuel tank capacity [ℓ]		62

Table 20 Hyundai Tucson Specification[11] [12]

9 Based on given fuel consumption (Urban and Highway (ℓ/100km), and fuel tank capacity (ℓ)

10 Based on given fuel consumption (Urban and Highway (ℓ/100km), and fuel tank capacity (ℓ)

11 Tucson has 3, 2-WD models. The Tucson 2.0 MPI 2WD 17'' model (corresponding the ix35 FCEV) has been picked here as the control group

5.3.3. BEVs as a Reference

One of the main research questions (see §4.4), is: "*What is the fuel efficiency of the participating vehicles*". For comparison of the results, the fleet of comparative vehicles is not that big at all:

- [13]:"*Close to 2,500 hydrogen fuel cell vehicles were sold or leased in 2016, representing a three-fold increase compared to 2015*";
- [14]: In 2016, 77.31M cars have been sold;
- In 2016 hydrogen driven vehicles hold a market share of 0,32*10^{-6}%;
- [15, p. 50]: Globally, in 2016, 466,430 EV's we sold;
- In 2016 hydrogen driven vehicles hold a market share of 66,33*10^{-6}%.

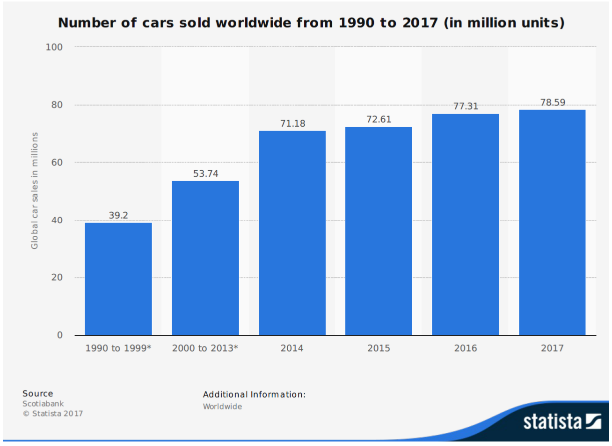


Figure 15 Global Car sales (© Statista)

For comparison reasons, the energy consumption of similar Battery Electric Vehicles (BEVs) will be compared to the ix35FCEV.

		NEDC		EPA J1634		EC_{SPEC} [kWh.100km^{-1}.t^{-1}]	
Electric car	**Weight [kg]**	**S [km]**	**EC [kWh.100km^{-1}]**	**S [km]**	**EC [kWh.100km**	**NEDC**	**EPA**
Renault Zoe R240 (23,3 kWh battery)	1435	240	13,3			9,27	
Renault Zoe Q90 (41 kWh battery)	1468	370	14,6			9,95	
Renault Zoe Q210 (22 kWh battery)	1468	210	14,6			9,95	
Peugeot iOn (new 14,5 kWh battery version)	1140	150	12,6			11,05	
Mitsubishi i-MiEV (> 2015)	1085	160	12,5			11,52	
Citroen C-Zero (new 14,5 kWh battery version)	1120	150	12,6			11,25	
2018 Kia Soul EV	1465	250	14,3			9,76	
2017 Volkswagen e-Golf	1485	300	12,7			8,55	
2017 Hyundai IONIQ Electric	1420	280	11,5	200	15,4	8,10	10,85
2017 Ford Focus Electric	1700	225	16,4	185	19,57	9,65	11,51
2017 Chevrolet Bolt EV	1624	520	14,5	383	17,64	8,93	10,86
2017 BMW i3 (94 Ah battery)	1440	300	13,1	183	17,75	9,10	12,33
2017 Nissan Leaf (30 kWh battery)	1525	250	15,0	172	18,7	9,84	12,26
Tesla Model S 60D	2110			351	20,13		9,54

Table 21 Overview Energy Consumption measurements according EPA standards (J1634)

Remember that like EPA, NEDC figures also measure plug-to-wheels consumption, this means that the internal charger efficiency matters.

More recent results, acquired during daily usage of the vehicle, for the Tesla Model X (weight: 2514 kg), showed an energy consumption of 230 Wh/km[12], and the Tesla Model S (weight: 2188 kg): 225 – 252Wh/km[13]. Recently (May 2016) BMW introduced the i3 EV, using a 94Ah traction battery system. This vehicle , (weight 1320kg), shows an energy consumption of 110Wh/km[14].

The average energy consumption of 9 EVs, assessed in a roller bench test during driving a NEDC [16], is 190Wh/km (average empty vehicle weight: 1696 kg). Rated to the weight of the ix35FCEV, the average energy consumption would have been 215Wh/km (NEDC). Considering that the NEDC result is 30% more energy efficient, these vehicles would have an operational energy usage of 279Wh/km.

5.4. Hydrogen production

More than 400 years ago, hydrogen was first discovered as a gas, and 150 years later it was for the first time produced by a chemical reaction [17]. In 1804, Isaac de Rivaz invented the first internal combustion engine that used hydrogen gas as fuel [3]. Today, after two centuries of development, the hydrogen industry uses several production methods. The four main feedstocks for the commercial production of hydrogen are natural gas, oil, coal, and water. These account for 48%, 30%, 18%, and 4% of the world's hydrogen production, respectively [18].

Natural gas consists predominantly of methane, and steam reforming of methane is one of the most popular methods to produce hydrogen for industrial use. 95% of hydrogen production in the USA is by steam methane reforming (SMR) [19]. In their study on automotive fuels in Europe, the Joint Research Centre (JRC) of the European Commission mentions that the bulk of industrial hydrogen is produced via steam reforming of natural gas [7], [17]:

1. Some countries have decided in favour of rather specific pathways such as high temperature electrolysis using nuclear electricity and heat (ES, FR) <write the full name of the countries>;
2. Gasification of hard coal (PL);
3. Solar thermal high temperature conversion (IT);
4. Natural gas is used in different pathways [20, p. 7 <idea: remove page number>]:
    4.1. Steam methane reforming (SMR).
    4.2. Partial oxidation (POX).
    4.3. Autothermal reforming (ATR).

Other hydrogen production methods exist, but these are not widely used because of technical limitations or low productivity [18]. Therefore these methods are not discussed here.

The vehicles involved in this project are fuelling with hydrogen produced by SMR (Rhoon, and Arnhem) or via electrolysis of water (Helmond), so this report focuses on these two production methods.

[12] https://tff-forum.de/viewtopic.php?f=25&t=12875
[13] https://steinbuch.wordpress.com/2014/02/08/de-eerste-10-000-km-met-de-tesla-model-s/
[14] https://www.nrc.nl/nieuws/2016/09/08/nu-al-een-designmonument-4188875-a1520407

This report aims to determine the greenhouse gas (GHG) emissions from using hydrogen fuelled FCEVs. The vehicles themselves do not emit greenhouse gases, but hydrogen production may result in GHG emissions. Hydrogen production requires a feedstock, and transport from this feedstock to the actual production plant. Once hydrogen is produced, it is distributed to refuelling stations. The five stages from feedstock production until vehicle use are generally known as well-to-wheel (WTW) fuel chain (Figure 16). For a fair comparison of the GHGs produced by vehicles that use different energy carriers (fuels), the comparison must be based on the WTW fuel chain, and not on vehicle emissions only. This report section addresses the well-to-tank (WTT) part of the fuel chain. A WTW comparison of hydrogen FCEVs with gasoline and diesel cars can be found in §10.6.

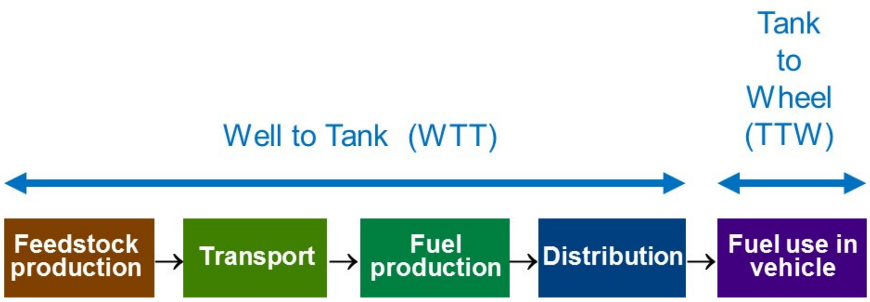


Figure 16 Well-to-wheel (WTW) fuel chain, consisting of well-to-tank and tank-to-wheel parts.

5.4.1. Electrolysis

Hydrogen production by the electrolysis of water is a long established process. The energy efficiency of this process itself is largely unaffected by its scale, but the auxiliaries and the operating pressure may vary and have a significant impact on the total efficiency of the hydrogen production plant [19, p. 74]. The water that is electrolysed can be either in liquid or gaseous (steam) form. According to [20], the energy efficiency of the electrolysis is independent of the water temperature. The source of electricity determines the amount of GHG emissions that is released at the hydrogen production. Electricity from coal results for example in much higher GHG emissions than electricity that is produce by solar energy or wind power.

Besides pure electrolysis of water, carbon assisted electrolysis is another option. In this process, the oxygen that is set free at the electrolysis is used to oxidise carbon to CO_2. In this way, the energy content of the carbon replaces more than half of the electric energy for the production of hydrogen. The total amount of energy per kg of hydrogen remains the same. Instead of oxygen as a by-product from pure electrolysis, at the carbon assisted electrolysis CO_2 is the by-product [21].

Based on different information sources, Table 22 presents GHG emissions of hydrogen production for a number of electrolysis processes, and for different sources of electricity. The numbers in this table should be considered as indicative values and may not be fully comparable, because different sources will have used different system boundaries. Also geographical differences may play a role. [20] and [21] originate from Australia, while [22] is from the Netherlands.

The latter is the supplier of the hydrogen in Helmond that is used in this Hyundai project. In this case wind energy is used for electricity production, resulting in GHG emissions of 1.5 [$kgCO_{2EQ}/kgH_2$] from electrolysis [23].

Electrolysis is the fuel production stage of the well-to-tank hydrogen chain (see also figure <xx>). After production, the hydrogen will be compressed and needs to be transported to refuelling stations, where it will be pumped into the vehicle tank. Depending on the type of energy that is used, all these processes may be sources of GHG emissions. JRC has determined the GHG emissions of a multitude of European hydrogen pathways, including electrolysis using wind power [17]. Using 120 [MJ/kg] for the lower calorific value of hydrogen, the JRC value has been converted to [$kgCO_{2EQ}/kgH_2$] (see Table 22). The result is not zero, because JRC calculated for the compression of hydrogen and transportation by pipeline with the average GHG emissions of the electricity that is produced in 27 EU countries (which includes fossil energy carriers). For comparison, also GHG emissions for two scenarios based on the EU electricity production mix are included in Table 22.

WTT production route [17, p. 79] [19, p. 134]	**Emissions [$kgCO_{2EQ}/kgH_2$]**
EU electricity production mix, central electrolysis, pipeline transport of H_2.	27.1
EU electricity production mix, on-site electrolysis.	27.8
Wind power electricity, central electrolysis, pipeline transport of H_2.	1.6

Table 22 Hydrogen well-to-tank (WTT) greenhouse gas emissions for different European electrolysis based production pathways, based on [24, p. 33]

The electricity that is used for the electrolysis based hydrogen in this project is generated by wind power. Based on information from the supplier of the hydrogen in this project and from the European JRC well-to-wheel study [17] [19], leads to 1.6 [$kgCO_{2EQ}/kgH_2$].

5.4.2. Steam Methane Reforming

Steam Methane Reforming (SMR) is the fuel production stage in the WTW chain. Today, steam methane reforming is relying on fossil energy (natural gas). Natural gas in the Netherlands contains more than 80% methane[15] (CH_4), which can be used to produce hydrogen with thermal processes [25]. In 80% of hydrogen produced using thermal processes originates from natural gas, and the remaining 20% is produced from other fuels such as ethanol, propane, or even gasoline.

SMR consists of two stages. In the first stage, the gas is heated to 700°C - 1000°C, and then reacts with steam (H_2O) in an endothermic reaction [26]:

$$CH_4 + H_2O \rightarrow 3H_2 + CO \qquad (1)$$

Equation (1) Hydrogen and carbon monoxide production from water and methane.

The hydrogen-rich gas mixture that arises from this first stage (see also Figure 17) contains, among others, carbon monoxide (CO) [27]. This gas mixture is not suitable as fuel for FCEVs because carbon monoxide is disadvantageous as fuel component at low temperature in fuel cells, as it decreases [28]:

1) the lifetime of the anode catalyst, and
2) the performance of the fuel cell.

This is an important reason to convert the CO after the first stage. Another reason is to improve hydrogen yield. The carbon monoxide can be further oxidised in a water-gas-shift reactor (see figure 17 and equation (2)).

[15] https://www.fluxenergie.nl/samenstelling-aardgas/

The second stage (mildly exothermic) reaction is:

CO + H2O → H2 + CO2 (2)

Equation (2) Hydrogen and carbon dioxide production from carbon monoxide and water. This chemical reaction is called 'water-gas-shift' or 'CO-shift'.

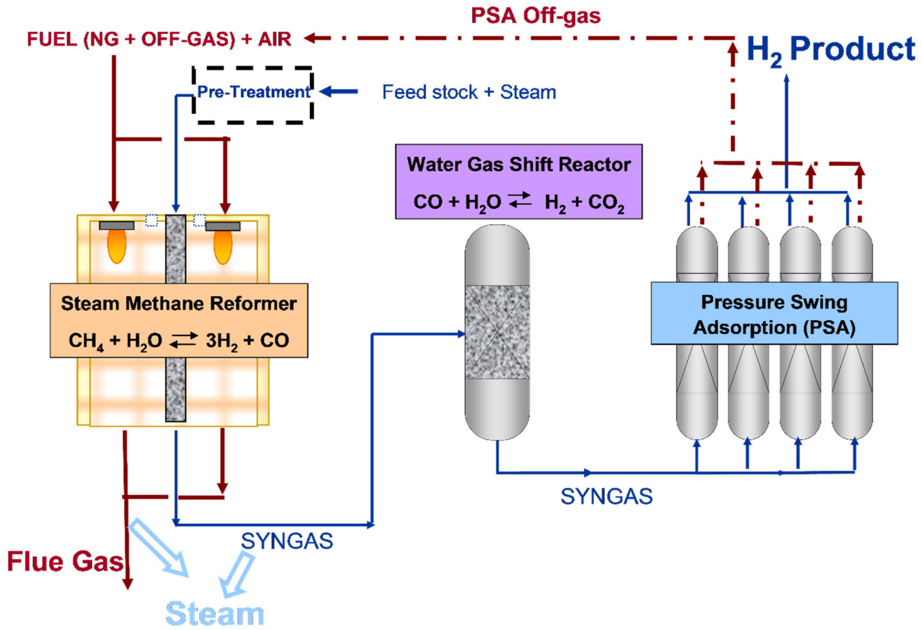


Figure 17 Schematic overview of SMR hydrogen production plant [27]

The chemical process of steam reforming generates both CO_2 and H_2. CO_2 is one of the biggest industrial GHG emission sources (62%, [29]). In case the SMR production plant is using fossil energy, this will be an additional source of CO_2 emissions from H_2 production. Modern SMR based hydrogen production plants are using mature technology, have achieved high efficiencies and their CO_2 emissions are close to the theoretical minimum [30, p. 3]. Since the production of hydrogen is concentrated in one facility, it is possible to separate and capture the CO_2, and dispose of it without atmospheric release. According to an evaluation by the IEA GHG R&D programme, Carbon Capture and Storage (CCS) would be the only way to further reduce the SMR CO_2 emissions in the future [30, p. 3].

Besides CO_2, also CH_4 and N_2O (nitrous oxide) are important greenhouse gases. On a mass basis, the global warming potential (GWP) of these gases is higher than for CO_2. JRC in their 2014 WTW fuel study uses the 2007 IPCC (Intergovernmental Panel on Climate Change) weighing factors for a 100 year time horizon, these are 25 for CH_4 and 298 for N_2O [19, p. 17]. This means that the GWP of one gram CH_4 is equivalent to the GWP of 25 grams of CO_2. Calculating with the respective quantities, using the respective weighing factors, and adding up the results, the total GHG emissions can be expressed in grams of CO_2-equivalent [gCO_{2EQ}]. When hydrogen is produced from natural gas, small quantities of natural gas that escape for example at production or during transport to the hydrogen production plant may contribute substantially to the WTW greenhouse gas emissions. JRC has taken these kind of effects into account for a number of different SMR based hydrogen pathways for Europe, and estimated the WTT GHG emissions. JRC presents their values for a certain FCEV in [gCO_{2EQ}/km]. Using 120 [MJ/kg] for the lower calorific value of hydrogen, the JRC values can be converted to [$kgCO_{2EQ}/kgH_2$]. The result is presented in Table 23.

#	**WTT production route** [19, p. 145]	**Emissions [$kgCO_{2EQ}/kgH_2$]**
1	Compressed hydrogen from reforming of natural gas piped over 7,000 km in small plant at or near retail site.	15.3
2	Compressed hydrogen from reforming of natural gas piped over 4,000 km in small plant at or near retail site.	14.0
3	Compressed hydrogen from reforming of natural gas piped over 4,000 km in large EU plant, distributed by pipeline.	12.9
4	Compressed hydrogen from reforming of natural gas piped over 4,000 km in large EU plant, liquefied, distributed by road and compressed on retail site.	16.2
5	Compressed hydrogen from reforming of imported LNG (Liquefied Natural Gas) in small plant at or near retail site.	14.9
6	Compressed hydrogen from reforming of imported LNG in large EU plant, distributed by pipeline.	13.3

Table 23 Hydrogen well-to-tank (WTT) greenhouse gas emissions for different European SMR based production pathways, based on [24, p. 32]

5.5. Hydrogen Consumer Price and Production Costs

Just an unclassified search on the internet learned that in general over the years 2012 – 2017, for the consumer at the fuelling station, the price of 1kg of hydrogen is approx.: €10/kg (see table 24).

#	**Cost**	**Reference**
1	**€12,50/kg (12 €ct.km^{-1})**	https://maartendewit66.wordpress.com/**2016**/02/21/de-waterstofauto-gaat-nooit-echt-wat-worden/
2	**€9,99/kg**	http://www.egear.be/waterstof-maken/ (juli **2017**)
3	**€12/kg**	http://blog.toyota.nl/updates/vragen-en-antwoorden-over-de-waterstof-toyota-mirai/ Geplaatst op 22 december **2014**
4	**€10/kg**	http://www.h2-fuel.nl/nl/h2fuel_pdf/onafhankelijke-rapportage-aan-de-nederlandse-overheid/ (**2010**)
5	**€10/kg**	http://www.autowereld.com/nieuws/autonieuws/id/14164/hyundai-ix35-op-waterstof-klaar-voor-consument (27 september **2012**)

Table 24 Unclassified internet search on Hydrogen prices "at the pump"

In 2004, CE (Delft), performed an analysis on hydrogen production costs [22], with the costs analysis based on a NAS study from 2004 [31] (see Table 25 and Figure 18). CE presented for a so-called 'distributed scale of production' ($480kgH_2.day^{-1}$, 800vehicles) [22, p. 19], a production price[16] for reforming: 3,04€/kg H_2 , up to 24,38€/kg H_2, for PV electrolysis (see table 25). In this study a price for 'future scenarios'[17] has been estimated for reforming: 2,02€/kg H_2 up to: 5,35€/kg H_2, for PV electrolysis.

[16] Conversion rate: $1=€0,8649 – period: 1/7 - 4/8/2017 (https://www.ecb.europa.eu/stats/policy... ..._and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html

[17] No specific time frame has been defined

Scale of Production	Primary source / Energy source	Technology	Production costs 2004 (€.kg-1 H_2)	Production costs Future
Distributed	Natural gas	Reforming	**3,04**	**2,02**
	Grid	Elektrolysis	**5,69**	**3,40**
	Wind	Elektrolysis	**9,25**	**2,47**
	Wind/Grid	Elektrolysis	**5,74**	**2,92**
	Photo Voltaic (PV)	Elektrolysis	**24,38**	**5,35**
	PV/Grid	Elektrolysis	**8,23**	**3,64**
	Natural gas	Steam/Elektrolysis	**-**	**2,72**

Table 25 Hydrogen Production Costs [22, pp. 19,20, table 8&9]

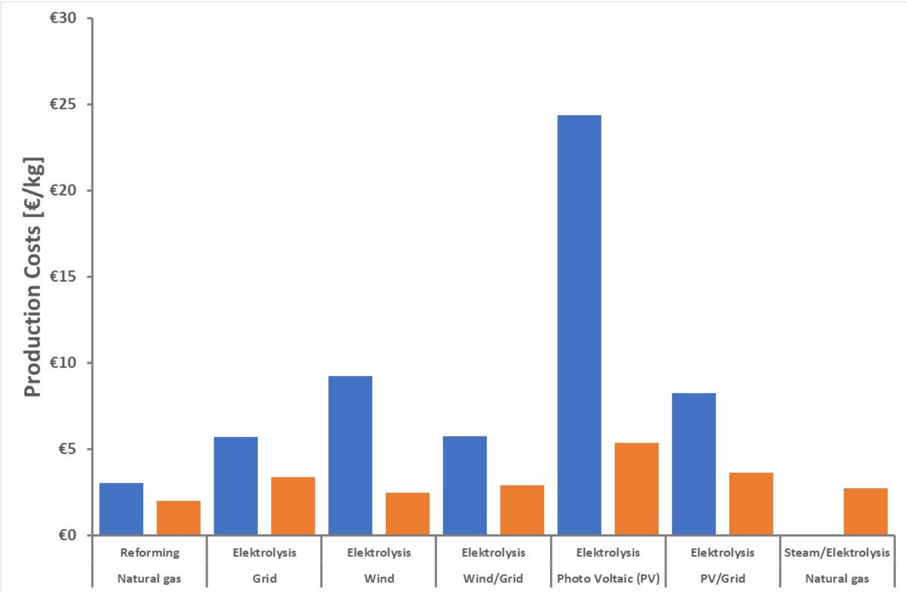
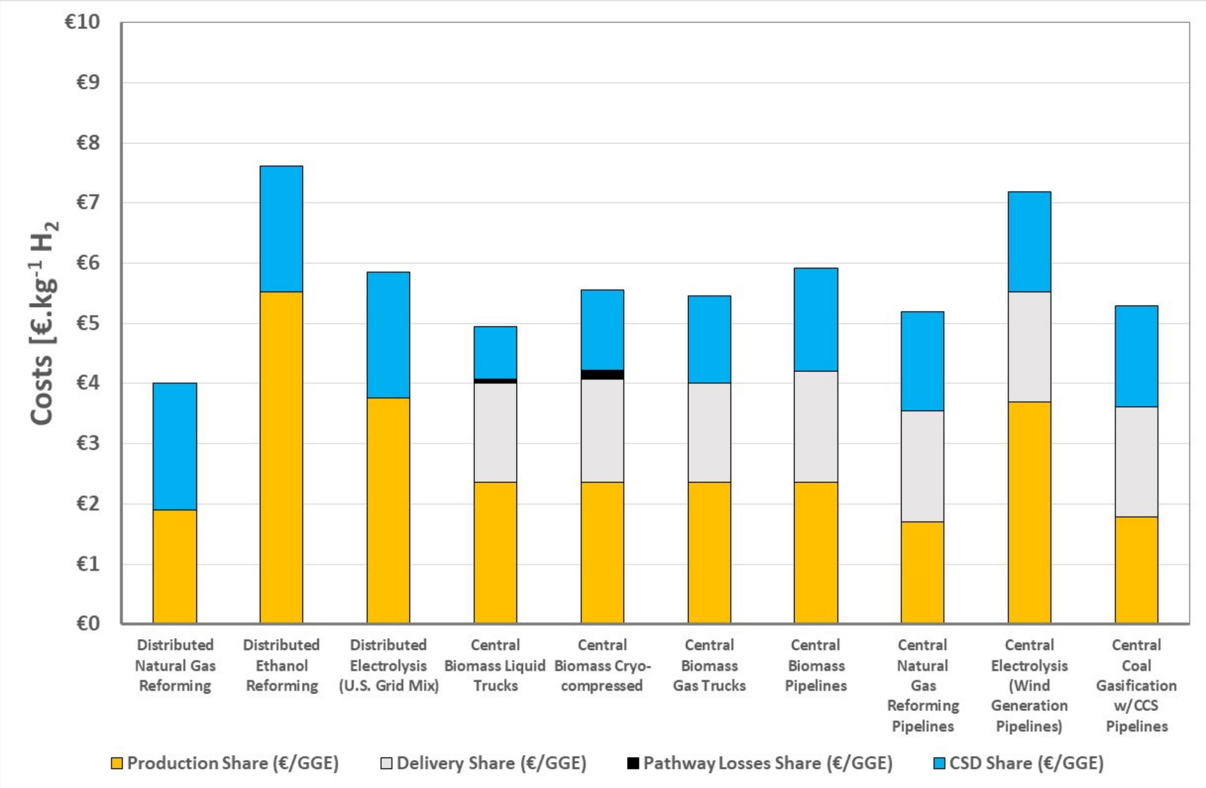


Figure 18 Hydrogen Production Costs [22, pp. 19,20, table 8&9]

Ramsden, et al. [32], reported in 2013, in assignment of the US Department of Energy (US-DOE), for 10 different production methods of hydrogen, the effects of costs (see figure 19).



Pathway / Cost Share	Distributed Natural Gas Reforming	Distributed Ethanol Reforming	Distributed Electrolysis (U.S. Grid Mix)	Central Biomass Liquid	Central Biomass Cryo-compressed	Central Biomass Gas Trucks	Central Biomass Pipelines	Central Natural Gas	Central Electrolysis (Wind	Central Coal Gasification
CSD Share (€/GGE)	€2,09	€2,09	€2,09	€0,88	€1,34	€1,44	€1,72	€1,66	€1,66	€1,68
Pathway Losses Share (€/GGE)	€0,00	€0,00	€0,00	€0,06	€0,14	€0,00	€0,00	€0,00	€0,00	€0,00
Delivery Share (€/GGE)	€0,00	€0,00	€0,00	€1,64	€1,70	€1,64	€1,83	€1,83	€1,83	€1,83
Production Share (€/GGE)	€1,90	€5,53	€3,76	€2,37	€2,37	€2,37	€2,37	€1,70	€3,69	€1,77
Total [€]	**€4,00**	**€7,62**	**€5,86**	**€4,95**	**€5,55**	**€5,45**	**€5,92**	**€5,19**	**€7,18**	**€5,29**

Figure 19 Hydrogen production levelled costs for 10 pathways [32, pp. 162, Fig7.0.1.]

5.6. Fuel Cell degradation

Since fuel cells are used in vehicles, life time assessment of the fuel cell is becoming more relevant. In 2016, the USA Department of Energy (DOE) targeted a 10% voltage degradation over a 8000h (equivalent to >240.000km), balancing a the average for a gasoline car in the Netherlands: 236.000[18].

The main difference between in-vehicle fuel cells and fuel cells used as a steady state power source, is the dynamic load cycling. According to Pei [33]: "*Load cycling sometimes leads to water management and gas transport problems, which further leads to degradation of fuel cell performance and attenuation of internal parts*".

Extensive research has been carrie out on the topic of degradation, e.g. Pei [33], and Wu [34]. The most relevant mechanisms to degradations for the fuel cell application in the vehicle, are:

- Wu [34]: thermal load, electrochemical constrains
- Pei [33]: load cycling, water management

[18] NL: average vehicle age before being demolished (May, 2015): petrol car 18,2 year and diesel: 15.9 year. Average mileage: 13.000km.year^{-1} (source: CBS)

Thermal load [34, pp. 106,107]– operational conditions in a vehicle can and will be varying, not only due toe environmental conditions, but to vehicle performance as well. Both can induce significant temperature effects in the fuel cell.

Electrochemical constrains [34, p. 107] – contamination of the hydrogen can significantly decrease the cell performance, by damaging the membrane and used catalysts.

Load cycling [33, pp. 62-64] – load cycling has enormous impact on the active area of the catalyst layer. Charging, start-stop cycles, idling and high performance, have significant impoact on the life time.

Water management [33, pp. 64-68] – water management is vital for stable operation, high efficiency and maintaining power density. Humidity affects catalyst and membrane degradation and largely determins the electrical conductivity and efficiency of the fuel cell power generation.

6. Methodology

In this chapter, the methods used to obtain the required data and process the raw data to relevant and presented data, are explained.

In this project, the Copenhagen project [10] is the reference in the perspective of fuel efficiency. There the fuel efficiency is expressed in: [km/kgH_2][19]. Therefore, we defined it accordingly and comply with our reference project the ix35 in the Copenhagen project [10].

For evakuating the research questions, the following methods were used:

1. What is the fuel efficiency of the participating vehicles

   For calculating and evaluating the fuel efficiency, data was acquired from the driving vehicle and stored in a local (at HanAR) database, data was verified and cleaned. Based on the acquired data the hydrogen mass was calculated according REFPROP [35]. The obtained data on fuel efficiency was compared to the fuel consumption of conventional vehicles. This was done by converting fuel efficiency data to fuel consumption data and based on a model, using standard drive cycles.

2. Insights in the well-to-wheel fuel efficiency, related to different production methods and the subsequent CO_2 emissions

   For the evaluation of the subsequent CO_2 emissions using the Hyundai ix35 FCEV, a literature study was done.

3. What are the user experiences of the drivers of the vehicle

   The user experience was obtained by using an online survey. In §6.5: Questionnaires (p.57), an outline of the questionnaire is given.

6.1. Data Acquisition and Processing

For monitoring the fuel efficiency of the ix35FCEV, data has been retrieved from the ix35FCEV while driving, to quantify the behavior, status and performance of the:

- Fuel tank
- Fuel cell system
- Driver
  - Subjective: surveys
  - Objective: steering, braking, lateral- and longitudinal behaviour (acceleration)
  - AC and Drive Selector

[19] For conventional vehicles, using fossil fuels, it is very common to use the public standard: [km/ℓ], though the last decade and more common in the world of research, the unit: [ℓ/100km] is used. For vehicles running on hydrogen, in general fuel cell technology, the source of the energy is indirect. Hydrogen must be produced, sometimes it is a so-called by-product, however mostly in mobile applications, it is produced from other (mostly fossil) sources, or derived from water (electrolyzing). Thus, terminology like: fuel consumption, fuel economy, energy usage, are not adequate, if just 'not applicable/appropriate'. Therefore, it is decided to use the term fuel efficiency [10] to express the way the FCEV is using its energy sources, to cover a certain distance.

- Driveline

Since information (data) from these so-called sub-systems of the ix35FCEV, communicate over the EOBD CAN bus, the Hyundai "GDS-M Workshop Tester[20]" has been used to define a sub-set of the available data. In "Appendix 4 Data Acquisition – Obtained Vehicle Parameters", an overview is given of the process steps to decode the information, and a complete overview is given of the parameters obtained from the vehicle, while driving.

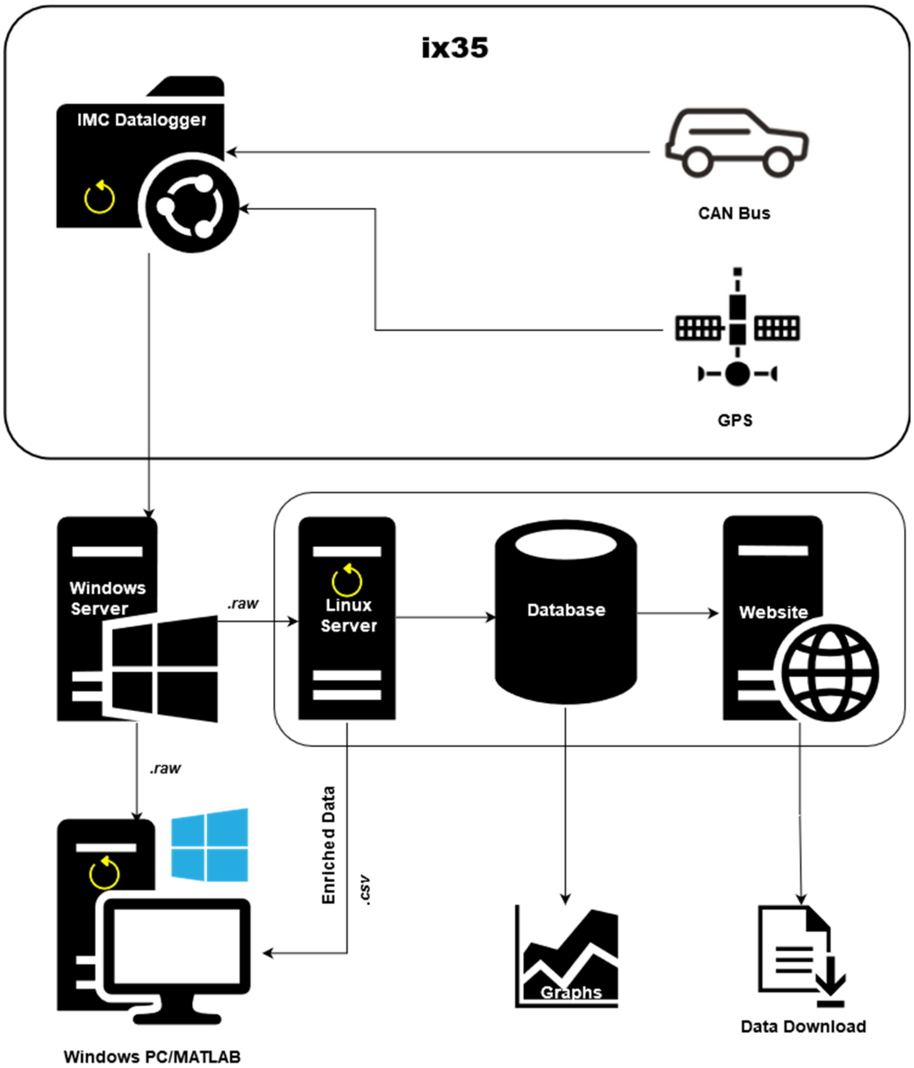


Figure 20 Layout of Acquisition system

In Figure 20 the layout of the data acquiring system is given:

A dataset is continuously collected on the vehicle, over the EOBD port ((1) IMC BusDAQ). The previous mention data set includes all driver inputs, voltage and currents in the electrical system, hydrogen pressures, temperatures, etc. Periodically, after the vehicle is switched off, the data is saved to local storage in the vehicle. The next time the vehicle is switched on, the data is sent over a 4G connection (A⇨B⇨C⇨D) to an in-company server, copied to another server, and processed and stored in an InfluxDB database.

[20] Brand name of the tester

In 0Appendix 3 Data Acquisition – Data management (p. 85), more details are given on the server infrastructure, specific information on the data set, cleansing rules and noise cancelling on mass calculation.

6.2. Hydrogen Mass Calculations

The hydrogen mass in the fuel tanks of the Hyundai ix35FCEV, is calculated according the so-called: ion-mass principle. The number of ion's is directly related to the current from the fuel cell system and thus to the mass of hydrogen.

Figure 21 shows (blue line) the reduction of the hydrogen mass ($m_{H_2}(t)$) inside the tanks during the trip as derived from both pressure and temperature and using the state equation presented in [36] (see formula 1). Also shown (red line) is the cumulative mass flow as derived from the stack current I_{FC} (see Figure 21), according to [36].

$$\widehat{m}_{H_2} = \frac{\widehat{m}_{H_2} N_{CELL}}{2F} \int I_{FC}\, dt + m_{H_2}(t=0) \qquad \text{\{formula 1\}}$$

Where (M_{H_2}) equals the molar mass of hydrogen, 434 cell N_{CELL} the number of cells and F the Faraday constant.

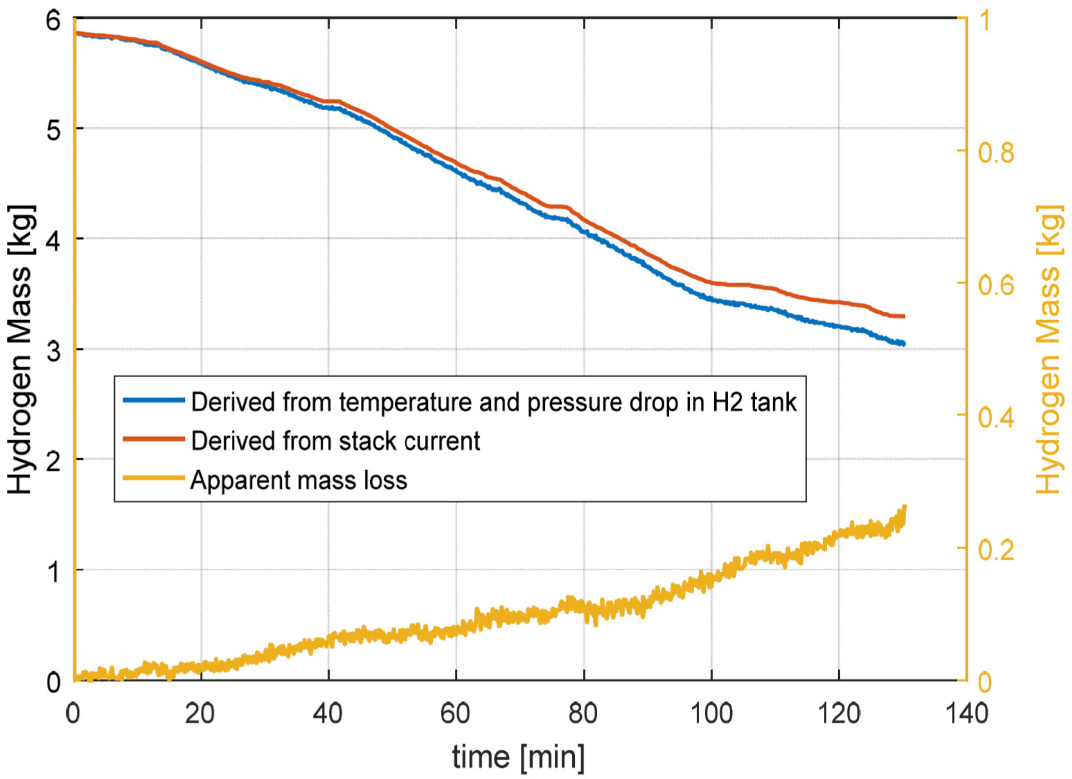


Figure 21 . Hydrogen mass vs time. Apparent mass loss

The difference between the two lines is also represented in the figure and labelled "Apparent mass loss". This difference may be attributed to purging or bleeding losses and amounts to ~0.08 [kg/h], and is discounted is the mass calculations accordingly.

6.3. Energy Efficiency

6.3.1. Equivalency

To create perspective on the fuel efficiency of hydrogen driven electric vehicles, often an equivalent fuel consumption is calculated (method, see Appendix 10 Method - Energy Efficiency, equivalency, p.107). The reference vehicle in the Copenhagen project [37], shows an operational fuel efficiency (E) of 75km/kgH_2 (max.: 68km/kgH_2, min.: 82km/kgH_2). Table 26 shows an overview, using in the public domain known expressions for fuel consumption.

		Petrol equivalent			Diesel equivalent		
Fuel efficiency	**FE [km/kgH_2]**	Mass Petrol [kg/100km]	Volume Petrol [ℓ/100km]	**"1:"**	Mass Petrol [kg/100km]	Volume Petrol [ℓ/100km]	**"1:"**
Average	**75**	**4,1**	**5,5**	**18**	**4,1**	**4,8**	**21**
minimal	**82**	**3,7**	**5,1**	**20**	**3,7**	**4,4**	**23**
maximal	**68**	**4,5**	**6,1**	**16**	**4,5**	**5,3**	**19**

Table 26 Conversion: Hydrogen equivalent – Copenhagen project

According to "Autoweek" [38], the fuel consumption of a Hyundai ix35, propelled by a conventional drive line, is for petrol: **1 to 11** (9,07 [ℓ/100km]) and for diesel: **1 to 15** (6,78 [ℓ/100km]). Converted to hydrogen equivalents, the diesel has a fuel efficiency of 53 km/kgH_2 and the petrol version: 46 km/kgH_2.

In 0 Appendix 10 Method - Energy Efficiency, equivalency (page P2-107), the translation from fuel efficiency (km/kgH_2) to fuel consumption (ℓ/km) is given.

6.4. Modelling

As a part of the Well-to-wheel analysis and the assessment of the fuel efficiency (Research Questions 1 and 2, see §4.4, page P2.39), a model of the ix35FCEV [39] has been set up. Based on the model the performance (here: fuel efficiency) of the ix35FCEV, using normalized load definitions (e.g. NEDC, WLTP) can be assessed. Results from these simulations can be compared to the available data of conventional ix35 drive line.

The master report [39] presents fuel consumption data, in combination with driver behaviour (gear shift lever position, use of air conditioning) and vehicle parameters. The data is used to validate a model describing the energy flows in the drive train. As mentioned before, the model is used to elaborated the standard driving patterns (NEDC., WLTP, FTP, etc.) on fuel efficiency in comparison to real-world consumption data. In Figure 22 ix35 FCEV, Mathematical model, the overall layout of the model is shown.

As a first stop a simple model has been set up, using just the main components of the driveline of the ix35FCEV:

i. Fuel cell
ii. Battery
iii. DC-DC converter
iv. Electric motor drive

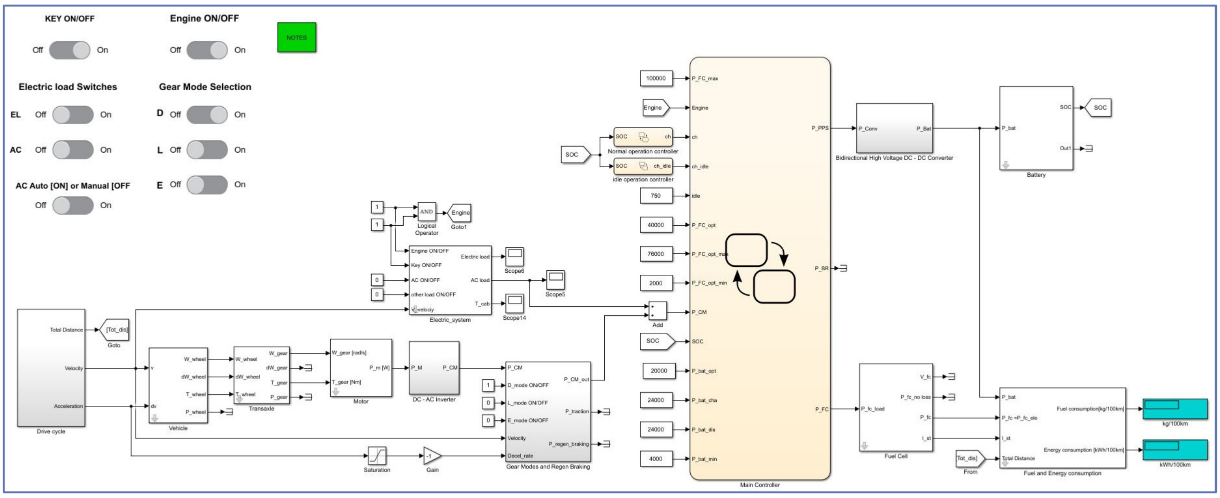


Figure 22 ix35 FCEV, Mathematical model [39]

6.5. Questionnaires

As mentioned in §4.4: Project Focus and Research Questions, research question no. 3, focusses on the user aspects of the ix35FCEV. This has been done by using a questionnaire in the following categories:

1. Start of the questionnaire, and identification of the user;
2. Range Anxiety
3. Driving and refuelling instructions
4. Experiences at refuelling
5. Choice and preference for driver selector
6. Number of passengers
7. Driving style;
8. Environment
9. Driving experience
10. End of the questionnaire, and optional support

In appendix 8, the total questionnaire[21] has been given.

[21] Since this is a Dutch research program, the questionnaire has not been translated

7. Results - Fuel efficiency of the participating vehicles

In this chapter the first research question: "*What is the fuel efficiency of the participating vehicles*" (see §4.4: Project Focus and Research Questions, p.39), is presented and discussed.

7.1. Fuel Efficiency

Analysis of the fuel efficiency (FE) in the data base learned that, though the accumulated hydrogen mass required to drive a distance seems to be linear (see Figure 23) with respect to distance driven, the calculated value for FE in km/kgH_2 (see Figure 24) shows a significant deviation from the average value. This is due to calculating the fuel efficiency on trip level: per km driven. On this level (see Figure 23, zoom window) the mass diviates significantly.

From Figure 23, can clearly be concluded that the Helmond vehicle is more fuel efficient than the Rhoon and Arnhem vehicle.

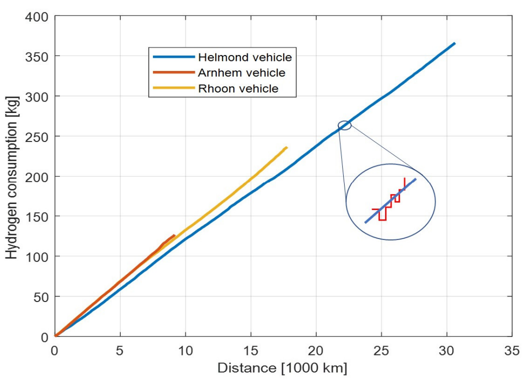


Figure 23 Linearity of H_2-mass related to distance driven

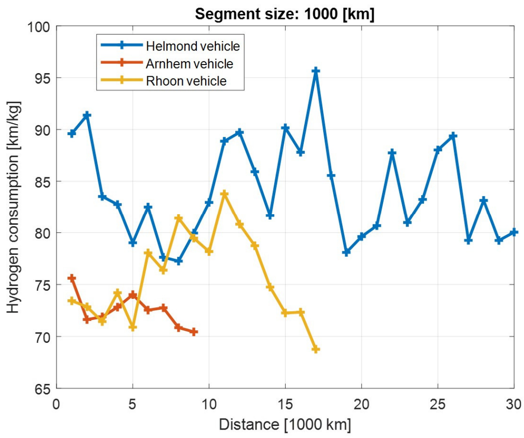


Figure 24 FE related to distance driven

In paragraph, 7.1.1 to 0, the impact on fuel efficiency of subsequently 1) ambient temperature is discussed, 2) the road type, 3) the speed selector and concluding, 4) the AC usage. Table 27 shows the *aggregated results* per vehicle. The last row shows accumulated data for all three vehicles. In total, almost 741,1 [kg] of hydrogen was used for 62.356 km, resulting in a test fleet average of 83,0 km/kgH_2.

VehicleID	#Trips	Σ(Trip time)	Σ(Distance)	ΣH_2 mass	Mean values			Energy Consumption
					Trip distance	Speed	Fuel Efficiency	
	-	hr	km	kg	km	km/hr	km/kgH_2	Wh/km
Helmond	**681**	**477**	**32084**	**358,6**	**47**	**67**	**89,5**	**204,1**
Arnhem	**596**	**213**	**10205**	**124,8**	**17**	**47**	**81,8**	**245,1**
Rhoon	**1108**	**353**	**20067**	**257,8**	**18**	**57**	**77,9**	**235,4**
All	**2385**	**1043**	**62356**	**741,1**	**-**	**-**	**83,0**	**220,3**

Table 27 Results aggregated per vehicle

Basically, the Hyundai ix35FCEV, is an electric vehicle, having a fuel cell available as a electric power generator. Thus, comparing the fuel economy, expressed in energy per distance driven (Wh/km), to a pure battery driven vehicle will show the efficiency of the ix35FCEV drive line.

The energy consumption of the ix35FCEV (empty vehicle weight: 1921 kg) is 220 Wh/km, rated to weight: 115 Wh/ton.km. Whereas a modern battery Electric Vehicles (BEVs, see Table 21) achieve an energy consumption of e.g. 110 Wh/km for the BMW i3 (weight 1440 kg, 92 Wh/ton.km) or 252 Wh/km for the Tesla Model S (weight: 2188 kg, 115 Wh/ton.km).

Concluding remarks

On average, the Helmond vehicle drove considerably more kilometres per refuelling than the other two. Which might be due to the fact that the Helmond vehicle drove over 50% on highways (see Figure 29). The average fuel cell stack power is rather consistent over the three vehicles and only about 15% of the rated power of the stack.

By integrating stack and battery power the total amount of electric energy in Wh per km (energy consumption) was calculated. Consistently with the fuel efficiency, the Helmond vehicle shows lower value for energy consumption compared with the Arnhem and Rhoon. Detailed analysis shows that this difference is mainly caused by the way the fuel stack is used. In the Helmond vehicle, the stack is used at a more constant operating point on longer trips with more constant speed. This might be due to drivers focused on efficient driving, like riding significant time (thus: distance) behind an articulated vehicle at a relatively low, but very constant speed. Whereas in the Arnhem and Rhoon the vehicle and thus the stack, is used in more varying operating points (or: as any other conventional vehicle). Whereas the Helmond vehicle on more than average occasion, has been used.

7.1.1. Impact of Environmental Temperature

The Copenhagen project [37] results mentioned in §5.3.1 mark a good baseline with which to compare the vehicles covered in this report. The Copenhagen project uses the national average temperature in each month, whilst we record the local temperature at the vehicle location and take the average over the month.

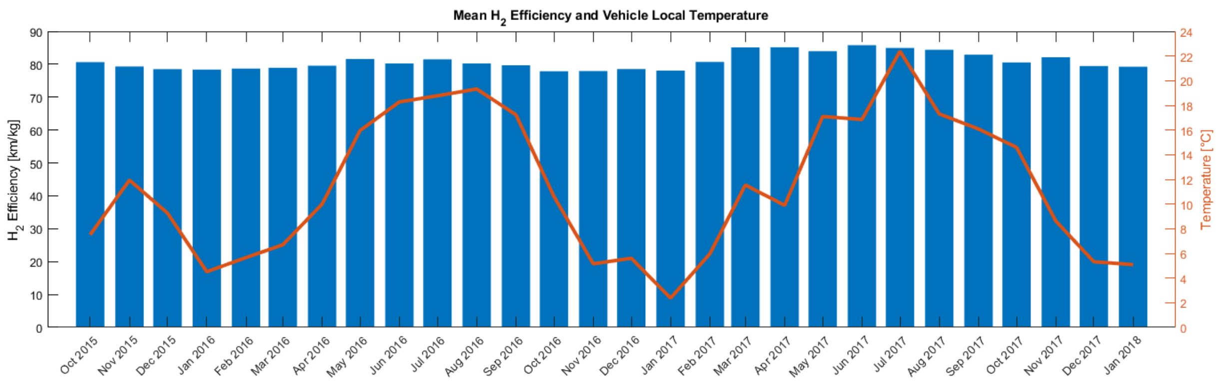


Figure 25 Aggregated value for 3 Vehicles - fuel consumption and temperature

Figure 25 shows the result on the impact of the environmental temperature on the fuel efficiency of all three vehicles aggregated for 2015/Q4 – 2017/Q4, per month (see also in 0“Appendix 23 Fuel Efficiency and Ambient Temperature – Project Fleet” (p.139)). The fuel efficiency, aggregated for the three vehicles[22] and over the total project period, is: **83,0** km/kgH_2, min. value: **78,0** km/kgH_2, max. value: **88,3** km/kgH_2.
As can be conducted from this figure, no significant impact has been found.

[22] Perhaps redundant and obvious: individually, per vehicle, this will differ.

In Figure 26 to Figure 28, the fuel consumption is shown as a bar and the temperature as a line, consistent with the presentation of the Copenhagen project results.
In general the Helmond vehicle shows the best fuel efficiency.

The Helmond vehicle (see Figure 26) has an average fuel efficiency of: **89,5 km/kgH_2** (min. 82 km/kgH_2, max. 98 km/kgH_2), see 0"Appendix 24 Fuel Efficiency and Ambient Temperature – Helmond vehicle", p.140). No impact of the environmental temperature on the fuel efficiency could be established. A minor effect could be seen in de min./max. value; during the summer months these values are little less than the winter months.

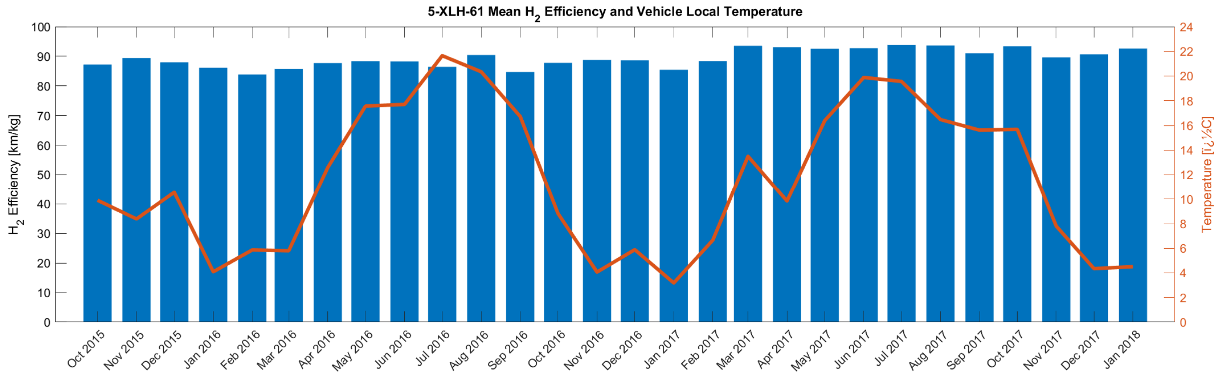


Figure 26 Helmond - fuel consumption and temperature

The Rhoon vehicle (see Figure 27) has an average fuel efficiency of: **77,9 km/kgH_2** (min. 75 km/kgH_2, max. 89 km/kgH_2), see 0"Appendix 25 Fuel Efficiency and Ambient Temperature – Rhoon vehicle", p. 141). No impact of the environmental temperature on the fuel efficiency could be established. An effect could be seen in de min./max. value; during the summer months these values are less than the winter months.

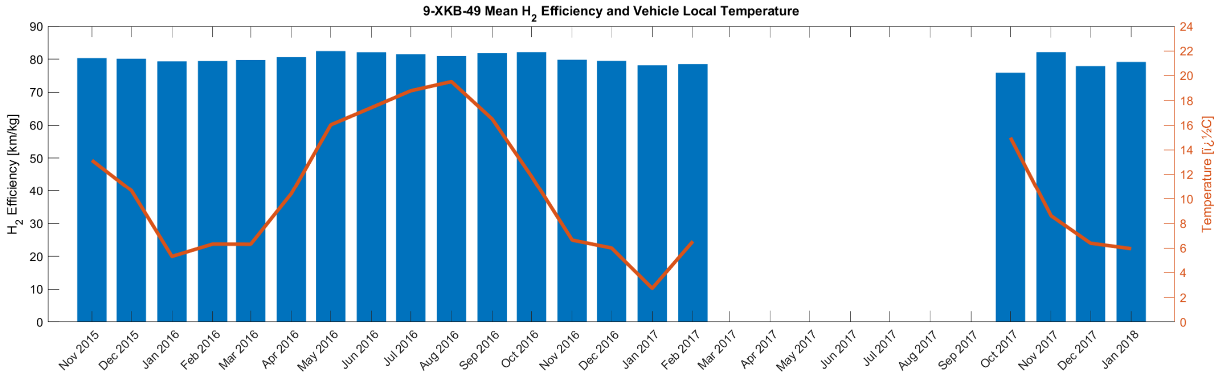


Figure 27 Rhoon - fuel consumption and temperature

The Arnhem vehicle (see Figure 28) has an average fuel efficiency of: **81,8 km/kgH_2** (min. 73 km/kgH_2, max. 87 km/kgH_2), see 0"Appendix 26 Fuel Efficiency and Ambient Temperature – Arnhem vehicle", p. 142). No impact of the environmental temperature on the fuel efficiency could be established. A minor effect could be seen in de min./max. value; during the summer months these values are little less than the winter months. The results during the month of august (2016 and 2017) can be affected by the repairs on the vehicle in those periods.

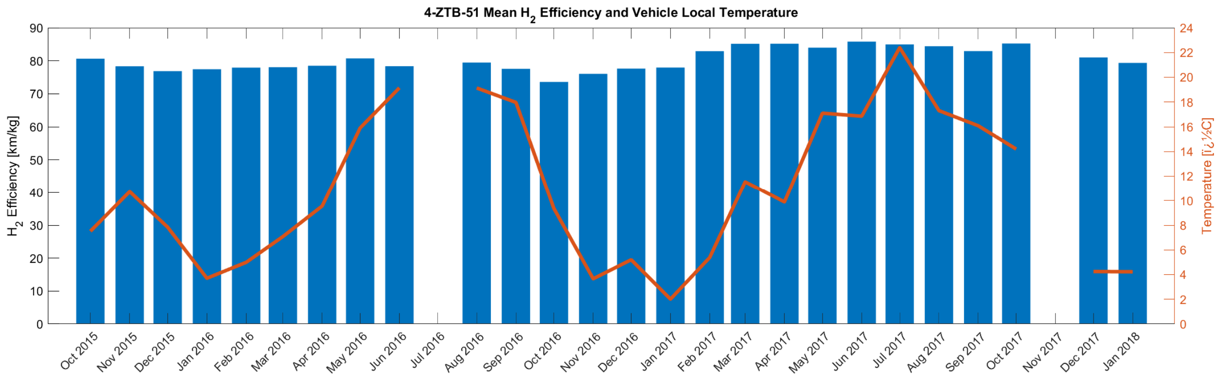


Figure 28 Arnhem vehicle - fuel consumption and temperature

Concluding remarks

Compared to Copenhagen project [37], the three vehicles in the reported project, operated in wider temperature range: 4-26°C, versus for the Copenhagen project: 6-17°C. The fuel efficiency for all three vehicles is: **83,0** (**78,0**$_{MAX}$**-88,3**$_{MIN}$ **km/kgH**$_2$), whereas the Copenhagen project resulted in a The fuel efficiency of: **75** (**68**$_{MAX}$**-82**$_{MIN}$ **km/kgH**$_2$). There appears to be a correlation between a decreased environmental temperature and decreased fuel consumption, however minimums of a slightly higher magnitude also occur when the temperature is at its highest. While the decrease is greater with decreasing temperature, most variations in seasonal fuel consumption do not correspond with the changes in environmental temperature.

7.1.2. Impact of Road Type

0"Appendix 22 Road type and Fuel Efficiency" (p.138) and Figure 29, show the car usage during the trips over the monitoring period, when driving on specific roads

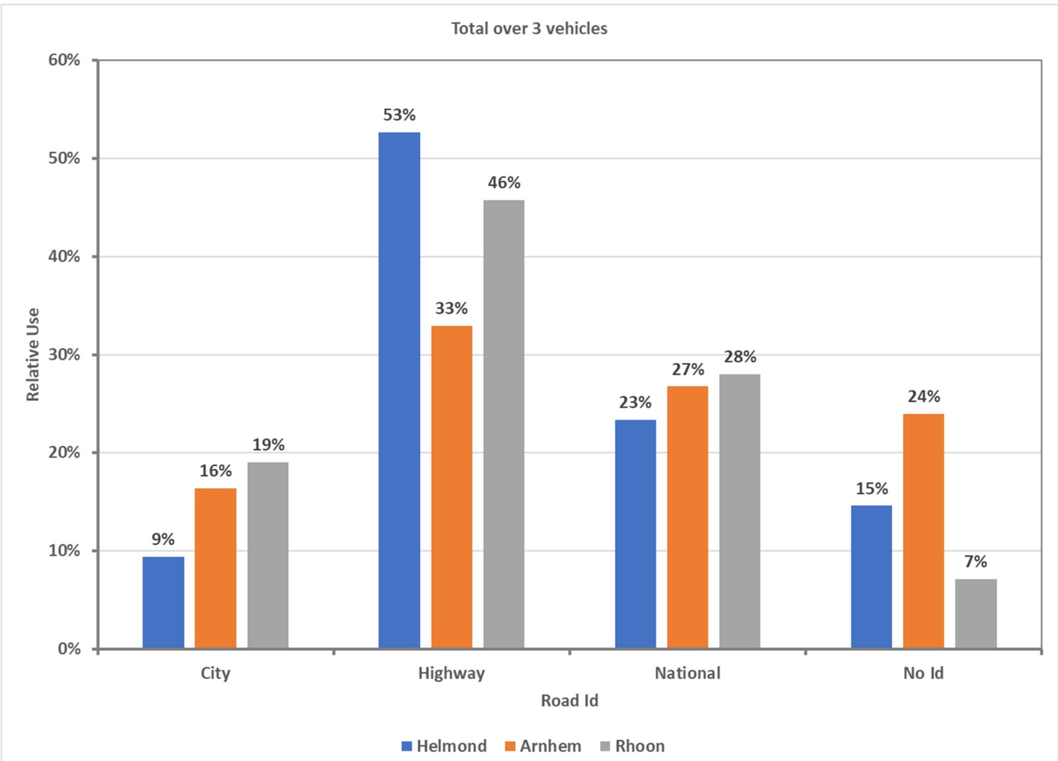


Figure 29 Helmond, Arnhem & Rhoon – Impact of road usage

These roads are classified as: 1) Inner city roads – roads within city boundaries, with a limited speed range of 30, 50 (and sometimes 70) km/hr, 2) high way roads, the so-called A-roads in the Netherlands, with a limited speed range of 100, 120 (ans sometimes 130) km/hr, and 3) national roads, connecting cities or villages, in general having a speed limit of 80 km/hr. The forth group: "No Id"-label, is due to driving on an "undefined, but not off-road[23]", track. These are roads are undefined, being: 1) exit- and entrance roads to highways, 2) (un- or not yet defined) roads, 3) roads not identified due to GPS inaccuracy, etc.

In 0"Appendix 22 Road type and Fuel Efficiency" (p.138), the results are summarized.

Observations

The "No Id" part of the results is quit substantioally; Helmond: 15%, Rhoon: 7% and Arnhem: 24%. Elaborating the results, the "No Id" roads show a speed and standard deviation (StDev), in the rame level (range). This shows that it's a wide mix of roads; the fuel efficiency is accordingly: the value is within the /Highway/City/National range:

- Helmond: 87,8 km/kgH_2 (85,9 - 91,1)
- Arnhem: 80,4 km/kgH_2 (79,4 - 81,8)
- Rhoon: 75,5 km/kgH_2 (79,6 - 82,4)

In Table 28, the relative road use is given for the three vehicles, divided in the major groups: City, Highway and National. Quite clear is the dominant high way and national road (between/inter cities) part in the total road usage. The Helmond has approx. 53%, and the Rhoon vehicle approx. 46%, whereas the Arnhem vehicle shows "only" 33%, despite of the fact that for refuelling, the vehicle is refuelled at Helmond, a 100km drive, during the first two years of the project.

Vehicle / Road Id	Helmond	Arnhem	Rhoon
City	**9%**	**16%**	**19%**
Highway	**53%**	**33%**	**46%**
National	**23%**	**27%**	**28%**

Table 28 Overall road use

Driving the national road is for all three vehicles a similar percentage of the daily routine. And the fuel efficiency is for all three vehicles, the most efficient: Helmond: 91,1 km/kgH_2, Rhoon: 82,4 km/kgH_2, and for Arnhem: 81,8 km/kgH_2.

Driving the highway requires the highest performance, and though the fuel cell efficiency improves at higher power demands, the fuel efficiency is in between "City", and "National": : Helmond: 89,1 km/kgH_2, Rhoon: 79,6 km/kgH_2, and for Arnhem: 81,5 km/kgH_2.

Driving within city premises or city limits (referred by as: "City"), shows the lower fuel efficiency, as could be expected due toe frequently stop and go routine at traffic lights, etc. when the mean speed is considered, a negative speed (rearward driving) can be observed (StDev is bigger than the mean value): Helmond: 20,4 km/hr, ±25,8 km/hr, Rhoon: 17,2 km/hr, ±21,0 km/hr and Arnhem: 15,4 km/hr, ±20,2 km/hr. The fuel efficiency during driving in the city is: Helmond: 85,9 km/kgH_2, Rhoon: 79,6 km/kgH_2, and for Arnhem: 79,4 km/kgH_2.

[23] Undefined: in-door parking, GPS inaccuracy, leading to "no-road" id's

7.1.3. Impact of Speed Selector

Data analysis learned that the main difference between E-, L- & D-mode is the response from the accelerator position to the power command of the stack (see Figure 30).

In consequence of this control strategy, the fuel efficiency is completely determined by the driver. When the driver accepts that the acceleration of the vehicle is reduced due to the usage of the E-mode, a significantly better fuel efficiency can be achieved, provided that approximately the same accelerator pedal position (AP) is kept!. The graph shows that whenever the acceleration pedal is pushed to the limit, the power command to the FC, is by fact the same[24]: maximum power is required. The same effect can be seen during regenerative braking: E- and D-mode will give similar braking behaviour. Only L-Mode will lead to significant extra regenerative power.

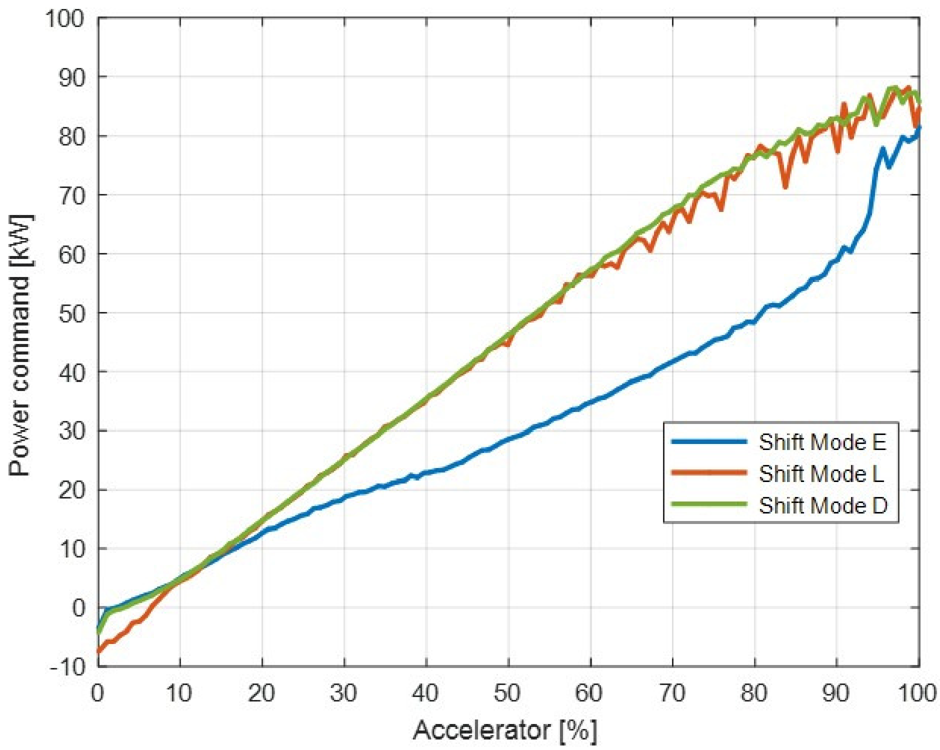


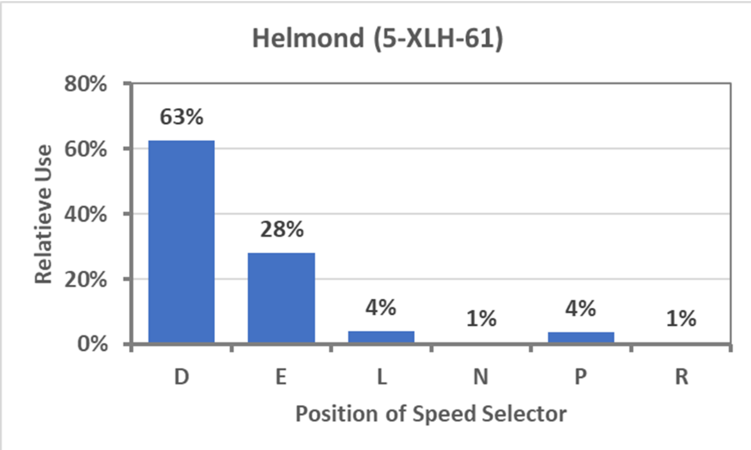
Figure 30 Power command, defined by the accelerator position

Figure 31 - Figure 33, show the gear selector usage during the trips over the monitoring period. Quite clear is the dominant D-mode part in the total. Driving in E-mode is 50% less for the Helmond and Rhoon car; whereas the Arnhem cast show only a 10% difference in D- of E-Mode choice.

What can be seen in all three results – the tables – is that the mean speed in both D- and E-Mode are similar, whereas the accelerator position in E-Mode is significantly higher than in the D-Mode; the driver is using the accelerator pedal more dynamically and thus strongly influences the actual fuel efficiency by doing so. During driving in E-Mode, the accelerator

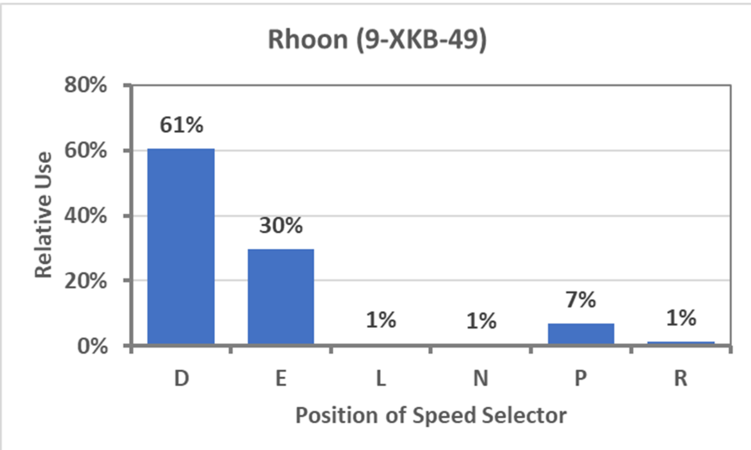
[24] When maximum power is required – e.g. due to an emergency – the driver must not be and desires not to be, confronted with reduced power capabilities due to economy constrains; it’s an emergency!!

pedal is pushed deeper (mean AP value) and operated with higher spread (σ-value), than in D-Mode. Most presumably, this is done since the driver wants to maintain speed according traffic flow. When the vehicle, driving in E-Mode, is operated with a pedal position equivalent to the position as if the vehicle is operated in D-Mode, the result will be a significant lower acceleration. In consequence of this, in the perception of the driver, the vehicle can't match the traffic flow and to solve this, the pedal will be pushed deeper and with more dynamics.



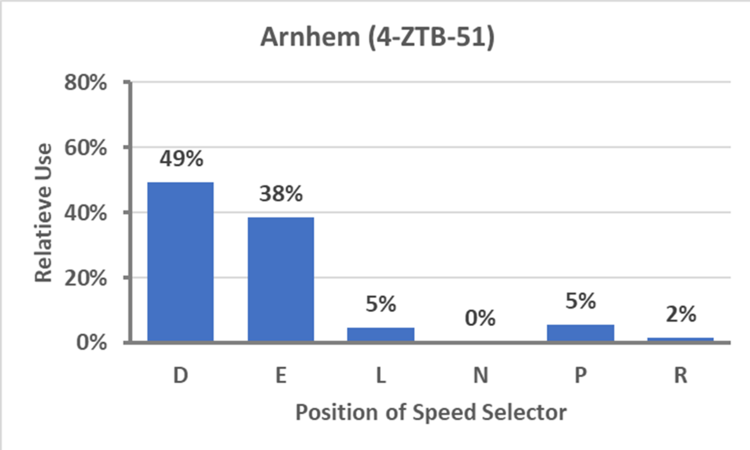
Drive Mode	#Count	Mean AP	Mean Vehicle Speed	Mean Power	Mean Fuel Efficiency	StDev Fuel Efficiency
	-	%	km/hr	kW	km/kgH_2	km/kgH_2
D	1075716	20,9 (σ:16,6)	71,4	15,0	88,8	20,4
E	483584	27,6 (σ:22,1)	72,3	14,1	90,9	19,2
L	70948	16,5 (σ:17,2)	52,0	9,3	91,8	20,4

Figure 31 Helmond Vehicle – Impact of speed selector



Drive Mode	#Count	Mean AP	Mean Vehicle Speed	Mean Power	Mean Fuel Efficiency	StDev Fuel Efficiency
	-	%	km/hr	kW	km/kgH_2	km/kgH_2
D	770062	19,2 (σ:18,4)	59,0	14,0	80,6	21,9
E	375920	31,2 (σ:25,0)	70,0	16,4	81,1	20,6
L	10801	12,5 (σ:17,0)	36,3	5,8	83,4	20,7

Figure 32 Rhoon Vehicle – Impact of speed selector



Drive Mode	#Count	Mean AP	Mean Vehicle Speed	Mean Power	Mean Fuel Efficiency	StDev Fuel Efficiency
	-	%	km/hr	kW	km/kgH_2	km/kgH_2
D	**379074**	**16,0 (σ:17,9)**	**50,6**	**12,5**	**81,6**	**19,0**
E	**295547**	**23,4 (σ:24,1)**	**53,6**	**12,9**	**80,0**	**20,0**
L	**36385**	**17,0 (σ:17,4)**	**46,8**	**11,8**	**80,4**	**20,3**

Figure 33 Arnhem Vehicle – Impact of speed selector

This will lead to a less fuel efficient driving than could be reached. The Helmond vehicle gains "only" a 2 km/kgH_2, the Rhoon vehicle gains a 0,5 km/kgH_2, and the Arnhem vehicle shows a better fuel efficiency in D-Mode: 1,6 km/kgH_2, more than in E-Mode.

Driving in the L-Mode induces a significantly higher energy regeneration, leading to a better fuel efficiency, except for the Arnhem vehicle.

7.1.4. Impact of AC usage

Figure 34 shows the power demand from the stack, due to switching on the AC (see Figure 35).

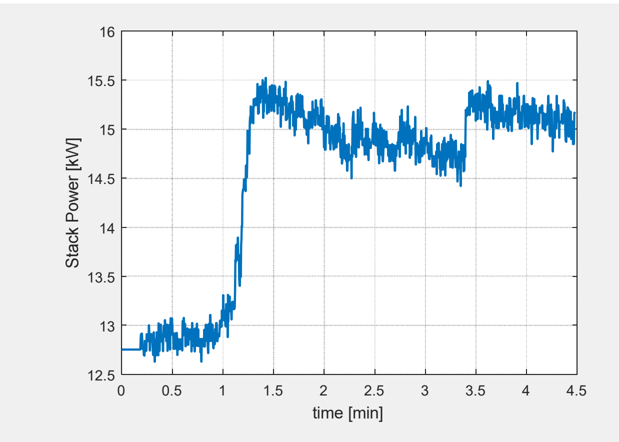


Figure 34 AC Stack power impact

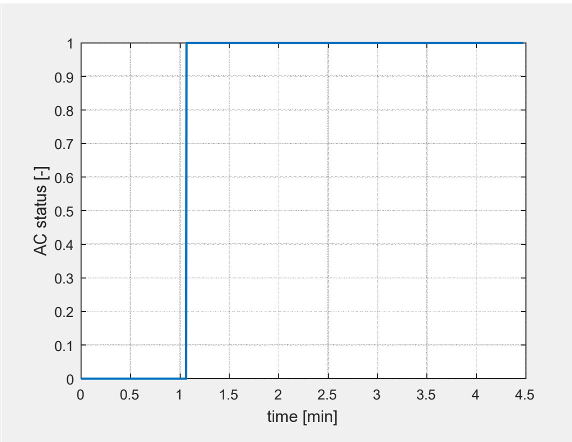


Figure 35 AC switch

The graph in Figure 34, shows that max power consumption of the AC is approx.. 2,5kW max., and that in time (due to decreasing temperature difference), the power demand varies between 1.5 and 2.5kW.

In Table 29, to Table 31, the impact of the AC On/Off om fuel efficiency is given. Given the fact that the AC is only 2,5% of the stack power (100 $kW_{MAX.}$), and the driver/environmental impact (see 7.1, page: P2.58), the variation in Fuel efficiency in Table 29, to Table 31, cannot be related to the AC usage.

AC	GroupCount	Mean Vehicle Speed	Mean Power	Mean Fuel Efficiency	StDev
		km/hr	kW	km/kgH_2	km/kgH_2
Off	**841097**	**62,2**	**12,7**	**88,5**	**19,4**
On	**874800**	**72,2**	**14,8**	**89,6**	**20,0**

Table 29 Helmond - Impact of the AC on fuel efficiency (FE)

AC	GroupCount	Mean Vehicle Speed	Mean Power	Mean Fuel Efficiency	StDev
		km/hr	kW	km/kgH_2	km/kgH_2
Off	**424731**	**50,7**	**12,4**	**79,0**	**20,2**
On	**845319**	**60,0**	**14,0**	**80,5**	**21,1**

Table 30 Rhoon - Impact of the AC on fuel efficiency (FE)

AC	GroupCount	Mean Vehicle Speed	Mean Power	Mean Fuel Efficiency	StDev
		km/hr	kW	km/kgH_2	km/kgH_2
Off	**441187**	**41,0**	**10,2**	**79,7**	**18,9**
On	**326666**	**57,1**	**14,0**	**81,3**	**19,5**

Table 31 Arnhem - Impact of the AC on fuel efficiency (FE)

7.2. Fuel Efficiency – equivalency to Diesel and Petrol

Under the assumption of a constant driveline efficiency (see 0), the fuel efficiency of the ix35FCEV is compared to the fuel consumption of conventional vehicles. In Table 32, the result are shown: for the

		Fuel Efficiency (km/kgH_2)			Fuel Consumption (ℓ/km)		
#	Vehicle Id	Average	Min.	Max	Average	Min.	Max
1	Helmond	**89**	82	98	**21**$_{PETROL}$/**25**$_{DIESEL}$	20$_{PETROL}$/23$_{DIESEL}$	24$_{PETROL}$/27$_{DIESEL}$
2	Rhoon	**81**	75	89	**20**$_{PETROL}$/**22**$_{DIESEL}$	18$_{PETROL}$/21$_{DIESEL}$	21$_{PETROL}$/25$_{DIESEL}$
3	Arnhem	**76**	58	87	**18**$_{PETROL}$/**21**$_{DIESEL}$	14$_{PETROL}$/16$_{DIESEL}$	21$_{PETROL}$/24$_{DIESEL}$

Table 32 Overall results and equivalency to Diesel and Petrol

The fuel consumption of the conventional ix35 vehicles, is for petrol: 1:11 (ℓ/km) and for the diesel version: 1:15 (ℓ/km) the [38] (these are results from real-world measurements, not reference tests, like the NEDC). This indicates that the ix35FCEV in this project is more fuel efficient than the conventional reference vehicle. When the results of the project's test fleet is compared to the Copenhagen reference project (see Table 26), the three vehicles are approx. 10% more fuel efficient.

7.3. Modelling – Results

The model presented in §6.4: Modelling (page: P2.56), has been compared to real life trips (16 trips, from 14.12.2015 to 29.9.2016, see 0page: P2.118). The results of the 16 trips, compared to real life trip results are shown. Table 33 shows a rather good average value of

<3% difference between real life results and simulation result. However, the standard deviation (StDEV) is relatively high, compared to the average value.

Real Life vs Simulation				
	δ: $L_{PARTIAL}$	1970 kg	δ: L_{GROSS}	2290 kg
Average	-2,3%		-2,9%	
StDEV	10,0%		16,4%	

Table 33 Results of the comparison: Model vs Real Life

A second coparison has been made by using the NEDC, simulating driving on highway, national road and inner city (see Figure 36).

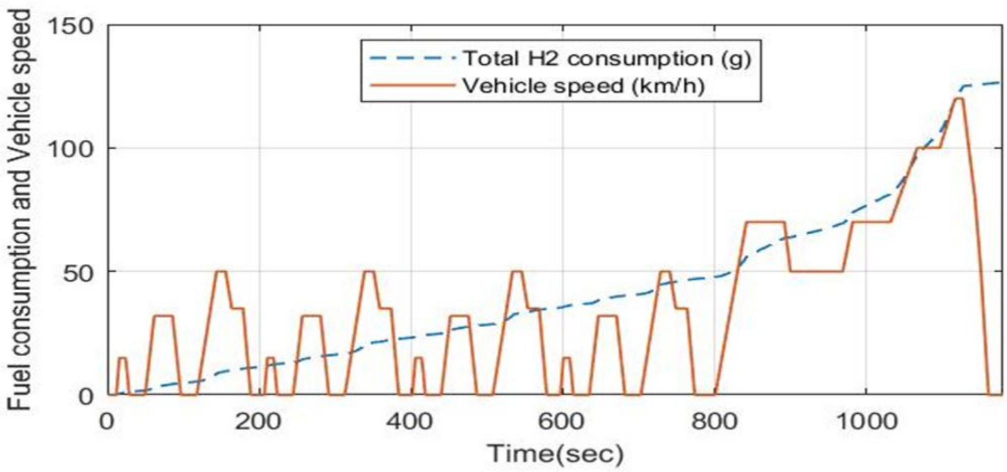


Figure 36 Hydrogen consumption and speed profile (NEDC)

The parameters of the speed profile used and the corresponding fuel and energy consumptions are included in the Table 34.

Parameters	**Total**	**Urban**	**Extra Urban/Highway**
Maximum speed [km/h]	120	50	120
Total distance covered [km]	10.9	4	6.9
Total time [s]	1180	780	400
Fuel Efficiency (km/kgH_2)	86	85	95
Energy consumption (Wh/km)	198	202	194

Table 34: NEDC parameters and fuel consumption (simulation results)

During operational driving the Helmond vehicle showed: 109.3 km/kgH_2, the Arnhem vehicle 81.1 km/kgH_2 and the Rhoon vehicle 85.8 km/kgH_2, whereas the reference vehicle shows 75 km/kgH_2.

Table 35 shows the difference in the obtained simulation values, compared to the data presented by the Original Equipment Manufacturer Hyundai [4].

Drive Cycle	OEM Info (**km/kgH_2**)	Simulation (**km/kgH_2**)	Error[25] (%)
Urban/City	112	85	-24
Extra Urban/Highway	103	95	-13
Combined	105	86	-18

Table 35: Fuel consumption: Measured and Simulation

The urban part of the NEDC, represents inner city driving, the parameters are shown Figure 37, the momentary hydrogen consumption [g/s] and the nominal speed. The extra urban part of the NEDC, represents national road (80km/h) high way driving (120 km/h), the parameters are shown in Figure 38, and, the momentary hydrogen consumption [g/s] and the nominal speed.

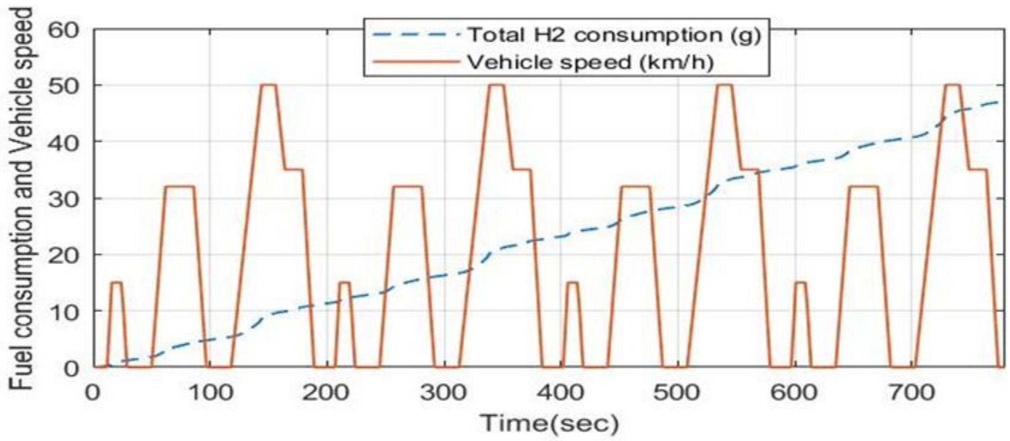


Figure 37: Hydrogen consumption in NEDC Urban cycle

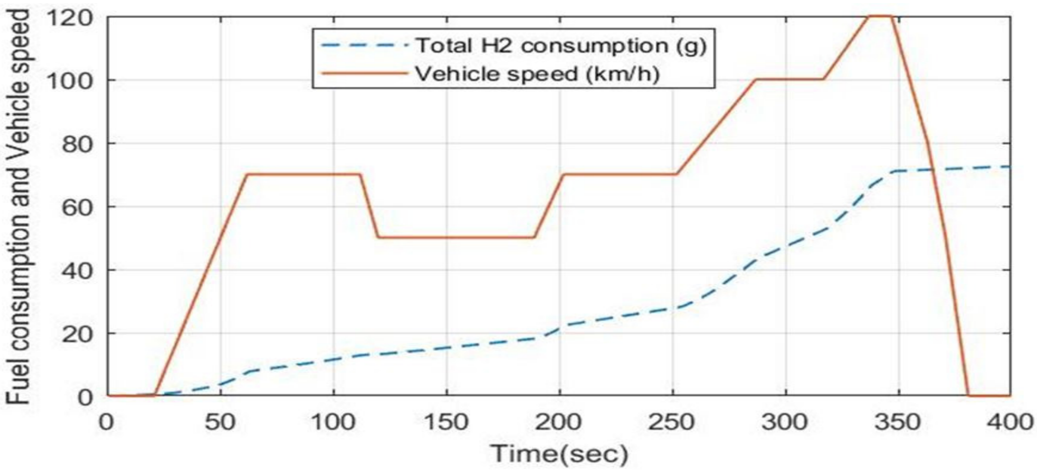


Figure 38: Hydrogen consumption in NEDC Extra Urban cycle

[25] Value relative to OEM info: (*Simulation* - *OEM Info*)/*OEM Info*

8. Results - Insights in the well-to-wheel fuel efficiency

In this chapter the first research question: "Insights in the well-to-wheel fuel efficiency, related to different production methods and the subsequent CO_2 emissions", is presented and discussed.
In the ix35 project, 3 hydrogen refuel stations are used, located at *Rhoon - Air Liquide (method SMR),* and *Helmond (Waterstofnet)* and *Arnhem (HyGear) (method electrolysis)*.

8.1. Rhoon (Air Liquide) and Arnhem (HyGear)

Hydrogen for the refuelling station in Rhoon is produced at the Air Liquide **SMR** plant in Antwerp (Belgium) and transported by pipe line to Rhoon. The pathway two and three in Table 23 seem to be the closest to our case. Therefore in this report a range of **12.9 - 14.0** $kgCO_{2EQ}/kgH_2$ is used as an approximate for the WTT emissions of the SMR hydrogen at Rhoon.
The MAF data from the Rhoon refuelling station (Table 15), indicates that Rhoon is supplied by hydrogen by pipeline, using **Chloride Electrolysis**, with green certificates, having a , having a CO-equivalence of **0.0** $kgCO_{2EQ}/kgH_2$.
Table 22 shows for hydrogen production using wind energy and transport by **pipe line**, a CO-equivalence of **1.6** $kgCO_{2EQ}/kgH_{2x}$
The hydrogen production in Arnhem can be considered as 'on location' (Table 23, 5). Therefore in this report a range of 14.9 $kgCO_{2EQ}/kgH_2$ is used as an approximate for the WTT emissions of the SMR hydrogen at Arnhem.

8.2. Helmond (Waterstofnet)

Waterstofnet claims that the average usage of electricity per kg of hydrogen is 1.5 [$kgCO_2/kgH_2$] Waterstofnet also claims that hydrogen for the fuel station is produced onsite. Therefore, there is very small additional transportation emission. Electricity for production is provided by Greenchoice, which is a green energy labelled electricity provider [40]. The value of 1.5 [$kgCO_2/kgH_2$] is used for the refuelling station in Arnhem (HyGear) as well.

8.3. Concluding remarks

In chapter §5.4: Hydrogen production based on different suppliers' production method different emission rates have been calculated. The fuel tank capacity of Hyundai ix35 FCEV is **5.63 [kg]** [9], combined with the typical CO_2 content rate, the GHG emissions per tank of fuel are shown in Table 36.

Helmond WaterstofNet	**Rhoon Air Liquide**			**Arnhem HyGear**
Electrolysis (on site)	Electrolysis (GC)	Electrolysis (GC_P)	SMR (pipe line)	SMR (on site)
8.5kg CO_{2EQ} per Tank	0.0kg CO_{2EQ} per Tank	9kg CO_{2EQ} per Tank	72.6 – 78.8kg CO_{2EQ} per Tank	83.9kg CO_{2EQ} per Tank

Table 36 Well-to-Tank - CO_{2EQ} Emission per max. capacity t the tank

9. Results - User experiences of the drivers of the vehicle

In this chapter the first research question: "*What are the user experiences of the drivers of the vehicle*" (see §4.439: Project Focus and Research Questions, page: P2.39), is presented and discussed.

In the project period 10.2015 – 21.2017, **33** questionnaires have been filled out (see 0Appendix 8 Questionnaire 10.2015/12.2017 - Response, page: P2.93). In a short additional period (12.2017 – 01.2018), the questionnaire was extended witth optional vehicles: Q1-4: Toyota Miray, Q2-4: Hydrogen City Bus and Q3-4: Hyundai ix35 FCV, other that the here reported fleet. During this period, **8** questionnaires were filled out (see 0Appendix 9 Questionnaire 12.2017/1.2018 - Response, page: P2.100). In total **41** questionnaires were filled out.

Some overall results:

27% of the trips were longer than 500km. and 19% of the drivers claimed: little ("enigszins") range anxiety (2% claimed: to strong ("Sterk tot zeer sterk")). 17% of the questionnaires were filled out by participants outside the project group; 12% Toyota Mirai, 2% a City Bus and 2% an ix35 FCEV outside the test fleet.

In 0and Appendix 10, the responses to the 31 questions are given; the following aspects are highlighted in this chapter:

- Fuelling
- Drive selector
- Vehicle appreciation
- And malfunctioning

9.1. Fuelling

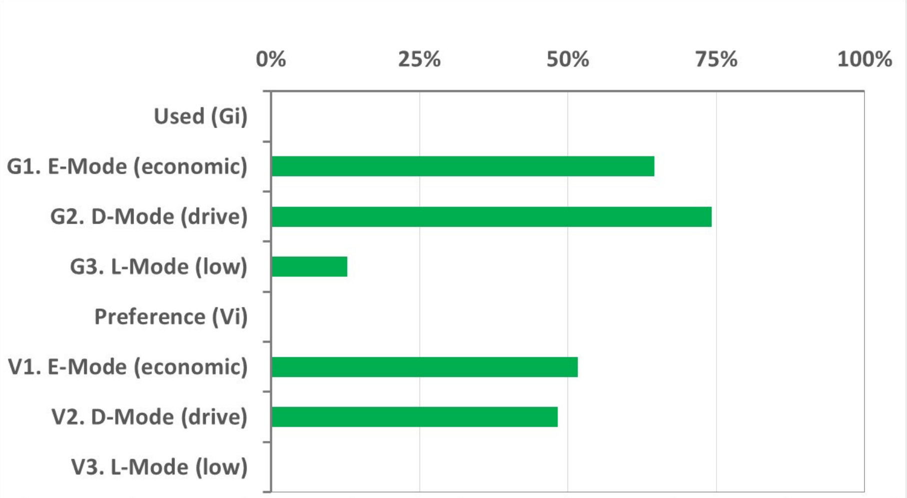
Fuelling is totally different compared to petrol and diesel and LPG as well: high pressure (700bar) and (therefore) requires safety instructions. The following results were found:

1. 72% of the respondents have had an instruction on fuelling;
2. 70% of the respondents had a negative judgement on refuelling options
3. Safety and safety measures (high pressure fuelling) were appreciated by 71% of the respondents;
4. Operational comfort was appreciated by 79% of the respondents;
5. Remarks on fuelling instructions:
   5.1. Extra information on: "Static Electricity", required
   5.2. Explanatory text required on non-zero pressure indication when decoupling;
   5.3. Local available hardcopy of fuelling instructions required;
   5.4. Automatic switching off of area lighting (Rhoon) is not appreciated

9.2. Drive Selector

Over 50% of the respondents pointed out to use mainly one position of the drive selector. 65% used only the E-Mode and 74% only the D-Mode[26], only a 13% used the L-Mode (see figure 39: G1-G3). Whilst 52% preferred E-Mode, and 48% D-Mode (see figure 39: V1-V3).

[26] Multiple answers for this questions could be selected



V3. L-Mode (low)	V2. D-Mode (drive)	V1. E-Mode (economic)	Preference (Vi)	G3. L-Mode (low)	G2. D-Mode (drive)	G1. E-Mode (economic)	Used (Gi)
0%	48%	52%		13%	74%	65%	

Figure 39 Drive selector (DS) usage

9.3. Vehicle appreciation

The respondents valued their overall appreciation for the vehicle, on a scale from 1 to 10, with 7.7 (see figure 40). The experienced comfort and braking was rated with 8.2, range however is valued with a 5.7.

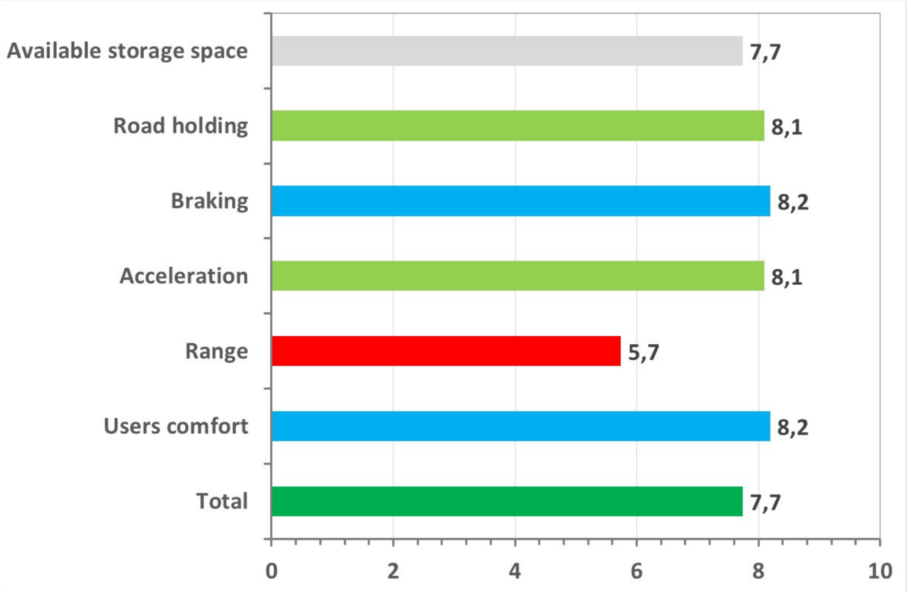


Figure 40 Vehicle appreciation

9.4. Vehicle malfunction

Respondents mentioned only two short interrupts (like in “power failure”) while driving on the Rhoon vehicle. Whilst the Arnhem vehicle has been not operational for two months due to an accident. Repairing the vehicle took several weeks, due to back ordering parts.

9.5. Concluding remarks

Due to the limited options to refuel – 2 options: “Rhoon”, and “Helmond”, in 2016 – it is not remarkable relatively few trips (15%) were over 500km. It is not unlikely that the 21% of the respondents with range anxiety, is due to this limited refuelling locations, as well as the low rated range of the vehicle (5,7, see figure 40 vehicle appreciation) . However, more frequent drivers got more confident on range anxiety; 24% of the more experienced driver were less effected by the phenomena.

10. Discussion

10.1. Fuel Efficiency

The mean value for the fuel efficiency for both Ministry of Infrastructure and the Environment, Rijkswaterstaat vehicles, are for the Helmond vehicle (5-XLH-61): 89,5 km/kgH_2, and for the Rhoon vehicle (9-XKB-49): 81,8 km/kgH_2. The vehicle of the Municipality of Arnhem (4-ZTB-51) has a mean fuel efficiency 77,9 km/kgH_2.
The mean value for the operational fuel efficiency for the overall fleet (3 previous mentioned vehicles) in this project is 83 km/kgH_2, with a maximum value of 88,3 km/kgH_2, and a minimum value of 78,0 km/kgH_2.
The operational fuel efficiency of the Hyunday ix35FCEV in this test (83 km/kgH_2) is 9,6% more fuel efficient than the reference vehicle in the Copenhagen project (75 km/kgH_2).

47% of the trip driven with the Hyundai ix35FCEV in this project was on the highway, with an mean fuel efficiency of 83,488,3 km/kgH_2. The 14% city trips resulted in 81,6 km/kgH_2, whereas the trips on national roads resulted in 85,1 km/kgH_2.

The impact of driving in the E-Mode, is strongly affected by the driver and traffic flow. E-Mode has been applied in 32% of the time driven, resulting is an mean fuel efficiency of 84 km/kgH_2. The D-Mode has been used for 58%, resulting in a fuel efficiency of 83,7 km/kgH_2.

The impact of the use of the Air Conditioning (AC) could not have been established; the energy consumption of the AC-system is not significant enough to be assessed,

10.2. Energy consumption compared to BEV

It is very interesting to see the energy usage (in Wh/km) of the ix35FCEV (empty vehicle weight: 1921 kg[27]) in Wh/km. The test fleet average, as shown in Table 27, is 220Wh/km[28], rated to weight: 115 Wh/ton.km. In this way, the energy performance can be compared to battery EVs.

Comparing real life data implies a certain comparability of using the vehicle, or a massive availability of data to let statistics deal with incompatible usage patterns. More recent results, acquired during daily usage of the vehicle, for the Tesla Model X (weight: 2514 kg), showed an energy consumption of 91Wh/ton.km (230 Wh/km[29]), and the Tesla Model S (weight: 2188 kg): 103-115 Wh/ton.km (225 – 252Wh/km[30]). Recently (May 2016) BMW introduced the i3 EV, using a 94Ah traction battery system. This vehicle , (weight 1320kg), shows an energy consumption of 110-132Wh/km[31].

[27] From: https://ovi.rdw.nl/

[28] This is the electric energy (Wh) consumed by the electric motor, to propel the vehicle over a distance of 1 km

[29] https://tff-forum.de/viewtopic.php?f=25&t=12875

[30] https://steinbuch.wordpress.com/2014/02/08/de-eerste-10-000-km-met-de-tesla-model-s/

[31] https://www.nrc.nl/nieuws/2016/09/08/nu-al-een-designmonument-4188875-a1520407

Table 37 shows for a series of modern cars the approximated real life energy consumption in Wh/ton.km. The data is according NEDC, conversion to real life data, based on an ICCT research project [41, pp. 20, Table 12]: conversion rate: β=0,7 or: 4,5%.

Merk	Type	Weight	Range	NEDC EC [Wh/km]	Real life$_{EQ}$ β=0,7% EC' [Wh/ton.km]	Real life$_{EQ}$ β=14,5% EC' [Wh/ton.km]
Renault Zoe	Q90	1468	240	146	100	116
Mitsubishi	i-MiEV	1085	160	125	116	135
Volkswagen	e-Golf (2017)	1485	300	127	86	100
Hyundai	IONIQ Electric	1420	280	115	82	95
Ford	Focus Electric	1700	225	164	97	113
BMW	is (94Ah)	1440	300	131	92	106
Nissan	Leaf (30kWh)	1525	250	150	99	115
Peugeot	iOn	1140	150	126	111	129
Chevrolet	Bolt EV (2017)	1624	520	145	90	104

Table 37 Overview Energy Consumption, Real Life vs NEDC [41]

Based on , the average real life energy consumption in Wh/ton.km is: 97 ±5 to 113 ±6, leaving the Hyundai ix35 FCEV, with 115 Wh/ton.km, in the higher categories.

10.3. Fuelling Mass

Limited data is available from fuelling stations regarding fuelling the vehicles participating in this project. In 0“Appendix 6 Comparison: Fuelling Station vs ix35FCEV” (p.90), overviews is shown on fuelling data from ‘Waterstofnet’, and Air Liquide, hydrogen supplier of respectively Helmond and Rhoon tank facilities. In appendix 2 the fuelling data from the participating vehicles are shown. In 0Appendix 11 Helmond - Vehicle Refuelling ; HRS-data (p.109) and 0Appendix 12 Rhoon - (p. 115), the fuelled hydrogen mass, per vehicle is given.

For the comparison, the fuelling data larger than a tanked hydrogen mass of: 0,2kg is used. And as well having a date- and time stamp of the refuelling moment (from both: vehicle data and fuelling station data), which are corresponding. Based on the previous the data from the suppliers and in vehicle data, the number of tank stops and subsequent fuelled hydrogen mass have been compared. For the period of this report (2016), the results of the comparison are shown in Table 38.

#	Test Vehicle	#Tank Stop		Fuelled mass		Valid fuelling		
		Station	Vehicle	Supplier	Vehicle	Supplier	Vehicle	Difference[32]
1	Helmond (5-XLH-61)	85	62	219,11kg	157,59kg	116,64kg	111,75	-4,4%
2	Arnhem (4-ZBT-49)	15	15	52,17kg	61,31kg	47,42kg	50,27kg	5,7%
3	Rhoon (9-XKB-49)	64	64	203,06	209,87	190,59kg	188,28kg	-1,2%

32 The difference is relative to the indicated mass of the fuel supplier: $\frac{(DATA_{VEHICLE} - DATA_{SUPLIER})}{DATA_{SUPPLIER}}$

Table 38 Overview of tank stop data

The differences between vehicle data and supplier data is calculated for "Valid Fuelling". Table 38 shows the difference between the calculated fuel mass of hydrogen, based on the parameters acquired from the vehicle data and the mass indicated by the fuelling companies Air Liquide and 'Waterstofnet'. The Arnhem Vehicle and the Helmond vehicle are basically both refuelling at the 'Waterstofnet' refuelling station. However, there's a significant difference: the Arnhem vehicle calculations result in a higher hydrogen mass. Whereas the Rhoon vehicle was fuelled with roughly the same mass.

The results of the vehicle mass calculations are based on temperature (ε ≤ 1%) and pressure (ε= ≤ 1%) measurements. Assuming that either side (fuelling station of vehicle) of the hydrogen mass calculation temperature and pressure has been used, the error in the calculated mass difference, is between 2,8%[33] and 8%[34].

10.4. Fuel Cell degradation

The percentage stack voltage drop relative to the begin-of-measurement is between 1.4% and 2.6% for all cars throughout all types of regression methods on a fuel cell operating time basis as well as produced electricity basis [42, pp. 7, table 2]. Average stack voltage drop is the largest for the Arnhem vehicle. This can be due to a relative larger number of transient phenomena. Arnhem shows low average speed and power output from the fuel cell, resulting from minimal or no power production, also highly contributing to the total zero current time, leading to a highest average stack voltage drop (degradation).

Using this degradation and the current driven distances (Helmond: 27459 km, Rhoon: 7917 km and Arnhem: 18004 km), an extrapolation to maximum allowed voltage drop of 10%, for the life time distance driven was made: Helmond: 164700km, Rhoon: 129000km and Arnhem: 39800km [42, pp. 9, table 3]. According to Oldenbroek m [42]. relatively low life cycle distance is due to the previous mentioned: "transient phenomena", "low average speed" and "lower power output".

33 Based on the statistic error value: $\epsilon_R = \sqrt[2]{\sum_{i=1}^{i=n} \varepsilon_{R,i}^2}$, $\varepsilon_{R,i}$ = the relative error in the subsequent measured value, here: pressure and temperature. Both vehicle- and fuelling station data have an error of 2%, leading to an error in the difference value of 2,8%.

34 Based on worst case: $\varepsilon_R = \sum \varepsilon_{R,i}$. $\varepsilon_{R,i}$ = the relative error in the subsequent measured value, here: pressure and temperature. Both vehicle- and fuelling station data have an error of 4%, leading to an error in the difference value of 8%.

10.5. Hydrogen Costs at the Fuelling station

The costs, including hydrogen production, delivery, and dispensing, range from €3.04/kg to €12.50/kg, depending on source (electrolyses, SMR), costs development over the years and distributor (fuelling station). Table 39 shows an overview of costs/kg found in literature and experienced at the fuelling station.

Source / Literature	Natural Gas, using SMR (€/kgH_2)	Electrolysis, using wind energy (€/kgH_2)
[22]	3.04, 2004, Table 25	9.25, 2004, Table 25
[32]	4.00, 2013, Figure 19	7.18, 2013, Figure 19
Unclassified	At the pump: 9.99 – 12.50, Table 24	

Table 39 Hydrogen Costs at the Fuelling station

10.6. Normalized Emission Labels

The Hyundai ix35 FCEV in this monitoring project, shows an overall fuel efficiency of 1.20 kg/100km (83 km/kgH_2). For the three participating vehicles; individually the:

#	Vehicle	kg/100km	km/kgH_2
i.	Helmond vehicle	1.12	89.5
ii.	Rhoon vehicle	1.28	77.9
iii.	Arnhem vehicle:	1.22	81.8

Since the driving range of the ix35FCEV is over 500km, the refuelling stations can be practically ‘anywhere’. Monitoring showed that refuelling took dominantly place at Arnhem, Helmond and Rhoon, however refuelling stations in e.g. Germany and Belgium were used as well. Therefore in , the consequences for the GHG-emission is shown, based on production technology.

Refuelling station		**Helmond**	**Rhoon**			**Arnhem**
		electrolysis	chlorine electrolysis, with green certificates	Steam Methane Reforming: natural gas piped over 7,000k	Steam Methane Reforming: natural gas piped over 4,000km	Steam Methane Reforming
GHG-emissions in kg CO_{2EQ}/kgH_2		1.5	0	15.3	12.9	12.9
Vehicle	**km/kgH_2**	**gr/km**	**gr/km**	**gr/km**	**gr/km**	**gr/km**
Helmond	**89.5**	**17**	**0**	171	144	144
Arnhem	**81.8**	**18**	**0**	187	158	158
Rhoon	**77.9**	**19**	**0**	**196**	166	166

Table 40 GHG emissions in gr/km for different hydrogen production methods and the 3 vehicles

The Dutch energy label A – G is a relative value compared to the average value of CO_2-emissions in its class [43, pp. 19,20]. In Table 41, the class-values are shown for a ix35 ‘type of vehicle’, having a class average on CO_2-emissions of 160gr/km. A class A vehicle emits less than 128grCO_{2EQ}/km and class G emits more than 208 grCO_{2EQ}/km GHG emissions (see Table 41).

Label		Class average		160 gr/km
		CO_2 emission gr/km		Vehicle type
A	<20%	<128		ix35 FCEV, using electrolysis
B	10-20%	128	144	ix35 FCEV (Helmond) using SMR, natural gas piped over 4,000km
C	10 - 0%	144	160	Hyundai ix35 - 2.0 CRDi Business Edition (147 gr/km) ix35 FCEV (Arnhem & Rhoon) using SMR, natural gas
D	0-10%	160	176	
E	10-20%	176	192	Hyundai ix35 - 2.0i Active (177gr/km)
F	20-30%	192	208	ix35 FCEV (Rhoon, using SMR, natural gas piped over 7,000km)
G	>30%		>208	

Table 41 CO_{2EQ} Rating (Well to Wheel)

11. Literature

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Appendix 1 Hyundai ix35FCEV; Vehicle performance assessment

Appendices

{Part 3: Appendices – Background information and data tables}

Appendix 2 CBS data on Emissions to Air

CO_2 Emissions 2 Air (Dutch Area, totals, mln kg)

Period	Total - SS & MS	SS (total)	MS (total)	Road	Ships (inland)	Ships (sea)	Agro	Remaining
1990	170830	137320	33510	23960	1850	3610	1110	2980
2000	183020	143210	39810	28300	2090	4550	1130	3740
2010	199380	157710	41660	30410	1930	5100	1080	3140
2013	182900	142520	40380	29310	2170	4810	1100	2990
2014	177040	136730	40310	29010	2210	5070	1100	2920
2015 *	185600	145030	40580	29240	2240	5070	1100	2930
1990	170830	80%	20%	72%	6%	11%	3%	9%
2000	183020	78%	22%	71%	5%	11%	3%	9%
2010	199380	79%	21%	73%	5%	12%	3%	8%
2013	182900	78%	22%	73%	5%	12%	3%	7%
2014	177040	77%	23%	72%	5%	13%	3%	7%
2015 *	185600	78%	22%	72%	6%	12%	3%	7%

Table A1-1 Overview CO2 Emission's on a National Level

Emissions 2 Air (Dutch Area, totals, mln kg)

Component	Periods	Total - Stationary & Mobile	SS (total)	MS (total)	Road	Ships (inland)	Ships (sea)	Agro
CO_2	1990	**170830**	**137320**	**33510**	**23960**	**1850**	**3610**	**1110**
CO_2	2015 *	**185600**	**145030**	**40580**	**29240**	**2240**	**5070**	**1100**
Δ: 1990 - 2015		*-14770*	*-7710*	*-7070*	*-5280*	*-390*	*-1460*	*10*
CH_4	1990	1316,55	1308,18	8,37	7,61	0,25	0,12	0,11
CH_4	2015 *	755,63	752,9	2,73	2,3	0,13	0,13	0,03
CO	1990	1155,2	365,3	789,9	710,4	22,1	14,2	5,2
CO	2015 *	615	180,6	434,4	327,3	26,3	21,1	2,3
NO_X	1990	704,3	276,1	428,1	255,1	30,7	88,5	14,5
NO_X	2015 *	345,2	110,4	234,8	77,3	28,6	101,8	7,5
PM10	1990	76,5	47,65	28,85	17,44	1,36	6,13	1,32
PM10	2015 *	29,89	19,02	10,86	4,75	0,93	3,93	0,41

Table A1-2 Overview of Emissions to Air

Δ: 1990 - 2015	Total - Stationary & Mobile	SS (total)	MS (total)	Road	Ships (inland)	Ships (sea)	Agro
CO2	**9%**	**6%**	**21%**	**22%**	**21%**	**40%**	**-1%**
Δ: SR versus MR		**48%**	**52%**				
CH4				**-70%**			
CO				**-54%**			
NOx				**-70%**			
PM10				**-73%**			

Table A1-3 Regulated emissions; relative data: 2015 to 1990

Appendix 3 Data Acquisition – Data management

Server Infrastructure

Multiple servers are required for processing the data as the server that is connected to, and receives the data from, the vehicles must run Windows due to the unavailability of the IMC program on another platform. The tools and services used to process large datasets are heavily concentrated on Linux systems and as such this was the platform chosen for data processing and storage.

Data set

The data sets sent from the vehicles via 4G modems and OpenVPN are direct copies of the '**.raw*' files saved per signal by the data loggers on vehicle. Once a new trip is added to the server, it is synced to the Linux server where a program will run at night, importing any new data sets to the database. There are several steps to this process, consisting of removing data sets and points of insufficient quality, correcting invalid data, and adding additional data. A data set is a collection of a selection of all available signals on the vehicle ranging from 60 to 67 signals depending on the vehicle and its configuration, covering the time between vehicle power on to vehicle power off. The number of signals varies as the vehicles were configured and reconfigured at different times, as requirements changed, and missing and unnecessary signals became clear. The dataset is also mirrored for analysis; with the raw data import being combined with the database data to quickly create a local copy for use within MATLAB by researchers.

Cleansing rules

Entire datasets are removed if:

- More than 3 data files (one per signal) are empty
- They contain less than 50 data files
- More than half of the tank pressure measurements are zero
- Hydrogen tank pressure/temperature has less than 12 non-zero measurements

Datasets are modified as follows:

- GPS Latitude and Longitude are divided by 10000000 to correctly scale the units
- G Sensor Latitudinal values of -3.25g are replaced by 0g
- G Sensor Longitudinal values of -1.99g and -1.2378740176g are replaced by 0g
- Hydrogen temperature signals recorded in degrees Celsius are converted to Kelvin
- Accelerometer data is smoothed use a 5-point moving average to eliminate signal noise
- Shift lever is corrected to eliminate cases of invalid recorded data, i.e., D/N/P/R all selected
- Ambient weather conditions around the vehicle (GPS based) are added at least at trip start, end, and any refuel point. A new point is added when the car has moved more than one kilometre, or more than one hour has passed since the last weather data point.
- Road type is added based on OpenStreeMap data and GPS location, for every GPS point. The road is classified as Highway, Intercity and City, unless there is no GPS, or an unclassified road type such as cycleway.

p-T Mass Noise

Part of the inaccuracy in mass calculation from pressure and temperature comes from the fact that both signals can have changes due to noise quicker than the hydrogen consumption rate in normal use. As such it was necessary to identify the level of this noise so that consumption calculations are not a measure of changes due to noise. The noise was found to be 0.0197, 0.0173, 0.0075 kg for the Helmond, Arnhem and Rhoon vehicles respectively, which allows for better filtering of data for analysis.

Appendix 4 Data Acquisition – Obtained Vehicle Parameters

This appendix gives an overview of the parameters sampled during driving, in the following subgroups:

1. Fuel cell
2. Auxiliaries/Miscellaneous
3. Vehicle behaviour – General
4. Vehicle behaviour; GPS – Sensor
5. Vehicle behaviour; Performance
6. Traction Batteries

#Chan.	(E)OBD Parameters tbv Monitoring	Units	f [#/h]
Hydrogen - Fuel Cell			
1	Number of Refueling for 40L (Tank 1)	-	6
2	Number of Refueling for 104L (Tank 2)	-	6
3	Infrared Measured Pressure	Mpa	360
4	Infrared Measured Temperature	K	3600
5	H2 Tank Pressure	kPa	3600
6	H2 Tank1 Temperature	°C	360
7	H2 Tank2 Temperature	°C	360
8	H2 Storage of Fuel	%	360
13	Stack Inlet Air Temperature Senor Value	0	3600
14	Stack Exhaust Air Temperature Senor Value	0	3600
36	FC_total_Voltage		3600
37	FC_total_current		3600

#Chan.	(E)OBD Parameters tbv Monitoring	Units	f [#/h]
Auxiliaries/Miscellaneous			
9	Ignition state	-	360
12	Fuel Door Open	-	360
10	Auxiliary Battery Voltage	V	360
11	Shift Lever	-	360
38	AC status		360

Appendix 3 Vehicle data (continued)

#Chan.	(E)OBD Parameters tbv Monitoring	Units	f [#/h]
Vehicle behaviour - General			
15	Accelerator A Value	%	18000
16	G-Sensor Longitudinal	G	18000
17	Steering Angel Sensor (CAN) (ESP Only)	DEG	18000
18	Lateral G-Sensor (ESP Only)	G	18000
19	Yaw Rate Sensor (ESP Only)	1/S	18000
20	Brake Padel Sensor Travel - PDF	mm	18000
34	Vehicle Speed	km/h	3600
35	Steering Angle Sensor	DEG	18000

#Chan.	(E)OBD Parameters tbv Monitoring	Units	f [#/h]
Vehicle behaviour; GPS - Sensor			
-	X	[°]	
-	Y	[°]	
-	Z	[m]	

#Chan.	(E)OBD Parameters tbv Monitoring	Units	f [#/h]
Vehicle behaviour; Performance			
21	Torque Reference	%	18000
22	Torque Command	Nm	18000
23	Rotor Speed	RPM	18000
24	Motor Temperature	°C	3600
25	Inverter Temperature	°C	3600

#Chan.	(E)OBD Parameters tbv Monitoring	Units	f [#/h]
Traction Batteries			
26	State of Charge of Battery(BMS)	%	3600
27	Battery DC Voltage	0	3600
28	Battery DC Current	0	3600
29	Accumulative Charge Current	Ah	360
30	Accumulative Discharge Current	Ah	360
31	Accumulative Charge Power	kWh	360
32	Accumulative Discharge Power	kWh	360
33	Accumulative Operating Time	S	6

Appendix 5 Retrieving data from the EOBD

Retrieving data from the EOBD CAN bus connector

Making use of a Hyundai GDS-M workshop tester an overview of all available data was made. From this list of over 100 signals a selection was made of signals which where relevant to quantify the behavior, status and performance of the:

- Fuel tank
- Fuel cell system
- Driver
- Driveline

The GDS-M gets its data from multiple sources. To limit the project size only data was selected from control units communicating over the CAN protocol. In Appendix 4 Data Acquisition – Obtained Vehicle Parameters, a complete overview is given of the parameters obtained from the vehicle, while driving.

In a next step the GDS-M was used to understand the way of communicating, and the format of the data, exchanged between car and tester. For this the CAN-datastream was logged, while working with the tester. This made clear what replies both the car and the tester expected on requests, to keep the communication alive. After some experiments this structure was so well understood, it could be composed in a Simulink model. Making use of the Vehicle Network toolbox, this model could perform real-time CAN communication over a Peak interface.

With this model running we could keep the GDS-M alive, without being connected to the car. By going through the list of previous monitored CAN-ID's, sending them one by one to the GDS-M and finding out which parameter became active, a relation between parameter and CAN-ID could be achieved. By varying the content of each parameter, the applied scaling and numeric format was found out.

Since the monitoring project must be performed with only a datalogger, and no workshop tester, as a next step the communication of the GDS-M was simulated in Simulink. In this way, it made clear which information had to be sent to the car, to keep the communication alive and have the car sending the requested data. Once found out, this structure was implemented in an IMC CAN datalogger. This is the hardware built into the car which takes care of the communication, and stores the results.

To have the data not only available on the car, but also on a server, a communication structure was set up where the datalogger is connected to a 4G modem, which sends its data to a HAN server by OPENVPN.

A dataset is continuously collected on the vehicle, over the EOBD port. It includes all driver inputs, voltage and currents in the electrical system, Hydrogen pressures, temperatures, etc. Periodically the data is sent over a 4G connection to a MySQL database on an in-company server.

Appendix 6 Comparison: Fuelling Station vs ix35FCEV

Overall data between tanks stops – Arnhem Vehicle

Vehicle	"Arnhem"	Total Mass:	47,42	**[kg]**	**"Producer"**
	(4ZTB51)		50,27	**[kg]**	**ix35FCEV**

data "Producer"				data ix35FCEV		**Delta**
"Prod."	Date & Time		Mass [kg]	Date&Time	Mass [kg]	**[%]**
WN	06-01-2016 om 11:16		4,89	06-01-2016 11:09:08	5,12	**4,5**
AL	01-18-2016	om 9:36	3,14	18-01-2016 9:24:56	3,65	**13,9**
WN	28-01-2016 om 15:57		4,76	28-01-2016 15:50:06	5,01	**5,0**
	11-02-2016 om 12:02		3,90	11-02-2016 11:36:34	4,04	**3,4**
	23-02-2016 om 13:16		4,45	23-02-2016 13:10:24	4,74	**6,2**
	10-03-2016 om 11:01		3,63	10-03-2016 10:53:48	3,72	**2,3**
	24-03-2016 om 11:52		4,70	24-03-2016 11:43:08	4,96	**5,3**
AL	05-17-2016	om 12:34	2,68	17-05-2016 11:26:59	2,94	**8,8**
	05-17-2016	om 13:19	2,08	17-05-2016 12:12:46	2,14	**2,7**
WN	20-05-2016 om 10:54		4,02	20-05-2016 9:40:49	4,20	**4,4**
AL	06-02-2016	om 12:28	4,40	02-06-2016 11:15:36	4,61	**4,6**
WN	23-12-2016 om 11:06		4,77	23-12-2016 10:51:02	5,14	**7,3**
			47,42		50,27	**5,7**

Overall data between tanks stops – RWS - Helmond Vehicle

Vehicle	"Helmond"	Total Mass:	116,64	**[kg]**	**"Producer"**
	(5XLH61)		111,75	**[kg]**	**ix35FCEV**

data "Producer"				data ix35FCEV		**Delta**	data Waterstofnet		data ix35FCEV		**Delta**
"Prod."	Date & Time		Mass [kg]	Date&Time	Mass [kg]	**[%]**	Date & Time	Mass [kg]	Date&Time	Mass [kg]	**[%]**
WN	07-01-2016 om 15:36		2,53	7-1-2016 15:30	2,44	**-3,7**	21-04-2016 om 16:41	4,45	21-4-2016 13:21	4,37	**-1,7**
	12-01-2016 om 07:36		2,82	12-1-2016 7:31	2,54	**-11,2**	10-05-2016 om 06:19	3,28	10-5-2016 5:10	3,16	**-3,9**
AL	18-01-2016	18:26	3,23	18-1-2016 18:18	3,47	**6,9**	11-05-2016 om 12:06	2,74	11-5-2016 6:29	2,59	**-5,8**
WN	19-01-2016 om 18:15		4,45	19-1-2016 18:08	3,99	**-11,4**	10-06-2016 om 10:18	0,89	10-6-2016 9:07	0,86	**-3,0**
	21-01-2016 om 17:23		3,46	21-1-2016 17:12	3,24	**-6,7**	10-06-2016 om 15:50	2,77	10-6-2016 14:40	2,61	**-6,0**
	27-01-2016 om 16:03		3,13	27-1-2016 15:56	2,94	**-6,3**	14-06-2016 om 15:48	2,32	14-6-2016 14:36	2,23	**-3,8**
	28-01-2016 om 19:18		3,9	28-1-2016 19:09	3,66	**-6,6**	27-06-2016 om 12:22	1,16	27-6-2016 10:30	1,10	**-5,7**
	01-02-2016 om 14:47		2,93	1-2-2016 14:41	2,69	**-9,1**	07-07-2016 om 17:17	2,22	7-7-2016 16:07	2,09	**-6,4**
	10-02-2016 om 08:56		2,71	10-2-2016 8:50	2,59	**-4,6**	12-07-2016 om 16:00	1,86	12-7-2016 14:06	1,78	**-4,6**
	10-02-2016 om 14:32		2,74	10-2-2016 14:26	2,68	**-2,4**	04-08-2016 om 16:29	2,49	4-8-2016 15:18	2,42	**-3,0**
	25-02-2016 om 12:40		1,8	25-2-2016 12:33	1,67	**-8,0**	17-08-2016 om 14:30	3,18	17-8-2016 13:18	3,06	**-3,8**
	26-02-2016 om 14:40		3,9	26-2-2016 14:22	3,86	**-1,1**	18-08-2016 om 16:20	1,25	18-8-2016 15:10	1,24	**-0,4**
	02-03-2016 om 13:01		2,72	2-3-2016 11:11	2,63	**-3,5**	23-08-2016 om 14:56	3,17	23-8-2016 13:44	3,11	**-2,0**
	03-03-2016 om 11:44		1,11	3-3-2016 11:35	1,09	**-1,4**	29-08-2016 om 14:50	3,11	29-8-2016 13:38	2,98	**-4,4**
	09-03-2016 om 17:04		3,73	9-3-2016 16:56	3,63	**-2,8**	31-08-2016 om 07:53	3,18	31-8-2016 6:36	3,06	**-4,0**
	17-03-2016 om 15:03		3,73	17-3-2016 14:54	3,50	**-6,4**	31-08-2016 om 16:36	2,53	31-8-2016 15:24	2,46	**-2,7**
	18-03-2016 om 15:28		2,3	18-3-2016 15:20	2,24	**-2,5**	09-09-2016 om 13:08	0,93	9-9-2016 9:53	0,96	**3,3**
	31-03-2016 om 14:13		3,39	31-3-2016 13:05	3,15	**-7,7**	12-10-2016 om 07:20	3,11	12-10-2016 4:15	3,00	**-3,5**
	06-04-2016 om 16:59		2,35	6-4-2016 15:52	2,28	**-3,0**	12-12-2016 om 21:33	3,93	12-12-2016 14:32	3,76	**-4,4**
	08-04-2016 om 16:14		2,56	8-4-2016 15:06	2,42	**-5,6**	13-12-2016 om 15:36	2,44	13-12-2016 12:57	2,36	**-3,4**
AL	12-04-2016	16:01	1,86	12-4-2016 13:58	1,71	**-8,7**	23-12-2016 om 09:09	4,28	23-12-2016 7:02	4,10	**-4,4**
			61,35		58,43	**-5,0**		55,29		53,32	**-4,4**

Appendix 5 Comparison: Fuelling Station vs ix35FCEV (End)

Overall data between tanks stops – RWS - Rhoon Vehicle

Vehicle	"Rotterdam"	Total Mass:	190,59	**[kg]**	**Air Liquide**
	(9XKB49)		188,28	**[kg]**	**ix35FCEV**

data Air Liquide			data ix35FCEV		**Delta**	data Air Liquide			data ix35FCEV		**Delta**
Date	Time	Mass [kg]	Date&Time	Mass [kg]	**[%]**	Date	Time	Mass [kg]	Date&Time	Mass [kg]	**[%]**
07-01-16	12:27	2,79	07-01-2016 9:56	3,02	**7,7**	02-06-16	14:29	2,58	02-06-2016 11:26	2,47	**-4,5**
13-01-16	8:02	3,07	13-01-2016 6:57	3,33	**7,9**	09-06-16	15:55	2,97	09-06-2016 12:52	2,87	**-3,6**
17-01-16	16:28	1,41	17-01-2016 15:24	1,44	**2,3**	24-06-16	11:09	3,67	24-06-2016 9:55	3,53	**-3,9**
21-01-16	11:00	1,77	21-01-2016 9:56	1,83	**3,1**	12-07-16	13:10	3,17	12-07-2016 11:27	3,01	**-5,2**
22-01-16	15:14	2,49	22-01-2016 14:09	2,66	**6,5**	14-07-16	14:31	4,40	14-07-2016 5:52	4,24	**-3,8**
29-01-16	14:35	3,86	29-01-2016 13:28	4,38	**11,8**	21-07-16	08:56	2,34	21-07-2016 8:48	2,21	**-5,9**
04-02-16	9:17	2,75	04-02-2016 7:58	3,07	**10,3**	10-08-16	11:51	4,45	10-08-2016 14:04	4,23	**-5,1**
06-02-16	10:47	1,33	06-02-2016 9:42	1,39	**4,5**	12-09-16	15:58	2,65	12-09-2016 11:54	2,34	**-13,1**
08-02-16	5:56	3,90	08-02-2016 3:51	4,40	**11,3**	20-09-16	17:08	3,05	20-09-2016 4:15	2,77	**-10,3**
10-02-16	13:25	2,46	10-02-2016 11:21	2,73	**9,8**	26-09-16	08:48	3,65	26-09-2016 4:49	3,38	**-8,0**
12-02-16	15:25	3,88	12-02-2016 5:49	4,29	**9,6**	27-09-16	15:00	3,20	27-09-2016 4:48	2,88	**-11,2**
17-02-16	15:33	3,68	17-02-2016 4:29	4,00	**8,1**	28-09-16	07:19	3,43	28-09-2016 13:31	3,19	**-7,4**
20-02-16	10:39	4,32	20-02-2016 8:33	4,86	**11,1**	05-10-16	07:54	3,47	05-10-2016 4:53	3,16	**-10,0**
23-02-16	9:53	3,93	23-02-2016 7:49	4,45	**11,8**	08-10-16	07:53	2,84	08-10-2016 6:40	2,53	**-12,3**
26-02-16	6:05	2,65	26-02-2016 4:02	2,93	**9,5**	08-10-16	16:41	4,34	08-10-2016 10:05	4,04	**-7,4**
09-03-16	16:33	3,58	09-03-2016 5:45	3,98	**10,0**	21-10-16	15:58	3,81	21-10-2016 18:50	3,52	**-8,3**
12-03-16	13:09	3,58	12-03-2016 3:55	4,03	**11,1**	28-10-16	13:10	3,57	28-10-2016 3:01	3,20	**-11,7**
25-03-16	15:25	4,04	25-03-2016 13:08	4,53	**10,8**	03-11-16	09:45	2,77	03-11-2016 5:57	2,48	**-11,8**
29-03-16	16:25	0,82	29-03-2016 4:31	0,82	**0,2**	04-11-16	21:59	3,54	04-11-2016 13:06	3,24	**-9,3**
31-03-16	14:14	3,53	31-03-2016 11:09	3,99	**11,5**	10-11-16	06:06	4,39	10-11-2016 11:43	4,06	**-8,2**
11-04-16	7:53	2,77	11-04-2016 4:48	2,53	**-9,5**	11-11-16	08:04	2,97	11-11-2016 6:31	2,56	**-15,8**
14-04-16	19:47	2,88	14-04-2016 16:41	2,76	**-4,3**	14-11-16	15:19	3,62	14-11-2016 5:52	3,28	**-10,2**
18-04-16	8:04	4,93	18-04-2016 4:59	4,72	**-4,5**	18-11-16	13:49	3,93	18-11-2016 6:15	3,68	**-6,7**
20-04-16	15:40	4,06	20-04-2016 12:35	3,83	**-6,1**	21-11-16	08:36	2,81	21-11-2016 14:02	2,60	**-8,3**
22-04-16	8:22	3,75	22-04-2016 5:17	3,54	**-6,0**	01-12-16	07:56	4,53	01-12-2016 11:47	4,21	**-7,6**
13-05-16	14:50	3,42	13-05-2016 11:45	3,48	**1,9**	07-12-16	08:20	3,71	07-12-2016 4:02	3,37	**-10,2**
24-05-16	13:26	3,66	24-05-2016 8:02	3,49	**-4,8**	09-12-16	16:07	3,69	09-12-2016 9:33	3,44	**-7,3**
25-05-16	11:58	3,20	25-05-2016 8:55	3,02	**-6,0**	23-12-16	13:53	4,80	23-12-2016 3:45	4,64	**-3,4**
31-05-16	16:43	3,73	31-05-2016 13:36	3,66	**-1,9**						
		92,24		97,16	**5,1**			98,35		91,12	**-7,9**

Appendix 7 Questionnaire – Overview of questions

Due to the fact that this is a Dutch research program, the questionnaire has not been translated.

Questionnaire: 10.2015 – 12.2017

1. Welke auto heeft u gereden
2. Hoeveel kilometer heeft u deze keer gereden
3. In welke mate heeft u DEZE KEER last gehad van range anxiety
4. Heeft u al eerder met de brandstofcelauto gereden
5. Is de range anxiety (twijfel over de actieradius van het voertuig)veranderd...
6. Heeft u deze enquête al eerder ingevuld? (Bij Ja worden de vragen overslaan...
7. Heeft u een instructie over het rijden met het brandstofcelvoertuig gehad?
8. Heeft u een instructie over het tanken van het voertuig gehad?
9. Heeft u waterstof getankt?
10. Ervaring als berijder met het tanken: 1. Locaties/dekkingsgraad tankstations
11. Ervaring als berijder met het tanken: 2. Veiligheid (tanken onder hoge druk)
12. Ervaring als berijder met het tanken: 3. Gebruiksgemak
13. Heeft u passagiers meegenomen?
14. Aantal passagiers?
15. Heeft u met open ramen gereden?
16. Percentage met open raam gereden?
17. Welke transmissiestanden heeft u gebruikt? (meerdere antwoorden mogelijk)
18. Welke transmissiestanden heeft u gebruikt? (meerdere antwoorden mogelijk)
19. Heeft u uw rijstijl bij het rijden in de brandstofcelauto aangepast in verg...
20. Ik zal het gebruik van de brandstofcelauto aan collegae
21. Brandstofcelauto en milieu De bijdrage aan een beter milieu (luchtvervuiling, CO2, NOx)
22. Mijn waardering voor de brandstofcelauto: Gebruiksgemak
23. Mijn waardering voor de brandstofcelauto: Actieradius
24. Mijn waardering voor de brandstofcelauto: Acceleratie
25. Mijn waardering voor de brandstofcelauto: Remmen
26. Mijn waardering voor de brandstofcelauto: Wegligging/weggedrag/stabiliteit
27. Mijn waardering voor de brandstofcelauto: Beschikbare bagageruimte
28. Mijn waardering voor de brandstofcelauto: Totaalbeoordeling
29. Brandstofcelauto en veiligheid i.v.m. een benzine- diesel- of LPG-auto. De veiligheid bij het rijden in een brandstofcelauto vind ik:
30. Heeft u problemen of pech gehad met de auto?
31. Voor vragen over deze enquête mag contact met mij opgenomen worden.

Additional Questionnaire: 12.2017 – 01.2018

Aangepaste vraag: 1) Welke auto heeft u gereden – extra keuzes:

- Een andere Hyundai ix35 FCEV
- Toyota Mirai
- Waterstofbus

Appendix 8 Questionnaire 10.2015/12.2017 - Response

Legenda:
n = aantal respondenten dat de vraag heeft gezien; **tot 31.12.2017, zijn dat er 33 geweest**
# = aantal ontvangen antwoorden op een bepaalde vraag

1) Welke auto heeft u gereden?

1-ZTB-51 (Gemeente Arnhem)	10 (34.48 %)
5-XLH-61 (Rijkswaterstaat Helmond)	15 (51.72 %)
9-XKB-49 (Rijkswaterstaat 's-Gravenhage)	4 (13.79 %)

n = 29
# 29

2) Hoeveel kilometer heeft u deze keer gereden?

1: < 100 km	9 (27.27 %)
2: tussen 100 en 500 km	19 (57.58 %)
3: meer dan 500 km	5 (15.15 %)

n = 33
# 33

3) In welke mate heeft u DEZE KEER last gehad van range anxiety (twijfel over ...

1. Niet - nauwelijks	26 (78.79 %)
2. Enigszins	7 (21.21 %)
3. Sterk tot zeer sterk	0 (0 %)

n = 33
# 33

4) Heeft u al eerder met de brandstofcelauto gereden?

Ja	22 (66.67 %)
Nee	11 (33.33 %)

n = 33
# 33

5) Is de range anxiety (twijfel over de actieradius van het voertuig)veranderd...

1. Niet - nauwelijks	16 (76.19 %)
2. Enigszins verbeterd	4 (19.05 %)
3. Sterk tot zeer sterk verbeterd	1 (4.76 %)

n = 21
# 21

Questionnaire 10.2015/12.2017 - Response (continued)

6) Heeft u deze enquête al eerder ingevuld? (Bij Ja worden de vragen ove...

Ja	7 (21.88 %)
Nee	25 (78.13 %)

n = 32
# 32

7) Heeft u een instructie over het rijden met het brandstofcelvoertuig gehad?

Ja	21 (84 %)
Nee	4 (16 %)

n = 25
# 25

8) Heeft u een instructie over het tanken van het voertuig gehad?

Ja	18 (72 %)
Nee	7 (28 %)

n = 25
# 25

9) Heeft u waterstof getankt?

Ja	24 (75 %)
Nee	8 (25 %)

n = 32
# 32

10) Ervaring als berijder met het tanken:
Locaties/dekkingsgraad tankstations

Zeer slecht	5 (20.83 %)
Slecht	12 (50 %)
Neutraal	6 (25 %)
Goed	1 (4.17 %)
Zeer Goed	0 (0 %)

n = 24
# 24

11) Ervaring als berijder met het tanken:
Veiligheid (tanken onder hoge druk)

Zeer slecht	1 (4.17 %)
Slecht	0 (0 %)
Neutraal	6 (25 %)
Goed	12 (50 %)
Zeer Goed	5 (20.83 %)

n = 24
# 24

Questionnaire 10.2015/12.2017 - Response (continued)

12) Ervaring als berijder met het tanken:
Gebruiksgemak

Zeer slecht	0 (0 %)
Slecht	3 (12.5 %)
Neutraal	2 (8.33 %)
Goed	17 (70.83 %)
Zeer Goed	2 (8.33 %)

n = 24
# 24

13) Aantal passagiers?
Heeft u passagiers meegenomen?

1	6 (37.5 %)
2	5 (31.25 %)
3	5 (31.25 %)

n = 16
# 16

14) Aantal passagiers?

1	6 (40 %)
2	4 (26.67 %)
3	5 (33.33 %)

n = 15
# 15

15) Heeft u met open ramen gereden?

Ja	3 (9.38 %)
Nee	29 (90.63 %)

n = 32
# 32

16) Percentage met open raam gereden?

minder dan 20%	2 (100 %)
tussen 20 en 50%	0 (0 %)
tussen 50 en 80%	0 (0 %)
boven 80%	0 (0 %)

n = 2
# 2

Questionnaire 10.2015/12.2017 - Response (continued)

17) Welke transmissiestanden heeft u gebruikt? (meerdere antwoorden mogelijk)

1. e-stand (economic)	20 (64.52 %)
2. d-stand (drive)	23 (74.19 %)
3. l-stand (low)	4 (12.9 %)

n = 31
\# 47

18) Welke transmissiestand heeft uw voorkeur?

e-stand (economic)	15 (51.72 %)
d-stand (drive)	14 (48.28 %)
l-stand (low)	0 (0 %)

n = 29
\# 29

19) Heeft u uw rijstijl bij het rijden in de brandstofcelauto aangepast in verg...

Ja	13 (41.94 %)
Nee	18 (58.06 %)

n = 31
\# 31

20) Ik zal het gebruik van de brandstofcelauto aan collegae:

Ten zeerste aanraden	23 (74.19 %)
Niet aanraden maar ook niet afraden	8 (25.81 %)
Ten zeerste afraden	0 (0 %)

n = 31
\# 31

21) Brandstofcelauto en milieu
De bijdrage aan een beter milieu (luchtvervuiling, CO2, NOx) van het rijden met de brandstofcelauto vind ik:

1. Zeer slecht	0 (0 %)
2. Slecht	0 (0 %)
3. Neutraal	3 (9.68 %)
4. Goed	9 (29.03 %)
5. Zeer Goed	19 (61.29 %)

n = 31
\# 31

Questionnaire 10.2015/12.2017 - Response (continued)

22) Mijn waardering voor de brandstofcelauto: Gebruiksgemak

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	3 (9.68 %)
7.	3 (9.68 %)
8.	13 (41.94 %)
9.	9 (29.03 %)
10. Hoog	3 (9.68 %)

n = 31
# 31

23) Mijn waardering voor de brandstofcelauto: Actieradius

1. Laag	0 (0 %)
2.	1 (3.23 %)
3.	3 (9.68 %)
4.	5 (16.13 %)
5.	3 (9.68 %)
6.	7 (22.58 %)
7.	8 (25.81 %)
8.	3 (9.68 %)
9.	0 (0 %)
10. Hoog	1 (3.23 %)

n = 31
# 31

24) Mijn waardering voor de brandstofcelauto: Acceleratie

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	2 (6.45 %)
7.	8 (25.81 %)
8.	10 (32.26 %)
9.	7 (22.58 %)
10. Hoog	4 (12.9 %)

n = 31
# 31

Questionnaire 10.2015/12.2017 - Response (continued)

25) Mijn waardering voor de brandstofcelauto:
Remmen

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	1 (3.33 %)
7.	4 (13.33 %)
8.	16 (53.33 %)
9.	6 (20 %)
10. Hoog	3 (10 %)

n = 30
# 30

26) Mijn waardering voor de brandstofcelauto:
Wegligging/weggedrag/stabiliteit

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	2 (6.45 %)
7.	6 (19.35 %)
8.	12 (38.71 %)
9.	9 (29.03 %)
10. Hoog	2 (6.45 %)

n = 31
# 31

27) Mijn waardering voor de brandstofcelauto:
Beschikbare bagageruimte

1. Laag	0 (0 %)
2.	0 (0 %)
3.	1 (3.23 %)
4.	0 (0 %)
5.	1 (3.23 %)
6.	4 (12.9 %)
7.	6 (19.35 %)
8.	8 (25.81 %)
9.	8 (25.81 %)
10. Hoog	3 (9.68 %)

n = 31
# 31

Questionnaire 10.2015/12.2017 - Response (continued)

28) Mijn waardering voor de brandstofcelauto:
Totaalbeoordeling

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	1 (3.23 %)
6.	0 (0 %)
7.	11 (35.48 %)
8.	14 (45.16 %)
9.	4 (12.9 %)
10. Hoog	1 (3.23 %)

n = 31
# 31

29) Brandstofcelauto en veiligheid i.v.m. een benzine- diesel- of LPG-auto.
De veiligheid bij het rijden in een brandstofcelauto vind ik:

1. Lager	3 (10 %)
2. Gelijk	25 (83.33 %)
3. Beter	2 (6.67 %)

n = 30
# 30

30) Heeft u problemen of pech gehad met de auto?

Ja	2 (6.45 %)
Nee	29 (93.55 %)

n = 31
# 31

Tabel B3.30 Heeft u problemen of pech gehad met de auto?

31) Voor vragen over deze enquête mag contact met mij opgenomen worden.

Ja	23 (74.19 %)
Nee	8 (25.81 %)

n = 31
# 31

Appendix 9 Questionnaire 12.2017/1.2018 - Response

Legenda:
n = aantal respondenten dat de vraag heeft gezien; **van 01.12.2017 tot 1.1.2018, zijn dat er 8 geweest**
# = aantal ontvangen antwoorden op een bepaalde vraag

1) Welke auto heeft u gereden?

1-ZTB-51 (Gemeente Arnhem)	0 (0 %)
5-XLH-61 (Rijkswaterstaat Helmond)	1 (12.5 %)
9-XKB-49 (Rijkswaterstaat 's-Gravenhage)	0 (0 %)
Een andere Hyundai ix35 FCEV	5 (62.5 %)
Toyota Mirai	1 (12.5 %)
Waterstofbus	1 (12.5 %)

n = 8
# 8

2) Hoeveel kilometer heeft u deze keer gereden?

1: < 100 km	0 (0 %)
2: tussen 100 en 500 km	2 (25 %)
3: meer dan 500 km	6 (75 %)

n = 8
# 8

3) In welke mate heeft u DEZE KEER last gehad van range anxiety (twijfel over ...

1. Niet - nauwelijks	6 (75 %)
2. Enigszins	1 (12.5 %)
3. Sterk tot zeer sterk	1 (12.5 %)

n = 8
# 8

4) Heeft u al eerder met de brandstofcelauto gereden?

Ja	5 (62.5 %)
Nee	3 (37.5 %)

n = 8
# 8

5) Is de range anxiety (twijfel over de actieradius van het voertuig)veranderd...

1. Niet - nauwelijks	3 (75 %)
2. Enigszins verbeterd	1 (25 %)
3. Sterk tot zeer sterk verbeterd	0 (0 %)

n = 4
# 4

Questionnaire 12.2017/1.2018- Response (continued)

6) Heeft u deze enquête al eerder ingevuld? (Bij Ja worden de vragen ove...

Ja	0 (0 %)
Nee	7 (100 %)

n = 7
\# 7

7) Heft u een instructie over het rijden met het brandstofcelvoertuig gehad?

Ja	4 (57.14 %)
Nee	3 (42.86 %)

n = 7
\# 7

8) Heeft u een instructie over het tanken van het voertuig gehad?

Ja	7 (100 %)
Nee	0 (0 %)

n = 7
\# 7

9) Heeft u waterstof getankt?

Ja	7 (100 %)
Nee	0 (0 %)

n = 7
\# 7

10) Ervaring als berijder met het tanken:
Locaties/dekkingsgraad tankstations

Zeer slecht	3 (42.86 %)
Slecht	3 (42.86 %)
Neutraal	0 (0 %)
Goed	0 (0 %)
Zeer Goed	1 (14.29 %)

n = 7
\# 7

11) Ervaring als berijder met het tanken:
2. Veiligheid (tanken onder hoge druk)

Zeer slecht	0 (0 %)
Slecht	0 (0 %)
Neutraal	1 (14.29 %)
Goed	4 (57.14 %)
Zeer Goed	2 (28.57 %)

n = 7
\# 7

Questionnaire 12.2017/1.2018- Response (continued)

12) Ervaring als berijder met het tanken:
3. Gebruiksgemak

Zeer slecht	0 (0 %)
Slecht	0 (0 %)
Neutraal	1 (14.29 %)
Goed	3 (42.86 %)
Zeer Goed	3 (42.86 %)

n = 7
# 7

13) Heeft u passagiers meegenomen?

Ja	4 (57.14 %)
Nee	3 (42.86 %)

n = 7
# 7

14) Aantal passagiers?

1	0 (0 %)
2	2 (50 %)
3	2 (50 %)

n = 4
# 4

15) Heeft u met open ramen gereden?

Ja	2 (28.57 %)
Nee	5 (71.43 %)

n = 7
# 7

16) Percentage met open raam gereden?

minder dan 20%	2 (100 %)
tussen 20 en 50%	0 (0 %)
tussen 50 en 80%	0 (0 %)
boven 80%	0 (0 %)

n = 2
# 2

17) Welke transmissiestanden heeft u gebruikt? (meerdere antwoorden mogelijk)

1. e-stand (economic)	5 (83.33 %)
2. d-stand (drive)	3 (50 %)
3. l-stand (low)	3 (50 %)

n = 6
# 11

18) Welke transmissiestand heeft uw voorkeur?

e-stand (economic)	4 (66.67 %)
d-stand (drive)	1 (16.67 %)
l-stand (low)	1 (16.67 %)

n = 6
# 6

19) Heeft u uw rijstijl bij het rijden in de brandstofcelauto aangepast in verg...

Ja	2 (28.57 %)
Nee	5 (71.43 %)

n = 7
# 7

20) Ik zal het gebruik van de brandstofcelauto aan collegae:

Ten zeerste aanraden	6 (85.71 %)
Niet aanraden maar ook niet afraden	1 (14.29 %)
Ten zeerste afraden	0 (0 %)

n = 7
# 7

21) Brandstofcelauto en milieu
De bijdrage aan een beter milieu (luchtvervuiling, CO2, NOx) van het rijden met de brandstofcelauto vind ik:

1. Zeer slecht	0 (0 %)
2. Slecht	0 (0 %)
3. Neutraal	0 (0 %)
4. Goed	0 (0 %)
5. Zeer Goed	7 (100 %)

n = 7
# 7

22) Mijn waardering voor de brandstofcelauto:
Gebruiksgemak

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	1 (14.29 %)
6.	0 (0 %)
7.	0 (0 %)
8.	3 (42.86 %)
9.	1 (14.29 %)
10. Hoog	2 (28.57 %)

n = 7
# 7

Questionnaire 12.2017/1.2018- Response (continued)

23) Mijn waardering voor de brandstofcelauto: Actieradius

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	1 (14.29 %)
6.	0 (0 %)
7.	3 (42.86 %)
8.	1 (14.29 %)
9.	0 (0 %)
10. Hoog	2 (28.57 %)

n = 7
# 7

24) Mijn waardering voor de brandstofcelauto: Acceleratie

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	1 (14.29 %)
7.	2 (28.57 %)
8.	1 (14.29 %)
9.	1 (14.29 %)
10. Hoog	2 (28.57 %)

n = 7
# 7

25) Mijn waardering voor de brandstofcelauto: Remmen

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	0 (0 %)
7.	1 (14.29 %)
8.	2 (28.57 %)
9.	2 (28.57 %)
10. Hoog	2 (28.57 %)

n = 7
# 7

26) Mijn waardering voor de brandstofcelauto: Wegligging/weggedrag/stabiliteit

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	1 (14.29 %)
7.	1 (14.29 %)
8.	2 (28.57 %)
9.	2 (28.57 %)
10. Hoog	1 (14.29 %)

n = 7
# 7

27) Mijn waardering voor de brandstofcelauto: Beschikbare bagageruimte

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	0 (0 %)
7.	1 (14.29 %)
8.	2 (28.57 %)
9.	2 (28.57 %)
10. Hoog	2 (28.57 %)

n = 7
# 7

28) Mijn waardering voor de brandstofcelauto: Totaalbeoordeling

1. Laag	0 (0 %)
2.	0 (0 %)
3.	0 (0 %)
4.	0 (0 %)
5.	0 (0 %)
6.	0 (0 %)
7.	1 (14.29 %)
8.	3 (42.86 %)
9.	2 (28.57 %)
10. Hoog	1 (14.29 %)

n = 7
# 7

Questionnaire 12.2017/1.2018- Response (continued)

29) Brandstofcelauto en veiligheid i.v.m. een benzine- diesel- of LPG-auto.
De veiligheid bij het rijden in een brandstofcelauto vind ik:

1. Lager	0 (0 %)
2. Gelijk	4 (57.14 %)
3. Beter	3 (42.86 %)

n = 7
# 7

30) Heeft u problemen of pech gehad met de auto?

Ja	1 (14.29 %)
Nee	6 (85.71 %)

n = 7
# 7

31Voor vragen over deze enquête mag contact met mij opgenomen worden.

Ja	6 (85.71 %)
Nee	1 (14.29 %)

n = 7
# 7

Legenda:
n = aantal respondenten dat de vraag heeft gezien
# = aantal ontvangen antwoorden

Appendix 10 Method - Energy Efficiency, equivalency

Background information on Conversion

Based on both previously presented equivalence calculations, this can give the distinct assumption that an ix35FCEV is very fuel efficient in comparison to diesel- or petrol equivalents. On the other hand, the hydrogen equivalent of a conventional ix35 (diesel of petrol) appears to be a vehicle with very low fuel economy. A misleading part of these calculation methods is that the amount of energy ($E_{REF.}$) to drive a defined trajectory (here: 100km) is assumed to be delivered by drivelines with identical efficiencies. Which is far from the truth. In Table 42, driveline efficiencies are given for petrol, diesel and (compressed) hydrogen, according to LNE (η_{LNE}) [44] and SAE (η_{SAE}) [45].

Driveline	η_{LNE}	η_{SAE}
Petrol	18,2%	14,1%
Diesel	25,5%	18,5%
(Compressed) Hydrogen	44,3%	46,6%

Table 42 Driveline Efficiency and Configuration

These driveline efficiencies should have been considered in the conversion. However, the given “constants” are far from constant. The driveline efficiency changes by:

- Use of the vehicle, i.e. momentary performance
- Environmental circumstances, like
    - Traffic
    - Weather
    - Road conditions
- The driver
- Etc.

Taking this into account requires a continues known and validated efficiency for all driveline configurations on the same trajectory, during the same circumstances. Since this is impossible the presented method is used, generating mutual comparison possibilities, not utilising any real-world value.

Basic information on calculating the Energy Efficiency equivalency

In both evaluations, the amount of energy used to cover a distance of a 100km, based on a given fuel efficiency (FCEVs) of fuel consumption (ICEs) is used. Using the lower calorific value and the hereunder given specific density:

- Hydrogen: $H_{0,H}$ = 130,655[MJ/kg] ρ_H = 0,0825 [kg/dm^3] [46]
- Diesel: $H_{0,D}$ = 43,0 [MJ/kg] ρ_D = 0,84 [kg/dm^3] [47]
- Petrol: $H_{0,P}$ =42,5 [MJ/kg] ρ_P = 0,74 [kg/dm^3] [47]

The ix35FCEV reference vehicle has a fuel efficiency of 75[km/kgH_2]. The amount of energy (E) used for driving 100km, is 174MJ (see equation 3).

- $$E_{REF.} = \frac{H_{0,(D)(P)}}{FE} * 100 \quad (8)$$

- *Equation 0-1 Energy use per 100km*

- Converting $E_{REF.}$, of the hydrogen vehicle to diesel or petrol equivalents, the appropriate H_0 values are applied for mass equivalents (see equation 4), of volume equivalents (see equation 5).

- $$\emptyset_{M(D)(P)} = E_{REF.} * \frac{H_{0,(D)(P)}}{H_{0,H}} \quad (9)$$

Equation 0-2 Mass equivalent energy use

- $$\emptyset_{\ell(D)(P)} = E_{REF.} * \frac{H_{0,(D)(P)}}{H_{0,H} * \rho_{(D)(P)}} \quad (10)$$

Equation 0-3 Volume equivalent energy use

In table 43, the fuel consumptions in diesel and petrol equivalents are given, based on the operational fuel efficiency of 75[km/kgH$_2$].

Converted to	Energy over 100km		Mass Petrol [kg/100km]	Volume Petrol [ℓ/100km]
- Petrol	**174,2**	MJ	**4,10**	**5,54**
- Diesel	**174,2**	MJ	**4,05**	**4,82**

Table 43 Conversion FE to Diesel of Petrol equivalents

In Table 44 the conversion of conventional fuels, diesel and petrol, to H2-equivalents is shown, based on average fuel consumption according to “Autoweek” [38].

Fuel	**Volume**	**Hydrogen**	
	[ℓ/100km]	**[kgH$_2$/100km]**	**[km/kgH$_2$]**
- Diesel	6,78	**1,87**	**53**
- Petrol	9,07	**2,18**	**46**

Table 44 Conversion Diesel and Petrol to H_2-equivalents

Appendix 11 Helmond - Vehicle Refuelling ; HRS-data

VEHICLE REFUELLING DATA (HYDROGEN REFUELLING STATION) HYLIGHTS						
Date, time	Vehicle ID	Refuelling station ID	Refuelling duration [min]	CGH_2 35 MPa	CGH_2 70 MPa	LH_2
03-10-2014, at 11:47	9-XKB-49	Helmond - Waterstofnet	4:07		3,90	
08-10-2014, at 21:23	9-XKB-49	Helmond - Waterstofnet	4:47		5,06	
04-11-2014, at 20:12	5-XLH-61	Helmond - Waterstofnet	4:47		3,63	
28-11-2014, at 18:22	5-XLH-61	Helmond - Waterstofnet	3:49		4,11	
08-12-2014, at 17:47	5-XLH-61	Helmond - Waterstofnet	3:57		4,30	
17-12-2014, at 11:48	5-XLH-61	Helmond - Waterstofnet	3:04		2,83	
22-12-2014, at 22:05	5-XLH-61	Helmond - Waterstofnet	4:02		4,53	
14-01-2015, at 11:56	5-XLH-61	Helmond - Waterstofnet	3:34		3,74	
23-01-2015, at 13:44	5-XLH-61	Helmond - Waterstofnet	2:40		1,19	
02-02-2015, at 15:04	5-XLH-61	Helmond - Waterstofnet	6:41		5,16	
06-02-2015, at 10:53	5-XLH-61	Helmond - Waterstofnet	4:02		4,81	
09-02-2015, at 17:08	5-XLH-61	Helmond - Waterstofnet	3:44		4,77	
23-02-2015, at 10:19	5-XLH-61	Helmond - Waterstofnet	3:37		4,85	
04-03-2015, at 14:16	5-XLH-61	Helmond - Waterstofnet	3:22		4,14	
17-04-2015, at 13:20	4-ZTB-51	Helmond - Waterstofnet	3:12		3,30	
23-04-2015, at 10:22	5-XLH-61	Helmond - Waterstofnet	2:58		3,02	
29-04-2015, at 21:39	5-XLH-61	Helmond - Waterstofnet	3:14		3,72	
30-04-2015, at 13:38	5-XLH-61	Helmond - Waterstofnet	3:03		3,21	
30-04-2015, at 23:36	5-XLH-61	Helmond - Waterstofnet	3:26		4,23	
01-05-2015, at 10:04	4-ZTB-51	Helmond - Waterstofnet	3:24		3,76	
13-05-2015, at 12:38	5-XLH-61	Helmond - Waterstofnet	1:00		0,29	
21-05-2015, at 13:57	5-XLH-61	Helmond - Waterstofnet	2:54		2,90	
27-05-2015, at 06:58	5-XLH-61	Helmond - Waterstofnet	1:50		0,15	
27-05-2015, at 07:04	5-XLH-61	Helmond - Waterstofnet	2:11		2,32	
16-06-2015, at 18:47	5-XLH-61	Helmond - Waterstofnet	2:25		2,69	
22-06-2015, at 07:25	5-XLH-61	Helmond - Waterstofnet	2:56		3,92	
23-06-2015, at 15:30	5-XLH-61	Helmond - Waterstofnet	2:19		1,79	
26-06-2015, at 10:04	4-ZTB-51	Helmond - Waterstofnet	3:05		3,96	
08-07-2015, at 17:44	9-XKB-49	Helmond - Waterstofnet	3:15		4,39	
09-07-2015, at 14:02	4-ZTB-51	Helmond - Waterstofnet	3:49		4,74	
09-07-2015, at 14:55	9-XKB-49	Helmond - Waterstofnet	2:56		3,24	
14-07-2015, at 15:28	5-XLH-61	Helmond - Waterstofnet	2:27		2,34	
14-07-2015, at 16:00	4-ZTB-51	Helmond - Waterstofnet	2:33		2,89	
15-07-2015, at 15:41	5-XLH-61	Helmond - Waterstofnet	2:40		2,22	
16-07-2015, at 17:08	5-XLH-61	Helmond - Waterstofnet	3:14		2,57	
22-07-2015, at 08:03	5-XLH-61	Helmond - Waterstofnet	2:40		2,59	

10-08-2015, at 15:56	9-XKB-49	Helmond - Waterstofnet	3:13		4,22	
20-08-2015, at 08:30	5-XLH-61	Helmond - Waterstofnet	2:40		2,54	
24-08-2015, at 15:00	5-XLH-61	Helmond - Waterstofnet	1:46		1,14	
24-08-2015, at 18:12	5-XLH-61	Helmond - Waterstofnet	2:56		3,44	
27-08-2015, at 11:35	5-XLH-61	Helmond - Waterstofnet	2:38		2,01	
28-08-2015, at 10:22	4-ZTB-51	Helmond - Waterstofnet	3:17		4,43	
02-09-2015, at 13:23	5-XLH-61	Helmond - Waterstofnet	2:28		2,13	
02-09-2015, at 19:39	5-XLH-61	Helmond - Waterstofnet	2:08		1,31	
04-09-2015, at 06:08	5-XLH-61	Helmond - Waterstofnet	2:48		3,34	
04-09-2015, at 17:13	5-XLH-61	Helmond - Waterstofnet	2:55		3,62	
14-09-2015, at 15:10	4-ZTB-51	Helmond - Waterstofnet	3:08		3,78	
18-09-2015, at 16:08	5-XLH-61	Helmond - Waterstofnet	2:26		2,44	
24-09-2015, at 16:28	5-XLH-61	Helmond - Waterstofnet	3:02		3,89	
09-10-2015, at 13:18	5-XLH-61	Helmond - Waterstofnet	1:28		0,74	
10-10-2015, at 19:09	4-ZTB-51	Helmond - Waterstofnet	3:20		4,66	
14-10-2015, at 16:46	5-XLH-61	Helmond - Waterstofnet	2:57		3,88	
16-10-2015, at 14:44	4-ZTB-51	Helmond - Waterstofnet	2:34		2,71	
23-10-2015, at 16:41	5-XLH-61	Helmond - Waterstofnet	1:52		1,39	
27-10-2015, at 16:52	5-XLH-61	Helmond - Waterstofnet	2:28		2,32	
05-11-2015, at 17:48	5-XLH-61	Helmond - Waterstofnet	3:11		4,22	
11-11-2015, at 11:20	5-XLH-61	Helmond - Waterstofnet	0:35		0,01	
11-11-2015, at 11:21	5-XLH-61	Helmond - Waterstofnet	1:57		1,54	
24-11-2015, at 09:45	5-XLH-61	Helmond - Waterstofnet	1:53		1,51	
25-11-2015, at 16:08	5-XLH-61	Helmond - Waterstofnet	2:27		2,56	
30-11-2015, at 16:05	4-ZTB-51	Helmond - Waterstofnet	3:30		4,63	
30-11-2015, at 16:38	4-ZTB-51	Helmond - Waterstofnet	1:48		0,42	
02-12-2015, at 08:41	4-ZTB-51	Helmond - Waterstofnet	4:15		4,01	
02-12-2015, at 16:18	5-XLH-61	Helmond - Waterstofnet	2:42		2,55	
03-12-2015, at 13:48	5-XLH-61	Helmond - Waterstofnet	3:16		3,42	
04-12-2015, at 16:32	5-XLH-61	Helmond - Waterstofnet	2:47		2,72	
09-12-2015, at 16:08	5-XLH-61	Helmond - Waterstofnet	4:02		4,42	
10-12-2015, at 11:04	5-XLH-61	Helmond - Waterstofnet	1:57		0,88	
17-12-2015, at 19:28	5-XLH-61	Helmond - Waterstofnet	2:18		1,61	
18-12-2015, at 12:03	9-XKB-49	Helmond - Waterstofnet	2:39		2,01	
18-12-2015, at 14:36	5-XLH-61	Helmond - Waterstofnet	1:22		0,46	
20-12-2015, at 18:29	9-XKB-49	Helmond - Waterstofnet	4:17		4,90	
24-12-2015, at 15:24	5-XLH-61	Helmond - Waterstofnet	2:59		0,04	
28-12-2015, at 14:49	5-XLH-61	Helmond - Waterstofnet	3:15		3,38	
31-12-2015, at 16:24	5-XLH-61	Helmond - Waterstofnet	3:08		3,31	
02-01-2016, at 21:17	5-XLH-61	Helmond - Waterstofnet	3:54		4,23	
06-01-2016, at 11:16	4-ZTB-51	Helmond - Waterstofnet	4:26		4,89	
07-01-2016, at 15:36	5-XLH-61	Helmond - Waterstofnet	2:53		2,53	
12-01-2016, at 07:36	5-XLH-61	Helmond - Waterstofnet	2:51		2,82	
12-01-2016, at 17:02	5-XLH-61	Helmond - Waterstofnet	3:00		3,04	

14-01-2016, at 15:15	5-XLH-61	Helmond - Waterstofnet	3:50		4,06	
19-01-2016, at 18:15	5-XLH-61	Helmond - Waterstofnet	3:50		4,45	
21-01-2016, at 17:23	5-XLH-61	Helmond - Waterstofnet	3:13		3,46	
25-01-2016, at 16:04	5-XLH-61	Helmond - Waterstofnet	1:00		0,12	
26-01-2016, at 16:13	5-XLH-61	Helmond - Waterstofnet	2:47		2,70	
27-01-2016, at 16:03	5-XLH-61	Helmond - Waterstofnet	3:06		3,13	
27-01-2016, at 19:08	5-XLH-61	Helmond - Waterstofnet	3:26		2,78	
28-01-2016, at 15:57	4-ZTB-51	Helmond - Waterstofnet	4:23		4,76	
28-01-2016, at 19:18	5-XLH-61	Helmond - Waterstofnet	3:37		3,90	
01-02-2016, at 13:13	5-XLH-61	Helmond - Waterstofnet	3:15		2,13	
01-02-2016, at 14:47	5-XLH-61	Helmond - Waterstofnet	2:54		2,93	
02-02-2016, at 12:27	5-XLH-61	Helmond - Waterstofnet	2:49		2,45	
04-02-2016, at 13:41	5-XLH-61	Helmond - Waterstofnet	4:04		0,20	
04-02-2016, at 13:44	5-XLH-61	Helmond - Waterstofnet	2:06		1,35	
10-02-2016, at 08:56	5-XLH-61	Helmond - Waterstofnet	2:43		2,71	
10-02-2016, at 14:32	5-XLH-61	Helmond - Waterstofnet	2:47		2,74	
11-02-2016, at 12:02	4-ZTB-51	Helmond - Waterstofnet	3:51		3,90	
22-02-2016, at 08:10	5-XLH-61	Helmond - Waterstofnet	2:40		2,07	
22-02-2016, at 18:39	5-XLH-61	Helmond - Waterstofnet	4:03		4,59	
23-02-2016, at 13:16	4-ZTB-51	Helmond - Waterstofnet	4:09		4,45	
24-02-2016, at 09:35	5-XLH-61	Helmond - Waterstofnet	0:44		0,04	
24-02-2016, at 09:37	5-XLH-61	Helmond - Waterstofnet	1:00		0,12	
24-02-2016, at 12:07	5-XLH-61	Helmond - Waterstofnet	3:55		3,86	
25-02-2016, at 12:40	5-XLH-61	Helmond - Waterstofnet	2:27		1,80	
26-02-2016, at 14:40	5-XLH-61	Helmond - Waterstofnet	3:43		3,90	
02-03-2016, at 13:01	5-XLH-61	Helmond - Waterstofnet	3:07		2,72	
03-03-2016, at 11:44	5-XLH-61	Helmond - Waterstofnet	1:55		1,11	
09-03-2016, at 17:04	5-XLH-61	Helmond - Waterstofnet	3:26		3,73	
10-03-2016, at 11:01	4-ZTB-51	Helmond - Waterstofnet	3:47		3,63	
10-03-2016, at 11:10	4-ZTB-51	Helmond - Waterstofnet	1:25		0,13	
17-03-2016, at 15:03	5-XLH-61	Helmond - Waterstofnet	3:26		3,73	
18-03-2016, at 15:28	5-XLH-61	Helmond - Waterstofnet	2:46		2,30	
24-03-2016, at 11:52	4-ZTB-51	Helmond - Waterstofnet	4:23		4,70	
24-03-2016, at 12:13	4-ZTB-51	Helmond - Waterstofnet	1:33		0,31	
31-03-2016, at 14:13	5-XLH-61	Helmond - Waterstofnet	3:13		3,39	
04-04-2016, at 16:21	5-XLH-61	Helmond - Waterstofnet	3:21		3,52	
06-04-2016, at 16:59	5-XLH-61	Helmond - Waterstofnet	2:51		2,35	
07-04-2016, at 09:40	4-ZTB-51	Helmond - Waterstofnet	4:12		4,34	
07-04-2016, at 10:02	4-ZTB-51	Helmond - Waterstofnet	1:37		0,23	
08-04-2016, at 16:14	5-XLH-61	Helmond - Waterstofnet	2:42		2,56	
18-04-2016, at 16:36	5-XLH-61	Helmond - Waterstofnet	0:22		0,16	
18-04-2016, at 16:38	5-XLH-61	Helmond - Waterstofnet	0:37		0,14	
20-04-2016, at 10:01	4-ZTB-51	Helmond - Waterstofnet	4:04		4,12	
20-04-2016, at 11:43	5-XLH-61	Helmond - Waterstofnet	3:21		3,55	

21-04-2016, at 12:54	5-XLH-61	Helmond - Waterstofnet	2:18		2,67	
21-04-2016, at 16:41	5-XLH-61	Helmond - Waterstofnet	4:04		4,45	
10-05-2016, at 06:19	5-XLH-61	Helmond - Waterstofnet	3:15		3,28	
11-05-2016, at 12:06	5-XLH-61	Helmond - Waterstofnet	2:56		2,74	
20-05-2016, at 10:54	4-ZTB-51	Helmond - Waterstofnet	3:58		4,02	
10-06-2016, at 10:18	5-XLH-61	Helmond - Waterstofnet	1:44		0,89	
10-06-2016, at 15:50	5-XLH-61	Helmond - Waterstofnet	3:22		2,77	
14-06-2016, at 15:48	5-XLH-61	Helmond - Waterstofnet	2:55		2,32	
18-06-2016, at 03:07	5-XLH-61	Helmond - Waterstofnet	3:18		2,77	
21-06-2016, at 13:12	5-XLH-61	Helmond - Waterstofnet	3:38		1,77	
23-06-2016, at 10:09	5-XLH-61	Helmond - Waterstofnet	4:09		3,81	
23-06-2016, at 11:05	5-XLH-61	Helmond - Waterstofnet	9:53		3,01	
27-06-2016, at 12:22	5-XLH-61	Helmond - Waterstofnet	1:58		1,16	
29-06-2016, at 12:54	5-XLH-61	Helmond - Waterstofnet	3:39		3,43	
30-06-2016, at 14:32	5-XLH-61	Helmond - Waterstofnet	2:11		1,50	
04-07-2016, at 17:22	5-XLH-61	Helmond - Waterstofnet	2:54		2,41	
07-07-2016, at 17:17	5-XLH-61	Helmond - Waterstofnet	2:57		2,22	
11-07-2016, at 16:43	5-XLH-61	Helmond - Waterstofnet	4:26		5,12	
12-07-2016, at 16:00	5-XLH-61	Helmond - Waterstofnet	2:40		1,86	
04-08-2016, at 11:53	5-XLH-61	Helmond - Waterstofnet	2:53		2,13	
04-08-2016, at 16:28	5-XLH-61	Helmond - Waterstofnet	3:01		2,49	
16-08-2016, at 14:22	5-XLH-61	Helmond - Waterstofnet	0:45		0,14	
17-08-2016, at 14:30	5-XLH-61	Helmond - Waterstofnet	3:12		3,18	
18-08-2016, at 16:20	5-XLH-61	Helmond - Waterstofnet	1:54		1,25	
23-08-2016, at 14:56	5-XLH-61	Helmond - Waterstofnet	3:41		3,17	
29-08-2016, at 14:50	5-XLH-61	Helmond - Waterstofnet	4:22		3,11	
29-08-2016, at 18:05	5-XLH-61	Helmond - Waterstofnet	4:50		4,50	
29-08-2016, at 18:05	5-XLH-61	Helmond - Waterstofnet	4:50		4,50	
31-08-2016, at 07:53	5-XLH-61	Helmond - Waterstofnet	4:24		3,18	
31-08-2016, at 16:36	5-XLH-61	Helmond - Waterstofnet	3:43		2,53	
09-09-2016, at 13:08	5-XLH-61	Helmond - Waterstofnet	1:47		0,93	
05-10-2016, at 16:56	5-XLH-61	Helmond - Waterstofnet	1:31		0,01	
05-10-2016, at 16:56	5-XLH-61	Helmond - Waterstofnet	1:31		0,01	
10-10-2016, at 14:17	5-XLH-61	Helmond - Waterstofnet	1:53		1,04	
12-10-2016, at 07:20	5-XLH-61	Helmond - Waterstofnet	4:04		3,11	
27-10-2016, at 11:05	4-ZTB-51	Helmond - Waterstofnet	3:50		4,19	
27-10-2016, at 18:00	4-ZTB-51	Helmond - Waterstofnet	3:46		3,73	
09-11-2016, at 12:09	5-XLH-61	Helmond - Waterstofnet	2:51		2,85	
09-11-2016, at 15:07	5-XLH-61	Helmond - Waterstofnet	1:27		0,91	
22-11-2016, at 13:36	5-XLH-61	Helmond - Waterstofnet	2:54		3,13	
12-12-2016, at 21:33	5-XLH-61	Helmond - Waterstofnet	3:38		3,93	
13-12-2016, at 15:36	5-XLH-61	Helmond - Waterstofnet	2:53		2,44	
16-12-2016, at 07:17	5-XLH-61	Helmond - Waterstofnet	2:47		2,82	
16-12-2016, at 13:34	5-XLH-61	Helmond - Waterstofnet	3:39		2,84	

16-12-2016, at 22:26	5-XLH-61	Helmond - Waterstofnet	3:00		2,55	
23-12-2016, at 09:09	5-XLH-61	Helmond - Waterstofnet	3:56		4,28	
23-12-2016, at 11:06	4-ZTB-51	Helmond - Waterstofnet	4:26		4,77	
02-01-2017, at 17:38	5-XLH-61	Helmond - Waterstofnet	3:03		3,30	
04-01-2017, at 14:59	5-XLH-61	Helmond - Waterstofnet	2:41		2,54	
09-01-2017, at 15:19	5-XLH-61	Helmond - Waterstofnet	3:54		3,52	
12-01-2017, at 07:21	5-XLH-61	Helmond - Waterstofnet	2:56		2,85	
26-01-2017, at 11:37	4-ZTB-51	Helmond - Waterstofnet	3:55		4,08	
10-02-2017, at 17:17	5-XLH-61	Helmond - Waterstofnet	3:11		3,52	
15-02-2017, at 16:54	5-XLH-61	Helmond - Waterstofnet	3:46		4,11	
10-03-2017, at 09:57	5-XLH-61	Helmond - Waterstofnet	4:26		4,23	
13-03-2017, at 12:21	5-XLH-61	Helmond - Waterstofnet	4:09		3,14	
14-03-2017, at 11:49	5-XLH-61	Helmond - Waterstofnet	3:54		2,93	
16-03-2017, at 17:48	5-XLH-61	Helmond - Waterstofnet	3:58		2,84	
26-03-2017, at 13:30	5-XLH-61	Helmond - Waterstofnet	3:12		2,85	
26-03-2017, at 14:32	9-XKB-49	Helmond - Waterstofnet	3:31		3,93	
30-03-2017, at 19:37	5-XLH-61	Helmond - Waterstofnet	4:07		4,43	
04-04-2017, at 05:45	5-XLH-61	Helmond - Waterstofnet	3:28		3,29	
05-04-2017, at 06:05	5-XLH-61	Helmond - Waterstofnet	4:16		3,96	
05-04-2017, at 16:49	5-XLH-61	Helmond - Waterstofnet	3:53		3,58	
11-04-2017, at 15:41	5-XLH-61	Helmond - Waterstofnet	4:07		4,84	
14-04-2017, at 16:21	5-XLH-61	Helmond - Waterstofnet	4:10		4,83	
19-04-2017, at 14:56	5-XLH-61	Helmond - Waterstofnet	3:42		3,69	
21-04-2017, at 17:01	5-XLH-61	Helmond - Waterstofnet	3:42		4,09	
01-05-2017, at 09:47	5-XLH-61	Helmond - Waterstofnet	0:59		0,15	
02-05-2017, at 14:08	5-XLH-61	Helmond - Waterstofnet	3:01		2,97	
10-05-2017, at 10:20	5-XLH-61	Helmond - Waterstofnet	3:01		2,48	
11-05-2017, at 13:43	5-XLH-61	Helmond - Waterstofnet	3:42		2,97	
19-05-2017, at 11:37	5-XLH-61	Helmond - Waterstofnet	3:29		3,26	
23-05-2017, at 09:22	5-XLH-61	Helmond - Waterstofnet	2:49		2,24	
13-06-2017, at 09:05	5-XLH-61	Helmond - Waterstofnet	3:48		4,45	
13-06-2017, at 14:59	5-XLH-61	Helmond - Waterstofnet	3:45		3,59	
29-06-2017, at 18:08	5-XLH-61	Helmond - Waterstofnet	4:53		1,98	
30-06-2017, at 19:12	5-XLH-61	Helmond - Waterstofnet	3:08		2,65	
07-07-2017, at 09:10	5-XLH-61	Helmond - Waterstofnet	4:27		4,58	
11-07-2017, at 14:30	5-XLH-61	Helmond - Waterstofnet	3:16		3,42	
18-07-2017, at 05:25	5-XLH-61	Helmond - Waterstofnet	3:44		3,50	
19-07-2017, at 06:48	5-XLH-61	Helmond - Waterstofnet	3:45		3,62	
09-08-2017, at 08:41	5-XLH-61	Helmond - Waterstofnet	2:50		2,32	
06-09-2017, at 18:24	4-ZTB-51	Helmond - Waterstofnet	4:11		3,57	
08-09-2017, at 13:41	5-XLH-61	Helmond - Waterstofnet	3:42		4,12	
08-09-2017, at 18:04	4-ZTB-51	Helmond - Waterstofnet	3:57		3,82	
20-09-2017, at 08:00	5-XLH-61	Helmond - Waterstofnet	2:23		2,20	

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Appendix 12 Rhoon - Vehicle Refuelling ; HRS-data

VEHICLE REFUELLING DATA (HYDROGEN REFUELLING STATION) HYLIGHTS

Date, time	Vehicle ID	Refueling station ID	Refueling duration [min]	CGH_2 35 MPa	CGH_2 70 MPa	LH_2
07-01-2016, at 12:27	9-XKB-49	Rhoon - AirLiquide	-		2,79	
13-01-2016, at 08:02	9-XKB-49	Rhoon - AirLiquide	-		3,07	
17-01-2016, at 16:28	5-XLH-61	Rhoon - AirLiquide	-		1,41	
18-01-2016, at 09:36	5-XLH-61	Rhoon - AirLiquide	-		3,14	
18-01-2016, at 18:26	5-XLH-61	Rhoon - AirLiquide	-		3,23	
21-01-2016, at 11:00	5-XLH-61	Rhoon - AirLiquide	-		1,77	
22-01-2016, at 15:14	5-XLH-61	Rhoon - AirLiquide	-		2,49	
29-01-2016, at 14:35	5-XLH-61	Rhoon - AirLiquide	-		3,86	
04-02-2016, at 09:11	5-XLH-61	Rhoon - AirLiquide	-		3,43	
04-02-2016, at 09:17	5-XLH-61	Rhoon - AirLiquide	-		2,75	
06-02-2016, at 10:47	5-XLH-61	Rhoon - AirLiquide	-		1,33	
08-02-2016, at 05:56	5-XLH-61	Rhoon - AirLiquide	-		3,90	
10-02-2016, at 13:25	5-XLH-61	Rhoon - AirLiquide	-		2,46	
12-02-2016, at 15:25	5-XLH-61	Rhoon - AirLiquide	-		3,88	
17-02-2016, at 15:33	4-ZTB-51	Rhoon - AirLiquide	-		3,68	
20-02-2016, at 10:39	5-XLH-61	Rhoon - AirLiquide	-		4,32	
23-02-2016, at 09:53	5-XLH-61	Rhoon - AirLiquide	-		3,93	
26-02-2016, at 06:05	5-XLH-61	Rhoon - AirLiquide	-		2,65	
09-03-2016, at 16:33	5-XLH-61	Rhoon - AirLiquide	-		3,58	
12-03-2016, at 13:09	4-ZTB-51	Rhoon - AirLiquide	-		3,58	
25-03-2016, at 15:25	5-XLH-61	Rhoon - AirLiquide	-		4,04	
29-03-2016, at 16:25	5-XLH-61	Rhoon - AirLiquide	-		0,82	
31-03-2016, at 14:14	5-XLH-61	Rhoon - AirLiquide	-		3,53	
08-04-2016, at 15:36	5-XLH-61	Rhoon - AirLiquide	-		4,47	
11-04-2016, at 07:53	5-XLH-61	Rhoon - AirLiquide	-		2,77	
12-04-2016, at 16:01	5-XLH-61	Rhoon - AirLiquide	-		1,86	
14-04-2016, at 19:40	5-XLH-61	Rhoon - AirLiquide	-		3,84	
14-04-2016, at 19:47	4-ZTB-51	Rhoon - AirLiquide	-		2,88	
18-04-2016, at 08:04	9-XKB-49	Rhoon - AirLiquide	-		4,93	
20-04-2016, at 15:40	4-ZTB-51	Rhoon - AirLiquide	-		4,06	
22-04-2016, at 08:22	9-XKB-49	Rhoon - AirLiquide	-		3,75	
13-05-2016, at 14:50	5-XLH-61	Rhoon - AirLiquide	-		3,42	
13-05-2016, at 14:55	4-ZTB-51	Rhoon - AirLiquide	-		0,07	
17-05-2016, at 12:34	5-XLH-61	Rhoon - AirLiquide	-		2,68	
17-05-2016, at 12:37	5-XLH-61	Rhoon - AirLiquide	-		0,00	
17-05-2016, at 13:19	5-XLH-61	Rhoon - AirLiquide	-		2,08	
24-05-2016, at 13:26	9-XKB-49	Rhoon - AirLiquide	-		3,66	
25-05-2016, at 11:58	5-XLH-61	Rhoon - AirLiquide	-		3,20	
31-05-2016, at 16:43	5-XLH-61	Rhoon - AirLiquide	-		3,73	
02-06-2016, at 12:28	5-XLH-61	Rhoon - AirLiquide	-		4,40	
02-06-2016, at 14:29	5-XLH-61	Rhoon - AirLiquide	-		2,58	

09-06-2016, at 11:09	4-ZTB-51	Rhoon - AirLiquide	-		0,04	
09-06-2016, at 11:11	5-XLH-61	Rhoon - AirLiquide	-		0,00	
09-06-2016, at 15:55	5-XLH-61	Rhoon - AirLiquide	-		2,97	
24-06-2016, at 13:10	5-XLH-61	Rhoon - AirLiquide	-		3,67	
07-07-2016, at 16:44	5-XLH-61	Rhoon - AirLiquide	-		0,00	
07-07-2016, at 16:48	4-ZTB-51	Rhoon - AirLiquide	-		0,00	
12-07-2016, at 13:50	5-XLH-61	Rhoon - AirLiquide	-		0,00	
12-07-2016, at 14:31	5-XLH-61	Rhoon - AirLiquide	-		3,17	
14-07-2016, at 08:56	5-XLH-61	Rhoon - AirLiquide	-		4,40	
21-07-2016, at 11:51	4-ZTB-51	Rhoon - AirLiquide	-		2,34	
03-08-2016, at 15:58	5-XLH-61	Rhoon - AirLiquide	-		4,65	
10-08-2016, at 17:08	4-ZTB-51	Rhoon - AirLiquide	-		4,45	
23-08-2016, at 08:48	5-XLH-61	Rhoon - AirLiquide	-		2,69	
12-09-2016, at 15:00	5-XLH-61	Rhoon - AirLiquide	-		2,65	
20-09-2016, at 07:19	5-XLH-61	Rhoon - AirLiquide	-		3,05	
26-09-2016, at 07:54	5-XLH-61	Rhoon - AirLiquide	-		3,65	
27-09-2016, at 07:53	5-XLH-61	Rhoon - AirLiquide	-		3,20	
28-09-2016, at 16:32	5-XLH-61	Rhoon - AirLiquide	-		0,00	
28-09-2016, at 16:41	5-XLH-61	Rhoon - AirLiquide	-		3,43	
05-10-2016, at 15:58	4-ZTB-51	Rhoon - AirLiquide	-		3,47	
08-10-2016, at 09:45	4-ZTB-51	Rhoon - AirLiquide	-		4,34	
08-10-2016, at 13:10	4-ZTB-51	Rhoon - AirLiquide	-		2,84	
21-10-2016, at 21:52	5-XLH-61	Rhoon - AirLiquide	-		0,00	
21-10-2016, at 21:59	5-XLH-61	Rhoon - AirLiquide	-		3,81	
28-10-2016, at 06:06	5-XLH-61	Rhoon - AirLiquide	-		3,57	
02-11-2016, at 08:47	5-XLH-61	Rhoon - AirLiquide	-		0,00	
03-11-2016, at 08:04	5-XLH-61	Rhoon - AirLiquide	-		2,77	
04-11-2016, at 15:19	5-XLH-61	Rhoon - AirLiquide	-		3,54	
10-11-2016, at 13:49	9-XKB-49	Rhoon - AirLiquide	-		4,39	
11-11-2016, at 08:36	5-XLH-61	Rhoon - AirLiquide	-		2,97	
14-11-2016, at 07:56	9-XKB-49	Rhoon - AirLiquide	-		3,62	
18-11-2016, at 08:20	5-XLH-61	Rhoon - AirLiquide	-		3,93	
21-11-2016, at 16:07	5-XLH-61	Rhoon - AirLiquide	-		2,81	
23-11-2016, at 15:59	5-XLH-61	Rhoon - AirLiquide	-		0,00	
01-12-2016, at 13:53	5-XLH-61	Rhoon - AirLiquide	-		4,53	
07-12-2016, at 15:12	4-ZTB-51	Rhoon - AirLiquide	-		3,71	
09-12-2016, at 11:38	5-XLH-61	Rhoon - AirLiquide	-		3,69	
23-12-2016, at 05:53	5-XLH-61	Rhoon - AirLiquide	-		4,80	
23-12-2016, at 05:53	5-XLH-61	Rhoon - AirLiquide	-		4,80	
11-01-2017, at 14:21	5-XLH-61	Rhoon - AirLiquide	-		0,00	
11-01-2017, at 14:31	5-XLH-61	Rhoon - AirLiquide	-		2,76	
13-01-2017, at 15:43	5-XLH-61	Rhoon - AirLiquide	-		2,84	
17-01-2017, at 07:35	5-XLH-61	Rhoon - AirLiquide	-		1,83	
23-01-2017, at 11:00	5-XLH-61	Rhoon - AirLiquide	-		1,63	
25-01-2017, at 13:16	5-XLH-61	Rhoon - AirLiquide	-		2,86	
01-02-2017, at 15:25	5-XLH-61	Rhoon - AirLiquide	-		3,12	
06-03-2017, at 11:03	4-ZTB-51	Rhoon - AirLiquide	-		1,97	
11-03-2017, at 14:48	5-XLH-61	Rhoon - AirLiquide	-		3,76	

14-03-2017, at 16:36	5-XLH-61	Rhoon - AirLiquide	-		5,29	
23-03-2017, at 12:54	5-XLH-61	Rhoon - AirLiquide	-		0,00	
23-03-2017, at 13:00	5-XLH-61	Rhoon - AirLiquide	-		3,38	
01-04-2017, at 15:36	5-XLH-61	Rhoon - AirLiquide	-		4,37	
18-04-2017, at 13:21	5-XLH-61	Rhoon - AirLiquide	-		4,28	
09-05-2017, at 11:19	5-XLH-61	Rhoon - AirLiquide	-		3,43	
31-05-2017, at 13:23	5-XLH-61	Rhoon - AirLiquide	-		4,26	
05-08-2017, at 05:31	4-ZTB-51	Rhoon - AirLiquide	-		0,56	
05-08-2017, at 13:14	5-XLH-61	Rhoon - AirLiquide	-		0,00	
05-08-2017, at 13:21	5-XLH-61	Rhoon - AirLiquide	-		4,76	
07-08-2017, at 13:16	4-ZTB-51	Rhoon - AirLiquide	-		4,07	
11-08-2017, at 12:16	5-XLH-61	Rhoon - AirLiquide	-		4,67	
25-09-2017, at 11:04	5-XLH-61	Rhoon - AirLiquide	-		4,12	
08-10-2017, at 13:10	5-XLH-61	Rhoon - AirLiquide	-		1,98	
12-10-2017, at 11:17	5-XLH-61	Rhoon - AirLiquide	-		4,58	
18-10-2017, at 12:50	5-XLH-61	Rhoon - AirLiquide	-		1,82	
19-11-2017, at 19:38	5-XLH-61	Rhoon - AirLiquide	-		0,11	
19-11-2017, at 19:47	5-XLH-61	Rhoon - AirLiquide	-		4,55	

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Appendix 13 Comparison Real Life Data vs Simulation Results

#	Trip No	Parameter	Life data	Simulation			
				$L_{PARTIAL}$	δ: $L_{PARTIAL}$	L_{GROSS}	δ: L_{GROSS}
1	14th Dec 2015, 13:49:49 to 14:19:01 (38.19km)	E_C [Wh/km]	**241.5**	**248.3**	-2,8%	**261.8**	-8,4%
		FE [km/kgH_2]	**74.8**	**73.7**	1,5%	**70.0**	6,4%
2	14th Dec 2015, 14:25:34 to 14:57:22 (30.31km)	E_C [Wh/km]	**217.5**	**246.6**	-13,4%	**264.0**	-21,4%
		FE [km/kgH_2]	**81.0**	**73.5**	9,3%	**68.5**	15,4%
3	14th Dec 2015, 16:55:58 to 17:57:16 (72.7km)	E_C [Wh/km]	**234.5**	**248.0**	-5,8%	**266.8**	-13,8%
		FE [km/kgH_2]	**76.1**	**73.6**	3,3%	**68.7**	9,7%
4	18th Dec 2015, 10:07:05 to 10:37:55 (44.5km)	E_C [Wh/km]	**220.0**	**239.0**	-8,6%	**255.7**	-16,2%
		FE [km/kgH_2]	**82.2**	**77.8**	5,4%	**72.6**	11,7%
5	18th Dec 2015, 10:56:26 to 11:59:25 (84km)	E_C [Wh/km]	**247.5**	**250.0**	-1,0%	**264.5**	-6,9%
		FE [km/kgH_2]	**72.7**	**74.13**	-2,0%	**69.8**	4,0%
6	18th Dec 2015, 17:52:09 to 18:26:35 (29.5km)	E_C [Wh/km]	**200.0**	**224**	-12,0%	**244**	-22,0%
		FE [km/kgH_2]	**85.3**	**80.0**	6,2%	**73.4**	14,0%
7	16th Feb 2016, 06:46:18 to 07:20:03 (43.55km)	E_C [Wh/km]	**224.3**	**232.0**	-3,4%	**250.1**	-11,5%
		FE [km/kgH_2]	**79.6**	**79.4**	0,3%	**73.6**	7,5%
8	16th Feb 2016, 14:35:02 to 15:07:04 (44.6km)	E_C [Wh/km]	**239.8**	**250.0**	-4,3%	**270**	-12,6%
		FE [km/kgH_2]	**74.9**	**74.0**	1,2%	**68.5**	8,5%
9	17th Feb 2016, 04:53:36 to 05:29:18 (43.84km)	E_C [Wh/km]	**283.9**	**252**	11,2%	**271.6**	4,3%
		FE [km/kgH_2]	**62.8**	**72.0**	-14,6%	**66.53**	-5,9%
10	17th Feb 2016, 14:34:28 to 15:10:26 (44.59km)	E_C [Wh/km]	**246.4**	**251.4**	-2,0%	**270.4**	-9,7%
		FE [km/kgH_2]	**72.9**	**72.9**	0,0%	**66.5**	8,8%
11	17th Sept 2016, 09:22:43 to 09:47:03 (10.84km)	E_C [Wh/km]	**202.8**	**250.7**	-23,6%	**278.6**	-37,4%
		FE [km/kgH_2]	**76.0**	**66.7**	12,2%	**60.5**	20,4%
12	19th Sept 2016, 13:51:25 to 14:30:25 (44.74km)	E_C [Wh/km]	**196.4**	**241**	-22,7%	**260.6**	-32,7%
		FE [km/kgH_2]	**86.4**	**76.6**	11,3%	**70.5**	18,4%
13	20th Sept 2016, 04:43:58 to 05:15:50 (43.44km)	E_C [Wh/km]	**208.7**	**246**	-17,9%	**264.7**	-26,8%
		FE [km/kgH_2]	**85.1**	**74.4**	12,6%	**68.6**	19,4%
14	20th Sept 2016, 05:21:27 to 06:47:49 (95.5km)	E_C [Wh/km]	**217.8**	**240.0**	-10,2%	**258**	-18,5%
		FE [km/kgH_2]	**80.1**	**75.8**	5,4%	**70.5**	12,0%
15	21st Sept 2016, 03:35:54 to 04:06:31 (44.25km)	E_C [Wh/km]	**266.6**	**277.7**	-4,2%	**296.7**	-11,3%
		FE [km/kgH_2]	**65.8**	**64.8**	1,5%	**60.3**	8,4%
16	26th Sept 2016, 14:51:55 to 16:34:11 (110.3km)	E_C [Wh/km]	**220.3**	**250.6**	-13,8%	**270.5**	-22,8%
		FE [km/kgH_2]	**79.0**	**72.0**	8,9%	**66.8**	15,4%

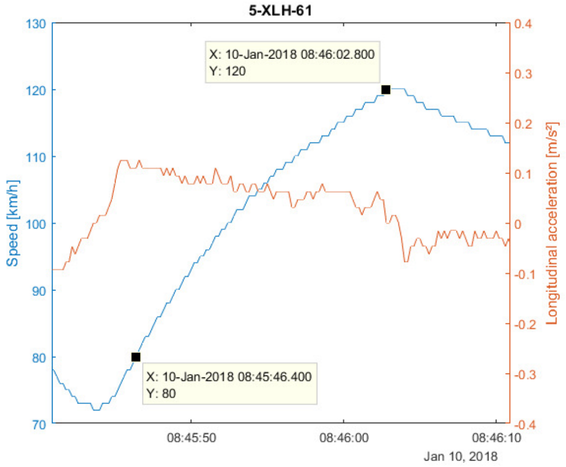
Appendix 14 Helmond - Accelerations and Driveline Elasticity

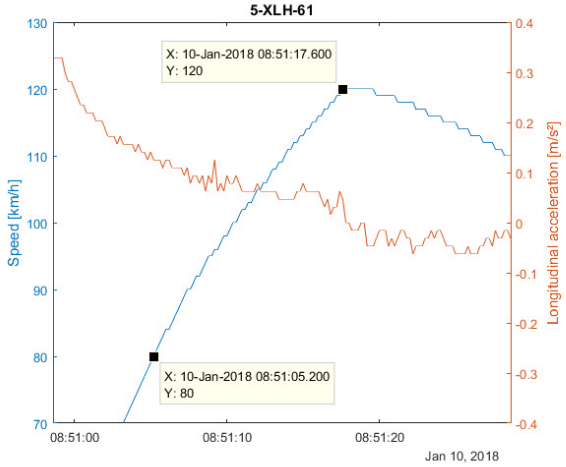
Test [km/h]	Time	Δt [s]		Test [km/h]	Time	Δt [s]
0-50	8:40:13	4,8		0-98	9:02:57	14,8
0-50	8:42:33	5,0		0-100	8:47:38	15,4
0-50	8:43:18	4,5		0-100	8:50:55	15,2
0-50	8:52:24	4,4		**Average**	t_{AVGR}	**15,1**
0-50	8:57:30	5,6		**StDev**	σ_T	**0,3**
0-50	8:59:07	4,6				
0-50	9:00:10	4,7				
0-50	9:00:54	4,8				
0-50	9:01:50	4,8				
0-50	9:02:57	4,8				
0-50	9:03:41	4,7				
0-50	9:06:28	4,6				
0-50	9:10:20	4,5		80-120	8:44:00	15,8
0-50	9:15:43	4,7		80-120	8:45:46	16,4
0-50	9:16:05	4,8		80-120	8:51:05	12,4
Average	t_{AVGR}	**4,8**		**Average**	t_{AVGR}	**14,9**
StDev	σ_T	**0,2**		**StDev**	σ_T	**2,2**

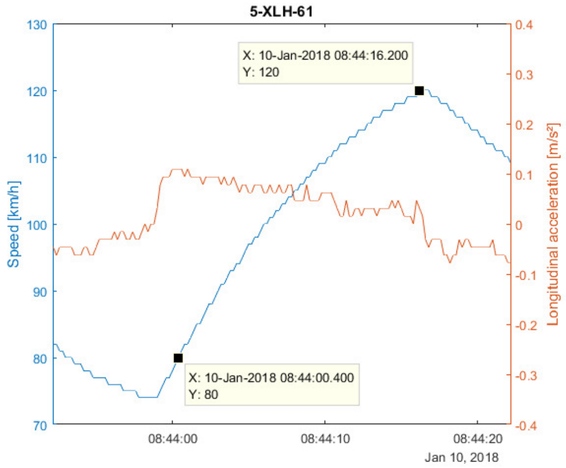
Table 45 Helmond: 5-XLH-61 Average values

Appendix 13 Helmond - Accelerations and Driveline Elasticity

Speed range: 80-120km/h

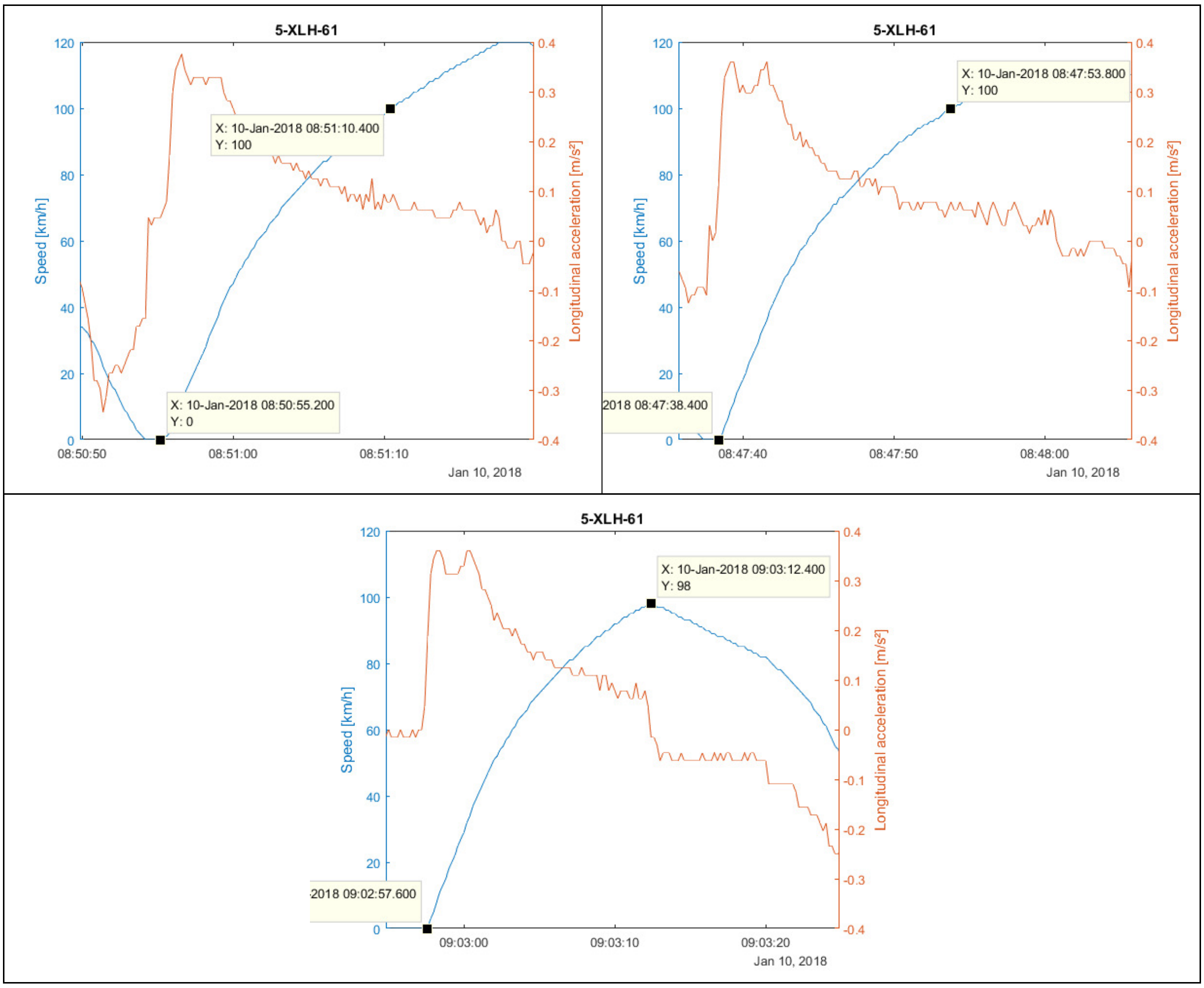






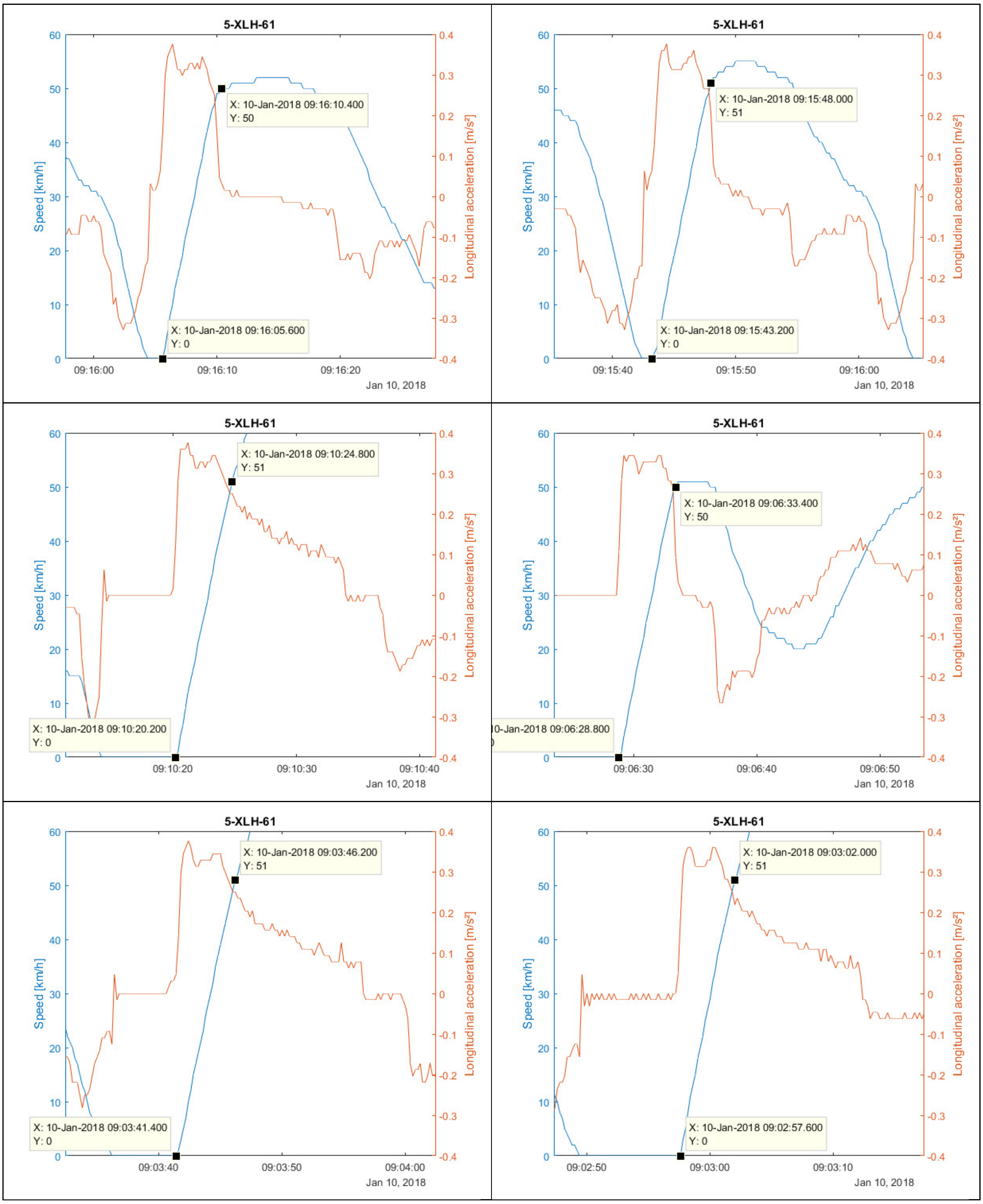
Appendix 13 Helmond - Accelerations and Driveline Elasticity

Speed range: 0-100km/h



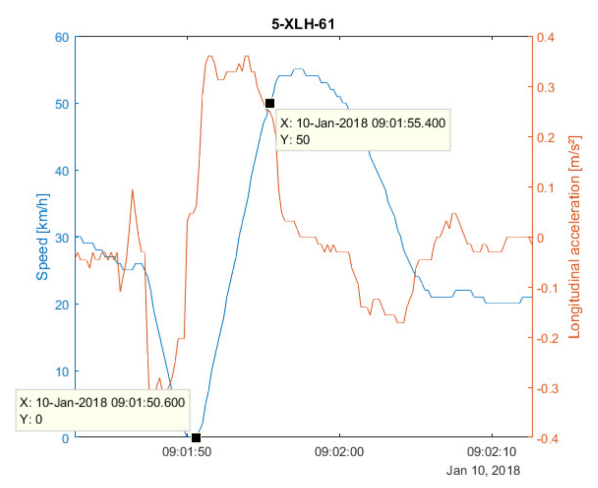
Appendix 13 Helmond - Accelerations and Driveline Elasticity

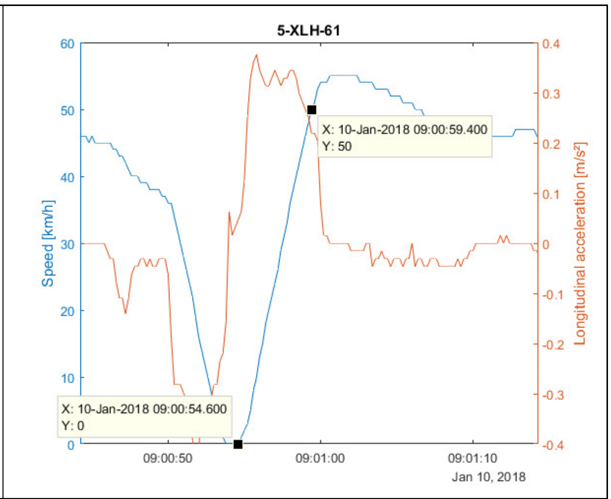
Speed range: 0-50km/h

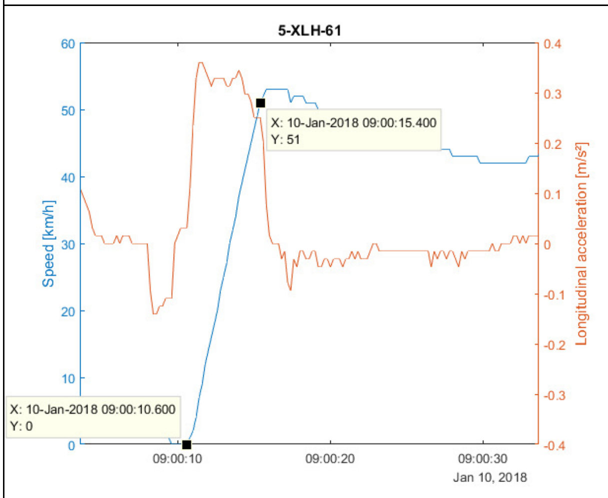


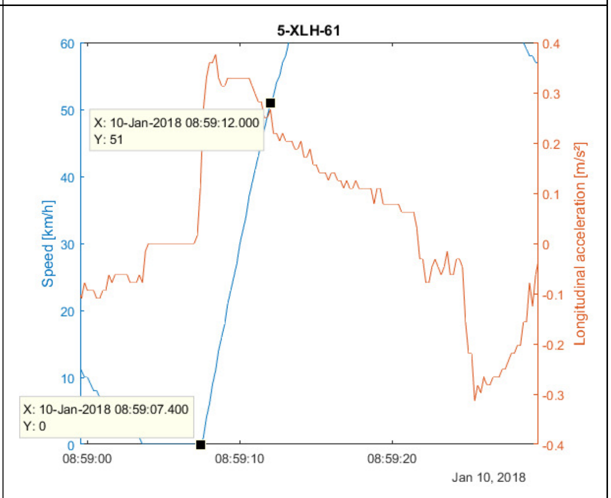
Appendix 13 Helmond - Accelerations and Driveline Elasticity

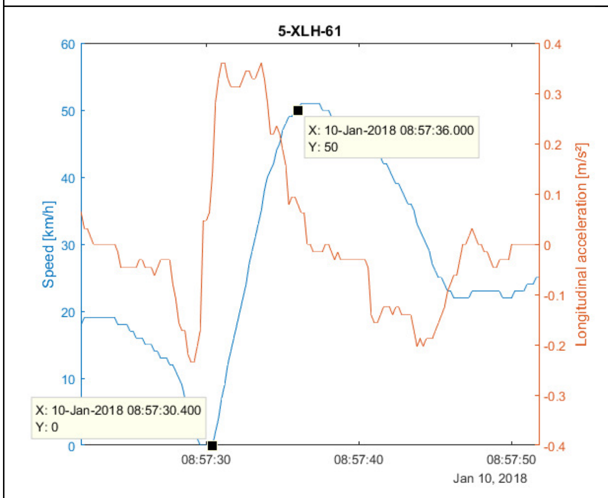
Speed range: 0-50km/h

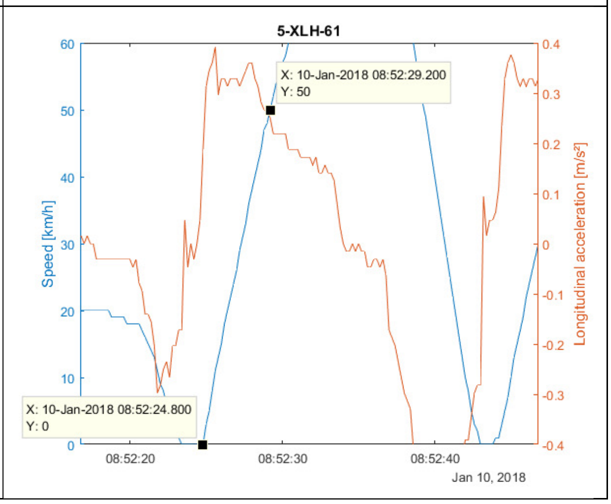






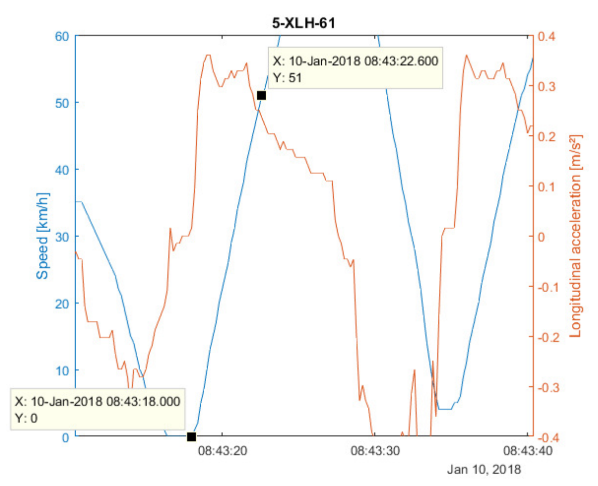


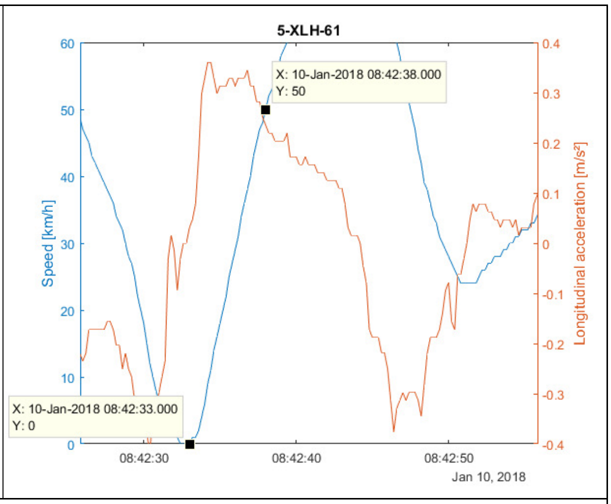


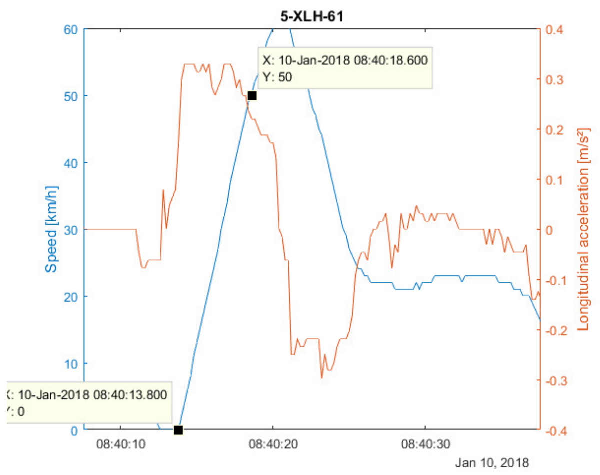


Appendix 13 Helmond - Accelerations and Driveline Elasticity

Speed range: 0-50km/h







Appendix 15 Arnhem - Accelerations and Driveline Elasticity

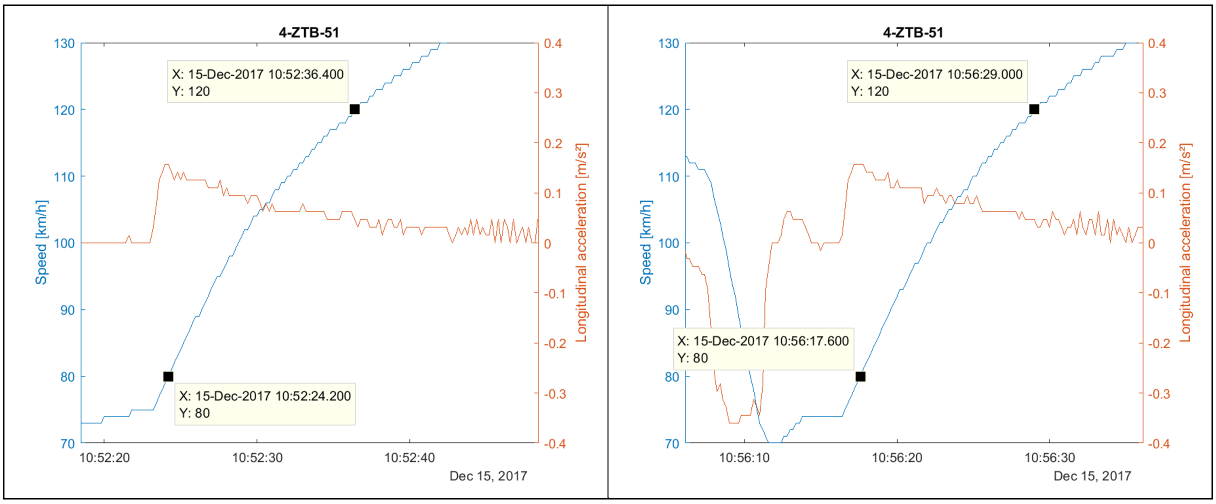
Test [km/h]	Time	Length [s]		Average	StDev
0-49	10:37:02	4,2			
0-50	10:40:00	4,7		t_{AVGR}	4,4
0-50	10:43:47	4,3		σ_T	0,3
0-100	10:40:20	14,0		t_{AVGR}	13,8
0-100	10:47:05	13,6		σ_T	0,3
80-120	10:56:17	11,4		t_{AVGR}	11,8
80-120	10:52:24	12,2		σ_T	0,6

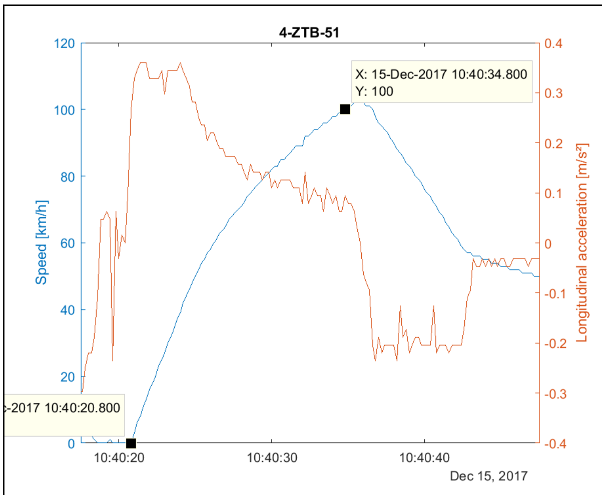
Table 46 Arnhem: 4-ZTB-51

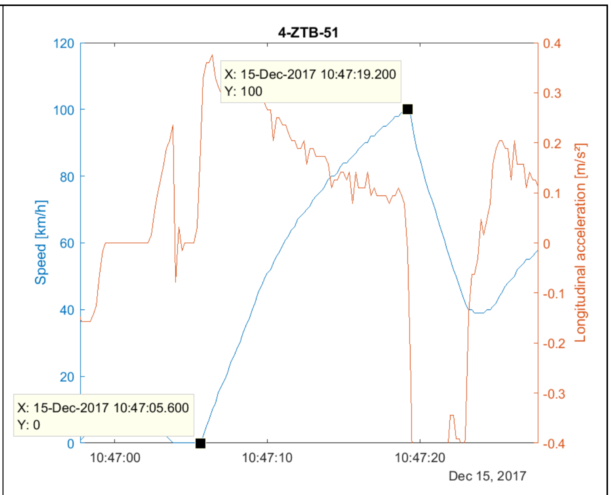
Figure AI.1-1 6 launches from start for: ARNHEM (4-ZTB-51)

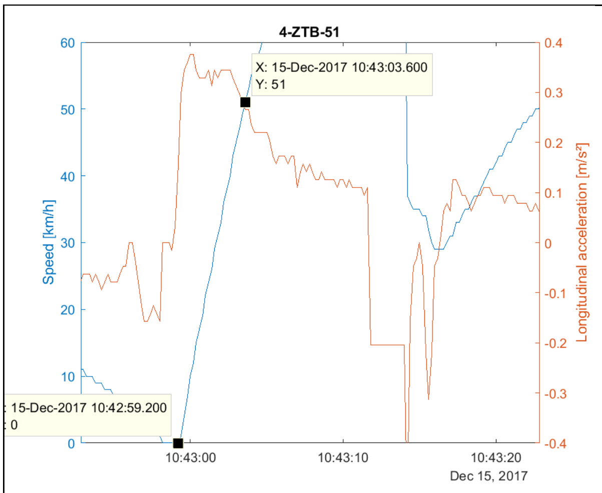
Remarks to figure AI.1:

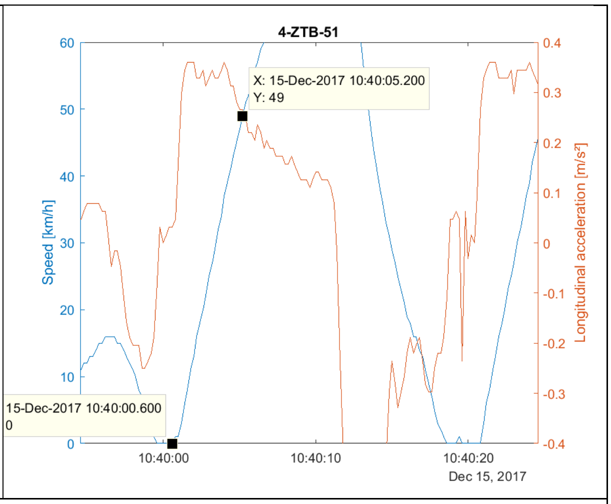
- trip: 136; duration: 13.6 [sec]
- trip: 134; duration: 12.6 [sec]
- trip: 171; duration: 10 [sec]
- trip: 124; duration: 9.4 [sec]
- trip: 4; duration: 8.8 [sec]
- trip: 136; duration: 8.8 [sec]
- The delayed one (in blue) is caused by a 5 second stall condition (brake and accelerator depressed simultaneously).

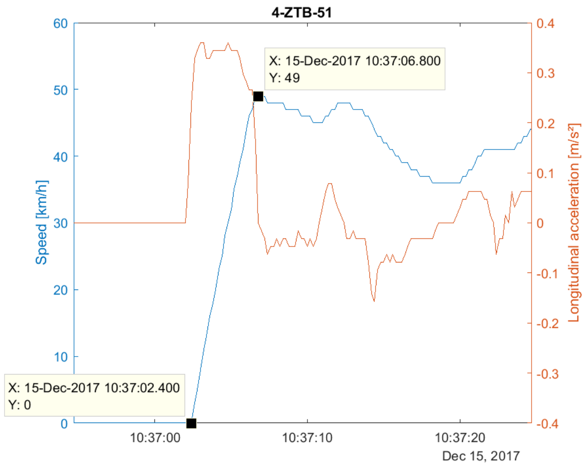



4-ZTB-51
X: 15-Dec-2017 10:40:34.800
Y: 100
-2017 10:40:20.800
Speed [km/h]
Longitudinal acceleration [m/s²]
10:40:20
10:40:30
10:40:40
Dec 15, 2017


4-ZTB-51
X: 15-Dec-2017 10:47:19.200
Y: 100
X: 15-Dec-2017 10:47:05.600
Y: 0
Speed [km/h]
Longitudinal acceleration [m/s²]
10:47:00
10:47:10
10:47:20
Dec 15, 2017


4-ZTB-51
X: 15-Dec-2017 10:43:03.600
Y: 51
15-Dec-2017 10:42:59.200
0
Speed [km/h]
Longitudinal acceleration [m/s²]
10:43:00
10:43:10
10:43:20
Dec 15, 2017


4-ZTB-51
X: 15-Dec-2017 10:40:05.200
Y: 49
15-Dec-2017 10:40:00.600
0
Speed [km/h]
Longitudinal acceleration [m/s²]
10:40:00
10:40:10
10:40:20
Dec 15, 2017


4-ZTB-51
X: 15-Dec-2017 10:37:06.800
Y: 49
X: 15-Dec-2017 10:37:02.400
Y: 0
Speed [km/h]
Longitudinal acceleration [m/s²]
10:37:00
10:37:10
10:37:20
Dec 15, 2017

Appendix 16 Rhoon - Accelerations and Driveline Elasticity

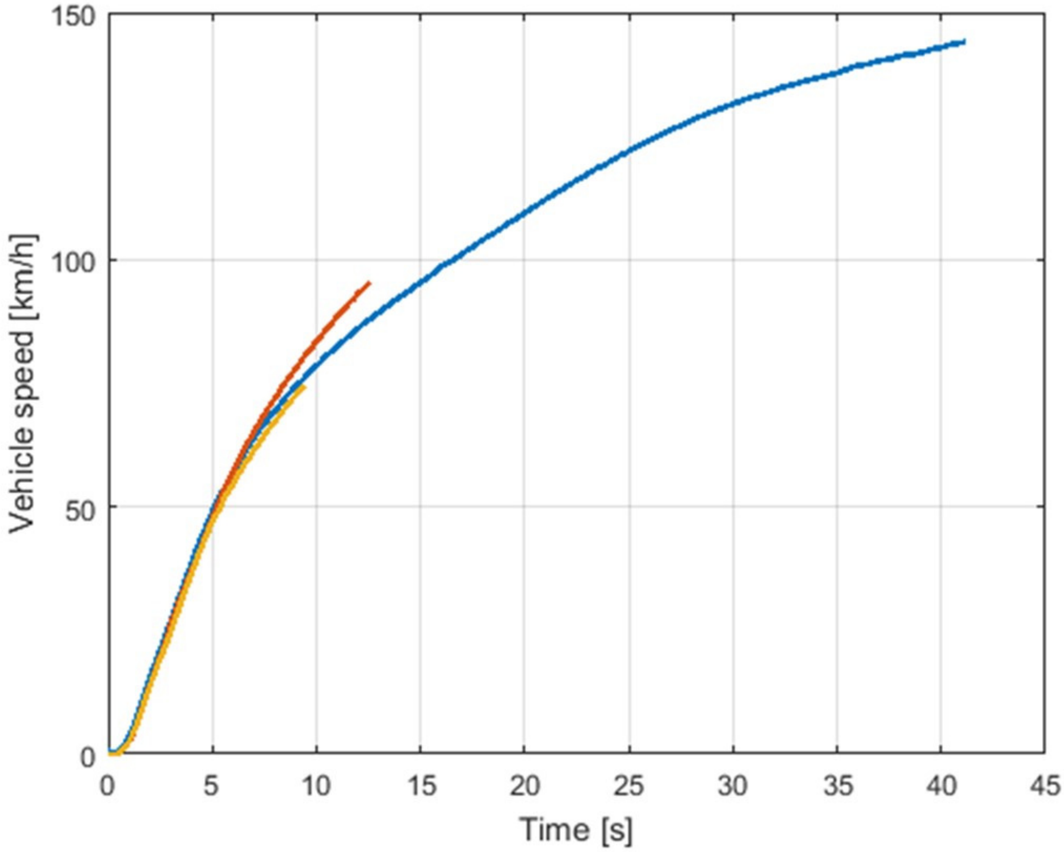


Figure 41 3 launches from start, for: RHOON (9-XKB-49)

Figure 41 3 launches from start, for: RHOON (9-XKB-49)represent 3 full “throttle” accelerations, by the blue line accelerates to max. speed:

- 0-50 kph: ~5.3 [s];
- 0-100kph: ~16.5 [s];
- 80-120kph: ~14[s];

Appendix 17 Environmental impact of lithium batteries

The lithium-ion polymer 24-kWh battery [48] Developed with LG chemical, it also contains a rechargeable battery for system start up.

To produce the lithium-ion polymer, lithium is needed. Lithium is separated from water in mineral springs, brine pools and brine deposits. It is produced through electrolysis from a mixture of fused lithium chloride and potassium chloride. [49] When the lithium is made, it is transported to a battery plant via plane, train, truck and boat; all of which currently use fossil fuels as their energy carrier, resulting in GHG emissions in transport. Transport is required by the producer of the batteries to the OEM of the hydrogen vehicles, where they are used in the driveline. The batteries have a long lifetime and can be recycled. [50]

As concluded by Notter [51], the share of the total environmental impact of E-mobility caused by the battery (measured in Ecoindicator 99 points) is 15%. The impact caused by the extraction of lithium for the components of the Li-ion battery is less than 2.3% (Ecoindicator 99 points [52]). The major contributor to the environmental burden caused by the battery is the supply of copper and aluminum for the production of the anode and the cathode, plus the required cables or the battery management system.

Romare & Dahllöf [53] found a great diversity in CO_2-equivalence due to lithium-ion batteries (see Figure 42). Various reasons were given, apart from differerences in design: due to choice of binder: tetrafluoretylene, which has high CO_2 emissions in its production, CO_2 emissions from the higher use of copper, very low energy use in cell production, relatively high greenhouse gas emissions during manufacturing [53, pp. 18,19].

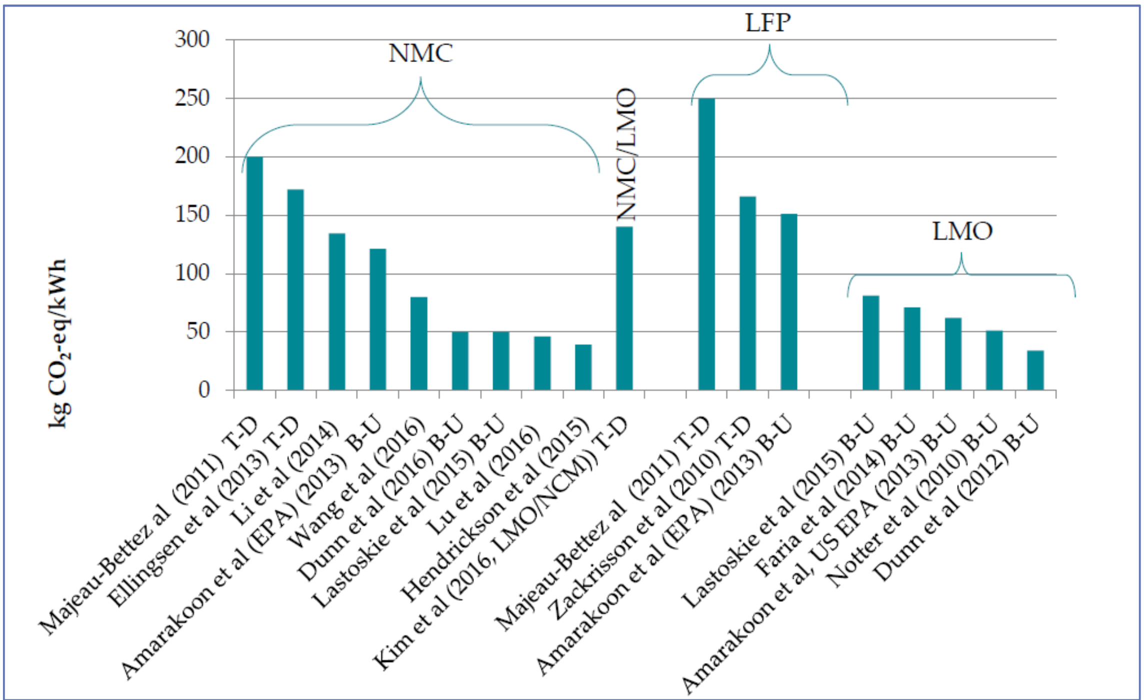


Figure 42 Calculated greenhouse gas emissions for different LCA studies of lithium-ion batteries for light vehicles for the chemistries NMC, NMC/LMO, LFP and LMO. T-D=Top-down approach for manufacturing and B-U is Bottom-Up approach. [53, p. 18]

The disadvantages of lithium:

- Elemental lithium is flammable and very reactive. In nature, lithium occurs in compounded forms such as lithium carbonate requiring chemical processing to be made usable.
- Lithium is typically found in salt flats in areas where water is scarce. The mining process of lithium uses large amounts of water. Therefore, on top of water contamination because of its use, depletion results in less available water for local populations, flora and fauna.
- Toxic chemicals are used for leaching purposes, chemicals requiring waste treatment. There are widespread concerns of improper handling and spills, like in other mining operations around the world.
- The recovery rate of lithium ion batteries, even in first world countries, is in the single digit percent range. Most batteries end up in landfill.
- Nickel and cobalt are used in the production of lithium ion batteries, represent significant additional environmental risks.

Appendix 18 Helmond - Vehicle Refuelling ; Vehicle data

VEHICLE REFUELLINGS

HYLIGHTS

Number of refuelling #	Date; time	Vehicle identification id-#	Driver identification id-#	Refuelling time coupling/de-coupling	Amount of refuelled H2		
					CGH2 at 35MPa	CGH2 at 70MpPa	LH2
1	14-10-2015 4:42 PM	5-XLH-61	NN	unknown		3,72	
2	23-10-2015 7:39 AM	5-XLH-61	NN	unknown		1,29	
3	27-10-2015 5:46 PM	5-XLH-61	NN	unknown		2,20	
4	03-11-2015 8:20 PM	5-XLH-61	NN	unknown		3,83	
5	05-11-2015 6:41 PM	5-XLH-61	NN	unknown		4,10	
6	11-11-2015 12:17 PM	5-XLH-61	NN	unknown		1,50	
7	24-11-2015 10:39 AM	5-XLH-61	NN	unknown		1,42	
8	25-11-2015 4:51 PM	5-XLH-61	NN	unknown		2,31	
9	26-11-2015 2:30 PM	5-XLH-61	NN	unknown		3,23	
10	02-12-2015 5:13 PM	5-XLH-61	NN	unknown		2,35	
11	03-12-2015 2:41 PM	5-XLH-61	NN	unknown		3,25	
12	04-12-2015 5:23 PM	5-XLH-61	NN	unknown		2,38	
13	08-12-2015 3:17 PM	5-XLH-61	NN	unknown		2,72	
14	17-12-2015 4:46 PM	5-XLH-61	NN	unknown		4,41	
15	17-12-2015 8:23 PM	5-XLH-61	NN	unknown		1,51	
16	28-12-2015 2:33 PM	5-XLH-61	NN	unknown		3,27	
17	30-12-2015 1:05 PM	5-XLH-61	NN	unknown		3,17	
18	07-01-2016 4:29 PM	5-XLH-61	NN	unknown		2,44	
19	12-01-2016 8:30 AM	5-XLH-61	NN	unknown		2,57	
20	12-01-2016 5:53 PM	5-XLH-61	NN	unknown		2,94	
21	14-01-2016 4:10 PM	5-XLH-61	NN	unknown		3,93	
22	18-01-2016 7:17 PM	5-XLH-61	NN	unknown		3,49	
23	19-01-2016 7:08 PM	5-XLH-61	NN	unknown		4,38	
24	21-01-2016 6:11 PM	5-XLH-61	NN	unknown		3,27	
25	26-01-2016 5:07 PM	5-XLH-61	NN	unknown		2,58	
26	27-01-2016 4:55 PM	5-XLH-61	NN	unknown		2,95	
27	28-01-2016 8:09 PM	5-XLH-61	NN	unknown		3,74	
28	01-02-2016 3:41 PM	5-XLH-61	NN	unknown		2,78	
29	02-02-2016 1:20 PM	5-XLH-61	NN	unknown		2,38	
30	04-02-2016 10:00 AM	5-XLH-61	NN	unknown		3,78	
31	04-02-2016 2:33 PM	5-XLH-61	NN	unknown		1,53	
32	10-02-2016 9:50 AM	5-XLH-61	NN	unknown		2,61	
33	10-02-2016 3:25 PM	5-XLH-61	NN	unknown		2,70	
34	16-02-2016 5:26 PM	5-XLH-61	NN	unknown		1,94	
35	22-02-2016 3:42 PM	5-XLH-61	NN	unknown		2,65	
36	25-02-2016 1:33 PM	5-XLH-61	NN	unknown		1,67	
37	26-02-2016 3:22 PM	5-XLH-61	NN	unknown		3,86	
38	02-03-2016 12:10 PM	5-XLH-61	NN	unknown		2,64	
39	03-03-2016 12:35 PM	5-XLH-61	NN	unknown		1,09	
40	09-03-2016 5:55 PM	5-XLH-61	NN	unknown		3,63	
41	17-03-2016 3:53 PM	5-XLH-61	NN	unknown		3,65	
42	18-03-2016 4:18 PM	5-XLH-61	NN	unknown		2,25	
43	31-03-2016 2:05 PM	5-XLH-61	NN	unknown		3,22	
44	04-04-2016 1:40 PM	5-XLH-61	NN	unknown		3,43	
45	06-04-2016 4:52 PM	5-XLH-61	NN	unknown		2,29	
46	08-04-2016 4:05 PM	5-XLH-61	NN	unknown		2,44	
47	11-04-2016 5:08 PM	5-XLH-61	NN	unknown		2,24	

48	12-04-2016 2:58 PM	5-XLH-61	NN	unknown		1,72	
49	14-04-2016 7:26 PM	5-XLH-61	NN	unknown		3,60	
50	18-04-2016 4:28 PM	5-XLH-61	NN	unknown		3,72	
51	21-04-2016 9:28 AM	5-XLH-61	NN	unknown		3,20	
52	10-05-2016 6:08 AM	5-XLH-61	NN	unknown		3,19	
53	11-05-2016 7:28 AM	5-XLH-61	NN	unknown		2,61	
54	24-05-2016 4:06 PM	5-XLH-61	NN	unknown		2,66	
55	26-05-2016 9:39 AM	5-XLH-61	NN	unknown		4,67	
56	10-06-2016 3:39 PM	5-XLH-61	NN	unknown		2,70	
57	14-06-2016 3:35 PM	5-XLH-61	NN	unknown		1,66	
58	17-06-2016 5:53 AM	5-XLH-61	NN	unknown		2,66	
59	21-06-2016 1:00 PM	5-XLH-61	NN	unknown		1,74	
60	27-06-2016 11:29 AM	5-XLH-61	NN	unknown		1,11	
61	29-06-2016 11:43 AM	5-XLH-61	NN	unknown		2,38	
62	30-06-2016 2:21 PM	5-XLH-61	NN	unknown		1,48	
63	04-07-2016 5:11 PM	5-XLH-61	NN	unknown		2,34	
64	07-07-2016 5:07 PM	5-XLH-61	NN	unknown		2,16	
65	11-07-2016 4:32 PM	5-XLH-61	NN	unknown		5,08	
66	12-07-2016 3:02 PM	5-XLH-61	NN	unknown		1,79	
67	18-07-2016 2:12 PM	5-XLH-61	NN	unknown		0,40	
68	31-07-2016 8:07 PM	5-XLH-61	NN	unknown		2,00	
69	04-08-2016 4:18 PM	5-XLH-61	NN	unknown		2,43	
70	16-08-2016 2:13 PM	5-XLH-61	NN	unknown		3,22	
71	18-08-2016 4:10 PM	5-XLH-61	NN	unknown		1,29	
72	23-08-2016 2:43 PM	5-XLH-61	NN	unknown		3,11	
73	29-08-2016 2:38 PM	5-XLH-61	NN	unknown		3,00	
74	31-08-2016 7:35 AM	5-XLH-61	NN	unknown		3,07	
75	31-08-2016 4:23 PM	5-XLH-61	NN	unknown		2,47	
76	09-09-2016 10:52 AM	5-XLH-61	NN	unknown		0,97	
77	05-10-2016 2:49 PM	5-XLH-61	NN	unknown		0,97	
78	12-10-2016 5:14 AM	5-XLH-61	NN	unknown		3,00	
79	12-10-2016 11:53 AM	5-XLH-61	NN	unknown		3,54	
80	10-11-2016 11:26 AM	5-XLH-61	NN	unknown		2,57	
81	10-11-2016 6:03 PM	5-XLH-61	NN	unknown		4,19	
82	11-11-2016 8:34 AM	5-XLH-61	NN	unknown		1,30	
83	08-12-2016 5:04 PM	5-XLH-61	NN	unknown		2,62	
84	12-12-2016 3:32 PM	5-XLH-61	NN	unknown		3,81	
85	13-12-2016 1:57 PM	5-XLH-61	NN	unknown		2,38	
86	15-12-2016 6:47 PM	5-XLH-61	NN	unknown		2,76	
87	16-12-2016 12:28 PM	5-XLH-61	NN	unknown		2,50	
88	22-12-2016 10:11 PM	5-XLH-61	NN	unknown		3,89	
89	02-01-2017 2:31 PM	5-XLH-61	NN	unknown		3,32	
90	04-01-2017 6:57 AM	5-XLH-61	NN	unknown		2,36	
91	04-01-2017 12:18 PM	5-XLH-61	NN	unknown		2,49	
92	09-01-2017 2:10 PM	5-XLH-61	NN	unknown		3,47	
93	11-01-2017 12:09 PM	5-XLH-61	NN	unknown		2,81	
94	17-01-2017 7:56 AM	5-XLH-61	NN	unknown		3,27	
95	15-02-2017 12:40 PM	5-XLH-61	NN	unknown		0,73	
96	15-02-2017 3:47 PM	5-XLH-61	NN	unknown		4,08	
97	20-02-2017 7:48 AM	5-XLH-61	NN	unknown		0,90	
98	24-02-2017 8:39 AM	5-XLH-61	NN	unknown		1,98	
99	10-03-2017 9:45 AM	5-XLH-61	NN	unknown		4,10	
100	13-03-2017 12:12 PM	5-XLH-61	NN	unknown		3,03	
101	14-03-2017 11:19 AM	5-XLH-61	NN	unknown		2,89	
102	16-03-2017 5:18 PM	5-XLH-61	NN	unknown		2,86	

103	30-03-2017 5:08 PM	5-XLH-61	NN	unknown		4,47	
104	04-04-2017 3:21 AM	5-XLH-61	NN	unknown		3,18	
105	05-04-2017 3:46 AM	5-XLH-61	NN	unknown		3,85	
106	05-04-2017 2:20 PM	5-XLH-61	NN	unknown		3,52	
107	11-04-2017 1:11 PM	5-XLH-61	NN	unknown		4,83	
108	14-04-2017 1:49 PM	5-XLH-61	NN	unknown		4,86	
109	19-04-2017 12:26 PM	5-XLH-61	NN	unknown		3,57	
110	21-04-2017 2:31 PM	5-XLH-61	NN	unknown		4,12	
111	02-05-2017 11:39 AM	5-XLH-61	NN	unknown		2,90	
112	10-05-2017 8:14 AM	5-XLH-61	NN	unknown		2,43	
113	11-05-2017 11:11 AM	5-XLH-61	NN	unknown		2,87	
114	19-05-2017 8:36 AM	5-XLH-61	NN	unknown		3,10	
115	13-06-2017 6:43 AM	5-XLH-61	NN	unknown		4,43	
116	15-06-2017 12:05 PM	5-XLH-61	NN	unknown		2,58	
117	30-06-2017 5:05 PM	5-XLH-61	NN	unknown		2,56	
118	07-07-2017 6:40 AM	5-XLH-61	NN	unknown		4,52	
119	11-07-2017 11:56 AM	5-XLH-61	NN	unknown		3,35	
120	18-07-2017 3:04 AM	5-XLH-61	NN	unknown		3,43	
121	19-07-2017 3:42 AM	5-XLH-61	NN	unknown		3,62	
122	09-08-2017 6:13 AM	5-XLH-61	NN	unknown		2,28	
123	08-09-2017 11:36 AM	5-XLH-61	NN	unknown		4,09	
124	12-09-2017 5:54 PM	5-XLH-61	NN	unknown		3,40	
125	19-09-2017 2:09 PM	5-XLH-61	NN	unknown		1,93	
126	27-09-2017 6:09 AM	5-XLH-61	NN	unknown		4,44	
127	29-09-2017 2:01 PM	5-XLH-61	NN	unknown		3,29	
128	29-09-2017 5:53 PM	5-XLH-61	NN	unknown		3,19	
129	29-09-2017 10:53 PM	5-XLH-61	NN	unknown		2,58	
130	30-09-2017 2:59 AM	5-XLH-61	NN	unknown		3,51	
131	30-09-2017 6:31 AM	5-XLH-61	NN	unknown		3,19	
132	30-09-2017 11:58 AM	5-XLH-61	NN	unknown		2,19	
133	02-10-2017 11:11 AM	5-XLH-61	NN	unknown		1,74	
134	28-11-2017 6:38 AM	5-XLH-61	NN	unknown		3,77	
135	14-12-2017 8:05 AM	5-XLH-61	NN	unknown		4,31	
136	10-01-2018 7:31 AM	5-XLH-61	NN	unknown		4,02	

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Appendix 19 Arnhem - Vehicle Refuelling ; Vehicle data

HYLIGHTS

VEHICLE REFUELLINGS

Number of refuelling #	Date; time	Vehicle identification id-#	Driver identification id-#	Refuelling time coupling/de-coupling	Amount of refuelled H2		
					CGH2 at 35MPa	CGH2 at 70MpPa	LH2
1	16-10-2015 12:55 PM	4-ZTB-51	NN	unknown		2,79	
2	04-11-2015 6:17 PM	4-ZTB-51	NN	unknown		2,90	
3	30-11-2015 4:01 PM	4-ZTB-51	NN	unknown		5,21	
4	06-01-2016 12:08 PM	4-ZTB-51	NN	unknown		5,16	
5	12-01-2016 1:17 PM	4-ZTB-51	NN	unknown		3,46	
6	18-01-2016 10:24 AM	4-ZTB-51	NN	unknown		3,73	
7	28-01-2016 4:48 PM	4-ZTB-51	NN	unknown		5,09	
8	11-02-2016 12:36 PM	4-ZTB-51	NN	unknown		4,10	
9	19-02-2016 5:28 PM	4-ZTB-51	NN	unknown		3,50	
10	10-03-2016 11:52 AM	4-ZTB-51	NN	unknown		3,89	
11	24-03-2016 12:42 PM	4-ZTB-51	NN	unknown		5,32	
12	07-04-2016 9:34 AM	4-ZTB-51	NN	unknown		4,81	
13	20-04-2016 9:52 AM	4-ZTB-51	NN	unknown		4,44	
14	17-05-2016 12:26 PM	4-ZTB-51	NN	unknown		2,97	
15	17-05-2016 1:12 PM	4-ZTB-51	NN	unknown		2,14	
16	20-05-2016 10:39 AM	4-ZTB-51	NN	unknown		4,27	
17	02-06-2016 12:15 PM	4-ZTB-51	NN	unknown		4,66	
18	24-10-2016 1:50 PM	4-ZTB-51	NN	unknown		4,53	
19	06-12-2016 11:21 AM	4-ZTB-51	NN	unknown		5,35	
20	23-12-2016 11:49 AM	4-ZTB-51	NN	unknown		5,24	
21	26-01-2017 12:21 PM	4-ZTB-51	NN	unknown		4,45	
22	03-02-2017 11:28 AM	4-ZTB-51	NN	unknown		1,13	
23	24-02-2017 3:03 PM	4-ZTB-51	NN	unknown		2,26	
24	15-03-2017 2:58 PM	4-ZTB-51	NN	unknown		1,18	
25	28-03-2017 9:06 AM	4-ZTB-51	NN	unknown		2,30	
26	12-04-2017 7:52 AM	4-ZTB-51	NN	unknown		1,69	
27	10-05-2017 8:05 AM	4-ZTB-51	NN	unknown		2,06	
28	18-05-2017 9:22 AM	4-ZTB-51	NN	unknown		1,53	
29	31-05-2017 7:48 AM	4-ZTB-51	NN	unknown		1,90	
30	31-05-2017 10:49 AM	4-ZTB-51	NN	unknown		4,46	
31	13-06-2017 6:08 AM	4-ZTB-51	NN	unknown		2,23	
32	04-07-2017 11:05 AM	4-ZTB-51	NN	unknown		1,87	
33	16-08-2017 12:44 PM	4-ZTB-51	NN	unknown		1,79	
34	06-09-2017 1:25 PM	4-ZTB-51	NN	unknown		1,38	
35	06-09-2017 3:01 PM	4-ZTB-51	NN	unknown		3,93	
36	08-09-2017 3:32 PM	4-ZTB-51	NN	unknown		4,17	
37	29-09-2017 1:07 PM	4-ZTB-51	NN	unknown		4,10	
38	29-09-2017 4:59 PM	4-ZTB-51	NN	unknown		2,11	
39	29-09-2017 7:26 PM	4-ZTB-51	NN	unknown		2,95	
40	29-09-2017 8:27 PM	4-ZTB-51	NN	unknown		1,51	
41	30-09-2017 2:20 AM	4-ZTB-51	NN	unknown		4,11	
42	30-09-2017 1:45 PM	4-ZTB-51	NN	unknown		3,92	

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Appendix 20 Rhoon - Vehicle Refuelling ; Vehicle data

VEHICLE REFUELLINGS

HYLIGHTS

Number of refuelling #	Date; time	Vehicle identification id-#	Driver identification id-#	Refuelling time coupling/de-coupling	Amount of refuelled H2		
					CGH2 at 35MPa	CGH2 at 70MpPa	LH2
1	10-11-2015 11:08 AM	9-XKB-49	NN	unknown		1,92	
2	17-12-2015 8:07 AM	9-XKB-49	NN	unknown		4,27	
3	18-12-2015 11:58 AM	9-XKB-49	NN	unknown		0,87	
4	20-12-2015 6:22 PM	9-XKB-49	NN	unknown		4,74	
5	21-12-2015 12:48 PM	9-XKB-49	NN	unknown		2,09	
6	30-12-2015 7:46 AM	9-XKB-49	NN	unknown		3,88	
7	07-01-2016 10:56 AM	9-XKB-49	NN	unknown		3,02	
8	13-01-2016 7:57 AM	9-XKB-49	NN	unknown		3,43	
9	17-01-2016 4:24 PM	9-XKB-49	NN	unknown		1,56	
10	21-01-2016 10:55 AM	9-XKB-49	NN	unknown		1,86	
11	22-01-2016 3:06 PM	9-XKB-49	NN	unknown		2,70	
12	26-01-2016 8:24 AM	9-XKB-49	NN	unknown		2,65	
13	29-01-2016 2:25 PM	9-XKB-49	NN	unknown		4,38	
14	04-02-2016 8:57 AM	9-XKB-49	NN	unknown		3,07	
15	06-02-2016 10:42 AM	9-XKB-49	NN	unknown		1,42	
16	08-02-2016 4:50 AM	9-XKB-49	NN	unknown		4,42	
17	10-02-2016 12:20 PM	9-XKB-49	NN	unknown		2,74	
18	12-02-2016 6:48 AM	9-XKB-49	NN	unknown		4,31	
19	17-02-2016 5:29 AM	9-XKB-49	NN	unknown		4,01	
20	20-02-2016 9:33 AM	9-XKB-49	NN	unknown		4,87	
21	23-02-2016 8:49 AM	9-XKB-49	NN	unknown		4,45	
22	26-02-2016 5:01 AM	9-XKB-49	NN	unknown		2,95	
23	07-03-2016 5:55 AM	9-XKB-49	NN	unknown		3,79	
24	09-03-2016 6:44 AM	9-XKB-49	NN	unknown		4,00	
25	12-03-2016 4:54 AM	9-XKB-49	NN	unknown		4,03	
26	25-03-2016 2:05 PM	9-XKB-49	NN	unknown		4,54	
27	29-03-2016 5:30 AM	9-XKB-49	NN	unknown		0,83	
28	31-03-2016 12:08 PM	9-XKB-49	NN	unknown		3,99	
29	08-04-2016 1:32 PM	9-XKB-49	NN	unknown		4,23	
30	11-04-2016 5:48 AM	9-XKB-49	NN	unknown		2,58	
31	14-04-2016 5:40 PM	9-XKB-49	NN	unknown		2,79	
32	18-04-2016 5:56 AM	9-XKB-49	NN	unknown		4,72	
33	20-04-2016 1:35 PM	9-XKB-49	NN	unknown		3,83	
34	22-04-2016 6:17 AM	9-XKB-49	NN	unknown		3,54	
35	13-05-2016 12:44 PM	9-XKB-49	NN	unknown		3,48	
36	24-05-2016 9:02 AM	9-XKB-49	NN	unknown		3,50	
37	25-05-2016 9:54 AM	9-XKB-49	NN	unknown		3,06	
38	31-05-2016 2:35 PM	9-XKB-49	NN	unknown		3,67	
39	02-06-2016 12:25 PM	9-XKB-49	NN	unknown		2,47	
40	09-06-2016 1:51 PM	9-XKB-49	NN	unknown		2,88	
41	24-06-2016 10:53 AM	9-XKB-49	NN	unknown		3,54	
42	12-07-2016 12:26 PM	9-XKB-49	NN	unknown		2,70	
43	14-07-2016 6:51 AM	9-XKB-49	NN	unknown		4,27	
44	19-07-2016 1:29 PM	9-XKB-49	NN	unknown		2,21	
45	02-08-2016 4:09 AM	9-XKB-49	NN	unknown		4,44	
46	10-08-2016 3:03 PM	9-XKB-49	NN	unknown		4,31	
47	19-08-2016 12:57 PM	9-XKB-49	NN	unknown		2,08	

48	02-09-2016 6:18 AM	9-XKB-49	NN	unknown		2,62	
49	12-09-2016 12:53 PM	9-XKB-49	NN	unknown		2,35	
50	20-09-2016 5:15 AM	9-XKB-49	NN	unknown		2,77	
51	26-09-2016 5:47 AM	9-XKB-49	NN	unknown		3,41	
52	27-09-2016 5:48 AM	9-XKB-49	NN	unknown		2,90	
53	28-09-2016 2:29 PM	9-XKB-49	NN	unknown		3,21	
54	05-10-2016 5:53 AM	9-XKB-49	NN	unknown		3,16	
55	08-10-2016 7:40 AM	9-XKB-49	NN	unknown		4,06	
56	08-10-2016 11:04 AM	9-XKB-49	NN	unknown		2,57	
57	21-10-2016 7:50 PM	9-XKB-49	NN	unknown		3,61	
58	28-10-2016 4:01 AM	9-XKB-49	NN	unknown		3,20	
59	02-11-2016 7:43 AM	9-XKB-49	NN	unknown		1,75	
60	03-11-2016 6:56 AM	9-XKB-49	NN	unknown		2,49	
61	04-11-2016 2:06 PM	9-XKB-49	NN	unknown		3,26	
62	10-11-2016 12:43 PM	9-XKB-49	NN	unknown		4,07	
63	11-11-2016 7:31 AM	9-XKB-49	NN	unknown		2,58	
64	14-11-2016 6:52 AM	9-XKB-49	NN	unknown		3,38	
65	17-11-2016 9:33 PM	9-XKB-49	NN	unknown		3,18	
66	21-11-2016 3:01 PM	9-XKB-49	NN	unknown		2,60	
67	23-11-2016 2:55 PM	9-XKB-49	NN	unknown		1,96	
68	01-12-2016 12:46 PM	9-XKB-49	NN	unknown		4,32	
69	07-12-2016 5:02 AM	9-XKB-49	NN	unknown		3,42	
70	09-12-2016 10:32 AM	9-XKB-49	NN	unknown		3,45	
71	23-12-2016 4:44 AM	9-XKB-49	NN	unknown		4,64	
72	11-01-2017 1:20 PM	9-XKB-49	NN	unknown		2,51	
73	13-01-2017 2:36 PM	9-XKB-49	NN	unknown		2,53	
74	16-01-2017 9:57 AM	9-XKB-49	NN	unknown		1,61	
75	17-01-2017 4:05 PM	9-XKB-49	NN	unknown		1,31	
76	25-01-2017 12:05 PM	9-XKB-49	NN	unknown		2,59	
77	01-02-2017 11:35 AM	9-XKB-49	NN	unknown		2,96	
78	22-02-2017 8:28 AM	9-XKB-49	NN	unknown		0,56	
79	23-10-2017 6:56 AM	9-XKB-49	NN	unknown		1,15	
80	25-10-2017 9:48 AM	9-XKB-49	NN	unknown		4,46	
81	22-11-2017 8:09 AM	9-XKB-49	NN	unknown		1,67	
82	28-12-2017 12:13 PM	9-XKB-49	NN	unknown		3,22	
83	30-12-2017 10:41 AM	9-XKB-49	NN	unknown		3,27	
84	01-01-2018 12:47 PM	9-XKB-49	NN	unknown		3,54	
85	02-01-2018 6:06 PM	9-XKB-49	NN	unknown		4,75	
86	03-01-2018 12:12 PM	9-XKB-49	NN	unknown		1,47	
87	04-01-2018 6:00 AM	9-XKB-49	NN	unknown		0,74	
88	04-01-2018 4:52 PM	9-XKB-49	NN	unknown		2,03	
89	05-01-2018 6:26 AM	9-XKB-49	NN	unknown		0,69	
90	07-01-2018 2:11 PM	9-XKB-49	NN	unknown		4,20	
91	08-01-2018 6:34 AM	9-XKB-49	NN	unknown		1,11	
92	11-01-2018 11:02 AM	9-XKB-49	NN	unknown		2,11	
93	15-01-2018 4:22 AM	9-XKB-49	NN	unknown		4,48	
94	22-01-2018 5:39 AM	9-XKB-49	NN	unknown		3,17	
95	23-01-2018 12:43 PM	9-XKB-49	NN	unknown		3,45	
96	25-01-2018 10:49 AM	9-XKB-49	NN	unknown		1,22	
97	26-01-2018 11:03 AM	9-XKB-49	NN	unknown		0,96	
98	26-01-2018 1:40 PM	9-XKB-49	NN	unknown		2,20	

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Appendix 21 Noticed in the Public Domain

WaterstofNet - ix35-FCEV, 60.000 km trouble free

Figure 43 WaterstofNet; trouble-free: 60.000km

HydrogenNet has, since we have been in possession of the Fuel Cell Electric Vehicle Hyundai ix 35 (October 2014), smoothly driven 60,000 km with the hydrogen car.

The car is zero emission and can drive about 500 km after a refuelling of 5 kg hydrogen at 700 bar. The refuelling takes less than 5 minutes. We usually refuel at our own hydrogen filling station at the Automotive Campus in Helmond or at the gas stations at Air Liquide in Zaventem or Rhoon (Rhoon).

Depending on the route and driving style, consumption varies, and on average it approximates the proposed consumption of 1 kg / 100 km.

In addition to the many trips in the Netherlands and Flanders, we have also made longer journeys with the car (eg to Denmark, Bolzano, ...). The various journeys to Germany also went smoothly. Moreover, we started and drove smoothly at temperatures between -15 ° C (Denmark) and + 37 ° C during our warm summer of last year in Belgium.

Toyota Mirai

(bron: https://www.toyota.de/news/details-2017-019.json)

Five stars for the Toyota Mirai in the new ADAC EcoTest
Best rating for the fuel cell sedan (fuel consumption (hydrogen) combined: 0.76 kg / 100km, combined power consumption 0kw / 100km, combined CO2 emissions 0g / km).
93 out of 100 points for the Toyota Mirai
Tests under real conditions on test bench and road
113 kW / 154 hp electric motor and 500 km range

Cologne, 09.03.2017. In the new ADAC EcoTest, the fuel cell sedan Toyota Mirai (fuel consumption (hydrogen) combines 0.76 kg / 100km, combined power consumption 0 kw / 100km, CO2 emissions combined 0g / km) achieves the highest rating of five with 93 points out of 100 Stars and demonstrates once again its high environmental compatibility. In addition to the current Prius (fuel consumption combined 3-3.3l / 100km, CO2 emissions combined 70-76g / km), he is thus already the second Toyota with a top rating in its environmental properties.

All vehicle models that achieve a four- or five-star result in the strict EcoTest procedure must overcome another hurdle in the current EcoTest: for the first time, they will also be subjected to pollutant measurement on the road. No problem for the Toyota Mirai, which converts hydrogen into electrical energy in its fuel cell, which drives the 113 kW / 154 hp electric motor. The only emission is water. Nevertheless, the 4.89-meter-long sedan of the upper middle class with 500 kilometers, a similar range as conventional-powered vehicles, the refuelling process takes about three minutes not much longer

Since 2003, the ADAC EcoTest has been providing consumers with economical and clean cars. The test criteria are being revised regularly, most recently in September 2016. Not only were the pollutant limit values tightened, but the class-based CO2 rating was also replaced by a uniform rating scale for all vehicle categories.

For electric vehicles, the ADAC now draws all CO2 emissions from the source to the wheel (WTW = Well-to-Wheel). The tank-to-wheel (TTW) CO2 emissions are added to those used to provide the fuel / electricity. This was based on the German electricity mix for the year 2013 amounting to 579 g / kWh. It provides information about how much carbon dioxide is emitted when generating one kilowatt hour of electricity.

Even after this calculation, the Mirai comes only on a CO2 emissions of 121 g / km and receives 43 out of 50 possible points. Together with the maximum score for zero pollutants, this makes 93 points and five stars in the ADAC EcoTest.

The fuel consumption and emission levels were determined according to the prescribed EU measurement procedure. Further information on official fuel consumption and the official specific CO2 emissions of new passenger cars can be found in the "Guide to Fuel Consumption, CO2 Emissions and Electricity Consumption of New Passenger Cars", which is available free of charge at all points of sale and at Deutsche Automobil Treuhand GmbH (DAT) is available.

Appendix 22 Road type and Fuel Efficiency

OVERALL

GPS_road	Mean Speed km/hr	Mean Fuel Efficiency km/kgH2
City	**17,7**	**81,6**
Highway	**88,7**	**83,4**
National	**41,7**	**85,1**
No Id	**40,7**	**81,2**

Vehicle / Road Id	Helmond	Arnhem	Rhoon
City	**9%**	**16%**	**19%**
Highway	**53%**	**33%**	**46%**
National	**23%**	**27%**	**28%**
No Id	**15%**	**24%**	**7%**

HELMOND VEHICLE (5-XLH-61)

Road type	#Count -	Mean Speed km/hr	StDev Speed km/hr	Mean Power kW	Mean Fuel Efficiency km/kgH$_2$	StDev Fuel Efficiency km/kgH$_2$
City	158741	20,4	25,8	4,4	85,9	18,3
Highway	890840	90,7	30,6	19,1	89,1	19,9
National	395099	44,5	26,6	7,9	91,1	20,3
No Id	246575	54,2	43,9	10,9	87,8	19,0

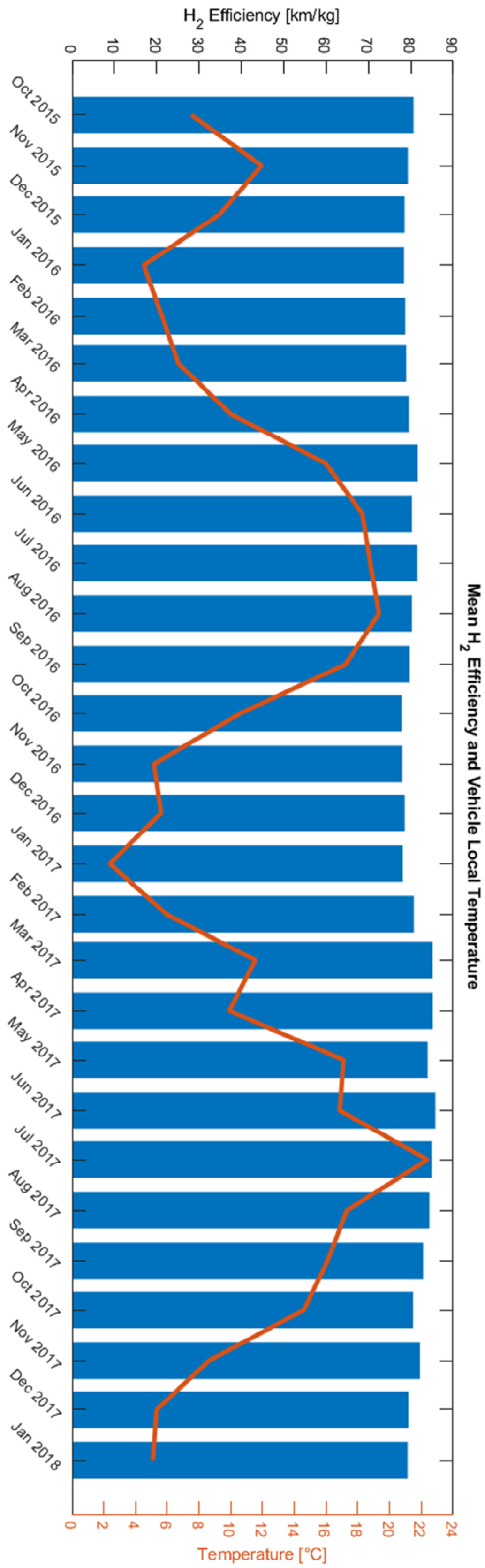
RHOON VEHICLE (9-XKB-49)

GPS_road	#Count -	Mean Speed km/hr	StDev Speed km/hr	Mean Power kW	Mean Fuel Efficiency km/kgH$_2$	StDev Fuel Efficiency km/kgH$_2$
City	232689	17,2	21,0	4,2	79,6	18,8
Highway	559624	87,9	31,3	20,7	79,6	19,4
Intercity	342823	45,4	28,7	10,3	82,4	24,5
No Id	87275	24,8	39,2	6,6	75,5	15,7

ARNHEM VEHICLE (4-Z TB-51)

GPS_road	#Count -	Mean Speed km/hr	StDev Speed km/hr	Mean Power kW	Mean Fuel Efficiency km/kgH$_2$	StDev Fuel Efficiency km/kgH$_2$
City	113552	15,4	20,2	4,6	79,4	18,9
Highway	228245	87,6	32,9	21,2	81,5	18,1
Intercity	185562	35,3	25,4	7,9	81,8	20,9
No Id	165723	42,9	46,9	10,9	80,4	17,5

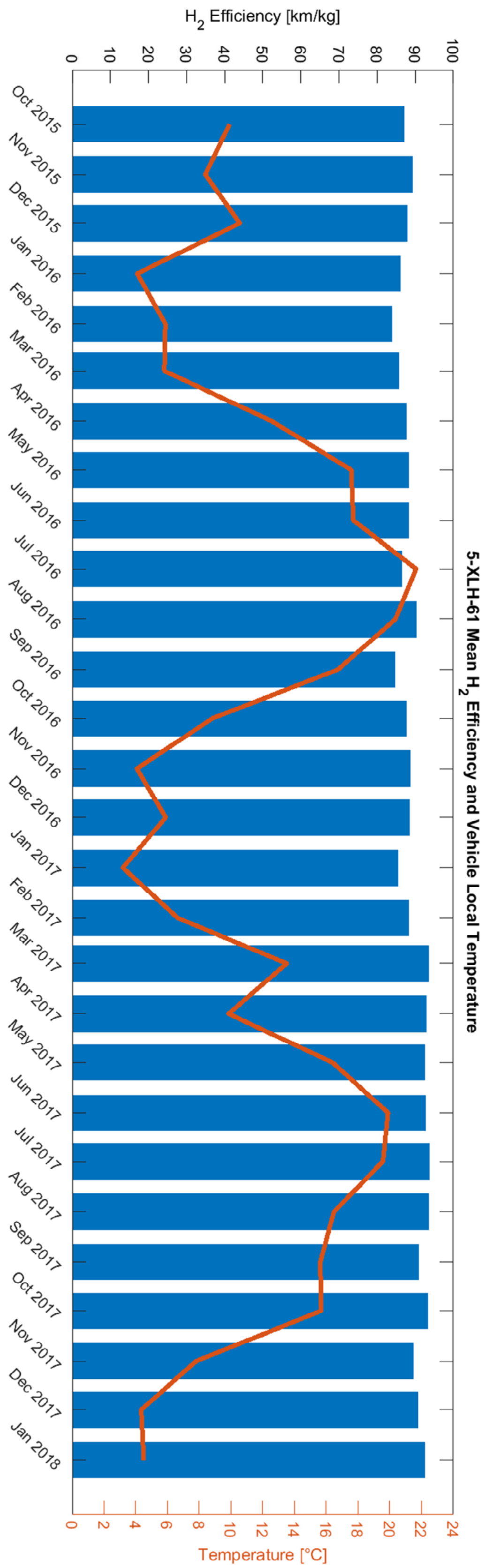
Appendix 23 Fuel Efficiency and Ambient Temperature – Project Fleet



Year	Month	FE km/kgH_2	T °C
2015	10	82,7	10,2
2015	11	82,6	9,9
2015	12	81,4	7,9
2016	1	81,0	4,7
2016	2	80,5	5,7
2016	3	81,5	7,8
2016	4	82,9	12,7
2016	5	83,7	17,0
2016	6	82,7	18,5
2016	7	83,7	20,6
2016	8	83,9	18,7
2016	9	81,5	15,5
2016	10	80,4	8,3
2016	11	81,4	4,6
2016	12	81,5	4,6
2017	1	80,6	3,9
2017	2	85,6	6,0
2017	3	89,3	12,5
2017	4	89,1	9,9
2017	5	88,3	16,7
2017	6	89,3	18,4
2017	7	89,4	21,0
2017	8	89,0	16,9
2017	9	83,3	15,6
2017	10	86,9	12,8
2017	11	83,8	7,1
2017	12	83,6	4,8

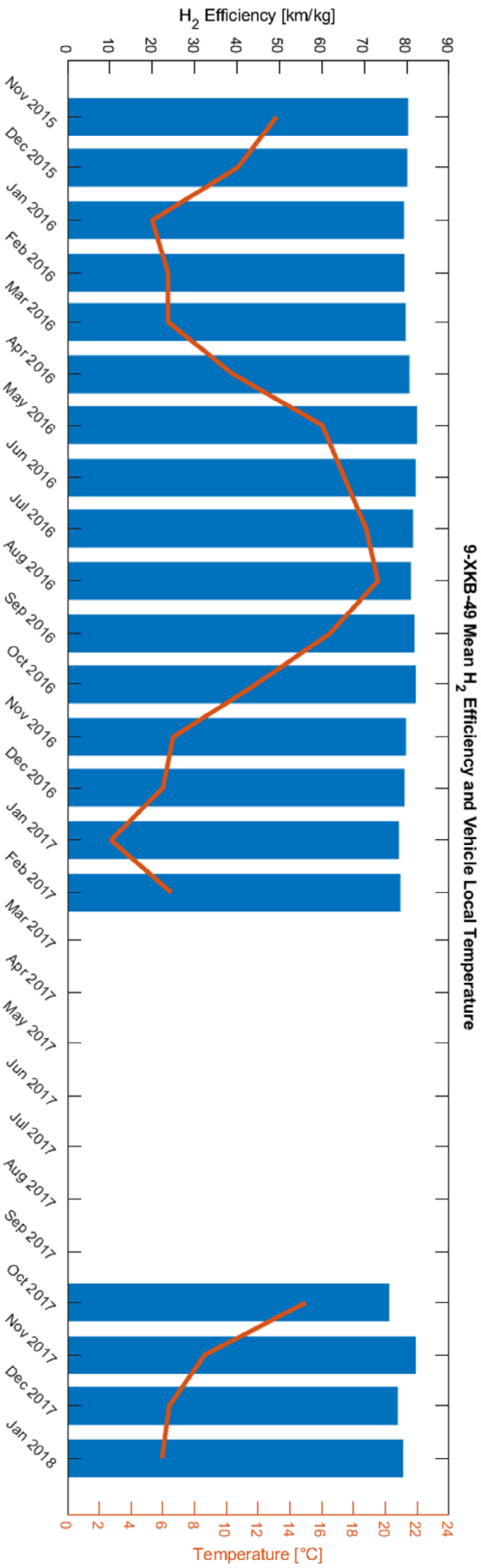
Mean	84,1	FE km/kgH_2
Min.	80,4	
Max.	89,4	

Appendix 24 Fuel Efficiency and Ambient Temperature – Helmond vehicle



Year	Month	FE km/kgH_2	T °C
2015	10	87,2	9,9
2015	11	89,4	8,4
2015	12	88,0	10,6
2016	1	86,2	4,1
2016	2	83,9	5,9
2016	3	85,8	5,8
2016	4	87,7	12,6
2016	5	88,4	17,6
2016	6	88,3	17,7
2016	7	86,5	21,6
2016	8	90,4	20,3
2016	9	84,7	16,7
2016	10	87,8	8,8
2016	11	88,8	4,1
2016	12	88,6	5,9
2017	1	85,5	3,2
2017	2	88,4	6,7
2017	3	93,5	13,5
2017	4	93,1	9,8
2017	5	92,6	16,4
2017	6	92,7	19,9
2017	7	93,9	19,6
2017	8	93,6	16,5
2017	9	91,0	15,6
2017	10	93,4	15,7
2017	11	89,6	7,8
2017	12	90,7	4,3
	Mean	89,2	FE km/kgH_2
	Min.	83,9	
	Max.	93,9	

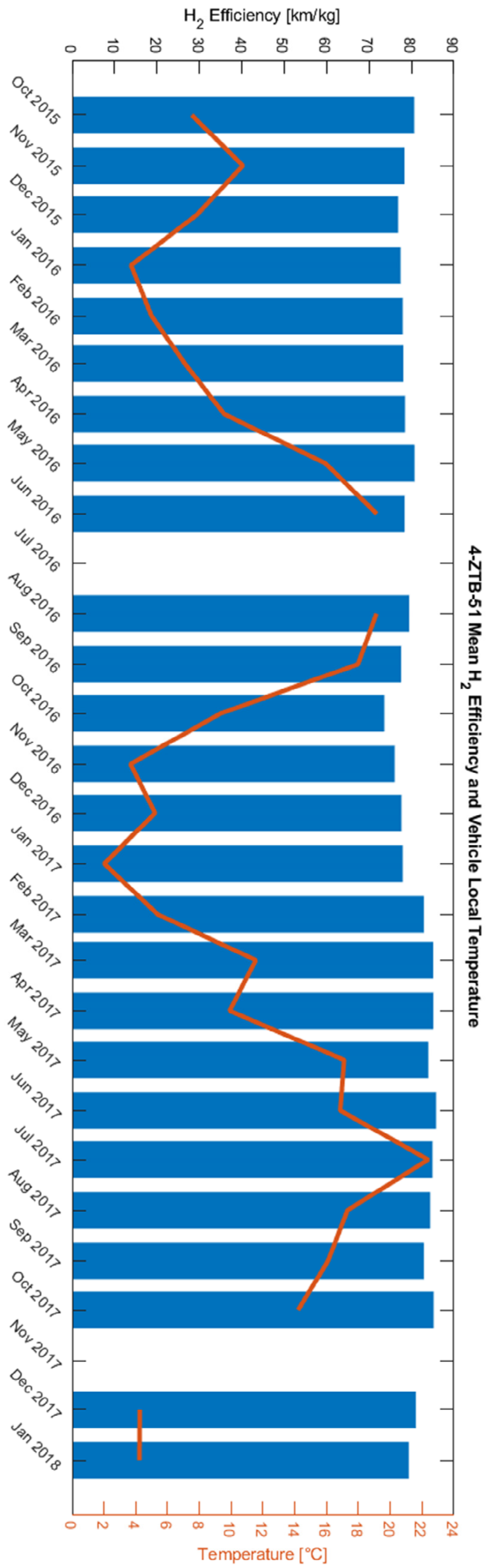
Appendix 25 Fuel Efficiency and Ambient Temperature – Rhoon vehicle



Year	Month	FE km/kgH_2	T °C
2015	11	80,3	13,1
2015	12	80,1	10,7
2016	1	79,4	5,3
2016	2	79,5	6,3
2016	3	79,8	6,3
2016	4	80,7	10,4
2016	5	82,5	16,0
2016	6	82,1	17,4
2016	7	81,5	18,8
2016	8	81,0	19,5
2016	9	81,8	16,5
2016	10	82,1	11,9
2016	11	79,8	6,6
2016	12	79,5	6,0
2017	1	78,2	2,7
2017	2	78,5	6,5
2017	3	NaN	NaN
2017	4	NaN	NaN
2017	5	NaN	NaN
2017	6	NaN	NaN
2017	7	NaN	NaN
2017	8	NaN	NaN
2017	9	NaN	NaN
2017	10	75,9	15,0
2017	11	82,1	8,6
2017	12	77,9	6,4
2018	1	79,2	6,0

Mean	80,1	FE km/kgH_2
Min.	75,9	
Max.	82,5	

Appendix 26 Fuel Efficiency and Ambient Temperature – Arnhem vehicle



Year	Month	FE km/kgH_2	T °C
2015	10	80,6	7,5
2015	11	78,3	10,7
2015	12	76,9	7,8
2016	1	77,4	3,7
2016	2	77,9	5,0
2016	3	78,1	7,1
2016	4	78,5	9,6
2016	5	80,7	15,9
2016	6	78,4	19,1
2016	7	NaN	NaN
2016	8	79,5	19,1
2016	9	77,6	18,0
2016	10	73,6	9,4
2016	11	76,0	3,7
2016	12	77,6	5,2
2017	1	77,9	2,0
2017	2	82,9	5,4
2017	3	85,1	11,5
2017	4	85,2	9,9
2017	5	84,0	17,1
2017	6	85,8	16,9
2017	7	84,9	22,4
2017	8	84,4	17,3
2017	9	82,9	16,1
2017	10	85,2	14,2
2017	11	NaN	NaN
2017	12	81,0	4,2

Mean	80,4	FE km/kgH_2
Min.	73,6	
Max.	85,8	