Clean energy for EU islands: Decarbonisation of Transport in Saaremaa and Ruhnu

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Decarbonisation of Transport in Saaremaa and Ruhnu

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Table of abbreviations

AC: Alternative Current
BEV: Battery Electric Vehicle
CBG: Compressed Biogas
CCS: Carbon Capture and Storage
CNG: Compressed Natural Gas
CO_2: Carbon Dioxide
DC: Direct Current
DRT: Demand Responsive Transport
DSO: Distribution System Operator
EV: Electric Vehicle
FAME: Fatty Acid Methyl Ester
LFP: Lithium Iron Phosphate
LPG: Liquid Petroleum Gas
GW: Gigawatt
GWh: Gigawatt-hour
H_2: Hydrogen
HVO: Hydrogenated vegetable oil
kW: kilowatt
kWh: kilowatt-hour
LBG: Liquid Biogas
LCOC: Levelised Cost Of Charging
LNG: Liquid Natural Gas
MaaS: Mobility as a Service
MGO: Marine Gas Oil
MW: Megawatt
MWh: Megawatt-hour
NMC: Nickel Manganese Cobalt
NO_x: Nitrogen Oxides
PV: Photovoltaic
PM: Particulate Matter
R&D: Research & Development
SMR: Steam Methane Reforming
SO_x: Sulphur Oxides
SWOT: Strengths, Weaknesses, Opportunities and Threats
TCO: Total Cost of Ownership
TSO: Transmission System Operator
V2G: Vehicle-to-Grid

1. Purpose and scope document

This report is a technological study of the decarbonisation of transport to satisfy the mobility needs of local stakeholders in Saaremaa and Ruhnu. The scope of the study covers road and maritime transport and does not address aviation.

Saaremaa (and Ruhnu) 's general goal is to reduce the number of vehicles, stop using fossil fuel-based technologies, and save money on transportation. The identified solution must be the most economically reasonable for the islands.

Several of the main objectives of Saaremaa and Ruhnu for their energy transition by 2030 are:

- Local municipality fleet should switch to the vehicle technology with the lowest possible carbon emissions (e.g. biomethane or electricity from renewable sources).
- Public buses should use renewable energy sources considering infrastructure and cost-effectiveness.
- The private transport fleet in Saaremaa should attain a 30% reduction in the use of fossil fuels.
- The private transport fleet in Ruhnu should be reduced by 70% by reducing vehicle usage or adopting electric vehicles.
- Ferry traffic between islands and the mainland should be 100% renewable.

2. Current context in Saaremaa

Saaremaa is an island with an area of 2,718 km^2 and a population of 32,129 as of the beginning of 2024.[1] The largest town in Saaremaa is Kuressaare, which has a population of 12,632.[2] The island experiences a strong influx of visitors during the summer (June-August). In 2023, 83,410 guests registered in hotels in Saaremaa, which accounted for approximately 45% of the total number of visitors.[3]

2.1. Energy

The table below shows the 2023 capacity and production of different renewable energy sources in Saaremaa, cumulating a net output of 62.4 GWh. Biogas in Saaremaa comes from a sewage-water treatment plant in Kuressaare.

	Solar	**Wind**	**Biomass**	**Biogas**
Capacity in GW	0.01962	0.0129	0.0024	0.0001
Production in GWh	18.9	34.7	8.6	0.179

Table 1: Renewable energy in Saaremaa in 2023

Saaremaa has the potential for different renewable energy sources. For example, hydrogen could be produced in Saaremaa at the airport next to the port of Roomassaare. Hydrogen could be

[1] https://www.elvl.ee/elanike-arv
[2] https://www.saaremaavald.ee/sites/default/files/documents/2024-01/Saaremaa%20Teataja%202024.01.11.pdf
[3] Visitsaaremaa

produced locally from intermittent offshore wind farms' peak electricity. This energy source is considered to have a good potential from electrolyse to bunkering in Saaremaa.

Next to hydrogen, biomethane production from feedstock waste also has some potential. The biomethane production is estimated to be able to achieve a production of 30 GWh of energy, of which almost 12 GWh could be used for transportation needs (demand estimated to be 3.3 GWh for public transport in Saaremaa and Muhu and 8.6 GWh for private and local government transport).[4]

Additionally, Saare Wind Energy is developing an offshore wind farm consisting of up to 100 wind turbines with a capacity of 1,400 MW. The project started in 2015, and construction is expected to begin in 2026. The wind farm will be operational in 2028.

Finally, other investments are planned for a 16 MW PV+16 MW wind farm from Evecon and a 16 MW PV farm from Sunly, which are currently scheduled to be built near Kuressaare.

	Electricity	**Diesel**	**Petrol**	**CNG /LNG**	**LPG**	**Other biomasses in Kuressaare Soojus**
Consumption	150.1 GWh	-	-	-	-	73 GWh
Price	Avg: 0.10984 €/kWh Local Gov: 0.277 €/kWh	1.6 €/l	1.74 - 1.79 €/l.	1.189 € /kg.	0.85 €/l	30 €/MWh, without the VAT (22% in 2024).

Table 2: Energy consumption and pricing in Saaremaa in 2023.

2.2. Road transportation

In 2023, 23,503 cars and vans were registered in Saare county (Saaremaa, Ruhnu, and Muhu islands), 2,264 of which were two-wheelers and three-wheelers of the categories L1-L7. The main vehicle technologies were diesel (11,249) and petrol (11,374).

	Total	**Battery electric**	**Hybrid**	**Diesel**	**Petrol**	**CNG**	**Other**
Total in Saaremaa							
Cars	20,778	124	691	8,970	10,939	53	1 LPG
Vans	2,725	1	2	2,279	435	8	

[4] NESOI, (2021). Sustainable Estonian Islands.

Other(s) (L1-L7, 2-3 wheelers)	2,264						

Table 3: Total fleet registered in Saaremaa in 2023

The municipality fleet is mostly dominated by diesel and petrol technologies, although there are already 22 electric cars out of the 86 cars in the fleet. All vans and other vehicles are fossil fuel-based.

	Total	Battery electric	Hybrid	Diesel	Petrol	CNG	Other
Municipality fleet							
Cars	86	22	1	16	37	1	3
Vans	25			25			
Other(s)	10			7		2	1 garbage truck

Table 4: Municipality fleet in Saaremaa in 2023

The public transport fleet serves the whole of Saare County and consists of buses, taxis, a car-sharing service and micro-mobility in the form of electric scooters. Since 2021, the public bus fleet has been mainly powered by natural gas with 24 CNG vehicles. How the bus fleet is distributed depends on the needs, but in general, four buses are used in Kuressaare (two CNG and two diesel) and 27 buses for the countryside bus lines (21 CNG and six diesel). The rest are reserve vehicles and can be used for trips ordered by private companies.

The car-sharing service only uses diesel vehicles; out of 53 taxis two are already electrified, and the rest are diesel vehicles.

	Total	Battery electric	Diesel	CNG
Public transport fleet				
Bus	35		11	24
Minibus/shuttle	2		2	
Car sharing	10-15		10-15	
Taxi	53	2	51	
Electric scooters	200	200		

Table 5:Public transport fleet in Saaremaa in 2023

Table 6 and Table 7 document the municipality and public transport fleet energy consumption and mileage in 2023.

	Battery electric	Diesel	Petrol	CNG	LPG
Municipality fleet					
Cars	21,699 kWh	49,400 l	45,695 l	505.79 kg	2,222
Other(s)		39,045 l		7,198,65 kg	
Public transport fleet					
Buses		142,301 l		268,722 kg	

Table 6: Energy consumption of the municipality fleet and the buses in Saaremaa in 2023

	Annual mileage (km)
Municipality	
Cars **EVs**	1,096,516 108,496
Other(s) **CNG** **LPG**	144,952 51,889;8 31,975
Total	1 433,829
Public transport	
Buses	1,934,172.3

Table 7: Annual mileage of the municipality and public transport fleet

Concerning the EV infrastructure, the latest information (2021) suggests that the infrastructure consists of 16 public charging points in Saare County and that the overall goal is to achieve 126 chargers by 2030. The estimated number of electric vehicles in 2030 would be 2,500 units.[5]

[5] NESOI, (2021), Sustainable Estonian Islands.

2.3. Maritime transportation

The access routes to Saaremaa are mainly by ferries and smaller airplanes. The ferry routes are an important mode of transportation between the islands and the mainland. Therefore, the transition to emission-free solutions must occur continuously and with known and well-tested technologies, so that operations take place undisturbed.

SHORT FACTS:

The Ferry line between Saaremaa (Muhu island) and Virstu consists of 2 big ferries, not only in Saaremaa waters**.**

- There is a land bridge between Saaremaa Island and Muhu island;
- Distance between Saaremaa (Muhu) and the mainland is 6 km;
- For this distance, it is a 26-minute ferry ride;
- One ferry has been converted to a hybrid solution with batteries (diesel as fuel);
- There is a wind farm on the mainland that can help with recharging the ferries.

Apart from a single ferry, all the ferries on the routes between Saaremaa and the mainland are exclusively powered by diesel, more specifically MGO. MGO is a fuel very similar to diesel but has a higher density (mass to volume ratio). Further insight into the individual ferries follows below.

The crossing between the mainland and Saaremaa is covered by two ferries and a stand-by ferry. The two main ferries, “Piret” and “Tõll”, are both double-ended types and were delivered as new builds for the route in 2017. The operator of the ferries is TS Laevad OÜ.

Figure 1: Piret

Figure 2: Tõll

In 2020, Tõll was retrofitted to become Estonia's first hybrid passenger ferry. This upgrade involved installing battery banks to complement its existing diesel engines, enabling partial travel on electricity. The retrofit aimed to reduce diesel consumption by 20%, cutting CO_2 emissions by approximately 1,600 tons annually. In 2023, the retrofit enabled a 16% reduction in fuel consumption compared to 2019 for the combined Saaremaa and Hiiumaa mainland lines. Additionally, this conversion helped reduce underwater noise and vibrations, enhancing the vessel's environmental friendliness.

Tõll represents a significant step in Estonia's efforts to modernise its ferry fleet with greener technologies, aligning with broader climate goals and reducing the environmental impact of maritime transport in the region.

The standby ferry “Regula” was built in 1971 and was previously used on the route between Denmark and Sweden (Helsingør and Helsingborg). Regula is used when one of the other two ferries must be docked. Regula is also called to cover the route to Hiiumaa when one of the two ferries is not navigable.

Figure 3: Stand-by ferry Regula.

The capacity of the two routes has been the subject of much discussion because there are often long waiting lines for the ferries during the high seasons. There have also been long periods when Piret was taken out of active operation due to mechanical damage. Therefore, there is a desire to increase the capacity.

The ferries are a key component for the connection to Saaremaa but comprise a significant portion of the energy consumption and carbon dioxide emissions of the islands' public transport. In 2020, the ferry route between the mainland and Saaremaa consumed approximately 2.3 million litres of diesel, resulting in over 6,000 tonnes of CO_2 emissions.

Sea transport **between Saaremaa and Hiiumaa** is carried out by the ferry “Soela”. The ferry, operated by Kihnu Veeteed, falls under the responsibility of the central government (Transportation Board). Soela is a 45 m double ended ferry, delivered in 2017, powered by two diesel engines each producing 1,000 kW with azimuth thrusters giving high manoeuvrability. Soela is built and registered as Arc4 ice class, comparable to 1A ice class. Soela can carry up to 200 passengers and 30 cars. The crossing is about 1 hour.

Figure 4: Soela. Source: Baltic Workboats

The **island of Vilsandi** in Saaremaa Parish of Estonia's Saare County is in the Baltic Sea. It covers an area of some 9 km^2 and is the westernmost populated island in Estonia. The surrounding waters are shallow and can be reached by boat or by truck with a suitable clearance or on foot by wading from Saaremaa. Much of the island is now part of Vilsandi National Park

The small watercraft named Vilsandi fits 11 passengers and is organised by the local municipality

Figure 5: Motorboat Vilsandi. Source: Visit Saaremaa

Figure 6: route map. Source: Visit Saaremaa

Figure 7: Ferry Abro. Source: AS Saarte Liinid

Figure 8: route map

The Ferry Abro is 15 m long and 4.5 m width, 302 kW diesel engine, 24 passengers. It rides **between Saaremaa and Abruka** and has a crossing time of approximately 1 hour.

A project for ferries using renewable energy was announced by the State Fleet Authority for an international tender for constructing the first renewable ferry. However, the idea was abandoned.[6]

Figure 9: Design proposal from Loyd´s Register.

2.4. Energy consumption and emissions

Based on Table 8 the most important transportation group to decarbonise is private transport, which accounts for 48,200 tCO2 emissions. Ferries are the second group emitting the most, with 6,070

[6] https://maritime-executive.com/article/estonia-proceeds-with-innovative-hydrogen-electric-ropax-ferry.

tCO2—the public transport and local government fleet account for 710 and 390 tCO2, respectively. The aviation group emits 680 tCO_2 but is out-of-scope for this report.

Consumer group	District heating, MWh/yr	Fuels, MWh/yr	Electricity, MWh/yr	Total energy consumption, MWh/yr	CO_2 emissions, tCO_2	Renewable energy sources, MWh/yr
Local govt buildings	9640	3270	2700	15 600	1830	11 500
Street lighting	-	-	930	930	510	-
Business sector	24 330	116 230	99 910	240 470	59 720	116 940
Building sector	29 640	66 760	54 580	150 970	29 950	96 130
Private transport	-	184 740	-	184 740	48 200	5730
Local govt vehicles	-	1480	-	1480	390	50
Public transport	-	3110	-	3110	710	100
Total	63 610	375 590	158 110	597 310	141 300	230 430
Ferries	-	22 830	-	22 830	6070	7
Aviation	-	2730	-	2730	680	-
Total	63 610	401 150	158 110	622 870	148 060	230 440

Table 8: Saaremaa 2020 Emission Inventory. Source: NESOI

3. Current context in Ruhnu

Ruhnu is a small island consisting of $12km^2$ and 141 inhabitants, of which 60 are permanent residents.[7]

3.1. Energy

In 2018, Enefit Green, an Estonian state-controlled renewable energy company, deployed renewable energy solutions in Ruhnu. The implementation consists of 212 kW of solar panels, 50 kW of wind turbines, a battery storage system with a capacity of 222 kWh, and two 160 kW biodiesel generators. In total, the solar and wind energy sources provided approximately 52% of the consumed energy in 2023.

3.2. Road transportation

Road transportation in Ruhnu mainly consists of old vehicles with high emissions. The island has one main road from the village to the port.

3.3. Maritime transportation

Ruhnu is in the Gulf of Riga and is connected between April and October by the ferry Runö. The ferry is a 24 m catamaran RoPax capable of carrying up to 60 passengers and two passenger vehicles (up to 6.5 m). During the winter season, the ferry route is closed, and all transportation is replaced by a small 8-seat plane.

The ferry routes from and to Ruhnu are long:

- The distance to/from Saaremaa is 74 km;
- The distance to/from the closest port on the mainland is 75 km;
- The distance to/from Pärnu is 100 km.

[7] NESOI, (2021). Sustainable Estonian Islands.

Figure 10: 24m Catemaran RO-Pax ferry, Runö - source MarineLink.

Figure 11: Gulf of Riga

3.4. Energy consumption and emissions

The long crossing to Ruhnu and the desire for a faster crossing time contributed to the delivery of the Runö ferry in 2012. It reduced the crossing time by 50% compared to the previous ferry. As a catamaran, Runö can sail up to 25 knots with the two diesel engines with a total power of approximately 1,100 kW.

The fuel consumption makes up for the speed, and the ferry uses around 164,000 litres annually.

The most important transportation mode to decarbonise in Ruhnu is the ferries. Ferries account for 436 tCO_2 emissions. Private transport is the second group emitting the most emissions with 32 tCO_2. Comparatively, public transport does not emit much CO_2. with 1 tCO_2. The aviation group emits 43 tCO_2 but is out-of-scope for this report.

Consumer group	Fuels, MWh/yr	Electricity, MWh/yr	Total energy consumption, MWh/yr	CO_2 emissions, tCO_2	Renewable energy sources, MWh/yr
Local govt buildings	64	83	147	-	107
Street lighting	-	7	7	-	7
Business sector	155	322	477	34	350
Building sector	525	123	648	-	648
Private transport	122	-	122	32	4
Local govt vehicles	-	-	-	-	-
Public transport	5	-	5	1	0.2
Special consumers (lighthouse, radar, mobile communication mast)	-	65	65	-	65
Total	871	601	1472	67	1182
Ferries	1640	-	1640	436	-
Aviation	172	-	172	43	-
Total	2683	601	3284	546	1182

Table 9: Ruhnu 2020 Emission Inventory. Source: NESOI

4. Technological analysis

This section discusses the different technologies for road and maritime transport that allow net zero emissions to be reached.

4.1. Road transportation

This section will mainly discuss passenger vehicles and heavier transport modes, such as buses, where applicable.

4.1.1. BEVs

4.1.1.1. Technology

BEVs are vehicles that operate using an electric drivetrain and a battery that stores the electricity, serving as an energy vector for the motor to propel the vehicle. BEVs can be considered a mature vehicle technology with considerable penetration in the European market. In 2023, there were almost 4.4 million BEVs registered in the EU's passenger fleet and 17,000 buses[8] Last year, the EU's market share for BEVs in passenger cars was almost 15%, and the market share for buses was around 7%. These values have continuously increased since 2019, denoting that battery electric technology is already finding its place in the current market. However, this effect is more limited in Estonia, where only 4,575 BEVs are registered, which accounts for almost 8% of the passenger vehicle registrations.

Lithium-ion-based battery technologies, such as LFP and NMC batteries, are currently state-of-the-art. LFP batteries are battery chemistry based on Lithium, Iron, and Phosphate elements, while NMC batteries are based on Lithium, Nickel, Manganese, and Cobalt. The main advantage of LFP batteries is their lower cost and high cycle life, and they are generally considered safer. NMC batteries are considered more performant than LFP batteries (higher energy density) but come at a higher cost.

Although the technology is mature, there is still a lot of research ongoing to improve the performance of the batteries (i.e., charging speed and driving range) and reduce their cost. Battery research mostly focuses on increasing energy density to reach higher densities that would allow heavier vehicle applications (i.e., long-haul trucks, aviation, etc.). More performant charging infrastructure is being developed to improve charging speed. Meanwhile, another focus is scaling the production and improving the manufacturing process to reduce the battery cost per kilowatt hour.

4.1.1.2. Cost

The main drawback of battery electric vehicle technology is its high upfront cost, which is mainly driven by the current cost of producing lithium-ion batteries.

However, on a TCO level, BEVs can already be cheaper than gasoline vehicles in specific cases (i.e., high yearly mileage).[9] This is mainly due to the technology's advantage of having low operating costs compared to other vehicle technologies. Given the possibility of charging the battery of an electric vehicle at a private location (i.e., home, office or depot) that benefits from low electricity prices, the running costs for the electric vehicle can be minimised.

Given the expected decreasing cost of batteries, the high purchase price of battery electric vehicles is expected to decrease accordingly. According to Bloomberg, BEVs for all passenger car segments should reach purchase price parity with internal combustion vehicles by 2028 at the latest.[10]

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[8]European Alternative Fuels Observatory (2024). Vehicles and fleet. URL: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/vehicles-and-fleet

[9] Scorrano, M., Danielis, R., & Giansoldati, M. (2020). Dissecting the total cost of ownership of fully electric cars in Italy: The impact of annual distance travelled, home charging and urban driving. *Research in Transportation Economics, 80*, 100799.

[10] Bloomberg NEF (2023). Electric Vehicle Outlook 2023.

Purchase price parity will positively impact the TCO perspective for BEVs, where their advantageous operating costs will result in a positive case compared to other vehicle technologies.

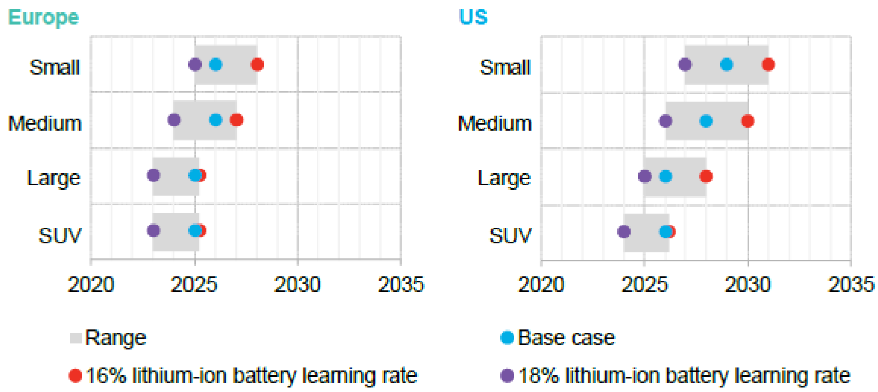

Figure 12: Purchase price parity forecast for the small, medium, large and SUV car segment in both Europe and the US. Source: BNEF.

Concerning buses, the TCO of battery electric buses is generally competitive compared to diesel buses and more positive than that of other alternative fuel buses.[11,12] Most TCO analyses for buses consider a fleet rather than an individual vehicle. This means these analyses also include infrastructure costs that are split across the number of buses considered in the fleet.

4.1.1.3. Energy/Environment

Two important environmental advantages of BEVs are the possibility to recharge only with electricity from renewable energy sources and zero tailpipe emissions while driving. These advantages translate into an advantageous life cycle assessment for BEVs, even including the often-criticised battery manufacturing. A life cycle assessment includes the emissions of all vehicle components and fuel or electricity production. As shown in Figure 13 (with Europe in 2021 as scope) and Figure 14 (with Europe in 2030 as scope),[13] the life cycle assessment of BEVs is lower than that of conventional vehicles, even when they are a biofuel/biogas blend, both now and in the future. The life cycle assessment is even more beneficial when using only electricity from renewable energy sources.

[11] Kim, H., Hartmann, N., Zeller, M., Luise, R., & Soylu, T. (2021). Comparative TCO analysis of battery electric and hydrogen fuel cell buses for public transport system in small to midsize cities. *Energies, 14*(14), 4384.
[12] Say, K., Brown, F. G., & Csereklyei, Z. (2024). The economics of public transport electrification: When does infrastructure investment matter?. *Applied Energy, 360*, 122809.
[13] The International Council of Clean Transportation (2021). A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars.

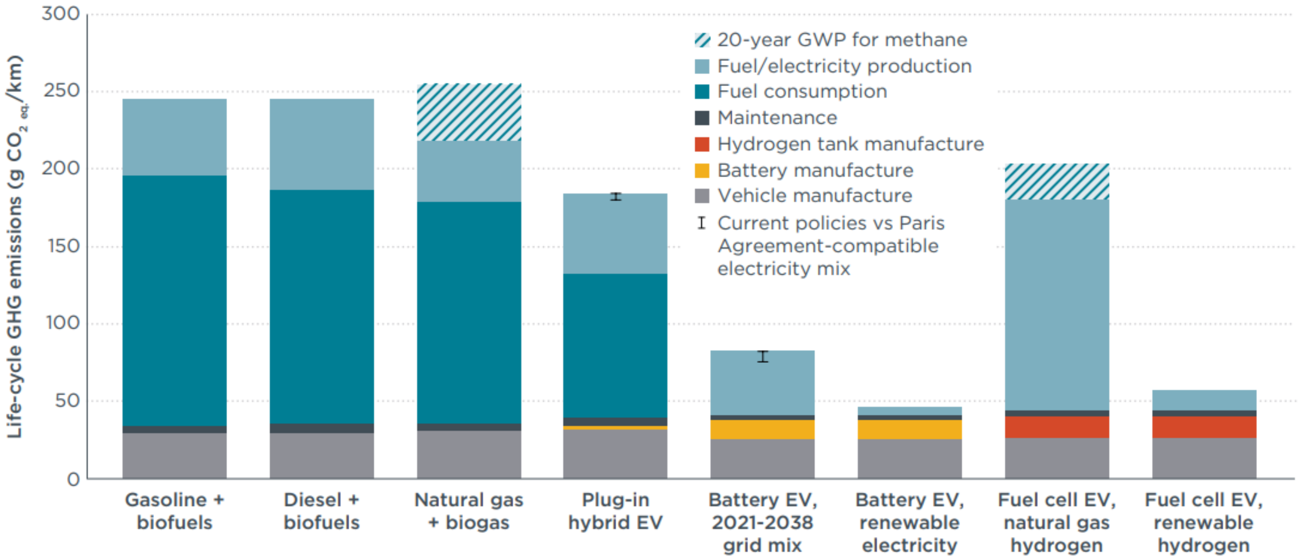

Figure 13: Life cycle assessment of various vehicle technologies considering vehicles from the medium car segment in 2021 with Europe as scope. Source: ICCT.

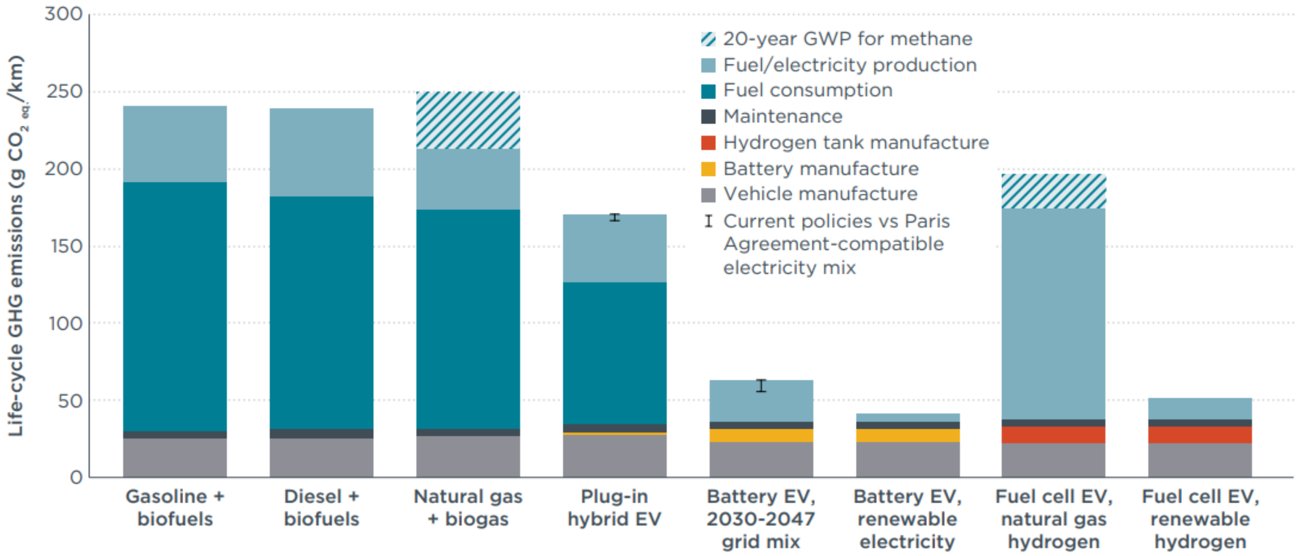

Figure 14: Life cycle assessment of various vehicle technologies, considering vehicles from the medium car segment in 2030, with Europe as the scope. Source: ICCT.

Another advantage in terms of energy is that BEVs are the most energy-efficient technology. This means that from a well-to-wheel perspective (energy production to energy use), BEVs have the least energy loss, as illustrated in Figure 15.[14] This is mainly due to the electric grid's reliability, with few losses and efficient energy transmission and use from the grid to the wheels.

[14] Transport & Environment. Direct electrification most efficient by far.

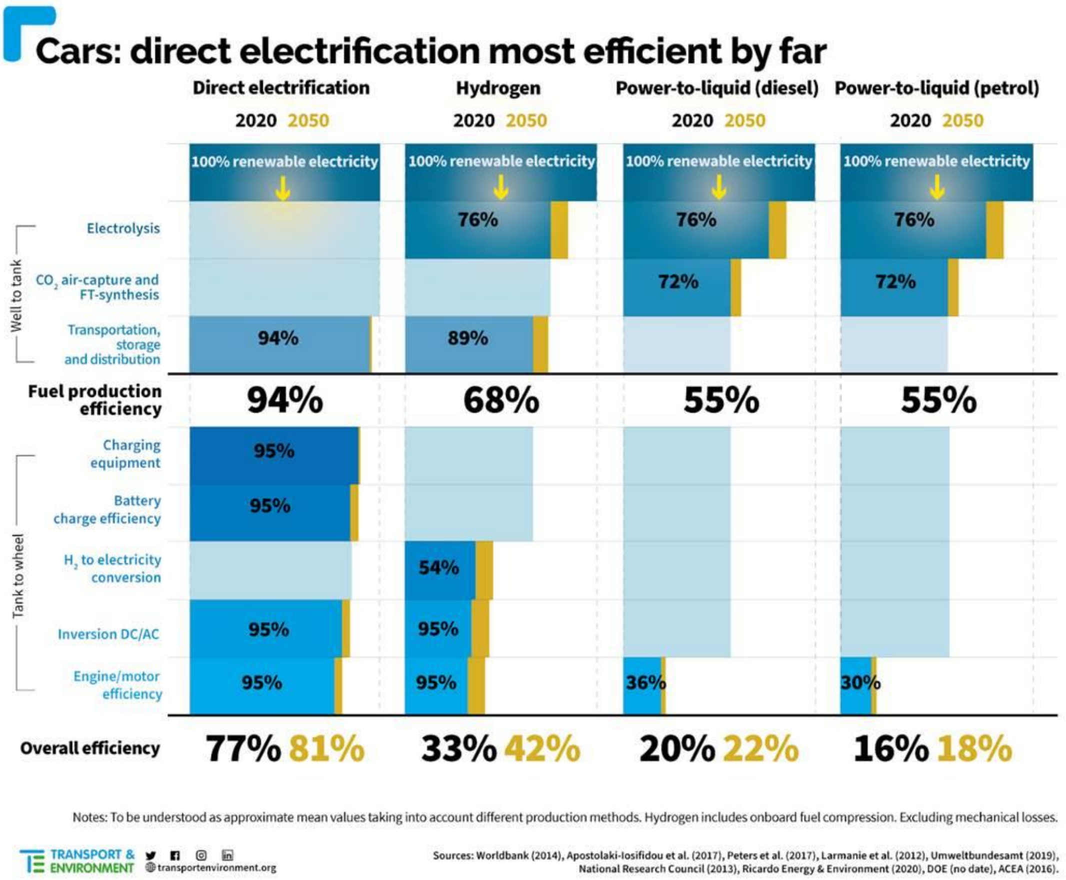

Figure 15: Energy efficiency cars with different drivetrains. Source: Transport & Environment

4.1.1.4. Infrastructure

As shown in the table below, the charging infrastructure already in place in the EU is more than 650,000 charging points.[15] This number is already very consequential, given that it translates to 6 BEVs per charging point in Europe. The amount of deployed charging infrastructure in Estonia seems much lower compared to the total amount in Europe; however, proportionally, it follows the same pattern with 1 charging point for 6 BEVs, therefore following its own growth.

Type of charging infrastructure	**European Union**	**Estonia**
AC charging **7,4 kW <= x <= 22 kW**	494,515	404
DC charging **<= 50 kW**	22,261	100
Fast DC charging **50 kW <= x < 150 kW**	7,153	110

[15] European Alternative Fuels Observatory (2024). Infrastructure. URL:: https://alternative-fuels-observatory.ec.europa.eu/transport-mode/road/european-union-eu27/infrastructure

Ultra-fast DC charging – level 1 150 kW <= x < 350 kW	31,569	96
Ultra-fast DC charging – level 2 >= 350 kW	39,045	22
Total	663,351	732

Table 10: Number of charging points per type installed in the EU and Estonia in March 2024. Source: EAFO.

Although the charging infrastructure of the EU is already quite developed, most of it is concentrated in Western Europe as demonstrated in Figure 16 (i.e., The Netherlands, Germany and France). This means that in for example in Eastern Europe, there is currently less infrastructure density.

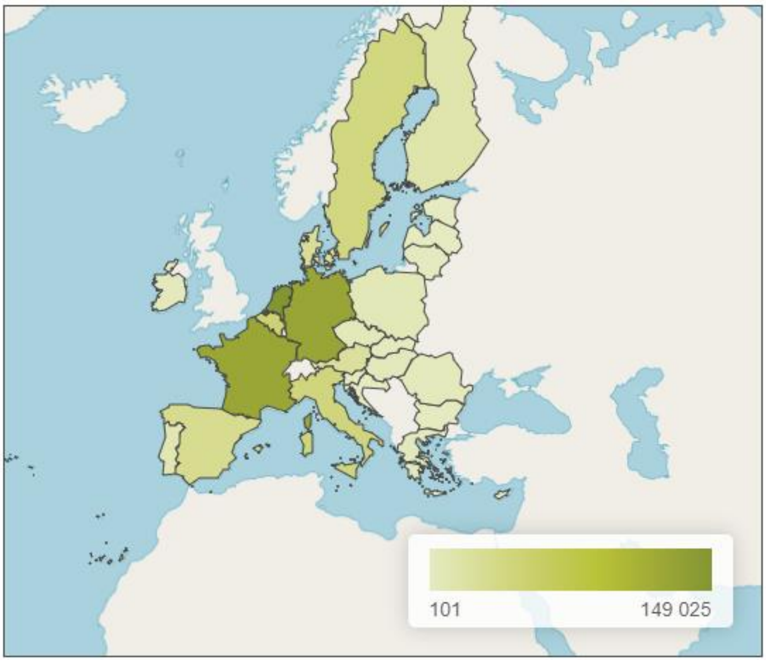

Figure 16: AC and DC charging points in the EU. Source: EAFO.

Concerning costs, the average cost of an AC charging infrastructure point in European cities (7 kW) is between € 4,000 and € 10,000, depending on the hardware cost and related installation costs (e.g., permits, and labour).[16] The price of DC charging infrastructure (50 kW) in urban areas is often around € 50,000 but can range up to € 150,000.[17] In remote locations, the cost can ramp up significantly if the location does not benefit from desirable electric infrastructure. In general, adding multiple charging points to the same location can spread the installation costs over the multiple points, which results in economies of scale.[18]

[16] The International Council of Clean Transportation (2021). Efficient planning and implementation of public chargers: Lessons learned from European cities.
[17] Gamage, T., Tal, G., & Jenn, A. T. (2023). The costs and challenges of installing corridor DC Fast Chargers in California. *Case Studies on Transport Policy, 11*, 100969.
[18] The International Council of Clean Transportation (2019). Estimating electric vehicle charging infrastructure costs across major U.S. metropolitan areas.

The LCOC represents the cost of operating the infrastructure (including equipment, installation, operation and maintenance), as well as the energy and transaction costs for charging. Estonia is on the lower end of the LCOCs in the EU.[19] This means that Estonia might have an interesting case for private electric vehicles (i.e., low-cost home charging) and for a Charge Point Operator operating a public infrastructure network, especially compared to other European countries such as Denmark, Belgium, Switzerland or Germany.

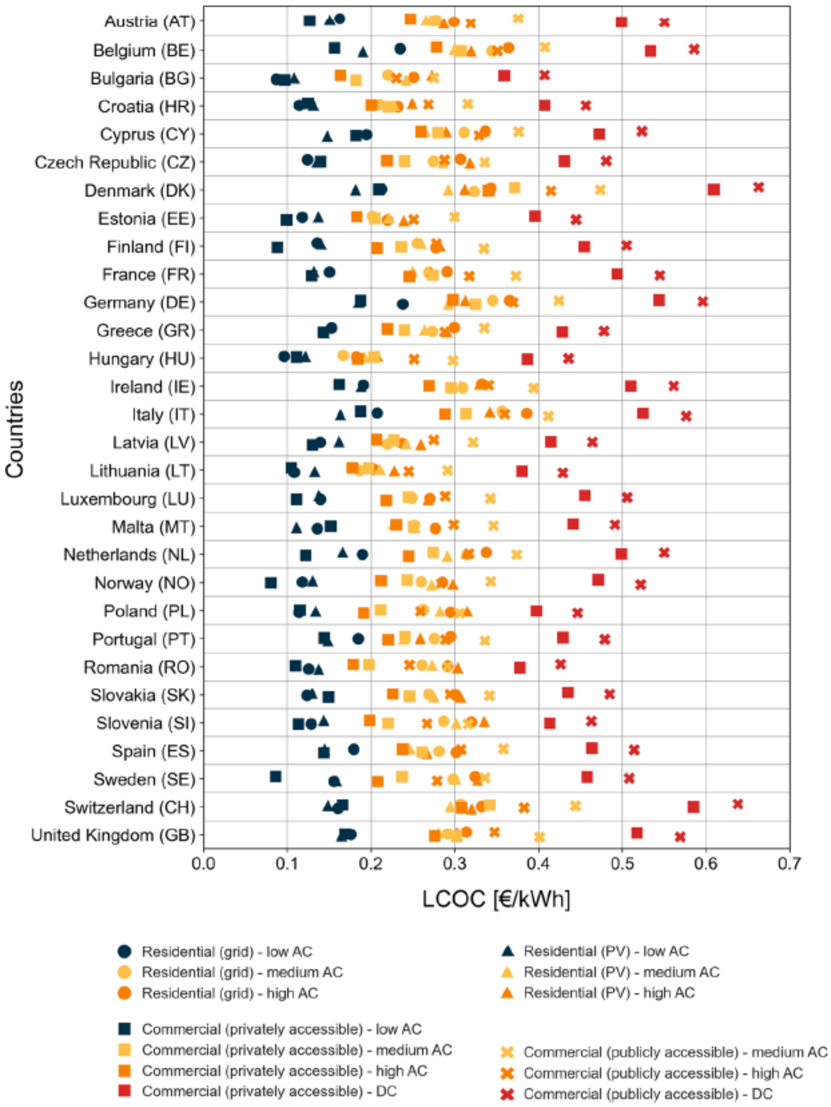

Figure 17: LCOC results in € per kWh of energy charged of different charging options in European countries. Source: Lanz et al. (2022).

One big concern about having a high penetration of electric vehicles and charging infrastructure is the expectation of creating a high load on the electric grid, especially at peak times. Therefore, reinforcing the local electric grid should be considered when installing new charging infrastructure.

Additionally, technologies exist to smoothen the charging load. Smart charging, for example, distributes the charging requirements to smooth the charging curve and spread the load over time. Another more long-term-oriented application is vehicle-to-grid (V2G). Charging infrastructure

[19] Lanz, L., Noll, B., Schmidt, T. S., & Steffen, B. (2022). Comparing the levelized cost of electric vehicle charging options in Europe. Nature Communications, 13(1), 5277.

supporting this technology enables electric vehicles to return electricity to the grid when additional capacity is required.

Both smart charging and V2G can be technologies that work together to support the electricity grid and charging infrastructure as the number of electric vehicles increases.

4.1.1.5. SWOT for electric vehicles for road transport

STRENGTHS	**WEAKNESSES**
- Low operating cost - Low installation cost per charging point - Possibility to recharge the vehicle at home, office, bus stop, … - Energy-efficient technology - Can be recharged on 100% renewable electricity - Technology is mature and commercially available for various transport modes	- High upfront cost - Limited maximum range compared to conventional vehicles - Lower charging speed than refuelling (30 minutes at fast charging)
OPPORTUNITIES	**THREATS**
- The battery technology is expected to improve energy density, increasing the range and reducing the upfront cost of the vehicles - A large European infrastructure is already existing - Expected decreasing Total Cost of Ownership	Cold or hot climates can impact the range of the vehicle due to the use of auxiliary equipment (e.g., air conditioning). - The increasing cost of the vehicles due to metal shortages. - Slowdown in technological innovation that hinders to decarbonise heavier vehicles with batteries. - Electricity needs to be produced through renewable energy sources.

4.1.2. Biogas/fuels

4.1.2.1. Technology

There exist different kinds of biogas/fuels, among which the following are the most advanced and already commercially available: [20]

- FAME: biodiesel derived from triglycerides and lipids through an esterification process;
- HVO (Hydrotreated vegetable oil): biodiesel derived from triglycerides and lipids through a hydrotreating and refining process;
- Bioethanol: derived from sugar and starch crops through a fermentation process;
- Biomethane: obtained by upgrading anaerobic digestion biogas.

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[20] IEA Bioenergy (2023). Transport biofuels. URL: https://www.ieabioenergyreview.org/transport-biofuels/

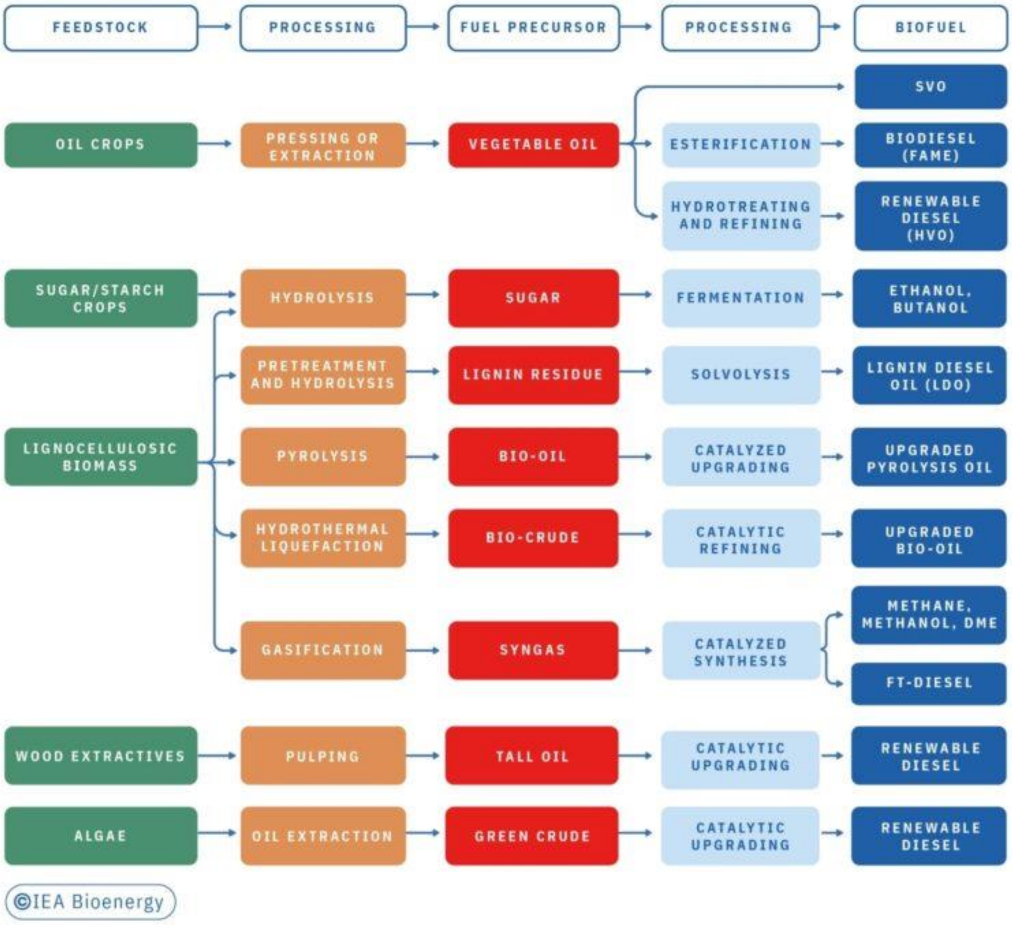


Figure 18: Production process of different biofuels. Source: IEA Bioenergy

Bioethanol, FAME, and HVOs are the most commonly used biofuels for road transportation. Bioethanol and FAME are currently almost exclusively used as blends. If the fuel is used as drop-in fuel (in its pure state), then conventional vehicle engines would require some adaptation to the fuel. Contrarily to FAME and bioethanol, HVO has the same structure as diesel and can, therefore, be used as drop-in fuel in the current diesel engines.[21] This is, for example, becoming more common in a freight context where pure HVO fuel is used as a decarbonisation pathway for larger vehicles. Similarly to HVO, biomethane can be used as a direct substitute for natural gas in vehicles without the need to adapt the engine to the fuel.

As hinted above, biofuels are mainly used for freight, especially in light-duty vehicles. However, biofuels are expected to be a future decarbonisation solution for heavier transportation modes, such as heavy-duty vehicles, aviation or maritime transport.

4.1.2.2. Cost

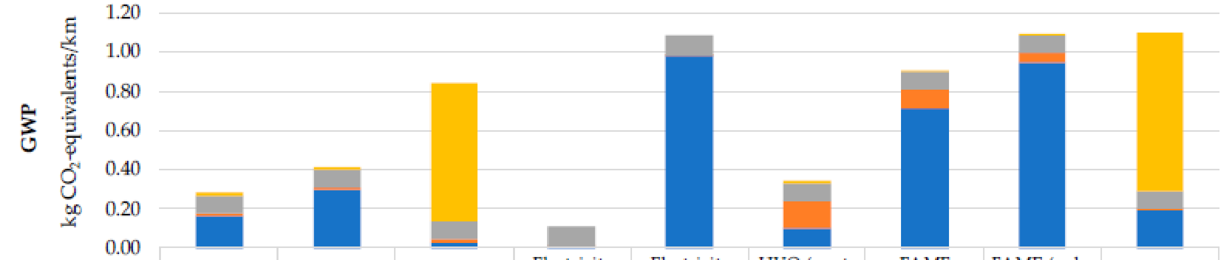
The production costs of transport biofuels are usually higher than those of fossil fuels. However, in Estonia, you can buy biomethane at the exact cost of CNG (1.19 €/kg from https://cngeurope.com/), making it a perfect replacement for CNG-based vehicles.

[21] Suarez-Bertoa, R., Kousoulidou, M., Clairotte, M., Giechaskiel, B., Nuottimäki, J., Sarjovaara, T., & Lonza, L. (2019). Impact of HVO blends on modern diesel passenger cars emissions during real world operation. *Fuel, 235*, 1427-1435.

Regarding the vehicle costs, existing CNG and diesel vehicle models can be combined with biomethane or HVO.

4.1.2.3. Energy/Environment

Regarding the global warming potential based on the life cycle of a bus, biomethane (biogas) buses have still higher global warming potential than compared to a battery electric bus[22]Even if biomethane is considered net zero emissions, it still emits CO2 emissions and, therefore, pollutes locally. However, biomethane from food waste or manure is still better than diesel, electricity produced from coal, or FAME biofuels.



	Biogas: Food waste	Biogas: Manure	Natural gas	Electricity: Electricity hydropower	Electricity: Electricity coal power	Biodiesel: HVO (waste cooking oil)	Biodiesel: FAME (rapeseed)	Biodiesel: FAME (palm oil)	Fossil diesel
Driving	0.01	0.01	0.70	0.00	0.00	0.01	0.01	0.01	0.81
Vehicle	0.09	0.09	0.09	0.10	0.10	0.09	0.09	0.09	0.09
Distribution	0.01	0.01	0.02	0.01	0.01	0.14	0.09	0.04	0.00
Production of fuel	0.17	0.30	0.03	0.00	0.98	0.10	0.71	0.95	0.20

Figure 19: Life Cycle Analysis of the global warming potential for different biofuels, electric and diesel vehicles: Source: Lyng & Brekke, (2019).

4.1.2.4. Infrastructure

The current CNG infrastructure does not need biomethane adaptations. There are currently 23 CNG stations in Estonia, one of which is in Kuressaare.[23]

4.1.2.5. SWOT for biofuel vehicles for road transport

STRENGTHS	**WEAKNESSES**
- Biogas has net zero emissions	- Still emits emissions and therefore still pollutes locally with undesirable side effects on nature and health - Cannot be scaled for the complete region and will therefore only be usable for specific applications such as buses
OPPORTUNITIES	**THREATS**

[22] Lyng, K. A., & Brekke, A. (2019). Environmental life cycle assessment of biogas as a fuel for transport compared with alternative fuels. *Energies, 12*(3), 532.
[23] CNG Europe (2023). Estonia. URL: https://cngeurope.com/countries/estonia/

- Use biomethane instead of CNG for the existing bus fleet to have a quick and economical transition to renewable energy for public transport - Use existing waste/residue feedstock for a useful application	- Limited availability of waste/residues for fuel production - Legislation forbidding the use of biofuel vehicles

4.1.3. Hydrogen

4.1.3.1. Technology

Hydrogen vehicles are electric vehicles equipped with a fuel cell that converts hydrogen into electricity for the electromotor.

There are different classifications of hydrogen, with the main ones being:

- Grey hydrogen: is hydrogen generated from natural gas through steam reforming. This is often considered as one of the least desirable sources of hydrogen due to the emissions during its production.
- Blue hydrogen: is hydrogen generated from steam reforming natural gas, but where a large amount of CO_2 is captured and stored. This hydrogen production method is, therefore, less damaging to the climate than grey hydrogen.
- Green hydrogen: is the cleanest production pathway for hydrogen, generated from renewable energy sources such as the sun or the wind.

Polymer electrolyte fuel cells are the best fuel cell technology for road transport. They have the advantages of high-power density, low operating temperature, quick start-up, and fast dynamic response.[24] This technology can be subdivided into two different types: the proton-exchange membrane and the anion-exchange membrane fuel cells. While the proton-exchange membrane technology has improved a lot during the last decades, the research focus has shifted more towards the anion-exchange membrane fuel cells due to its potential to alleviate the technical challenges of cost reduction and easier water management for the fuel cell.

Fuel cell technology is expected to be an interesting alternative to BEVs in the long term in cases where electrification through batteries is less evident, i.e., heavier vehicles that drive long ranges, such as intercity buses (300-500 km), coaches (>500 km), or long-haul trucks.[25]

Currently, only two vehicle models are available for cars: the Hyundai Nexo and the Toyota Mirai. The WLTP range of these models are of 666 km and 650 km, respectively, which is still superior to the higher range electric vehicles such as the Tesla Model S (600 km), but hydrogen vehicles still have an edge compared to more mainstream models such as the Volkswagen ID3[26] (between 392 and 558 km, depending on the model).

More models are available for buses, e.g. from European manufacturers Solaris, Van Hool or Wright. Most fuel cell buses have ranges between 300 km and 500 km. These buses are therefore seen as good opportunities for intercity operation, where longer distances are driven.

[24] Das, P. K., Barbir, F., Jiao, K., Wang, Y., & Li, X. (2023). Fuel cells for transportation—an overview. *Fuel Cells for Transportation*, 1-28.
[25] Hydrogen Europe (2024). Long-term outlook on zero-emission mobility.
[26] https://www.volkswagen.ee/et/chose-your-volkswagen/models/the-new-id3.html

4.1.3.2. Cost

Similarly to electric cars, hydrogen cars are characterised by their high upfront cost.

Regarding the purchase cost of two existing hydrogen passenger car models, the Hyundai Nexo has a retail price of €76,490[27] and the Toyota Mirai 2 has a retail price of €72,200.[28] To compare, the Hyundai Nexo is almost double the price of Hyundai Kona, a somewhat smaller electric and less powerful SUV from the same brand (€38,490).[29] A within-brand comparison can be made for the Toyota Mirai 2 with the Toyota bZ4X, the only electric car that Toyota manufactures (€56,900).[30] Regarding hydrogen buses, their purchase price ranges between €570,000 and €650,000 per unit for European Original Equipment Manager.[31]

The TCO for hydrogen vehicles is higher than diesel, petrol or electric vehicles.[32] The TCO of fuel cell cars is expected to drop significantly by 2050, resulting in a TCO equivalent to that of diesel and petrol cars. However, battery electric cars will still have a lower TCO than hydrogen cars.

The TCO of hydrogen buses is often considered higher than that of electric buses, even when infrastructure costs are taken into account.[33] The difference in TCO between a hydrogen and a battery electric bus operation, according to two case studies from the EU JIVE project, is of the order of approximately 10% higher costs for a hydrogen bus operation compared to a battery electric bus operation.[34]

The average levelized cost for hydrogen production in Europe is €9.85 across all production technologies.[35] This cost varies between € 3.89 and € 16.44, depending on the country and technology used for producing the hydrogen. Generally, steam methane reforming is used to produce hydrogen. This method is also the most cost-efficient way to produce hydrogen (€/kg in Europe, min: 4.481, median: 6.017, max: 9.567), while producing hydrogen using electricity from the grid is less cost-efficient (€/kg in Europe, min: 3.892, median: 10.617, max: 16.443). However, when the renewable energy source is directly connected to the electrolyser, the production cost can be reduced to almost similar levels to steam methane reforming (€/kg in Europe, min: 4.177, median: 6.807, max: 9.596). In the Estonian case, this is the most cost-efficient way to produce:

- Renewable hydrogen: 6.587 €/kg
- Steam methane reforming: 6.807 €/kg
- Reforming with carbon capture 7.015 €/kg
- Grid electrolysis: 8.207 €/kg

[27] https://www.hyundai.ee/mudelid/nexo/
[28] https://www.toyota.ee/new-cars/mirai
[29] https://www.hyundai.ee/mudelid/kona-electric/
[30] https://www.toyota.ee/new-cars/bz4x
[31] Joint Research Centre, Bravo Diaz, L. and Boillot, L., Historical Analysis of Clean Hydrogen JU Fuel Cell Electric Vehicles, Buses and Refuelling Infrasatructure Projects, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/892745, JRC137101.
[32] Ajanovic, A., & Haas, R. (2023). Heading towards low-carbon passenger car mobility: electricity vs hydrogen. *Renew Sust Energy, 1*, 0002.
[33] Zimmerer, A., Eckert, S. and, Roderer, V. (2023). Environmental Impacts and External Cost Benefits of FCBs and Comparison of FCBs with BEBs.
[34] https://www.fuelcellbuses.eu/projects/jive
[35] European Hydrogen Observatory (2022). Cost of hydrogen production. URL : https://observatory.clean-hydrogen.europa.eu/hydrogen-landscape/production-trade-and-cost/cost-hydrogen-production

Figure 20 shows the potential worldwide cost reduction potential for levelized costs of hydrogen production.[36] There is clearly a lot of room for improvements in hydrogen production based on renewable energy sources, but these are expected to be on the same level as steam reforming by 2030 and later.

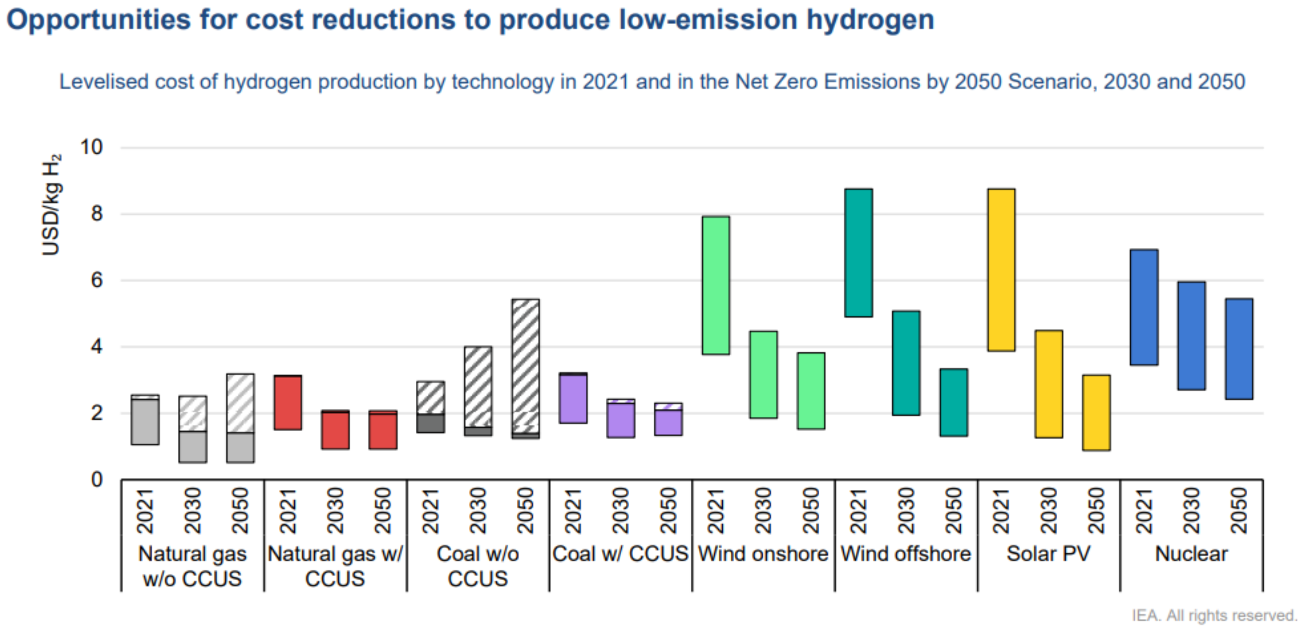


Figure 20: Current and future levelized cost of hydrogen production in the world. Source: IEA.

4.1.3.3. Energy/Environment

Hydrogen vehicles, both cars and buses, have a well-to-wheel energy efficiency of around 30%. This means that around 70% of the energy is lost due to leaks or energy conversion inefficiency.

On the environmental aspect, hydrogen vehicles have no emissions, which is positive for local air pollution. Similar to BEVs, the life cycle assessment of fuel cell vehicles is very dependent on how the hydrogen is produced.[37] Hydrogen produced from renewable energy sources gives the best life cycle assessment results, while hydrogen reformed from natural gas is almost as bad as gasoline.

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[36] IEA (2022). Global Hydrogen Review 2022. URL: https://iea.blob.core.windows.net/assets/c5bc75b1-9e4d-460d-9056-6e8e626a11c4/GlobalHydrogenReview2022.pdf

[37] The International Council of Clean Transportation (2021). A global comparison of the life-cycle greenhouse gas emissions of combustion engine and electric passenger cars.

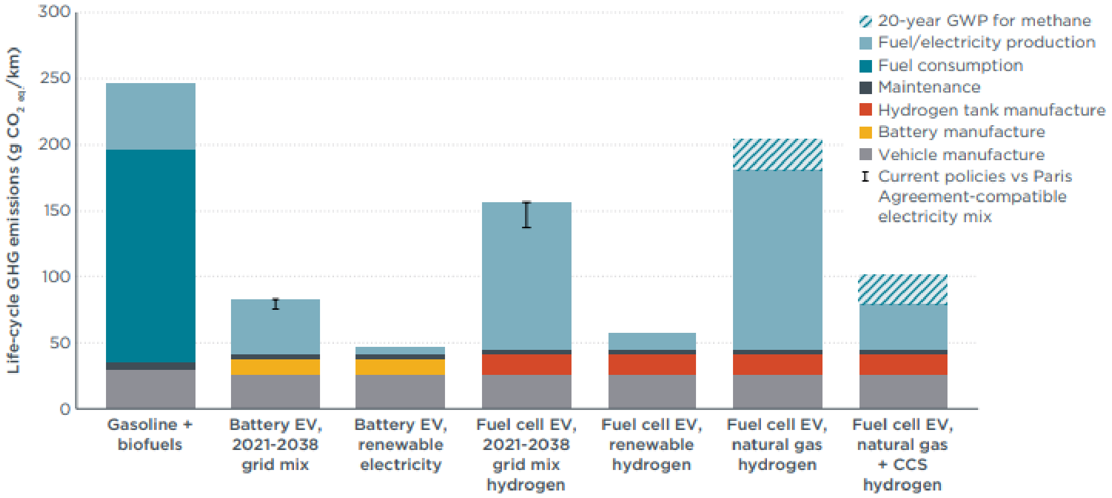

Figure 21: Life-cycle assessment of BEVs and FCEVs considering vehicles from the medium car segment in 2030 with Europe as scope. Source: ICCT.

4.1.3.4. Infrastructure

As of May 2023, 178 publicly accessible hydrogen refuelling stations were operational in Europe, with the vast majority (96 stations) in Germany.[38] This translates to a total of 254 H2 dispensers, with the majority being for cars (64% 700 bar dispensers and 21% 300 bar dispensers) and 15% for buses (350 bar dispensers). Now, there are no hydrogen refuelling stations in Estonia.

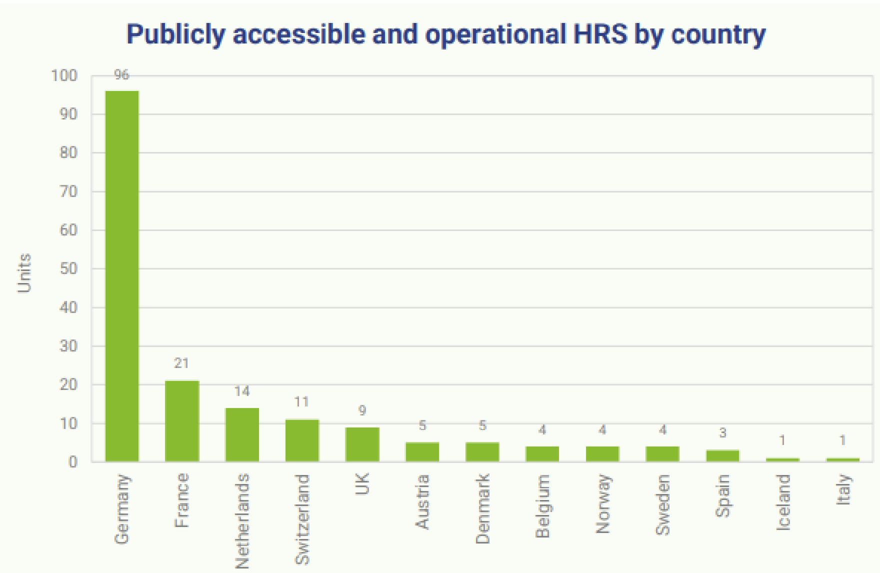

Figure 22: Hydrogen refuelling stations by country in the EU by May 2023. Source: European Hydrogen Observatory

Infrastructure costs range between € 2 and € 6 million for a median case depending on the capacity of the refuelling station.[39]

The energy efficiency of producing hydrogen from renewable energy sources is around 50% to 60% for small infrastructures and 65% to 70% for larger infrastructures.[40] Energy losses are partly due

[38] European Hydrogen Observatory (2024). The European hydrogen market landscape.
[39] Hydrogen Europe (2024). Long-term outlook on zero-emission mobility.
[40] Vodovozov, V., Raud, Z., & Petlenkov, E. (2022). Review of energy challenges and horizons of hydrogen city buses. *Energies, 15*(19), 6945.

to the electrolysis and leaks in the transportation of pipelines and storage of the hydrogen due to its low density (see Figure 15).

4.1.3.5. SWOT for hydrogen vehicles for road transport

STRENGTHS	WEAKNESSES
- H_2 can be generated based on renewable electricity - Shorter refuelling time than BEVs - Longer range than BEVs, especially for buses	- The technology is currently very expensive - There are only two car models available (Toyota & Hyundai) - There is currently no H_2 refuelling infrastructure in Estonia - Necessary infrastructure investment is very expensive - The energy efficiency of the vehicles is inferior compared to that of electric vehicles.
OPPORTUNITIES	**THREATS**
- Surplus renewable energy can be transformed into hydrogen - Creation of an infrastructure hub that could benefit both marine and heavy road transport Hydrogen vehicles could potentially help to decarbonise the heavier vehicle segments of road transport, where battery-electric technology might struggle.	- Technology is still being developed - The technology is not economically competitive yet with internal combustion and electric vehicles - Requires heavy financial investments in a technology for which it is still unknown whether the technology will be widely adopted.

4.2. Maritime transportation

4.2.1. Electrification

4.2.1.1. Retrofit solutions:

Tõll and Piret are relatively new ferries, built in 2017, and therefore have many operational years ahead of them. They were both built specifically for the Baltic Sea and are A1 ice-classed, built to operate in ice-filled waters in winter.

The route between the mainland and Saaremaa has a distance of approximately 6 km (3.2 nautical miles) and the crossing takes approximately 26 minutes, which is therefore suitable for electric ferries.

Since Tõll has already been converted to a hybrid ferry with electric propulsion and a battery pack, a retrofit to 100% electric operation will probably be the most optimal solution and the experience from Tõll can be transferred directly to the conversion of Piret.

Transitioning to electric ferries could significantly reduce emissions. This requires investment in charging infrastructure and developing renewable energy sources for electricity production.

Several ferry routes in Europe have been retrofitted to electric propulsion, including one on Regula's old workplace, the Helsingør —Helsingborg route. The two ferries, Tycho Brahe and Aura (built in 1991 and 1992), were retrofitted to 100% electric sailing with a 4,160-kWh battery pack.

The ferry route is a high-intensity route; each ferry makes 46 daily crossings. This requires an efficient charging system in each port. With an average port stay of 15 minutes, they charge 9 minutes in one port and 6 minutes in the other via an automatic charging system.

Figure 23: MF Tycho Brahe – Source ÖRESUNDLINJEN

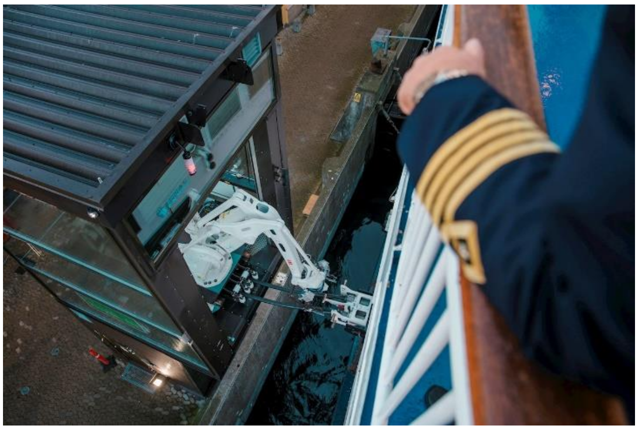

Figure 24: Charging station – Source ABB

Other Nordic all-electric ferries include:

- **Ampere**: a Norwegian ferry delivered in 2015 as a fully electric ferry, 1 MW battery pack, 20 minutes route length. Due to the low electric capacity in the local electrical grid, a 410-kWh battery pack is placed in each harbour, allowing quick charge upon arrival, which is 1 MWh in 9 minutes.
- **E-Ferry Ellen**: a fully electric ferry that operates in Denmark. It has an energy efficiency rating of 85%, significantly higher than traditional diesel-powered ferries. Ellen completed sea trials and operates on a 40-kilometer route between Danish Baltic islands. The ferry is powered primarily by wind energy, demonstrating a significant reduction in CO_2 emissions by up to 2,250 tonnes per year.

4.2.1.2. SWOT for electric ferries

STRENGTHS	**WEAKNESSES**
- Electricity has low or net zero emissions, depending on production. - Using renewable energy for production reduces local emissions to zero	- It still emits emissions and, therefore, still pollutes. - Expensive and requires investors to set up facilities for renewable energy production.
OPPORTUNITIES	**THREATS**
- Using renewable energy for electrical production can reduce or delay investments in the local electricity grid.	- Requires strengthening of the local and national power grid to ensure supply. - Ferries require a large capacity for a short period of time, which can cause instability in the electricity grid.

4.2.2. Biogas

Biogas for marine fuel must be upgraded to biomethane by removing impurities and CO_2, resulting in a high methane content similar to natural gas.

4.2.2.1. Environmental Benefits

Reduced Emissions: Biogas combustion produces significantly lower amounts of CO_2 compared to conventional fossil fuels. It also reduces emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x), which are harmful pollutants.

Carbon Neutrality: Since biogas is produced from organic waste, the CO_2 released during combustion is considered part of the natural carbon cycle, potentially making it a carbon-neutral fuel option.

4.2.2.2. Technical Feasibility

Engine Compatibility: Biogas can be used in dual-fuel engines operating on liquid fuels (like diesel) and gaseous fuels (like LNG or biomethane). These engines can be adapted for use with biogas with minimal modifications.

Infrastructure: The infrastructure required for biogas is similar to that for LNG (liquefied natural gas), which includes storage tanks and fuelling systems. Ports and bunkering facilities can be adapted to handle biogas.

4.2.2.3. Projects and Case Studies

Scandinavian Efforts: Several Scandinavian countries, particularly Norway and Sweden, are leading in the adoption of biogas for maritime use. For example, the ferry operator Stena Line has been exploring the use of biogas as a fuel alternative for its vessels.

Research and Development: Various R&D projects are being conducted to optimise biogas production, upgrading processes, and integration into marine engines. Collaboration between governments, research institutions, and private companies is crucial.

4.2.2.4. Challenges

Cost: The initial investment for infrastructure and retrofitting vessels can be high. However, long-term savings on fuel costs and environmental benefits can offset these expenses.

Energy Density: Biogas has a lower energy density than traditional marine fuels, which means that larger storage volumes are required, potentially impacting vessel design and cargo space.

4.2.2.5. Regulatory Support

Incentives and Policies: Governments and international bodies are providing incentives and establishing policies to promote using renewable fuels, including biogas, in the maritime sector. This includes subsidies, tax breaks, and regulations aimed at reducing emissions from shipping.

4.2.2.6. SWOT for biogas ferries

STRENGTHS	**WEAKNESSES**

- Biogas is considered CO_2 neutral as the emitted CO_2 during burning has been absorbed by the medium from which the biogas is produced. - Biogas is a good energy carrier where energy can be stored until it is needed.	- Establishing a reliable and scalable supply chain for biogas is a significant challenge. It requires coordination between biogas producers, suppliers, and maritime operators. - Biogas requires purification and as it contains approximately 40% CO_2, it must be separated out to achieve a gas quality (methane) that are high enough to be used in ferries. - The biogas must be converted into either liquid (LBG) or pressurised (CBG) - Liquid biogas requires continuous cooling to avoid boiloff gas. - Special requirements for bunker operations, and gas trained crew
OPPORTUNITIES	**THREATS**
- Provides the opportunity to use local bio-waste for gas production.	- Expensive rebuilding - requires conversion or replacement for gas engines and piping systems that must meet the requirements of the class companies. - Security of supply

4.2.3. Methanol

Methanol is increasingly considered an alternative fuel for ferry propulsion due to its lower emissions and ease of storage compared to other fuels.

About 110 million tons of methanol are produced each year. The production is based almost exclusively on fossil fuels and, therefore, emits significant amounts of CO_2 – for each tonne of methanol produced, approximately 1.4 tons of CO_2. The production capacity of green methanol is increasing rapidly due to high shipping demand.

4.2.3.1. Key benefits

Lower Emissions: Methanol combustion produces lower NOx, SOx, and particulate matter levels than traditional marine fuels. This makes it an attractive option for meeting stricter environmental regulations.

Ease of Storage and Handling: Methanol is a liquid at ambient temperature and pressure, simplifying storage and handling compared to liquefied natural gas (LNG) or hydrogen.

Availability and Cost: Methanol is widely available and can be produced from various feedstocks, including natural gas, biomass, and even renewable electricity through CO_2 conversion.

The ferry Stena Germanica, operated by Stena Line, was retrofitted to run on methanol in 2015. It is one of the world's first methanol-powered ferries and has shown significant reductions in emissions. The conversion was part of a project supported by the EU’s Motorways of the Seas initiative. Waterfront Shipping's Methanol-Diesel Dual Fuel Ships

4.2.3.2. *Challenges and Considerations*

Energy Density: Methanol has a lower energy density than diesel (approximately 50%), requiring larger fuel tanks or more frequent refuelling.

Infrastructure: Widespread adoption of methanol as a marine fuel will require significant investments in bunkering infrastructure.

Engine Adaptations: Existing marine engines need to be retrofitted to run on methanol or replaced by a new engine. The two most widespread solutions are two—or four-stroke dual-fuel engines that can modulate up to 95% methanol and use 5% diesel as ignition or smaller four-stroke methanol engines in which an ignition enhancer is added to the methanol.

4.2.3.3. *Methanol production*

Methanol can be classified into different types based on the feedstock and production methods. The main types are grey methanol, blue methanol, and green methanol, each with distinct characteristics and environmental impacts.

Figure 25: Stena Germania – first retrofitted methanol ferry Figure 26: Stena Newmax – source Stena Line

The first commercially operating ferry was Stena Line´s "Stena Germania," which in 2015 converted the existing main engines to dual fuel with methanol and diesel. Stena Line is building two brand new hybrid propulsion vessels designed to run on methanol/diesel, and the launch of Irish Sea operations is expected in 2025.

4.2.3.4. *Types of Methanol*

Grey methanol is produced from fossil fuels, primarily natural gas, through a process called steam methane reforming (SMR). This method involves reacting methane with steam to produce synthesis gas (a mixture of hydrogen and carbon monoxide), which is then converted to methanol.

→ Environmental Impact: This process generates significant CO_2 emissions, contributing to greenhouse gas emissions.

Blue methanol is also produced from natural gas but with the addition of carbon capture and storage (CCS) technology. The CO_2 generated during production is captured and stored underground or used in other industrial processes

→ Environmental Impact: The use of CCS significantly reduces the net CO_2 emissions, making blue methanol a cleaner alternative to grey methanol.

Green methanol is produced from renewable sources such as biomass (e.g., agricultural waste, forestry residues) or directly from CO_2 and hydrogen derived from renewable energy sources (e.g., wind, solar). Methods include gasification of biomass and electrochemical reduction of CO_2 using green hydrogen.

→ Environmental Impact: This type of methanol has the lowest carbon footprint as it is produced from renewable resources and can potentially be carbon-neutral or even carbon-negative, depending on the production process.

4.2.3.5. Production Processes

Steam Methane Reforming (SMR): Used for grey and blue methanol, SMR involves reacting natural gas with steam to produce hydrogen and carbon monoxide, which are then synthesised into methanol.

Gasification: This process converts organic material into synthesis gas through high-temperature reactions, and it is used for biomass to produce green methanol.

Electrochemical Reduction: Used for producing green methanol from CO_2 and green hydrogen, this process involves water electrolysis to produce hydrogen, which is then combined with captured CO_2 to produce methanol.

Engine Manufacturers: Most marine engine manufacturers are working on methanol solutions for their engines, so it is important to investigate the existing engines. Possible engine makers with ready dual-fuel methanol engines could be:

- ABC Diesel (up to 70% methanol)
- Wärtsilä, up to 95% methanol
- MAN Energy Solutions, up to 95% methanol

4.2.3.6. Conclusion

Methanol engines for ferry propulsion present a promising alternative to traditional marine fuels, offering significant environmental benefits. Examples like the Stena Germanica and more upcoming projects highlight methanol's growing interest and feasibility in the maritime sector. Continued research and development and investment in infrastructure will be crucial for the broader adoption of methanol-powered ferries.

4.2.3.7. SWOT for methanol ferries

STRENGTHS	WEAKNESSES
- Methanol is a good and stable energy carrier where energy can be stored until it is needed. As a liquid it is easy to store and transport. - A high-availability fuel, methanol can be supplied as green, blue, or grey. The different types can be mixed.	- Requires conversion of engines, tanks and fuel systems. - Some engines require diesel as ignition fuel or a fuel enhancer. - Requires more storage capacity. The calorific value is approximately 50% when compared to diesel.
OPPORTUNITIES	**THREATS**
- Local production of renewable energy generates jobs	- Highly flammable - low flash point (12°C)

4.2.4. Hydrogen

Hydrogen-powered ferries offer another viable option. Establishing hydrogen production facilities, ideally using renewable energy sources for green hydrogen production, would be necessary.

The MF Hydra is the world's first liquid hydrogen-powered ferry, launched by the Norwegian company Norled.[41]

Figure 27: MF Hydra

4.2.4.1. Challenges

Operating on liquid hydrogen presents several challenges, particularly for maritime applications:

Storage and Handling: Liquid hydrogen must be stored at extremely low temperatures, around -253°C. This necessitates highly specialised and insulated tanks to prevent evaporation and ensure safety, but handling such low temperatures is technically demanding and expensive.

Safety Concerns: Hydrogen is highly flammable, and its storage and use require strict safety protocols to prevent leaks and explosions. Safety standards and regulations for hydrogen-powered vessels are still evolving, and ensuring compliance with these standards is a significant challenge.

4.2.4.2. Hydrogen production

Power consumption: The energy required to produce hydrogen in an electrolyser can vary based on the efficiency of the electrolyser and the conditions under which it operates. Here are the key factors to consider:

Efficiency of the Electrolyser: This is typically expressed as a percentage, representing how much of the electrical energy is converted into the chemical energy of hydrogen. Modern electrolysers have efficiencies ranging from 60% to 80%.

Electricity Consumption: The theoretical energy required to split water into hydrogen and oxygen is about 39.4 kWh per kilogram of hydrogen. However, due to inefficiencies, the actual energy required is higher.

Cooling and Maintenance: In industrial settings, additional water may be used for cooling purposes and maintenance of the electrolyser systems. This water is not consumed in the electrolysis process but is necessary for maintaining operational efficiency and safety. The exact amount varies depending on the scale and design of the system.

System Efficiency: The overall efficiency of the electrolyser also impacts water usage. Higher-efficiency systems produce more hydrogen per unit of electricity and water, while less efficient

[41] Norled. MF Hydra sails on zero-emission liquid hydrogen. URL: https://www.norled.no/en/mf-hydra-sails-on-zero-emission-liquid-hydrogen/

systems require more resources. Improvements in electrolyser technology can reduce the water and energy required to produce hydrogen.

Water Usage: Producing hydrogen through electrolysis requires a substantial amount of water. The electrolysis process involves splitting water (H_2O) into hydrogen (H_2) and oxygen (O_2) using an electric current. To produce 1 kilogram of hydrogen through electrolysis, approximately 9 litres of water are needed.

Purity and Pre-Treatment: The electrolysis water must be high purity to avoid contaminating the electrolyser and reducing its efficiency. Pre-treatment processes to purify water, such as deionisation and filtration, can add to the overall water consumption.

4.2.4.3. Summary

- Theoretical Energy Requirement: 39.4 kWh/kg of hydrogen.
- Efficiency of electrolyser: 60% to 80%.
- For an electrolyser with 70% efficiency, the energy consumption would be approximately 56.3 kWh per kilogram of hydrogen produced.

4.2.4.4. SWOT for hydrogen ferries

STRENGTHS	**WEAKNESSES**
- Clean fuel - No emissions, no particles, no pollution - Emits only water and heat	- Requires a lot of cheap renewable energy and lots of clean water for production. - Requires highly trained crew
OPPORTUNITIES	**THREATS**
- Local production of renewable energy generates jobs	- Highly flammable - odourless - Explosive at concentrations of 18.3- 59%. - No visible flames when burning. - The low density of H_2 gives challenges on piping, storage and safety systems.

4.2.5. Biofuels

Biofuels are a fast and short-term solution that can be used as alternative fuels, such as HVO100, a synthetic diesel fuel made of hydrotreated vegetable oil (HVO).

4.2.5.1. Advantages

Reduction of CO_2 emissions: HVO100 can reduce CO_2 emissions by up to 90% compared to fossil diesel, depending on the raw materials used.

Cleaner combustion: HVO100 burns cleaner and produces fewer particles and NO_x emissions than conventional diesel.

Compatibility: HVO100 can be used directly in existing diesel engines without the need for modifications, making it easy to switch from fossil diesel to a more sustainable solution.

Improved stock stability: HVO has a longer shelf life than biodiesel (FAME) and is more resistant to oxidation and microbial growth.

4.2.5.2. Challenges

Cost: HVO100 is generally more expensive than traditional diesel due to production costs and limited accessibility of raw materials.

Sustainability of raw materials: The raw materials for HVO must be sustainable and do not contribute to deforestation or compete with food production.

Application: HVO100 is increasingly used in the transport sector, including buses, trucks and passenger cars, as well as in maritime applications and power plants. Its ability to reduce emissions makes it an attractive solution for businesses and governments who want to achieve their climate goals.

4.2.5.3. SWOT for biogas ferries

STRENGTHS	WEAKNESSES
- Drop in fuel with existing technology - Reducing emissions by up to 90%	- Not 100% emission-free
OPPORTUNITIES	**THREATS**
- Fast and technically simple solution	- Fuel availability - Price

4.3. Demand responsive transport

Demand Responsive Transport (DRT) is a flexible transportation concept that adjusts routes and schedules based on declared passenger demand, rather than following fixed routes and timetables like conventional buses. It operates through passenger requests made via phone, apps, or online platforms. DRT offers personalised services, including door-to-door or specific location pickups, and caters to groups like the elderly or those in rural areas. It can enhance efficiency by optimising routes, reduce unnecessary travel time, and minimise environmental impact. DRT can integrate with existing public transport networks, serving various purposes such as first-mile/last-mile connections or replacing less efficient fixed-route public transport services.

Several types of DRT exist with different objectives[42] [43]:

- **Interchange DRT**: A DRT service that acts as a feeder, connecting passengers to scheduled fixed-route public transport services, typically for last-mile or first-mile travel. Examples include shuttles that link city centres to airports or main train stations.
- **Substitute DRT**: A type of DRT service that fully or partially replaces traditional fixed-route public transport services, often in areas or situations where the fixed-route services are inefficient or uneconomical due to factors like sparse population or long distances.
- **Network DRT**: A DRT service that enhances the public transport network in specific areas or during certain time slots, particularly where traditional fixed-route services are not economically viable. It supplements or replaces these services to better meet the mobility needs of the population in those areas.

[42] International Transport Forum (2021). Innovations for Better Rural Mobility.
[43] Pavanini, T., Liimatainen, H., Sievers, N., & Heemsoth, J. P. (2023). The Role of DRT in European Urban Public Transport Systems—A Comparison between Tampere, Braunschweig and Genoa. *Future Transportation, 3*(2), 584-600.

- DRT is also used to combine fixed-route services or other subsidised transport services, including paratransit, school, and elderly transport.

Saaremaa ran a DRT pilot between 01/07/2021 – 30/06/2022 every day from 08.00 until 21.00[44]The service was very flexible, allowing door-to-door trips and all possible target groups. Two 7-seater vehicles provided by Toyota Baltic were used to perform the trips. The trips were ordered by phone through a dispatcher or a customer application, and the service was free of charge during the pilot. In general, the customer experience was positive; however, the service was discontinued due to the costs being too high.

4.3.1. Technology

The flexibility of DRT services is mainly based on changes in vehicle size, route, stops, and schedules. The table below summarises different levels of flexibility for several types of demand-responsive transport services.[45]

Flexibility	Service	Description
++	Taxi	Conventional taxi service picks people up and brings them to their desired destination.
+	Full flexible DRT	Door-to-door service with a tailored schedule and routing based on the declared demand.
	Semi-flexible DRT	Service with pre-defined physical or virtual stops, routes and schedules, but is adapted to actual demand. A certain number of detours and adapted pick-up times are allowed but limited.
-	Hybrid	Service is similar to a conventional bus service with a fixed schedule and route on which certain stops or off-peak hours are placed on demand.
--	Conventional bus	Conventional bus service picks people up and brings them to specific bus stops according to a predefined schedule.

Table 11: Summary of the flexibility of different DRT service configurations. Source: EIT Urban Mobility.

Advantages and disadvantages depend heavily on the provided DRT service. Very flexible taxi services have a high cost but are very flexible to the demand (door-to-door, one customer at a time) and therefore very reliable for the user. The reliability of a full-flexible DRT service is less feasible given that it aims to provide the same service as a taxi for multiple customers at a time, therefore allowing detours that create longer waiting times for other customers. However, full flexible DRT services are cheaper since they combine several customers simultaneously while still providing much flexibility. By reducing the flexibility even more and allowing only a very limited amount of

[44] Response – Interreg Baltic Sea Region (2021). Pilot in Saaremaa. Demand-Responsive Transport to ensure accessibility, availability and reliability of rural public transport.
[45] EIT Urban Mobility (2022). Urban Mobility Next 7 - Demand Responsive Transport: recommendations for successful deployment.

changes to the original route and timing, semi-flexible DRT services can reduce the cost even further and provide a more reliable service for the scheduled demands[46].

Another aspect of DRT services is the need to book the ride beforehand. There exist different possibilities on how to do so, of which the following are the most popular:

- Booking trips through a smartphone application
- Booking trips through a web application
- Booking trips by sending an SMS
- Booking trips by directly calling a call centre
- Booking trips by connecting directly with the drivers through phone

The last three options are particularly important for people without internet access or with limited digital skills. Payments are typically facilitated via online payments, such as an app or web booking. Other methods include paying on board or using a smart public transport card. Regarding the service fee, the cost is generally either a fixed ticket price or a dynamic fare based, for example, on the distance of the trip. The price of a DRT vehicle trip is often between a taxi ride and a public transport ticket. The DRT service is usually subsidised partly or entirely by the local authority.

You'll find below a non-exhaustive list of pilot projects and their scheme[47]. Most pilots in the list have been terminated or not renewed, except ArrivaClick (https://www.arrivabus.co.uk/arrivaclick), Northern Beaches,[48] mostly because of the limited number of passengers and the high costs of operating the service.

DRT System	Service Type	Booking Methods	Payment Methods	Time of booking	Pricing Strategy	Passengers per Vehicle per Hour
Kutsuplus **Helsinki, Finland**	Stops	Website, SMS	Smartphone app with credit card payment	< 1h before	Dynamic pricing	1.5
RideKC: Bridj **Kansas City, USA**	Stops	Smartphone app	Smartphone app with credit card payment	< 1h before	Fixed pricing	0.06
FLEX	Stops	Smartphone app, phone call	Smartphone app with	< 1h before	Dynamic pricing	0.2

[46] EIT Urban Mobility (2022). Urban Mobility Next 7 - Demand Responsive Transport: recommendations for successful deployment.
[47] Pettersson, F. (2019). An international review of experiences from on-demand public transport services.
More examples in:
- Stockholm Environment Institute Tallinn Centre (2020). Demand-responsive transport (DRT) in the Baltic Sea Region and beyond.
- EIT Urban Mobility (2022). Urban Mobility Next 7 - Demand Responsive Transport: recommendations for successful deployment.
[48] https://transportnsw.info/travel-info/ways-to-get-around/on-demand/northern-beaches

San José, USA			credit card payment			
Go Connect **Milton, Canada**	Door-to-door & stops	Website, smartphone app, phone call	Smartphone app with credit card payment	< 1h before	Dynamic pricing	1.4
ArrivaClick **Sittingbourne & Liverpool, UK**	Stops	Smartphone app	Smartphone app with credit card payment	< 1h before	Dynamic pricing	2.6
Northern Beaches **Sydney, Australia**	Door-to-door & stops	Website, smartphone app, phone call	Smartphone app with credit card payment, public transport smart card	< 1h before	Dynamic pricing	2.5
Breng Flex **Netherlands**	Stops	Smartphone app, phone call, public transport planner	Smartphone app with credit card payment, public transport smart card, on-board payment	< 1h before	Fixed pricing	2

Table 12: Examples of DRT pilot projects. Source: Pettersson.

4.3.2. Cost

As discussed above, many DRT pilots have been terminated due to high costs and low ridership. A plausible reason for these unsuccessful tests is that often the service was very flexible, using a minibus (5-17 places) or, in some cases, even buses (that were almost empty). This can be linked with the figure below, which illustrates how flexibility increases the operator's cost.

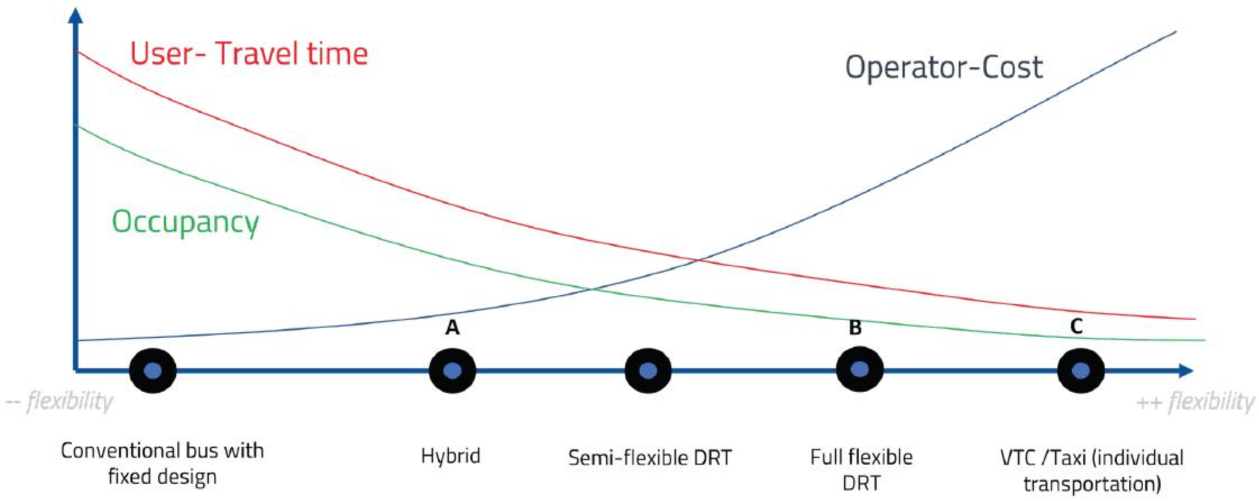

Figure 28: DRT cost-performance ratio across various service types. Source: EIT Urban Mobility

Therefore, semi-flexible DRT services are currently more recommended for low-demand areas. These services are more reliable as they limit vehicle detours, making waiting and travel times more predictable for customers. Reduced flexibility enables greater demand aggregation, allowing lower average costs per passenger. This type of DRT service might still require public subsidies to subsist. However, it is a more balanced economic model than a fully flexible taxi service while still being reliable and providing the customer with enough satisfaction. Finally, replacing conventional public transport with a DRT service is not expected to result in large public money savings since there are still costs related to the availability of dedicated vehicles and drivers[49].

On another note, some examples show that it is feasible to have a cost-efficient DRT service. The Mokumflex service[50] in Amsterdam replaced two fixed bus lines as a test[51]. During the test, they replaced three vans, operating a fixed route with a 60-minute headway between two services, with two on-demand vans (equipped with electric or CNG motors compared to previous diesel vans). The results showed that the operational cost decreased (fewer operating hours and total vehicle kilometres driven) but at the expense of a diminished ridership, which is consistent with what other DRT services experienced[52].

4.3.3. Energy/Environment

DRT can potentially reduce energy consumption and the environmental impact of public transport. This potential is mostly attainable in a low-demand context, where switching to fewer and smaller vehicles than what is currently in place and still fulfilling the existing transportation demand[53]. If the demand is high, DRT systems might have the undesired effect of requiring more vehicles and performing more vehicle kilometres than the previous system, hurting the energy and environment. Another situation where the DRT system can be more detrimental is when the DRT is only an addition to another transport system. More vehicles will contribute to more vehicle kilometres, and hence, no

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49 EIT Urban Mobility (2022). Urban Mobility Next 7 - Demand Responsive Transport: recommendations for successful deployment.

50 https://www.staxi.nl/en/mokumflex-taxi/

51 Coutinho, F. M., van Oort, N., Christoforou, Z., Alonso-González, M. J., Cats, O., & Hoogendoorn, S. (2020). Impacts of replacing a fixed public transport line by a demand responsive transport system: Case study of a rural area in Amsterdam. *Research in Transportation Economics, 83*, 100910.

52 Pettersson, F. (2019). An international review of experiences from on-demand public transport services.

53 Diana, M., Quadrifoglio, L., & Pronello, C. (2007). Emissions of demand responsive services as an alternative to conventional transit systems. *Transportation Research Part D: Transport and Environment, 12*(3), 183-188.

emissions and energy consumption reduction will be reached. Therefore, if one of the goals is to reduce vehicle consumption and emissions, it is important to have this system substitute another transportation mode, often an already existing bus line. The substitution can be partial or complete, with smaller or more energy-efficient vehicles. Additionally, the more flexible the system and allows detours or door-to-door transit, the more energy is consumed. Hence, a fixed route schedule DRT service that needs a reservation to be operational will consume significantly less energy. For example, the DRT service Mokumflex, which was presented in the previous section, obtained a reduction in emissions by replacing three diesel vans with a CNG van and an Electric van and only operating when the vans were reserved[54].

Deploying a DRT service is also an opportunity to include newer vehicle technologies in the transportation system[55]. More recent technologies often emit less CO_2, NO_X or PM and make less noise than older vehicles. Therefore, including these newer vehicle technologies in replacement of multiple older cars, vans, or buses can also contribute to a more positive effect on people's health, energy consumption and the environment.

4.3.4. Acceptance of the system

An essential step is to enable DRT services through appropriate regulations. For instance, if DRT services are classified under taxi regulations, taxi companies may perceive them as a threat due to DRT's taxi-like flexibility combined with public transport pricing (or even free services). However, this classification could also impose excessive restrictions, preventing DRT from operating effectively. Therefore, it is crucial to establish a tailored regulatory framework for DRT services[56]. Nonetheless, this can be challenging, as regulations may be governed at various levels, such as regional, national, and beyond.

Implementing DRT services in rural areas requires a tailored approach that addresses local needs, such as population density, social vulnerability, and mobility profiles. Key steps include identifying gaps in existing bus services, understanding user demographics, and determining if the service should focus on specific groups like the young or elderly. The DRT system must be dynamic, with well-planned stops, service hours, and routes. It is essential to clarify its role in rural mobility, whether as an interchange or substitute service and integrating it with public transport and trip planning tools. Building trust through high-level service (e.g., convenience and punctuality) rather than just competitive pricing is crucial for increasing ridership. Community involvement in the design process is also vital for fostering awareness, acceptance, and long-term success[57].

A stated choice survey was conducted in Skåne County, Sweden, to assess the acceptance of DRT services among three age groups: young people (6–17), adults (18–69), and the elderly (70+), with 343 respondents participating[58]. The results show acceptance levels are generally consistent across age groups, particularly regarding short delays (less than 10 minutes, whether notified in advance) and short departure time intervals (e.g., 10-minute intervals). However, older adults exhibited lower

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[54] Coutinho, F. M., van Oort, N., Christoforou, Z., Alonso-González, M. J., Cats, O., & Hoogendoorn, S. (2020). Impacts of replacing a fixed public transport line by a demand responsive transport system: Case study of a rural area in Amsterdam. *Research in Transportation Economics, 83*, 100910.

[55] Campisi, T., De Cet, G., Vianello, C., & Garau, C. (2024). Exploring Economic and Ethical Challenges of Implementing Demand-Responsive Transport Systems (DRT) in Italy. *European Transport/Transporti Europei*, (98).

[56] International Transport Forum (2021). Innovations for Better Rural Mobility.

[57] EIT Urban Mobility (2022). Urban Mobility Next 7 - Demand Responsive Transport: recommendations for successful deployment.

[58] Jevinger, Å., & Svensson, H. (2024). Stated opinions and potential travel with DRT–a survey covering three different age groups. *Transportation Planning and Technology*, 1-28.

acceptance of digital solutions. Approximately 60% of older adults preferred booking through a human operator, compared to around 35% who accepted a dedicated booking app as the next preferred option. This highlights a well-known barrier for this group[59]The majority of travellers were willing to book trips at least 30 minutes in advance, with 50-70% willing to book an hour ahead. They were generally willing to accept longer travel times compared to private car trips, but not if the travel time doubled. Older adults, however, are less receptive to changes in pick-up locations, especially if they involve walking significant additional distances.

The study concludes that offering a variety of booking methods, travel times, and pricing is important to cater to diverse preferences and attract more users. It also emphasises the importance of understanding the specific markets before implementing DRT systems and being patient, as changes in travel behaviour take time.

Another survey based on the UTAUT (Unified Theory of Acceptance and Use of Technology) was conducted for 205 households in rural German[60]. They concluded that creating an efficient DRT system tailored to user needs and integrating it with local public transport is essential for improving acceptance and usage. Clear communication and a careful rollout are crucial for successful adoption, focusing on highlighting customer benefits, such as reduced travel time, to boost motivation to use the DRT service.

4.3.5. Integration with other services (MaaS)

As described above, providing multiple ways to book a trip on a DRT is important. Therefore, providing a dedicated app is a must. However, it is also possible to integrate the DRT service into other apps that bundle different mobility services, such as public transport, car sharing and e-bike sharing. These types of applications are called Mobility as a Service (MaaS) and integrate multiple mobility services by allowing to search, book and pay for the most suitable trip to the destination based on all available services in the app[61].

There exist five levels of MaaS apps[62]:

- Level 0: No integration, meaning that all services have their app
- Level 1: Integration of information; therefore, only travel information is provided via a journey planner, for example
- Level 2: Integration of searching, booking, and paying for individual trips
- Level 3: Integration of transport services, offering bundled mobility services for a subscription
- Level 4: Integration of societal goals, where goals such as emission reduction or congestion avoidance are displayed for the user to raise awareness.

[59] Coutinho, F. M., van Oort, N., Christoforou, Z., Alonso-González, M. J., Cats, O., & Hoogendoorn, S. (2020). Impacts of replacing a fixed public transport line by a demand responsive transport system: Case study of a rural area in Amsterdam. *Research in Transportation Economics, 83*, 100910.

[60] König, A., & Grippenkoven, J. (2020). The actual demand behind demand-responsive transport: Assessing behavioural intention to use DRT systems in two rural areas in Germany. *Case Studies on Transport Policy, 8*(3), 954-962.

[61] Ministry of Infrastructure and Water Management of The Netherlands (n.a.). Case study Mobility as a Service (MaaS). URL: https://rwsenvironment.eu/subjects/sustainable-mobility/toolbox-smart-mobility-management/multimodal/map/case-study-mobility-as-service-maas/

[62] Ministry of Infrastructure and Water Management of The Netherlands (2023). Factsheet Mobility as a Service (MaaS). URL: https://rwsduurzamemobiliteit.nl/slag/toolbox-slimme-mobiliteit/factsheet-mobility-as-service-maas/

MaaS apps should at least provide a level 2 service to its users, enabling them to book and pay for trips using the different transport modes available in the app.

A survey analysis of the case study in Leidsche Rijn, Utrecht (The Netherlands), indicates that users of the local MaaS app, Gaiyo, have shifted their transportation habits[63] [64]. According to the survey, 22% of respondents reported increased use of public transport, while 66% noted greater reliance on shared mobility options. Additionally, 40% of respondents indicated a decrease in their use of personal vehicles, and 5% even stated that the app influenced their decision to sell their vehicle. These findings suggest that MaaS apps can, in some cases, encourage users to reduce personal vehicle use in favour of public and shared transportation options.

4.3.6. Implementation good practices

According to Brake, Mulley, and Nelson, the list below includes some good practices to keep in mind when setting up a DRT service.[65] Therefore, we also refer to their guide, "Good Practice Guide for Demand Responsive Transport Services using Telematics," for a more comprehensive explanation of each of these points.

4.3.6.1. Monitoring and Evaluation

- Collaboratively define user requirements and KPIs with all involved partners. These should be established before launching the service to assess whether it operates as expected later on.
- All stakeholders should be consulted to evaluate requirements and service performance.

4.3.6.2. Economic framework

- Incorporate the avoidable cost principle into the decision-making process.
- Leasing or contracting necessary equipment is preferable until the economic viability of the DRT service is determined. This approach may result in higher short-term costs than ownership but can help avoid increased expenses in the event of the service's termination.

4.3.6.3. Technologies for flexible transport

- Identify the most suitable way to schedule trips (algorithm or manually).
- The selected technologies will impact the cost of the service (administration, capital, operation, …).
- Take time to test the technologies before launching the DRT service.
- Working with a smart card enables more interoperability and integration with other transport services.

4.3.6.4. Service design

- The service objectives must be clear and consider the existing contextual constraints.
- The service design should consider the user requirements the involved partners define.

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[63] Ministry of Infrastructure and Water Management of The Netherlands (2023). Factsheet Mobility as a Service (MaaS). URL: https://rwsduurzamemobiliteit.nl/slag/toolbox-slimme-mobiliteit/factsheet-mobility-as-service-maas/
[64] Rebel (2023). MaaS Pilot Leidsche Rijn. URL: https://openresearch.amsterdam/nl/page/105023/mobility-as-a-service-maas-evaluatie-pilot-leidsche-rijn
[65] Brake, J. F., Mulley, C., & Nelson, J. D. (2006). Good practice guide for demand responsive transport services using telematics.

4.3.6.5. *Managing multiple services*

- Decentralised local dispatch centres are an interesting solution because of their local knowledge, but centralised regional dispatch centres are more cost—and organisational effective.
- It is important to consider the right software. Should we integrate an existing software solution or use a new one? What software already exists in the region that needs to be compatible?
- It is important to consider the staff's technical competencies and provide an appropriate level of training based on those competencies.
- Consider all existing lines of communication with the dispatching service.
- Adopt a level of telematics appropriate for the service's objectives and the long-term DRT service plans.
- Define the level of support for the customer outside the dispatch centre hours.

4.3.6.6. *Marketing and Promotion*

- The more flexible the service is, the less visible it becomes. Therefore, efforts should be encouraged to increase the visibility of the service. Have a clear branding of the system.
- Keep consulting and informing the stakeholders to conserve their trust.
- Keep informing and motivating the users to use the DRT service by providing them with all the necessary information: how the system works, the schedules, how to register, etc. This can be done through leaflets, public meetings, press releases, word-of-mouth, etc.

4.3.6.7. *Partnerships*

- Consider the needs of all stakeholders.
- The partnership should establish a long-term plan for daily operations.
- Dedicate time to addressing all stakeholders' (governance) concerns to achieve a stable partnership.
- It is essential to address each partner's concerns seriously to ensure the partnership's longevity.

4.3.7. SWOT for demand-responsive transport

STRENGTHS	**WEAKNESSES**
- Operational costs can be reduced - Enhance accessibility in rural areas - Reduce the travel time and travel time excess - Diversification of the mobility demand if used conjointly with other public transport services	- Require a certain degree of digital skills for booking the service if using app/web-based booking
OPPORTUNITIES	**THREATS**
- Replace bus lines that are not profitable by DRT - Use unused municipality fleet vehicles or public transport vehicles - The service can appeal to all types of consumers and attract new users	- Costs and environmental impacts can be increased if designed in addition to other public transport modes.

	- In some cases, the system can remain the same or increase the expenses as the replaced bus lines. - Not being able to get the target group on board using the system (i.e. elderly) - Regulatory barriers can exist

5. Proposed implementation

The proposed implementation is organised in three incremental phases based on the implementation challenge and considers the below objectives for the different transport fleets:

- Objective for the municipality fleet:
  - Local municipality fleet should switch to the vehicle technology with the lowest possible carbon emissions
- Objectives for the private transport fleet:
  - The private transport fleet in Saaremaa should attain a 30% reduction in the use of fossil fuels.
  - The private transport fleet in Ruhnu should achieve a 70% reduction by reducing vehicle usage or adopting electric vehicles.
- Objectives for the public transport fleet:
  - Public buses should use renewable energy sources considering infrastructure and cost-effectiveness
- Objectives for the ferries:
  - Ferry traffic between islands and the mainland should be 100% renewable

5.1. Phase 1

5.1.1. Private and municipality fleet

There are only 124 EVs in Saaremaa, of which 22 are from the municipality itself. Improving this number quickly is an absolute necessity to reach a reduction in emissions of 30% for the private fleet by 2030. Stimulating the adoption of battery electric cars in the private fleet must be one of the most important actions to consider in the coming years.

Action 1: Revise the electric vehicle charging infrastructure ambitions

Deploying a basic charging infrastructure network is an important way to increase confidence in the technology. Which entity is responsible for the network's deployment depends on who has the legal authority to approve the placement of infrastructure. This is often the local authority (e.g., municipality or regional government). The national government is often more responsible for higher-level legislation regarding electric vehicles.

There are several reasons why implementing a network of charging infrastructure is an effective measure. First, insufficient charging infrastructure is linked to range anxiety, which is often why people do not invest in EVs. Second, it provides visibility in the streets, demonstrates the region's commitment to the transition, and provides confidence that the technology will stay. Finally, it is not a very large economic investment to deploy a basic AC infrastructure, and it can stimulate private investors once they notice the potential of an increasing number of EVs.

The current ambitions regarding charging infrastructure are too low: 126 charging points are expected in Saare County by 2030 for 2500 EVs (less than 10% of the number of registered cars in Saaremaa). Using these 2030 estimates means one charging point per 20 electric cars, which is twice the EU recommendations of 10 EVs per charging point.

Since there should be a 30% decrease in emissions by 2030, an ambitious goal could be to replace 30% of the private car and van fleet with electric vehicles. In this scenario, the infrastructure goal should be to provide enough to cover at least the charging needs for this fraction of the private fleet. Assuming the private fleet stays constant, a total number of 705 AC charging points is required, given the recommendation from the EU for one charging point for 10 electric vehicles. Considering the private fleet should decrease, aiming for 750 AC chargers would certainly fulfil the recommended ratio and leave room for many visitors during the summer. As an illustration, in the Canary Islands, there were already 1,132 charging points in 2020 for 2,281 EV passenger cars (3,806 EVs in total). The ratio of EVs per charging point they had in 2020 already exceeded the EU recommendation, and they even ambition to have a ratio of 1.15 charging points per EV by 2040[66].

Note that public charging infrastructure should consider visitors. Still, hotel guests, for example, could benefit from private infrastructure installed by the hotels themselves. A more global deployment plan with a clear vision of the role of different actors in the transition should stimulate this. The development of such a plan is described in the following action, which takes this action a step further.

Action 2: Develop a detailed long-term regional plan for the deployment of charging infrastructure

An important step in the deployment of charging infrastructure is to develop a long-term regional vision and plan for how the deployment should proceed. The difference between this action and Action 1 is that this long-term plan goes further than ambitions and goal setting. It also includes stakeholders and policies to develop. Goal setting, as described in Action 1, is a part of this plan and could be included in this process.

A strategic deployment plan is an all-encompassing document that includes what the current and future need/demand/evolution are regarding energy, electric vehicles and charging infrastructure, what the roles are of the different stakeholders (i.e. charging point operators, DSO, TSO, hotels,…), how private charging infrastructure plays a role, what targets/ambitions are in number of EVs and charging infrastructure (for different charging modes) and how charging infrastructure will be deployed. An important aspect of the plan is also that it should be revised regularly (every 1 or 2 years) to be able to include the latest insights and adapt the plan accordingly. Figure 29 shows the different steps to formulate such a plan with examples of outcomes and activities per step.

Developing this plan is more time-consuming than expensive. A lot of data collection, analysis, and stakeholder consultations are required to formulate a plan that defines the right targets, strategy, necessary policies, and role of every stakeholder. However, this type of plan, validated

[66] Canarias Por la transición energética, Estrategia del vehículo eléctrico, https://www.gobiernodecanarias.org/energia/descargas/SDE/Portal/Planificacion/Estrategias/3_Presentacin_Estrategia_del_Vehculo_Elctrico.pdf

by the different stakeholders, provides a good base for an effective, well-thought-out deployment of charging infrastructure.

A short list of examples of strategic deployment plans are available for the following cities:

- London (EN): https://lruc.content.tfl.gov.uk/london-2030-electric-vehicle-infrastructure-strategy-executive-summary-december-2021.pdf
- Amsterdam (NL): https://openresearch.amsterdam/nl/page/65641/strategisch-plan-laadinfrastructuur-2020-2030
- Brussels (NL): https://leefmilieu.brussels/media/10329/download?inline
- Canary Islands (ES): https://www.gobiernodecanarias.org/energia/descargas/SDE/Portal/Planificacion/Estrategias/D3_Estrategia_Vehiculo_Electrico.pdf and https://www.gobiernodecanarias.org/energia/descargas/SDE/Portal/Planificacion/Estrategias/3_Presentacin_Estrategia_del_Vehculo_Elctrico.pdf

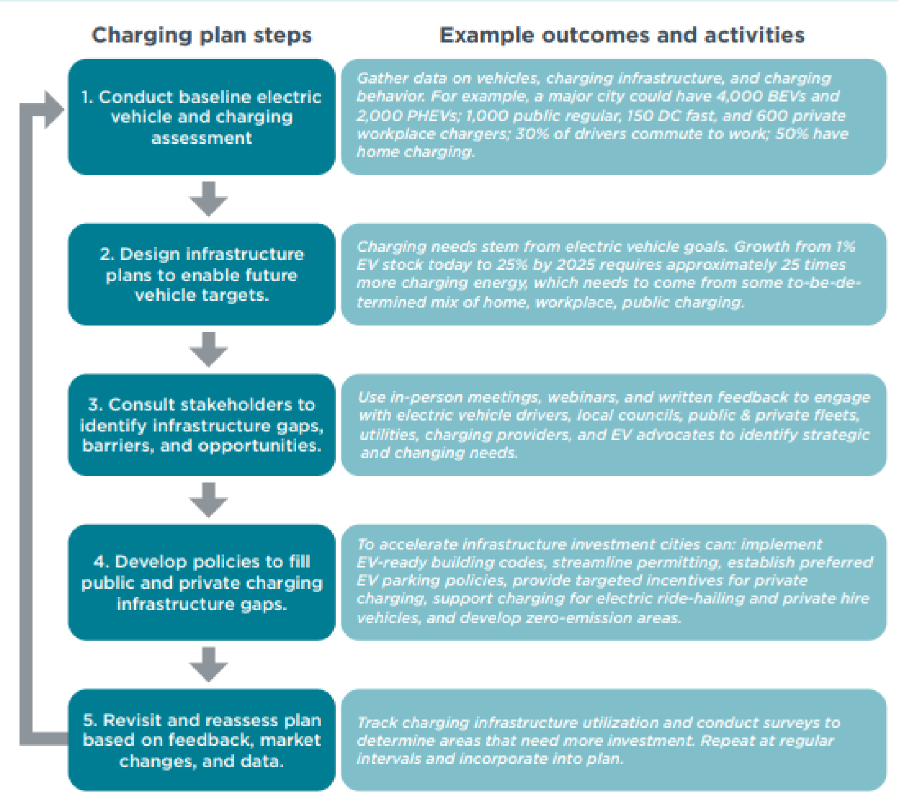

Figure 29: Template for creating a charging infrastructure plan. Source: Electric vehicle charging guide for cities, ICCT.

Action 3: Deploy a basic charging infrastructure network for charging infrastructure

An example of deployment planning could be based on the table below, with fewer yearly installations in the earlier years and a systematic increase in the installation pace. This makes sense since the deployment should follow the growth of the EV fleet. If the EV fleet grows faster than expected, the deployment schedule should also speed up. This table also considers a conservative installation time of 12 months per point (including obtention of permits, administrative procedures, delivery of the hardware, etc.); the deployment could start at the earliest end of 2025.[67]

	2021	2025	2026	2027	2028	2029	2030
AC	16	50	100	200	350	550	750
Increase		+34	+50	+100	+150	+200	+200

Table 13: Deployment schedule charging infrastructure

The deployment of the public charging infrastructure can be performed in several stages:

1. Utility-driven stage: prioritising locations based on their utility.
2. Demand-driven stage: prioritising locations based on the demands of the citizens.
3. Data-driven stage: prioritising locations based on data from the charging sessions.

The first stage is to identify locations based on their utility and visibility. These locations are often destinations where car users spend time. Typical locations targeted in this phase are the parking of shopping malls or supermarkets, public parking, activity centres, and social areas… These locations can be suitable for basic infrastructure and kickstart the uptake of EVs.

Based on the example in Table 10, the target for reaching the basic charging infrastructure could be 100-200 AC chargers by 2026 and 2027.

Action 4: Continue the municipality's effort to electrify its vehicle fleet

As mentioned in the previous action, an important step towards electrification of the private fleet is to create visibility for the technology. The municipality fleet currently consists of 86 vehicles, of which 22 are electric. Given that more than one-quarter of its vehicles are already electrified, the municipality can continue as a role model by extending its fleet's share of electric vehicles. This transition can be phased by tackling technology per technology, e.g., replacing diesel vehicles by 2026, then petrol vehicles by 2028 and finalising the transition with CNG and hybrid vehicles by 2030.

This action synergies well with the deployment of a basic public charging infrastructure. The municipality fleet can use the public network to recharge its vehicles and demonstrate to the citizens that the technology is reliable. Moreover, the network can be extended to locations useful to the municipality fleet. This will optimise the use of this charging infrastructure and provide an image of the public infrastructure being used.

Action 5: Replace Ruhnu's private fleet with electric vehicles

Regarding Ruhnu's private fleet, the objective is to mainly electrify the fleet. Given that most vehicles are old and mostly used on the island itself as second vehicles, replacing these vehicles with electric vehicles with small batteries to reduce their price would make sense. Therefore, a possible solution might be to prefer second-hand electric vehicles. Given their first use and inclusion of smaller batteries than the market standard, these vehicles would have a lower purchase price than retail EVs. To facilitate this transition, a subsidy scheme could be

[67] The International Council of Clean Transportation (2021). Efficient planning and implementation of public chargers: Lessons learned from European cities.

implemented that rewards the purchase of cheap (e.g., sub €35,000) or second-hand electric vehicle models. The reason for targeting cheaper or second-hand vehicles is not to provide subsidies for expensive and luxury vehicles that owners probably would be able to purchase without subsidy.

5.1.2. Public transport

Action 6: Transition from CNG public buses to biomethane public buses

The first step to achieving a public transport fleet using renewable energy sources is to switch the fuel from CNG buses to biomethane. High-purity biomethane has very similar properties to CNG and would enable a 1:1 replacement with minimal costs to adapt the existing refuelling infrastructure in Kuressaare. Therefore, this action can be performed quickly for very little, considering CNG and biomethane are similarly priced in Estonia. Additionally, this would synergise very well with the plan to produce biomethane directly on Saaremaa. Given the existing bus fleet's CNG fuel consumption (268,722 kg) and assuming a biomethane energy content of 13.9 kWh/kg[68], the energy required to operate the bus fleet on biomethane would require around 3.74 GWh. This would be approximately one-third of the expected 12 GWh available for transportation needs from the biomethane production project in Saaremaa (as described in the section Energy for the context of Saaremaa).

An important note to this action is that this is a transition measure that aims at including renewable energy in the current public transport system, without heavy investments, while waiting for the electric vehicle technology to become more affordable or more performant (i.e., longer driving range for countryside bus lines). It is not the goal to invest in new buses for biomethane, and the existing CNG buses should still be replaced by electric buses when economically and technically feasible (See Actions 10, 11 and 14).

Action 7: Incentivise the taxi and car-sharing fleet to transition to electric vehicles

The taxi and car-sharing fleets are relatively small but can also be role models for the electric transition.

Taxis are, in general, an interesting business case for switching to electric vehicles. Given that this fleet drives high kilometres per day, their potential savings on energy costs is very high. However, this high daily mileage also means that enough range is required. To provide this range, (fast) charging infrastructure in the cities they operate is a necessity. Therefore, (fast) charging infrastructure should be placed in agreement with the taxi services, where taxis usually wait if they want to switch from diesel to electric vehicles. Action 9 describes other interesting locations for fast-charging infrastructure, specifically for taxis.

Regarding car sharing, the infrastructure needs will differ depending on the type of service (station-based or free-floating). In a free-floating car-sharing service, the utility-based deployment should suffice. Some stations could be equipped with AC chargers if they commit to transitioning their fleet to electric vehicles in a station-based service. To reduce the ownership of vehicles in general, it is important to invest in alternative transportation modes. In that regard, car sharing is an interesting investment solution since multiple households can use one vehicle.

[68] Marconi, P., & Rosa, L. (2023). Role of biomethane to offset natural gas. Renewable and Sustainable Energy *Reviews, 187*, 113697.

But this requires that the car-sharing system provides a satisfying level of convenience in terms of vehicles (e.g., different types of vehicles available, compact city cars, family cars, vans, …), service coverage (e.g., number of charging and parking infrastructure dedicated to car sharing), customer support and reliability the bookings.

Given that both types of services are mobility businesses, monetary incentives (e.g., subsidies, reduced vehicle taxes, …) can help convince them to transition to electric vehicle technology. Other potential measures that can incentivize them are additional licences only for electric vehicles and access to bus-specific lanes.

5.2. Phase 2

5.2.1. Private fleet

Action 8: Extend the basic charging infrastructure network based on citizen demand

In the second stage, a demand-driven approach can be employed. This approach consists of enabling the owner of an EV to request a public charging point in the neighbourhood of its home. Usually, an online platform is set up for electric vehicle owners to submit their requests. This platform can be set up simultaneously to the deployment of the utility-based charging infrastructure or near its end.

Based on the example in Table 10, a target to reach with a citizen-driven infrastructure deployment could be around 500 AC chargers between 2028 and 2029.

Action 9: Consolidate the charging infrastructure with fast-charging infrastructure

DC charging can also fit in a more comprehensive infrastructure network deployment strategy. The number of required DC charging points is not as important in forming a solid infrastructure network, but mostly the distance between the chargers (especially along highways). As a reference, the European Commission recommends in the latest Alternative Fuels Infrastructure Regulation (AFIR) the installation of 150kW+ chargers every 60km along main European transport corridors (TEN-T)[69]. The installation of DC chargers should be considered mostly at locations between cities along highways or at a strategic location in the city itself (i.e. public transport hub, ferry port or airport for electric taxis).

5.2.2. Public transport

Running the bus fleet mostly on biomethane would positively impact climate change and reduce the overall CO_2 emissions of the island, especially when using biomethane produced on the island itself. However, the next step should be to transition to an emission-free technology to achieve even better energy efficiency and integrate solar and wind energy into the transport system. Currently, BEVs are the most affordable and reliable zero-emission technology (vehicle and infrastructure) for operating buses. These vehicles already have an interesting TCO case that will become more interesting in the years to come with decreasing battery costs. The only barrier that is still prevalent is the limited range of battery electric buses, especially for countryside operations where more than 300 km per

[69] Council of the EU (2023). Alternative fuels infrastructure: Council adopts new law for more recharging and refuelling stations across Europe. URL: https://www.consilium.europa.eu/en/press/press-releases/2023/07/25/alternative-fuels-infrastructure-council-adopts-new-law-for-more-recharging-and-refuelling-stations-across-europe/

day might be necessary to perform the daily public transport duty on the different lines. Nevertheless, the lithium-ion battery technology is expected to continue improving energy density. Therefore, the limited driving range might not be an issue in a couple of years when it is time to transition to electric vehicles for the countryside lines. For city lines, this problem is not present. The number of daily kilometres per line is well within the capacity of the possible replacement bus proposed in Table 14.

Vehicle	Line	Range	Passengers	URL
Isuzu Novociti Volt	City	up to 400 km	Up to 55	Novociti Volt
IVECO e-Daily	Countryside	up to 200 km	Up to 22	e-Daily
Feniksbus E Electric	Countryside	up to 300 km	Up to 33	E Electric
Isuzu Novo Volt	Countryside	up to 225 km	Up to 30	Novo Volt

Table 14: Possible similar replacement buses of the same brand as the current vehicles employed in the bus fleet

Action 10: Transition to electric buses in Kuressaare and directions 1 and 6

An important note when considering which directions to electrify is that no bus line in different directions is longer than the electric driving range of the buses. However, the buses must chain different lines to perform one day of operations. Therefore, without the exact planning of chained lines, a more general approach is employed where the daily mileage per direction is evaluated with the number of electric buses necessary to operate the directions. Afterwards, the number of simultaneous departures/arrivals on the direction's lines is evaluated to derive the minimal vehicles required. Note that considering these assumptions restricts the optimisations that could be performed, such as using a bus in different directions during the same day.

Table 15 This shows how many daily kilometres the buses on the line must drive per direction every day of the week. These values consider the maximum number of kilometres, including changes in the planning, such as summer/winter periods.

Direction	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Countryside 1	463	486	486	486	513	277	168
Countryside 2	1,501	1,564	1,501	1,518	1,565	381	466
Countryside 3	859	859	859	859	859	563	369
Countryside 4	1,034	1,137	1,034	1,035	1,143	586	564
Countryside 5	2,206	2,211	2,206	2,218	2,206	594	415
Countryside 6	212	212	212	212	212	45	45

Table 15: Maximum daily kilometres per direction

Given the above values and based on the Feniksbus E Electric 300 km driving range, the minimal number of battery electric buses necessary to operate in each direction on every day of the week are detailed in Table 16This analysis is only based on mileage and does not consider the complete operation's planning. Therefore, the number of lines that need to be operated simultaneously in the same direction could exceed the number of minimum battery electric buses required only based on average mileage (as described in the table below).

Directions	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Countryside 1	2	2	2	2	2	1	1
Countryside 2	6	6	6	6	6	2	2
Countryside 3	3	3	3	3	3	2	2
Countryside 4	4	4	4	4	4	2	2
Countryside 5	8	8	8	8	8	2	2
Countryside 6	1	1	1	1	1	1	1

Table 16: Average required electric buses based on maximum daily kilometres per direction

Based on these assumptions, following bus directions is the easiest way to electrify.

- Kuressaare: Four buses operate in the city of Kuressaare. These four buses do not cover more than 265km per day and could comfortably be replaced by the Isuzu Novociti Volt (range up to 400km).
- Countryside 1: The average bus line distance is 68 to 78km, and a maximum of 2 buses are simultaneously required in this direction. Two battery electric buses with a driving range of 300 km should be enough to cover this direction's service.
- Countryside 6: The average bus line distance is the shortest for all directions, 35km. When looking into more planning details, this direction requires two buses to operate simultaneously but at very small distances compared to other directions. Therefore, two battery electric buses could easily operate this line. Electric buses with shorter driving ranges than the Feniksbus E Electric (i.e., the Novo Volt or the IVECO e-Daily) could be operational in this direction. They would allow us to reduce the upfront purchase costs.

Action 11: Install dedicated fast-charging infrastructure at the bus depot

To ensure that the buses have enough energy to perform their duties, fast-charging infrastructure should be installed at the depot and at dedicated locations where buses wait between two trips. To recharge one bus overnight, the minimum requirement would be a DC charging station of 50kW, but installing chargers with a nominal power of around 100kW is recommended. One 100kW charger can be shared by two buses to reduce the installation cost, but then the charging process should be well managed to avoid one bus having insufficient energy stored for daily operations.

Another option is to invest in buses that allow charging using a pantograph and install pantographs where needed. This opportunity-oriented charging method uses roof-mounted equipment on the bus to recharge a significant amount of energy in minutes. However, pantographs are very expensive (~€450,000) since their nominal power is usually very high (300kW) [70].Given that this solution is not cost-effective, it is not considered a path suitable for Saaremaa.

Given that, at least 8 electric buses should be deployed for Kuressaare and directions 1 and 6, charging infrastructure will be required at the bus depot to provide the buses with energy. The easiest solution regarding battery management would be to have one 100kW charger per electric bus, for a total of 8 100kW chargers. A lower number of chargers can be considered for economic purposes, provided the charging process is monitored and optimised.

To conclude regarding Actions 10 and 11, these actions focus on making bus directions easy to electrify, but that does not mean that all directions need to transition at the same pace. They can be phased, like the implementation of charging infrastructure, by focusing on one direction at a time (e.g., Kuressaare) and installing a limited number of charging infrastructure at the depot (4 instead of 8).

Action 12: Develop a demand-responsive transport system to replace bus lines with low ridership.

To reduce the cost of the public transport system, a demand-responsive transport service can be deployed to replace bus lines with low ridership. This service would only operate when customers declared demand.

5.2.2.1. Identification of the DRT service requirements

The first step is to identify the key stakeholders that can contribute to this service. Who will lead this endeavour, and who can contribute to and benefit from providing this service? Two obvious leading partners should be the municipality and the transport operator. Other partners can be technology providers, taxi services,

Afterwards, it is important to set the objectives of the service and identify its needs and requirements. This can be done in consultation with the identified partners and through consultations/surveys with the population. Questions that need to be answered are: Why would people use the DRT service? When would they use the service? How flexible should the service be (time of booking, possible delays, stops, detours, etc.)? What type of software or payment method is desirable? … It is very important that the service is aligned with the users to foster their acceptance of the service and its success. In this step, several KPIs should also be determined to monitor and evaluate the progress of the DRT service. Examples of KPIs are the number of passengers per month, number of passengers per ride, number of orders per month, vehicle kilometres travelled per month, cost per ride, cost per passenger, cost per km, total cost per month, passenger kilometres per month, complaints, delays, etc.

Depending on the identified objectives and requirements, an appropriate type of DRT system should be designed. We recommend orienting the service towards a semi-flexible DRT service, replacing existing bus lines with low ridership levels. Allowing additional flexibility based on the user's need (e.g., limited detours) can be considered. A good place to start is with a pilot for a very limited

[70] Kim, H., Hartmann, N., Zeller, M., Luise, R., & Soylu, T. (2021). Comparative TCO analysis of battery electric and hydrogen fuel cell buses for public transport system in small to midsize cities. *Energies, 14*(14), 4384.

number of lines, and the level of service should be increased once experience and confidence are gained in the system.

The proposed semi-flexible DRT service idea could resemble the following:

- Fixed schedule.
- Fixed route with predetermined stops.
- Replacing lines that have a low demand.
- Is only operational if booked 24 hours beforehand.
- Can accept additional passengers up to 1 hour before the start of operating the line (limited also by the available capacity of the vehicle). This maximises the vehicle's capacity and reduces the cost per passenger.
- Decide on the vehicle to use depending on what is available and the effective demand from the day before. If customers can book operational vehicles 1 hour in advance, a vehicle with additional capacity could be desired.
- If the replaced bus line has multiple trips per day, reduce (if desired) the number of trips to an acceptable amount for the customer.

To summarise, a semi-flexible DRT service that would fit Saaremaa is a fixed-line fixed schedule type that allows some flexibility to the users ("last minute" booking), but that is limited per day and only drives if booked one day beforehand. This recommendation is based on what should result in fewer costs, energy consumption, and emissions.

5.2.2.2. Technologies

Identify what technologies are required, such as dispatching, routing, booking, and payment software. See what is available to you: Is there an existing commercial software that fits the need, or should you develop a new one from scratch? Beware that developing your software can be costly, especially if the service is quickly terminated. Look also to software already in use for other tasks in the municipality that could be adapted or reused for the DRT service, e.g. dispatch software for emergencies, or online/physical payment software/hardware used in the current public transport.

Test the selected technologies and their integration sufficiently before launching the service to the broad population. Make sure the different ways of booking or paying are flawless, that the software is adequate, and that the staff is sufficiently prepared for operation and customer support in case of problems.

Regarding the dispatch centre, a centralised regional dispatch that takes calls/web/app orders and schedules the service's routing should be sufficient for Saaremaa. The region and demand are not so large that they justify distributing small local dispatch centres.

A final technological recommendation would be to integrate the booking system for the users in a Maas app if available or feasible. These apps can promote alternative modes of transportation to private vehicles and are an additional platform to promote the DRT service.

5.2.2.3. Promotion

Before and after launching the service, make sure to promote it to the population and to the targeted groups. Use different channels of communication and insist on the positive aspects of the DRT service for the user (i.e., how this will improve their mobility, such as higher reliability, less waiting time, on time/faster at the destination, etc…).

Another important promotional action is the branding strategy for the DRT service. A good branding strategy will enhance the DRT service's visibility, help attract new customers or remind people that the service exists and is in operation.

5.2.2.4. *Booking a trip*

Aim for a flexible booking system that enables different ways to book a trip. Allow at least to order a trip via a smartphone app (e.g. MaaS app), on a dedicated webpage or through a call to a dispatch centre.

Trips should be booked at least one day ahead for the line to be operational on the next day. To allow for more flexibility, it might also be good to enable the customer to book a place on an already scheduled vehicle on short notice. For example, a van scheduled to transport 3 people could still have a place for another if it is noticed 30 minutes or 1 hour in advance before the requested stop. Allowing this might result in lower costs per passenger if the added flexibility does not bring large additional costs.

If a fare is desired, payments should be allowed by transfer through the app and webpage and at the vehicle's boarding time. If this service fits in a holistic public transport system, it might also be possible to integrate this payment with a smart card for public transport.

Currently, the public transport in Saaremaa is free; therefore, asking for a large fare would not be very attractive. A small amount might be envisaged, but the population’s willingness to pay should be determined beforehand, especially given the currently existing free public transport. If they are willing to pay to use the DRT service, it should not be excessively high and lower than a ride with a taxi. For example, a price of 2-5 euros can be considered (based on previous pilot data Saaremaa 2021). Dynamic fares might not be the best suited for customers, considering the longer distances in rural areas. A subscription could also be considered if integrated into a MaaS app that also provides other services such as car sharing, e-bike sharing and public transport (e.g., bus and ferries), etc.

In general, the DRT service will need to be financed by the municipality or another source of subsidies, even if the passengers contribute to some extent. Otherwise, the system should be commercial and too expensive for the customer to use.

5.2.2.5. *Type of vehicle*

The vehicle type used should depend on the bus line served and the demand for the service. The DRT service can use vehicles from the municipality fleet or a bus from the public transport organisation. The municipality vehicle should be used if the demand is relatively low that it fits the vehicle’s capacity. Otherwise, a bus can be envisaged if the demand is higher than the capacity. It is also possible that some lines become semi-flexible (e.g., the bus line, instead of 4 trips a day, now has two trips scheduled and two trips on demand) but that a bus is still needed to operate the demand if requested.

Note that adding a lot of flexibility to the service will require a larger number of vehicles and can result in an increased number compared to the current context. Therefore, it is important to remember how flexible the desired DRT service should be if the goal is to provide a mobility service that rationalises costs.

Finally, use preferably electric vehicles using renewable energy to reduce emissions as much as possible.

5.2.2.6. *Monitoring & Evaluation*

The service should be monitored and evaluated to improve its efficiency and growth. Monitor the defined KPIs and evaluate how the service evolves regularly (every 3 to 6 months). Use the call centre for support and dispatching to obtain additional information on how the system is performing.

5.3. Phase 3

5.3.1. Private fleet

Action 13: Data-driven charging infrastructure deployment

This last approach should be employed once the penetration of private electric vehicles is ramping up and a decently large public infrastructure network is in place and being used. Data-driven methods should then be employed to draw patterns from the data generated from the charging session data provided by public charging infrastructure operators. Examples of conclusions that can be drawn include which regions are saturated or underused. Additionally, more sophisticated methods such as location optimisation methods can be used based on parameters such as energy delivered, number of charging sessions, number of unique users, etc. This data analysis will provide insights into current use and allow predictions for future use.

This information can help shape the infrastructure network by identifying where additional charging points are required. This method of deploying infrastructure can only be used once the current infrastructure is sufficiently used. It requires substantial data from several hundreds of frequently used charging points. Therefore, this would mainly be an action for near the end of the decade, once the infrastructure is more developed (e.g. in 2028/29 in Table 10). Note that to be allowed to use this data, the region should have data-sharing agreements with the local charging point operators.

5.3.2. Public transport

Action 14: Transition to a complete electric bus fleet

A more complex action would be to transition to electric buses fully.

Regarding countryside 2, the average bus line distance is 60 to 65km. At least 6 battery electric buses should be required on average given the cumulative distances for that direction. However, only 4 buses are required to operate this line simultaneously. Therefore, this direction seems more challenging to fully electrify with the current battery technology without investing in more vehicles. A solution could be to electrify part of the direction and keep some biomethane buses running for the more complicated lines to electrify.

The average bus line distance for countryside 3 is 47km. This direction could be operated with three battery-electric buses with a driving range of 300km based on the daily mileage in Table 15However, with 859km divided amongst 3 electric buses, there is not much room for additional km. The theoretical maximum range of 300 km could not be sufficient in some cases in this direction.

For countryside 4, the average bus line distance is quite high, with around 80km. This direction needs at least four electric buses for distance, but in the morning, the direction needs more buses to operate the scheduled lines (5-6 buses). However, 2-3 buses should suffice in the afternoon and evening. Importantly, the distances in this direction are quite large for some lines (above 100). It might be a good idea to position at least a fast-charging infrastructure at a location where buses can recharge while waiting for their next trip.

Concerning countryside 5, the average bus line distance is 76km, with a lot of distance to cover to operate in that direction. At least seven buses are required simultaneously, and 8 to distribute the distance over electric buses with a driving range of 300 km. Additionally, three lines are very long (between 133km and 196km). Buses performing the very long lines would only be able to perform one or a maximum of two lines before needing to return charging at the depot or a dedicated location with a fast charger. Or these trips could be operated with biomethane buses.

Considering the current state of the battery technology, the above analysis allows several conclusions:

- Countryside 3 can be electrified but requires additional charging infrastructure at a waiting location (between two departures) to enable to electrification of this direction without range issues.
- The other directions (countryside 2, 4 and 6) seem more complex to electrify with the current technology due to the higher average km per trip. These would necessitate an adapted schedule, fast charging infrastructure on the lines, and using biomethane buses in combination with BEVs.

However, it is important to note that improved battery technologies are expected before 2030. The improvements will allow electric buses to cover a greater range. If a small electric bus (20-30 passengers) can cover 400 km, the above-mentioned issues will not remain relevant.

Similar to Action 11, fast charging infrastructure would be required at the depot for these vehicles, and the infrastructure would be required at waiting locations on the longer lines.

5.3.3. Maritime transport

Transitioning the ferries to be emission-free or neutral and running on renewable fuels such as green methanol and biomethane, electric or hydrogen power is a critical component of the islands' strategy to reduce CO_2 emissions.

This requires significant investments in infrastructure, collaboration with stakeholders, and pilot projects to assess feasibility and refine the implementation approach. The integration of renewable energy sources, particularly from offshore wind farms, plays a vital role in achieving these goals.

Electric ferries with battery packs will be the most mature and ready-to-implement solution at present. Battery technologies will increase efficiency, and a higher capacity must be expected, but we consider the technology mature now.

In recent years, methanol in a dual-fuel combination has been the most common solution when ordering new vessels, apart from the "normal" diesel or heavy-fuel solutions.

About 110 million tons of methanol are produced each year. The production is based almost exclusively on fossil fuels and, therefore, emits significant amounts of CO_2 – for each tonne of methanol produced, approximately 1.4 tons of CO_2. The production capacity of green methanol is increasing rapidly due to high shipping demand.

Hydrogen and battery-powered solutions have great potential but require further development and investment in infrastructure. They are particularly interesting for the future when the technologies become more mature and economically viable.

Liquefied Natural Gas (LNG) was one of the most recommendable fuels due to its reduction of NOx and particular matter until the energy crisis in 2022 when gas deliverance from Russia became unstable, and prices skyrocketed. Many maritime operators have since converted their vessels to dual-fuel LNG/diesel, thus having the possibility to change between fuels.

Biogas/biomethane can use the LNG structure already widely available there, which offers even greater environmental advantages, especially if the biogas production can be scaled up and made economically competitive.

Biofuels, the fast and short-term solution is to use an alternative drop in fuel as HVO100. Can be used in existing diesel engines and fuel infrastructure.

5.3.4. Transition of Estonian ferries to electric, green methanol, hydrogen, and bio-methane fuels

STRENGTHS	**WEAKNESSES**
- Environmental - Transition to emission-free fuels, innovation (hydrogen, electric, bio-methane), reducing local emissions, energy efficiency, and lower energy consumption compared to previous generations.	- Initial investment, regulatory challenges, technological risk, unproven technologies
OPPORTUNITIES	**THREATS**
- Supply market demand for sustainable travel. Collaboration with research institutions and technology providers.	- Fuel availability, infrastructure, new technologies

5.3.5. Challenges and Considerations in alternative fuels for ferries

Technical Feasibility: All emission-free solutions, methanol, electric and hydrogen ferries face technical challenges, including energy storage capacity, charging/refuelling times, and the development of robust supply chains for green methanol, electricity or hydrogen.

Economic Viability: The initial investment costs are high, but long-term savings on fuel and maintenance, along with environmental benefits, provide a compelling case for these technologies.

Regulatory Support: Regulatory frameworks, including incentives for renewable energy use and emission reductions, need to support the transition to low-carbon ferry operations.

Action 15: Electrify ferries Pirret & Tõll by retrofitting

For the ferries, Tõll and Piret, on the mainland route to Saaremaa, a retrofit for fully electric operation with batteries and charging stations in each port will be recommended. The spare ferry Regula should stay on diesel or be replaced with a new electric ferry.

This recommendation is since the technology is known, tested, and reliable. The supply is stable, and with the expansion of renewable energy suppliers, the crossing can be 100% CO_2 neutral and without engine noise.

If the power grid in both ports does not have sufficient capacity, a battery pack can be installed in each harbour and used as a buffer where the ferry is charging. A battery pack also has the advantage of helping to stabilise the electricity grid in the local area. A rough estimation of converting Piret and Tõll to 100% electric ferries is 10 to 12 million Euro each, and the infrastructure would cost around 1 million Euro/MW.

An alternative would be to retrofit to a green methanol solution. A rough cost estimate of this solution would be around 5 to 6 million Euro (not including infrastructure).

The recommendation also applies to the two sister ferries to Hiiumaa, whereby the ferries can be deployed on both routes.

Action 16: Switch to biofuels for ferry Runö

Due to its long crossing and high speed between Mainland—Ruhnu—Saaremaa, the ferry Runö is not suitable for a retrofit solution for electricity and batteries.

For this route, it is recommended that in the short term, the vehicle switch to HVO100 fuel and possibly retrofit rebuild to a green methanol solution at the next engine change.

HVO100 can be changed without engine rebuilds, resulting in up to 90% CO2 reduction. However, the fuel is currently significantly more expensive.

Biodiesel is also an option, but experience from other ferries has shown that the engine oil change interval must be increased, and there may also be an increased amount of soot from the exhaust. We should also keep an eye out for future green drop-in marine fuels to be used in marine diesel engines.

Action 17: Electrify ferry Soela by retrofitting

For the ferry Soela, which handles the route between Saaremaa and Hiiumaa, it is recommended that it be retrofitted to a 100% electric solution with a battery pack and charging solutions in the ports. The reasoning is the same as for Piret and Tõll. The conversion of Soela to a 100% electric solution (not including infrastructure) would cost € 6 to € 7 million.

Alternatively, both the HVO100 and green methanol solutions are viable options if the power grid's capacity is not sufficient. A rough estimate of the cost for a conversion to a dual fuel methanol/diesel operation is around 4 to 5 million Euro (not including infrastructure).

Action 18: Switch to biodiesel for ferry Abro & motorboat Vilsandi

For the two smaller vessels, a biodiesel solution such as HVO100 is recommended, as a conversion would be too expensive in relation to their value and use. When the time comes for the vessels to be replaced, it will be appropriate to look into alternative green solutions such as green methanol. Also, it is recommended that the two vessels pay attention to alternative drop-in fuels.

6. Final Recommendations

This report presents a technological perspective on actions that can be undertaken to improve the sustainability of the mobility system in Saaremaa and Ruhnu. The transportation modes considered in this report are passenger vehicles, public transport and ferries. Given the current state of the existing technological solutions (e.g., electric, biofuels, hydrogen or methanol), a transition implementation in the form of a sequence of technological actions has been proposed for each of these transportation modes. This list considers the implementation difficulty, the economic feasibility, the technological maturity of the solutions and the below objectives for Saaremaa and Ruhnu:

- Local municipality fleet should switch to the vehicle technology with the lowest possible carbon emissions (e.g. biomethane or electricity from renewable sources).
- Public buses should use renewable energy sources considering infrastructure and cost-effectiveness.
- The private transport fleet in Saaremaa should attain a 30% reduction in the use of fossil fuels.
- The private transport fleet in Ruhnu should be reduced by 70% by reducing vehicle usage or adopting electric vehicles.
- Ferry traffic between islands and the mainland should be 100% renewable

The proposed implementation for each transportation mode can be summarised in the following main recommendations.

The main recommendations for passenger vehicles are:

- Developing the public recharging infrastructure network.
- Keeping the efforts going to electrify the municipality fleet.
- Transitioning to electric vehicles in Saaremaa and Ruhnu.

The main recommendations for public transport are:

- Investing in electric buses in Kuressaare and feasible countryside directions 1 and 6.
- Transitioning to electric buses for the other countryside directions can be done once the electric bus technology is more performant for longer distances.
- Replace bus lines with low ridership with a demand-responsive transport solution.
- In the meantime, biomethane can be used instead of natural gas in the current CNG buses.

The main recommendations for ferries are:

- Switching to biofuels for the ferries Runö and Abro and the motorboat Vilsandi.
- Electrifying the ferries Pirret, Tõll and Soela by retrofitting.
- Green methanol can also be a solution if electrifying the vessels is too straining for the grid or at the next engine change if electrifying the ferry proves too difficult.

In general, it is recommended to transition to electric vehicles where possible since they are the most energy-efficient technology, are more cost-effective than other alternative fuel technologies, and have reached a good maturity level. Hydrogen vehicles have some advantages over electric vehicles (e.g., larger range and shorter refuelling time). Still, they are very expensive, require large investments in refuelling infrastructure, are less energy efficient, and the technology is generally less mature compared to electric vehicles, even for buses. Therefore, this technology is not recommended yet.