POWER2GAS IN THE AUTOMOTIVE INDUSTRY

POWER2GAS AUTORŪPNIECĪBĀ

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Abstract - *Because of the climate change and new laws to reduce the carbon dioxide emission, the automotive industry has a major potential. With alternative actuations and new ways to make fuels accessible, like Power2Gas, it is possible to drive nearly CO2 neutral. This examination considers especial passenger cars and lorries in Germany in terms of costs, different fuels and emission exhaust.*

Keywords: *Automotive Industry, car, CO2, Germany, Power2Gas*

1 Introduction

Because of an EU regulation, the reduction of carbon dioxide emissions from passenger cars is needed. [1] One possibility to achieve this, is the reduction of fossil fuels and their replacement by using the Power2Gas method. As an example, electricity is used to produce hydrogen which can be used as fuel. Thereafter, carbon dioxide from the environment is taken for the chemical reaction to produce natural gas. The following text shows the use of natural gas as fuel for passenger cars and lorries.

2 Natural gas in practice for cars in Germany

The regular consumption of energy in the transport sector, which has to be replaced for e-cars adds up to 683.000 GWh per year. [2] For this example, it is anticipated that every passenger car runs on electricity. To calculate the average fuel consumption, it is necessary to keep in mind that diesel cars are usually driven over longer distances. Therefor it is assumed that they drive 50 % more than cars with petrol actuation. With an estimated consumption of six litres for diesel cars and eight litres for cars with petrol actuation, an average consumption of 6,8 litres can be received.

Table 1

Average values from diesel and petrol

	Diesel	Petrol	Average
Efficiency [%] [3]	33,00	25,00	27,67
Volumetric energy density [kWh/l] [4]	9,86	8,77	9,32
Fuel consumption [l/100 km]	6,00	8,00	6,80

Table 2

Energy consumption per year

	Diesel	Petrol	Sum
Percentage [%] [5]	32,90	65,50	98,00
Number of passenger cars in Germany [5]	15.069.371	30.001.332	45.803.560
Average driving distance [km/a] [6]	14.000	14.000	14.000
Energy content per 100 km [kWh/100 km]	19,52	17,54	37,06
Energy content per kilometre [kWh/km]	0,1952	0,1754	0,3706
Total kilometres in Germany [km/a]	$2{,}1*10^{11}$	$4{,}2*10^{11}$	$6{,}3*10^{11}$
Energy consumption per year [GWh/a]	41.187	73.671	114.859

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In this scenario, the energy consumption increases by about 0,17 %. One possibility to supply the additional energy is the installation of wind turbines. If each of them has a power of 3,4 MW and runs with about 2440 full load hours per year [7], in amount of 596 new wind turbines is needed. Another point is, that cars which run on electricity have an increased loading time. Along with the limited space at the filling stations, a loading time of about one hour leads to potential shortages. Because of that, the mobility cannot be provided only with electricity. An opportunity is the Power2Gas method. The best advantage is that passenger cars which run on gas exhaust less carbon dioxide than passenger cars which run on petrol or diesel. The assembly for a gas passenger car is quite like a petrol or a diesel passenger car. A big difference can be seen in the tank for the gas. Since gas has a lower energy density, it can achieve a much higher range by setting it under high pressure of about 200 bar. Nowadays the tank is built in the end of the underbody. This has a positive effect on the driving dynamics and less space is taken up. The characteristic of the gas tank makes this passenger cars more expensive than a petrol or diesel version. This difference is shown in Table 3

Comparison of VW Passat Trendline with different actuations [9]

2.1 Costs of different sources of energy

Since there are no taxes on gas, the price is lower for gas compared to other fuels. An exact cost overview is shown in the following diagramm.

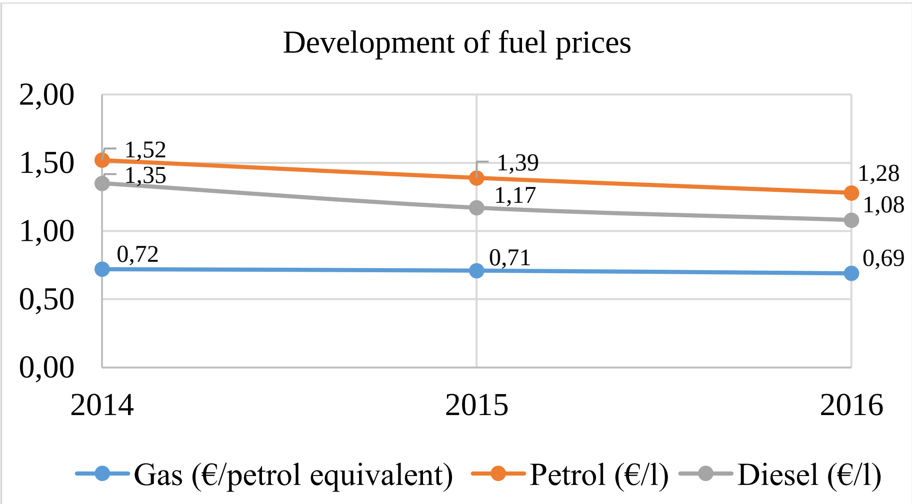

Figure 1: **Development of fuel prices [8]**

To specify the differences even more, the next table shows the comparison between a petrol, a diesel and a gas VW Passat Trendline. [9]

Table 3

Comparison of VW Passat Trendline with different actuations [9]

Motorization	1.8 TSI	2.0 TDI (DPF)*	1.4 TSI ECOFUEL	
Fuel	Petrol	Diesel	Natural gas	Petrol
Power (kW/HP)	118/160	103/140	110/150	
CO_2 emission (g/km)	180	146	123	166
Emission class	EURO 5	EURO 5	EURO 5	
Range (km)	946	1.250	467	431
Empty weight (kg)	1.469	1.527	1.602	
Basic price (€)	27.675	28.150	30.525	

* DPF means diesel particulate filters

To get a comparable range, the 1.4 TSI Ecofuel drives with petrol and natural gas. The descending order of the range starts with 1.4 TSI Ecofuel than 1.8 TSI and 2.0 TDI. Apart from the price and the weight the 1.4 TSI Ecofuel has the lowest CO_2 emission which is besides the fuel costs, shown in Figure 1, the major advantage of this version.

2.2 Efficiency

The specified comparison of the VW Passat Trendline shows that a gas passenger car can decrease the greenhouse gas emissions a lot. [9]

gas vs petrol
CO_2 reduce about 80%
NMHC reduce about 80%
THG reduce about 20%
OZON reduce about 40%

gas vs diesel
CO_2 reduce about 10%
NMHC reduce about 60%
NO_x reduce about 90%
THG reduce about 10%
OZON reduce about 80%

All in all the usage of gas has many advantages for customers and for the car industry, because in 2021 every new passenger car is allowed to exhaust only 95 g CO_2/km. [1] If the natural gas is produced in a green way a cycle of carbon dioxide emissions starts, in which present carbon dioxide is used to produce natural gas and the same amount of CO_2 is going to be released as exhaust gas from passenger cars. With this cycle, it is possible to drive CO_2 neutral.

2.3 Infrastructure

Germany has about 900 natural gas stations and more than 7.000 LPG filling stations. [10] In comparison, there are 6.500 electricity stations [10] and 14.531 regular filling stations [11]. A Disadvantage of the electricity station is, that the plug is not standardized, therefore not every station can be used by any car. This and the loading time problem is a handicap for many customers. The biggest problem for the politic is to supply the complete energy and reduce the carbon dioxide emission.

2.4 Alternative actuations for lorries

Because of the dramatically changing climate and thereby connected climate protection ordinances, the automotive industry had to discover new actuation-options to decrease CO_2 equivalent emissions. This is especially necessary for the logistic department since lorries made up 73% of Germany's haul capacity in the year of 2016. [12] As seen in the following table, the greenhouse gas output of lorries is much higher compared to freight trains and inland navigation vessels. Furthermore, the energy consumption of lorries is more than three times higher than the other two alternatives. Not biogenic petrol is a key factor to decrease these emissions and provide the needed energy.

Table 4

Comparison of average emissions for different transportation means in goods traffic - 2014 [13]

	Lorrie	Freight train	Inland navigation vessel
Greenhouse gas* [g/tkm]	101	24 **	31
Carbon monoxide [g/tkm]	0,125	0,019	0,077
Volatile organic compounds [g/tkm]	0,036	0,005	0,028

Nitrogen oxide [g/tkm]	0,344	0,063	0,433
Particulate matter [g/tkm]	0,005	0,001	0,01
Energy consumption [MJ/tkm]	1,4	0,3	0,44

* CO_2, CH_4 and N_2O specified in CO_2-equivalent
** Designated emission factors for the freight train are based on information about average electricity-mix in Germany

The following chapter shows the potential of not biogenic petrol in comparison to regular diesel for the logistic industry. Therefore, it is necessary to show the ecological and economical differences between a regular diesel lorry and models with LNG or CNG actuation. To show the general cost differences, the comparative cost method is going to be used.

2.4.1 Period-oriented cost comparison

To compare the costs properly the acquisition- and operation costs, capital consumption and capital costs are going to be determined. The acquisition costs are always dependent from amenities, model and brand. To make this comparison as significant as possible, it will concentrate only on the "Iveco Stralis" in its CNG, LNG and diesel version. The CNG and LNG versions use natural gas as fuel which is about 25 % better in matter of CO_2 – output than diesel. They have the least CO_2 – output of all fossil fuels because of their favourable proportion of carbon and hydrogen. CNG is a byword for "Compressed Natural Gas" which is stored at a compression rate of about 200 bar. However, LNG is the same natural gas but in a liquid form ("Liquefied Natural Gas"). The gas must be cooled down to at least 111 Kelvin in order to be fluid. LNG has a volumetric higher energy density than CNG but if there are long periods where the car or lorry is not ridden, there can be evaporation losses. That is why LNG can be perfectly used for lorries because of their continuously use. [14]

The higher acquisition costs of the LNG lorries are not to disregard for an industry that needs a large fleet. Therefore, the German ministry of economics plans facilitation to close the gap between diesel, CNG and LNG lorries and make the new technology more attractive for the logistic industry. The planned facilitation shall grant facilities from around 40 % of the additional costs for large scale manufacturer, 50 % for mid great corporations and 60 % for small corporations. [15] For this comparison the facilitation is going to be ignored since it is not significant yet.

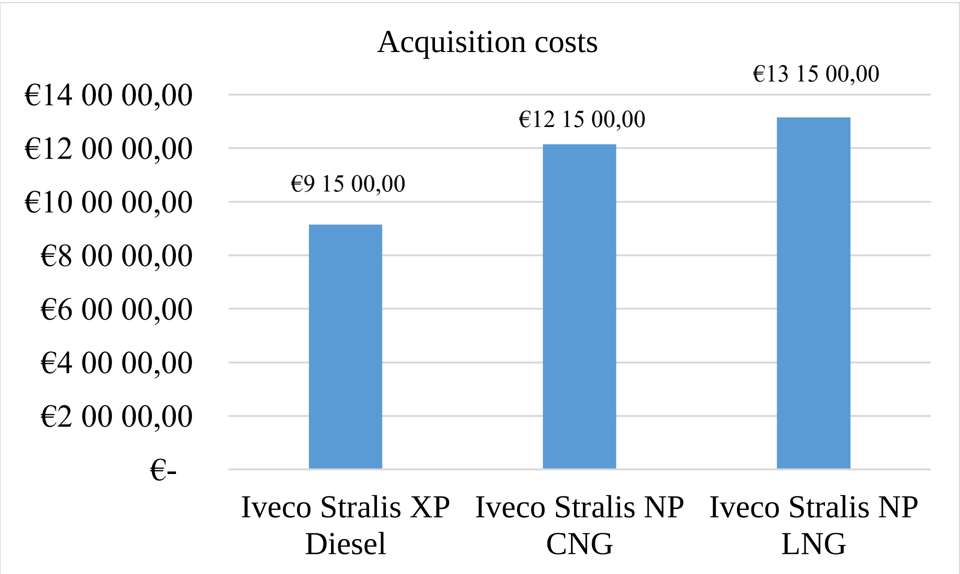

Figure 2: **Comparison of acquisition costs [15]**

To complete the cost comparison method, this diagram shows all annual costs of each version. All costs are for 60.000 kilometres per year and only the costs that are divergent from each other are mentioned. The operation costs consist of costs for: fuel, diesel exhaust fluid (DEF), repair and service. Other comparable costs are not included here because of their independency of the actuation type. The fuel prices can fluctuate depending on many different factors but it can be assumed that LNG always costs 0,20 € less then diesel. [15] The capital consumption is determined over five years corresponding to the AFA table for lorries linear. [16]

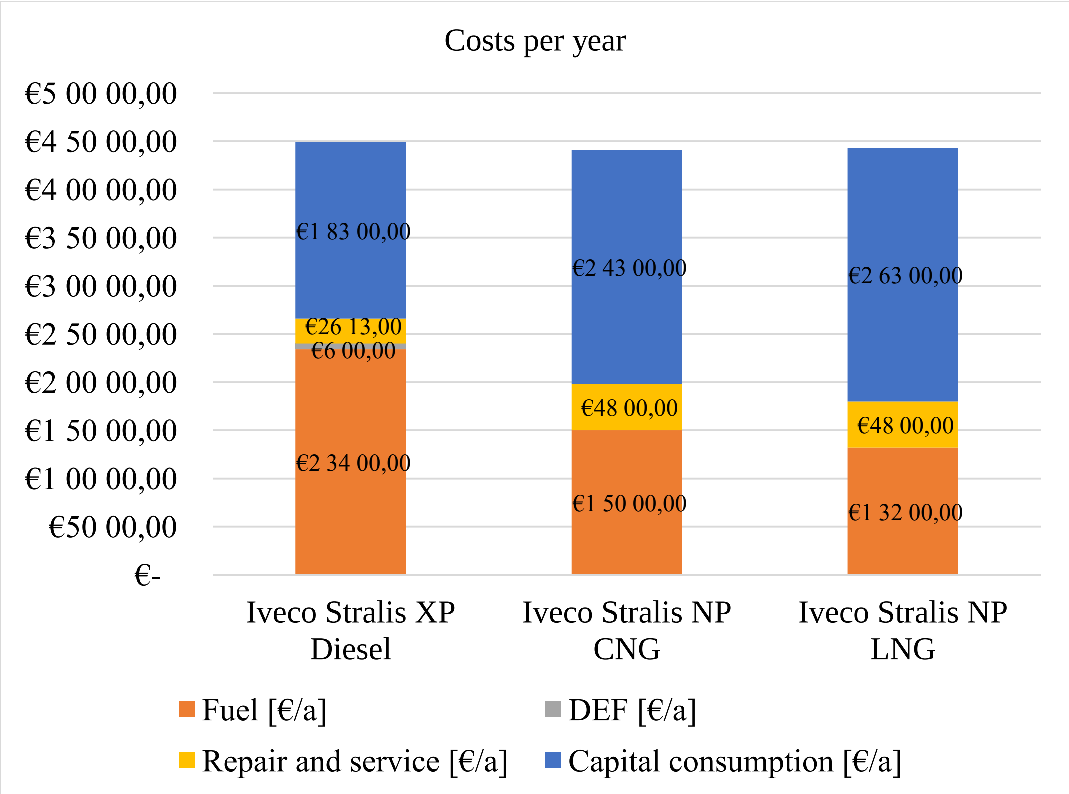

Figure 3: **Comparison of annual costs [15]**

As it is clearly seen in the diagrams above, both CNG and LNG are cheaper in terms of average costs per year compared to the Iveco Stralis XP. Because of much higher acquisition costs and fuel price compared to the Iveco Stralis NP with CNG actuation, the Stralis with LNG actuation could not beat the costs of the CNG-version. Another main difference can be seen between CNG and LNG. The CNG lorry has a range of about 570 kilometres which is way too little for national and international intercity transport. That is why the Iveco Stralis XP with LNG actuation and 1.500 kilometres of range is the best option out of these three. In addition to these economic benefits, there are many ecological benefits too, as seen in chapter 2.2.

3 Exemplary representation Germanys in 2030 and further

As explained in chapter 2, some federal states of Germany decided to avoid internal combustion engines for all new registered cars after 2030. Since this decision is not an actual law yet, a scenario is created in this chapter in which the decision is a general law for Germany. To concretize the first scenario, it is assumed that every new registered car after 2030 must be powered by a natural gas actuation. This change is not only a chance for the climate but has also massive financial impacts.

There are 55.600.000 motor vehicles in Germany in 2017 [17] and it can be anticipated that this number will probably not fluctuate that much anymore. If there are 55.600.000 of them in 2030 too, and every year around 3.000.000 motor vehicles are going to be registered, it would lead to the following calculation. [18]

$$\frac{55.600.000\ cars}{3.000.000\ \frac{cars}{a}} = 18{,}5333\ a$$

On basis of this calculation there would be no cars with internal combustion engine in 2049 anymore. To serve all these vehicles with natural gas, new filling stations must be built. Currently there are 14.531 filling stations in Germany [11] of which 877 are for natural gas already [19] [10]. If every remaining filling station would become a gas station at the cost of around 1.000.000 € [15], the total costs would be 13.654.000.000 €. Distributed onto the years that leads to investment costs of 718.631.578,90 € per year till there are no cars with internal combustion engine anymore. This economical effort is accompanied by the ecological chances. If every of the 30.001.332 passenger cars with petrol actuation [20] would change to natural gas, it would reduce the CO emission by 80 %. [9] With 0,66 g per car [13] that leads to a total decrease of:

$$0{,}66\ \frac{g}{car} * 0{,}8 * 30.001.332\ cars = 15.840.703{,}3\ g = 15.840{,}7\ kg$$

But not only the CO emissions decrease drastically in this scenario but also the CO_2 emissions for passenger cars compared to petrol or diesel with the same number of cars.

Table 5

CO2- emissions driven by different actuation (scenario 1)

	CNG	Diesel	Petrol
CO_2 output [g/km] [21]	86,4	145,8	174,0
Number of cars [20]	45.803.560	45.803.560	45.803.560
Average driving distance [km/a] [6]	14.000	14.000	14.000
Total CO_2 emissions [t/a]	$5{,}5404*10^7$	$9{,}3494*10^7$	$1{,}1158*10^8$

As seen in chapter 2.2 other greenhouse gases will reduce dramatically as well.

For the second scenario, it is assumed that 50 % of the new registered cars will run on natural gas and the other half will be powered by electricity. In this case, not only the gas filling stations have to be built but also more electricity stations must be built. Since there are 6.620 electricity stations already [10] and it is assumed that every new filling station has eight electricity dispensers, which cost between 590 € and 3.000 € [22], that leads to total investment costs of 13.767.601.960 €. Contrasted to the costs the compared CO_2 emissions for passenger cars show the major advantage e-cars.

Table 6

CO2- emissions driven by different actuation (scenario 2)

	CNG	E-cars	Diesel	Petrol
CO_2 output [g/km] [21]	86,4	57,0 [23]	145,8	174,0
Number of cars [20]	22.901.780	22.901.780	45.803.560	45.803.560
Average driving distance [km/a] [6]	14.000	14.000	14.000	14.000
Total CO_2 emissions [t/a]	$2{,}7702*10^7$	$1{,}8276*10^7$	$9{,}3494*10^7$	$1{,}1158*10^8$
Total CO_2 emissions for CNG and e-cars [t/a]	$4{,}5978*10^7$			

Table 6 clarifies the advantage of CNG and electricity actuations in terms of the reduction of CO_2 emissions. All in all, the adjustment to natural gas actuation can help to slow down the climate change dramatically and with future facilitation and a better environment, natural gas is a serious alternative to petrol or diesel.

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