Driving into the Future

Cars in the future

Vorwissenschaftliche Arbeit

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Abstract

Diskussionen über Umweltschutz sind angeheizt wie noch nie und somit ist auch die Frage der Mobilität aktueller denn je. Renommierte Zeitungen titeln mit Schlagzeilen wie ”Beerdigt endlich den Verbrennungsmotor” (*Süddeutsche*), “Autofahren muss das neue Rauchen sein” (*Die Zeit*) oder “Es ist keine Frage mehr, ob sich das Elektroauto durchsetzt” (*Frankfurter Allgemeine*). Diese Vorwissenschaftliche Arbeit beschäftigt sich damit, was wirklich dran ist an den alternativen Technologien. Als Orientierung können folgende Leitfragen dienen: Wie sieht das Auto der Zukunft aus und kann es sich gegen den Verbrennungsmotor durchsetzen?

Anfangs werden verschiedene Antriebsarten technisch erklärt und deren Nachhaltigkeit miteinander verglichen. Darauf aufbauend wird eine umweltfreundliche Verkehrsvision skizziert, in der nicht nur die Funktionsweise des Autos selbst, sondern auch dessen Rolle in unserem Leben erklärt wird.

Es fällt auf, dass kein Antrieb, der heute verfügbar ist, eine optimale Lösung repräsentiert. Es gibt kein “Auto der Zukunft”, Autos allgemein werden in welcher Form auch immer, nur einen kleinen Teil der komplexen Welt des Verkehrs ausmachen. In dieser müssen wir die Rolle des Automobils und des gesamten Individualverkehrs grundlegend überdenken und öffentliche Verkehrsmittel ausbauen. Zu dieser Erkenntnis führt zumindest die vorliegende VWA.

Aus dem Grund, dass solche schwerwiegende Veränderungen im Verkehrssystem zu erwarten sind, setzt sich die Arbeit nicht nur theoretisch, sondern auch empirisch mit dem Thema auseinander. Dazu wurden Personen aus verschiedenen Ländern, sozialen Hintergründen und verschiedenen Alters befragt und eines wird schnell klar: Den Menschen ist nicht nur das Problem und dessen Dringlichkeit bewusst, sondern sie sind vor allem dazu bereit ihr eigenes Verhalten nachhaltig zu verändern.

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1 Introduction

"We are flipping the switch."

Dieter Zetsche, CEO of Daimler AG[1]

It seems clear that cars and the way we use them is going to change in the near future. However, the most important question remains: How are the cars going to change? And how can we integrate the car of the future into our daily lives?

This paper is dealing with this exact issue and finally intends to find an answer not only on how the future could look like, but also aims to find out how willing people are to change towards such a more sustainable future. It can be separated into two main parts: In the first section, the technologies that are available today are described and compared in terms of their sustainability. Following the results on how environmentally friendly the different powertrains are, a picture of a utopic and as environmentally friendly as possible future is drawn. It is important to understand that the paper does not deal with the economic aspects of the topic but only focuses on environmentalism. Lastly, a survey, which was conducted internationally, is analyzed to find out how people think about the issue as a whole and to which extent they are prepared to change their own behavior.

Based on the questionnaire and its results, as well as the research in the literary section, a conclusion is drawn and an outlook into the future is given.

[1] Cf. Benz Mercedes, "Electric Mobility: Mercedes-Benz Flips the Switch: Generation EQ – Mobility Revisited," marsMediaSite, accessed January 28, 2020, https://media.daimler.com/marsMediaSite/en/instance/ko/Electric-mobility-Mercedes-Benz-flips-the-switch-Generation-EQ--mobility-revisited.xhtml?oid=13886650.

2 Available Powertrains

The powertrains that are available and most common today are described and compared in terms of sustainability. A basic description on how the car works follows a short introduction about the powertrain. At the end of every section the powertrains' most significant benefits and drawbacks are highlighted.

2.1 Internal combustion powertrain (ICE)

In the beginning of the automotive age, internal combustion engines, such as used in gasoline and diesel cars, were uncommon. When engineers started building horseless carriages, they preferred to use electric or steam motors. Those were well established and less complicated. This changed in the early 1800s, oil became cheap and accessible while battery technology was still under development and steam powered vehicles were lacking efficiency. Ever since, internal combustion engines took over and individual transport has been dominated by them.[2]

Petrol cars are the best-selling type of internal combustion propelled automobiles. This and the recent discussion about diesel in regards of clean fuel, are the reasons why gas driven cars will represent internal combustion engines in this paper. The engine used in the example below will be a conventional 4-stroke gasoline engine.

[2] Cf. Benz Mercedes, "Electric Mobility: Mercedes-Benz Flips the Switch: Generation EQ – Mobility Revisited," marsMediaSite, accessed January 28, 2020, https://media.daimler.com/marsMediaSite/en/instance/ko/Electric-mobility-Mercedes-Benz-flips-the-switch-Generation-EQ--mobility-revisited.xhtml?oid=13886650.

2.1.1 Technical description

Greatly simplified, a conventional petrol car consists of an engine, a gas tank, a drive shaft and a transmission. Firstly, the fuel is brought to the motor through a gas line. Secondly, the fuel is being mixed with air. After that, the mixture is injected into one of four barrels and explodes by ignition as the piston compresses it.
Every piston passes through a cycle of intake, compression, explosion and exhaust. The pistons in the barrels start moving up and down. This movement can be translated to the wheels by the crank- and driving shafts.

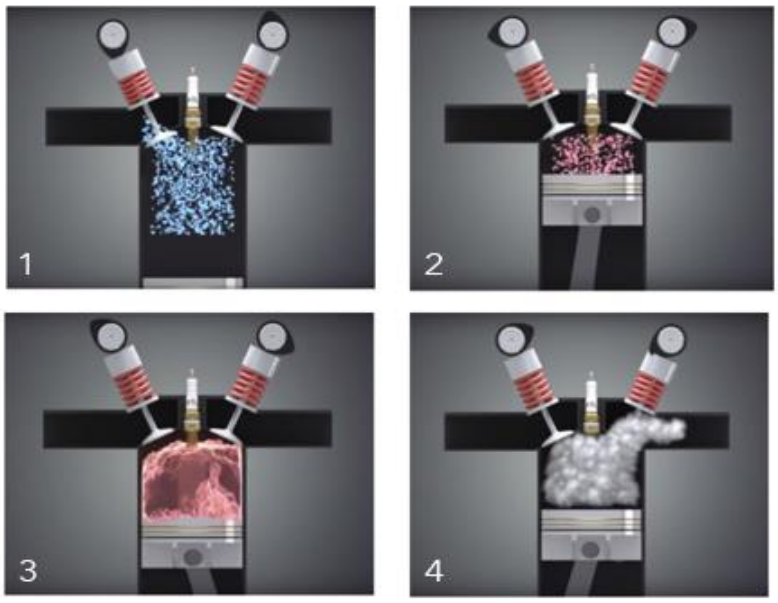

fig. 1: graphical illustration of a 4 - stroke engine cycle; own representation based on a video clip [3]

[3] "(17) How Car Engine Works - YouTube," accessed January 27, 2020, https://www.youtube.com/watch?v=DKF5dKo_r_Y.

A transmission is attached to the end of the driving shaft since the engine only manages to produce usable power outlets from 2,000 to roughly 6,000 RPM.[4] (revolutions per minute) The transmission enables the automobile to vary its driving speed.[5]

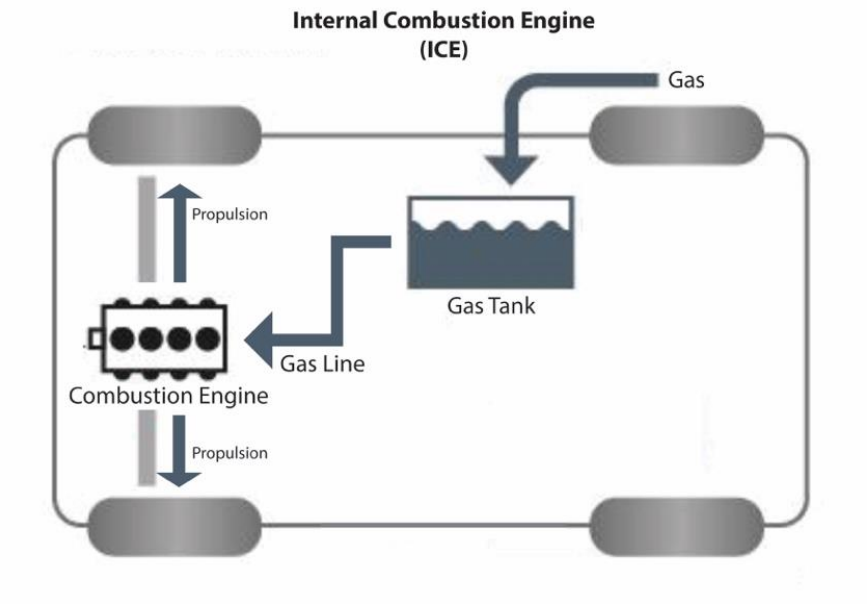

fig. 2: graphical illustration of a gasoline car; own representation based on Dr. Hoppe [6]

2.1.2 Benefits of internal combustion powered vehicles

One of the reasons that petrol cars have been successful is their convenience. They have a long range and operate efficiently at high speeds. More importantly, the fuel itself represents a major advantage as gas is widely available and quickly refillable. Gasoline also has a high energy density, which means that a great amount of chemical energy can be stored in a small and light fuel tank. This represents a major benefit, especially for larger vehicles such as trucks or buses.

[4] Cf. Publishers HarperCollins, "Rpm Definition and Meaning | Collins English Dictionary," accessed December 7, 2019, https://www.collinsdictionary.com/dictionary/english/rpm.
[5] Cf. Karle Anton, *Elektromobilität: Grundlagen und Praxis, p.52 ff.* (Carl Hanser Verlag GmbH Co KG, 2018).
[6] Dr. Hoppe, "E-Auto | ElektroMobilität NRW."

2.1.3 Drawbacks of internal combustion powered vehicles

The main disadvantage of gasoline cars is their overall inefficiency. Roughly 20 % of the chemical energy contained in the fuel is translated to the wheels, the rest is lost, predominately to heat and friction. This only represents the "tank-to-wheel" conversion. The real-life efficiency is even lower, considering the complicated gas-production process prior to usage.[7] Another drawback are the health risks, air pollution, as well as the dependency on fossil fuels. A conventional car also requires a lot of moving parts, which can be considered a disadvantage as they are more likely to break.[8]

2.2 Fully electric powertrain (BEV)

Electric cars lost their relevance relatively soon after the invention of the modern automobile. They continued to exist as niche products for a while, but when Henry Ford started mass-producing the Model T, they completely vanished and internal combustion vehicles took over.

After countless failed attempts to bring back the electric car, it seems like it has finally been done. There are still discussions about its sustainability, mainly because of the battery production, but today, electric vehicles are often seen as a promising alternative for conventional cars. Companies like Tesla have achieved important goals in development and sales. The essential charging infrastructure is growing throughout the Western world and electromobility is promoted by the government in many developed countries.[9]

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[7] Cf. Hanley Steve, "Electric Car Myth Buster — Efficiency | CleanTechnica," March 10, 2018, https://cleantechnica.com/2018/03/10/electric-car-myth-buster-efficiency/.
[8] Cf. Canada Health, "Human Health Risk Assessment for Gasoline Exhaust – Summary," guidance, aem, November 10, 2017, https://www.canada.ca/en/health-canada/services/publications/healthy-living/human-health-risk-assessment-gasoline-exhaust-summary.html.
[9] Cf. Bertram Mathias and Bongard Stefan, *Elektromobilität im motorisierten Individualverkehr: Grundlagen, Einflussfaktoren und Wirtschaftlichkeitsvergleich p. 86 ff.* (Springer Verlag, 2014), https://www.springer.com/de/book/9783658022631.

There are several common electric motors that are currently used in the car industry.[10] In this paper, the permanent magnet motor is used as an example since it is used in some of the best-selling electric vehicles. In most cases a lithium-ion accumulator is used because it is the most efficient type of battery, as it has an extremely high energy density and a low self-discharge rate.[11] Hence, the accumulator this paper is dealing with is a lithium-ion battery.

2.2.1 Technical description

Fundamentally, an electric car is made up of just two essential parts: the electric motor and the battery. The accumulator supplies the electric engine with energy. In the engine, two magnetic fields interact with each other. One of the magnets is attached on the outside of the engine, while the other one is on the inside. The stator magnet on the outside is an electromagnet with coils. Its electro-magnetic field sets the permanent magnet on the inside in motion. The rotor magnet on the inside is made from rare earth metals and has two poles. [12]

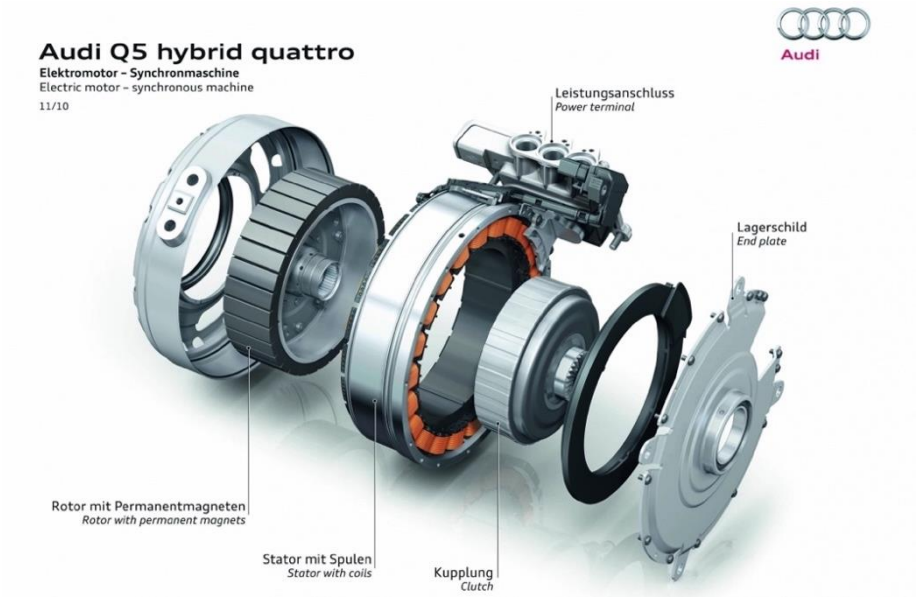


fig. 3: graphical illustration of an electric synchronous machine; Audi AG, 2013 [12]

[10] Cf. Wellnitz Joerg, Subic Aleksandar, and Leary Martin, eds., *Sustainable Automotive Technologies 2010: Proceedings of the 2nd International Conference* (Berlin Heidelberg: Springer-Verlag, 2009), https://www.springer.com/de/book/9783642107962.
[11] Cf. Czepelczauer, *The Invention Of The Car I THE INDUSTRIAL REVOLUTION*.
[12] Audi,AG, "Elektromotoren - Audi Technology Portal," June 6, 2013, https://www.audi-technology-portal.de/de/mobilitaet-der-zukunft/technikbausteine/elektromotoren.

The movement translates to the wheels using a clutch and a driveshaft, similarly to an internal combustion powered car.[13] Some electric vehicles have individual motors for each wheel and do not require these translation tools.
When breaking, the process can be turned around and mechanical energy can be converted to electric energy in the engine and stored chemically by the battery. The process in which the engine functions as a generator and regains energy from the wheels is called recuperating.[14]

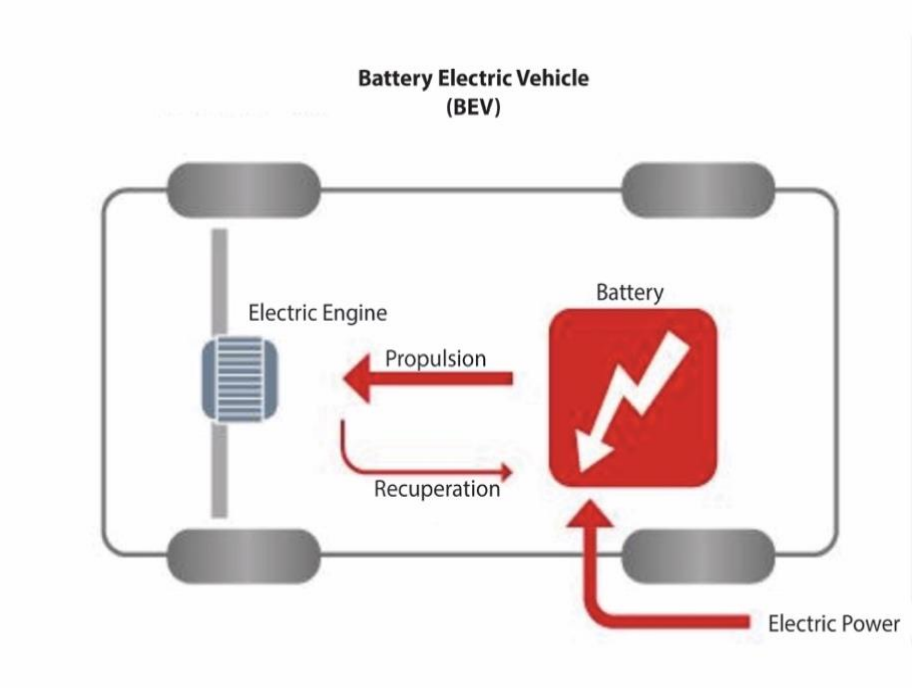


fig. 4: graphical illustration of a fully electric car; own representation based on Dr. Hoppe [15]

2.2.2 Benefits of fully electric vehicles

The main advantage of electric cars is their efficiency. Firstly, electric engines convert over 90 % of the electric energy in the accumulator to mechanical energy. Secondly, the electric engine can be used as a generator whenever the vehicle breaks. When recuperating, the engine itself slows the car down and charges the battery. Depending on how the electricity is produced, an electric car can be totally emission free in use.

[13] Cf. Karle, *Elektromobilität*. *p. 60 ff.*
[14] Cf. Karle. *p. 60 ff.*
[15] Cf. Dr. Hoppe, "E-Auto | ElektroMobilität NRW."

Another drastic benefit is the building structure. Electric vehicles do not require a lot of moving parts, which makes them less prone to damages.[16]

2.2.3 Drawbacks of fully electric vehicles

The biggest disadvantage is the accumulator. Its production and disposal is inefficient and critical for the environment as well as for the people involved. Rare materials, for instance cobalt and lithium, are contained in batteries. The exploitation of such substances is harmful for the environment and supports bad working conditions in developing countries.[17] In addition, batteries take an immensely large amount of energy to produce and even though they are often reused for some time, they cannot be fully recycled after their use in a car. Another drawback that is caused by the accumulator is its limited range, as every added kilogram of battery makes the vehicle heavier. A heavier car needs a more powerful engine, better brakes and building structure. These adjustments make the car heavier once again and requires it to have more batteries - a dilemma which limits the range. Until battery technology improves significantly, compounding weight is going to be a major weakness. Additionally, BEV take a relatively long time to recharge. Lastly, they are expensive to produce since the raw materials are difficult to extract.[18]

2.3 Hybrid powertrains (HEV/PHEV)

Hybrid means “mixed origins”. When used in context with automobiles, this usually labels a powertrain consisting of an internal combustion- and an electric engine. The concept of using both methods in one vehicle is essentially as old as the automobile itself. Soon after the invention of the automobile engineers started filing patent applications for such cars. Some companies, for example Porsche, even built prototypes, but hybrids never came into mass production. Heavy batteries made them inefficient and expensive.

[16] Cf. Karle, *Elektromobilität*. *p. 23-26*
[17] Cf. Gerding Jonas, “Kobalt: Ein Rohstoff und sein Preis,” *Die Zeit*, July 18, 2019, https://www.zeit.de/2019/30/kobalt-kongo-rohstoff-elektroautos-smartphones-bergbau.
[18] Cf. Univ.-Doz. Dipl.-Ing. Dr.techn. Wolfgang Wachter, “Zukünftige Mobilität,” (2018).

However, in 1997, when technology was advanced enough, Toyota started mass-producing the Prius, which is the best-selling hybrid car to this day.
Nowadays hybrids are considered a good transitional solution on the way to a more sustainable future. Many experts today argue that modern hybrid cars manage to combine benefits of both, the internal combustion- and the electric engine.[19]

There are countless variations of hybrid drives and there are several methods of subdividing them. They can be classified by degree of electrification (micro, mild, full, plug-in) and how the engines are installed and interact with each other (serial, parallel, power split, combined).
All of the different types of hybrids work similarly and only differ in detail. In this paper a full hybrid with a parallel engine system and a plug-in hybrid are discussed since most of the hybrid cars sold today follow these concepts.[20]

2.3.1 Technical descriptions

For the reason that two different types of hybrid cars are being introduced and compared, the *technical description* part is split into two sections. The first deals solely with the full hybrid vehicle, while the second one discusses the plug-in hybrid. The benefits and drawbacks of both hybrid systems are similar and differ only in detail, thus the benefit and drawback sections are not separated.

2.3.1.1 Full hybrid vehicle

Generally speaking, parallel hybrids are made up of an internal combustion engine with a gas tank, a drive shaft and a transmission, in combination with an electric engine powered by a lithium-ion battery (15- 50 kW). Both motors work as described in 2.1.1 / 2.2.1 and are directly connected to the wheels. The electric engine supports the combustion engine in meeting the peaks of power-demand and whenever ecologically worthwhile, for instance when driving off. This way the internal combustion engine operates close to its maximum efficiency at all times.

[19] Cf. Naughton Keith, "Prius Sales Are Falling, But Hybrids Are More Popular Than Ever," *Bloomberg.Com*, June 3, 2019, https://www.bloomberg.com/news/articles/2019-06-03/prius-preeminence-fades-as-hybrid-bets-shift-to-suvs-from-sedans.
[20] Cf. Hofmann.

The electric accumulator is charged by the spare energy that is produced by the gasoline engine, as well as the breaking energy, similar to fully electric vehicles where the electric engine can be used as a generator to recharge the battery. If beneficial, the electric engine takes over completely and the vehicle can be powered fully electrical for short distances. While this is advantageous in urban traffic, the combustion engine is more efficient for highway driving.[21]

A intelligent computer system in the car controls the synergy between the two powertrains.

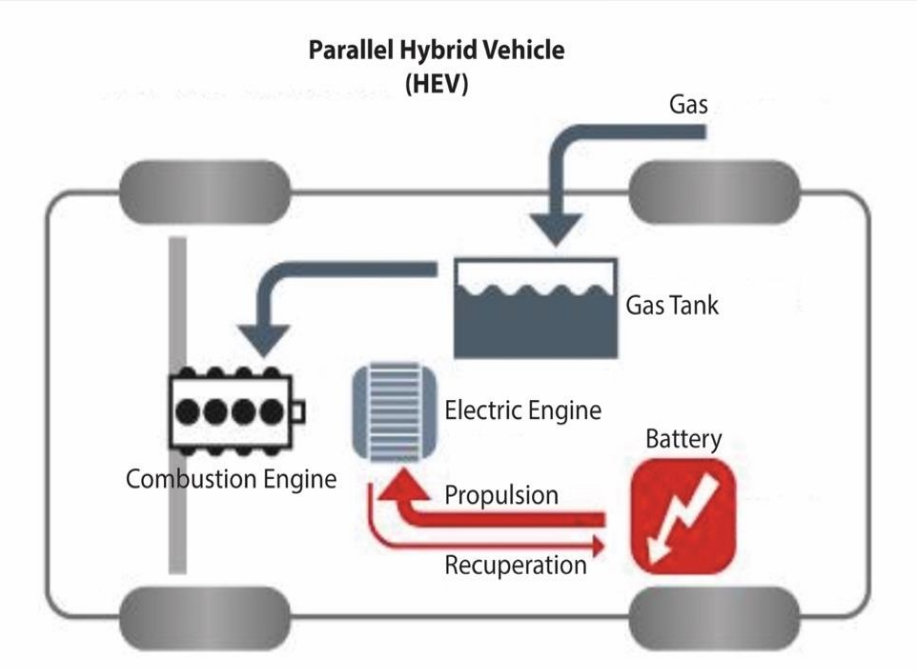


fig. 5: graphical illustration of a parallel hybrid car; own representation based on Dr. Hoppe [22]

[21] Cf. Karle, *Elektromobilität*. *p. 33 ff.*

[22] Cf. Dr. Hoppe, "E-Auto | ElektroMobilität NRW."

2.3.1.2 Plug-in hybrid vehicle

A plug-in hybrid is built from the same components as a full hybrid, however, the parts differ in their proportion. While the small electric engine in a traditional hybrid serves the purpose of supporting the combustion machine, the accumulator in a plug-in vehicle is more extensive (50 kwh+) and meant to power the car independently.[23] That being the case, the larger battery can also be recharged externally, comparable to an electric car. Equally important, the internal combustion engine is more compact than a regular hybrid's engine. It is intended to work supplementary to the electric engine for more energy-intensive situations such as highway driving or if the battery is too low to power the car exclusively.[24]

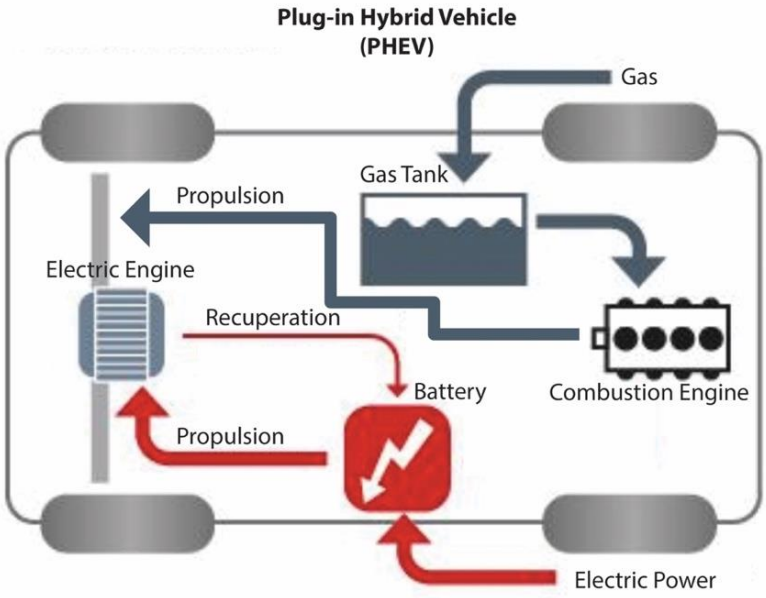


fig. 6: graphical illustration of a plug-in hybrid car; own representation based on Dr. Hoppe [25]

[23] Cf. Bertram and Bongard, *Elektromobilität im motorisierten Individualverkehr*. *p. 32 f.*
[24] Cf. Hofmann, *Hybridfahrzeuge*. *p. 60*
[25] Cf. Dr. Hoppe, "E-Auto | ElektroMobilität NRW."

2.3.2 Benefits of hybrid vehicles

The greatest advantage of hybrids is its fuel efficiency. A plug-in hybrid can cut urban fuel consumption in half, mainly because the electric powertrain and recuperative breaking are always active at low speeds.[26] The electric drive also enables the ICE to operate at higher speeds and closer to its maximum efficiency or shuts it off completely when running idle. Another leading edge is that mechanical pumps can be replaced by electric ones which are more power efficient.[27] If gained renewably, driving fully electric can also be a major upside since the vehicle does not emit any local exhaust fumes. This could help cities meet their air quality requirements and significantly increase the smog situation.[28]

2.3.3 Drawbacks of hybrid vehicles

The most problematic downside to a hybrid is its weight since it combines heavy batteries with a weighty combustion engine and a gas tank. The additional ballast makes the vehicle less efficient in situations like highway driving. Owing to the dual-powertrain concept, the drive occupies a wider range of space in the vehicle, which can have negative effects on the cars' size and seating capacity.[29] Furthermore, acquisition costs are high due to the batteries and the complicated building structure.[30]

[26] Cf. Hofmann, *Hybridfahrzeuge*. *p.30*
[27] Cf. Cui Hongyang, "Fuel-Efficiency Technology Trend Assessment for LDVs in China: Hybrids and Electrification," 2018, 22.
[28] Cf. Karle, Elektromobilität. p.34 f.
[29] Cf. Karle. Elektromobilität. p.34 ff.
[30] Cf. LaFontsee Greg, "Advantages & Disadvantages Of Hybrid Cars | Pros & Cons - ADS Auto," *Automotive Diagnostic Specialties* (blog), June 27, 2019, https://automotivediagnosticspecialties.com/advantages-disadvantages-of-hybrid-cars/.

2.4 Fuel cell electric powertrain (FCEV)

"I believe fuel cells will finally end the 100-year reign of the internal combustion engine." [31], said William Clay Ford Jr., executive chairman of Ford motors and grandson of Henry Ford. A quote such as this could have come from many large car manufacturers in the early 2000's, for the reason that hydrogen cars have been and still are considered to be the future by some experts. For many years, in fact since the invention of the automobile itself, engineers have been experimenting with hydrogen drives.

However, after ICE powered cars took over, hydrogen lost its relevance as a powertrain. But it made its comeback in the 1960s after general electric invented the first modern fuel cell and NASA used the technology in space.[32] From this point on, hydrogen was not used for combustion engines anymore, but as storage for electricity in an electric car. The fuel cell converts hydrogen into energy using a chemical process and passes it on to a battery. It is important to understand that hydrogen cars are electric cars that simply use a different method of storing energy.[33] In the early 2000s f-cell vehicles started gaining public attention as manufacturers like Toyota, Hyundai or Mercedes Benz started presenting prototypes and countries like China began investing in infrastructure.[34] Japan even set itself the goal of becoming the first hydrogen society. However, to this day, hydrogen cars are a niche product and have not made a breakthrough.[35]

[31] Cf. Day Erin, "Ford Believes in Hydrogen and Fuel Cell Future," *Connecticut Center for Advanced Technology, Inc.* (blog), August 4, 2017, https://www.ccat.us/2017/08/ford-believes-in-hydrogen-and-fuel-cell-future/.
[32] Cf. Matthey Johnson, "Fuel Cell History - Fuel Cell Today," 2019, http://www.fuelcelltoday.com/history.
[33] Cf. Bertram and Bongard, *Elektromobilität im motorisierten Individualverkehr*. *p. 36*
[34] Cf. Thomas Peter, "China's 'father of EV' urges more hydrogen infrastructure to develop fuel cell vehicles," *Reuters*, July 2, 2019, https://de.reuters.com/article/us-china-autos-electric-hydrogen-idUSKCN1TX17F.
[35] Cf. Kato Issei, "Japan Draws Support for Global Hydrogen Proposals, Including Refueling Stations," *Reuters*, September 25, 2019, https://www.reuters.com/article/us-japan-hydrogen-idUSKBN1WA19R.

2.4.1 Technical description

A fuel cell vehicle needs four main components to function: A hydrogen tank, a fuel cell, a battery and an electric engine. Firstly, the hydrogen that is stored in a high-pressure tank (700 bar) is brought to the fuel cell. The f-cell then converts the hydrogen to electricity with a chemical reaction similar to a reversed electrolysis. The cell consists of an anode and a cathode. Both of them are electrical conductors and the anode contains the hydrogen, while the cathode is filled with oxygen. In between the two, there is a PEM (proton exchange membrane) which only allows protons from the anode to pass through. The electrons that cannot pass are led through another route and create an electric current.[36]

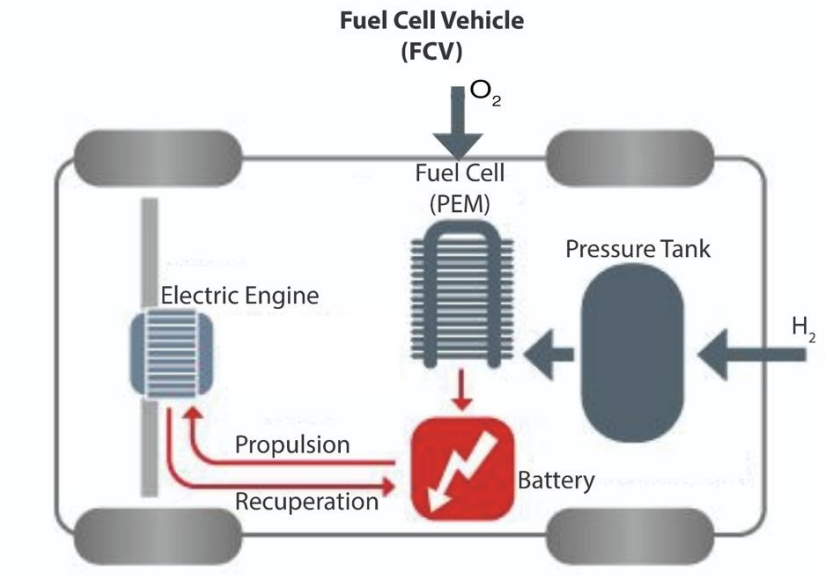


fig. 7: graphical illustration of a fuel cell vehicle; own representation based on Dr.Hoppe [37]

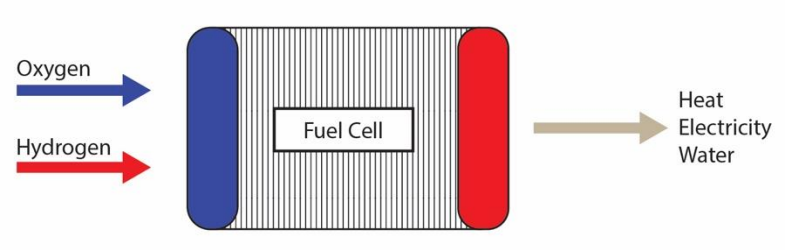


fig. 8: graphical illustration of a fuel cell; own design

[36] Cf. Scott Joe, *Hydrogen Fuel Cell Cars Aren't The Dumbest Thing. But... | Answers With Joe*, 2019, https://www.youtube.com/watch?v=xU-LDZ0HTGc&t=901s. *3:08-3:45*
[37] Dr. Hoppe, "E-Auto | ElektroMobilität NRW."

The current can be fed into a small battery which passes the electricity on to the engine. The process also produces heat and water in form of steam. The heat is lost and the clean H_2O is emitted through an exhaust pipe, comparable to an ICE powered vehicle. Some vehicles do not have a battery and the energy is lead directly to the engine, but most of them need a battery as it also heats up the fuel cell before starting the car as a minimum temperature of about 80°C is required for it to function.[38] The electric engine works similarly to the one in an electric car and powers the wheels. Comparably to an electric vehicle, the engine can also regain energy when slowing down.

2.4.2 Benefits of fuel cell vehicles

The decisive advantage of fuel cell vehicles is the hydrogen's energy density. Especially compared to other forms of electricity storage in cars, hydrogen offers a specific energy many times greater than batteries can do today.[39] An FCEV also has a higher range and can be recharged in a few minutes. Furthermore, the accumulators required are smaller, thus environmentally harmful cobalt and lithium mining is not supported in the same extent as in the production of electric vehicles.

The oxygen, which is required for the chemical process in the fuel cell, needs to be totally clean. For that reason, hydrogen cars have countless filter systems to clean the air which is needed for the electricity production. Therefore, they clean the air as they go. Hydrogen production only requires water, electricity and production infrastructure. Therefore, it can be produced nearly anywhere and makes countries less dependent on oil imports.

[38] Cf. Karle, *Elektromobilität*. *P.38 ff.*
[39] Cf. Thomas C.E., "Fuel Cell and Battery Electric Vehicles Compared," *International Journal of Hydrogen Energy* 34, no. 15 (August 2009): 6005–20, https://doi.org/10.1016/j.ijhydene.2009.06.003. *p. 3*

2.4.3 Drawbacks of fuel cell vehicles

The most drastic disadvantage of an FCEV is the inefficiency in the production of hydrogen. There are three ways of gaining hydrogen from organic matter: The most common form in industrial production is steam reforming, a process by which steam is combined with natural gas. This method causes pollution and is extremely ineffective as the natural gas needed for the extraction has more chemical energy than the outcome - hydrogen.[40] Another method is called electrolysis, by which hydrogen is extracted from water with an electric current. This seems to be a better procedure since the electricity can come from renewables, but this technique is still not suitable, as it requires an even greater energy input than steam reforming and around 30 % of the input energy is lost.[41] There is one more approach called PEM (proton exchange membrane) electrolysis, which is slightly more effective. However it still has an energy loss of about 20 %. After production, the hydrogen has to be stored and transported to the consumer, which poses another problem: the hydrogen has to be liquefied or compressed, which is an energy consuming process. Lastly, it has to be transported, unless it is produced on site, through pipes or by truck, which requires infrastructure that does not exist yet.[42]

[40] Cf. Karle, *Elektromobilität*. *P.38 ff.*
[41] Cf. Sammann Stephanie, *The Truth about Hydrogen*, 2018, https://www.youtube.com/watch?v=f7MzFfuNOtY.
[42] Cf. Sammann.

3 Comparison of powertrains

The following section compares the given powertrains. It ultimately intends to find the most promising technology in terms of sustainability and is built on experts' opinions as well as arguments from critics and supporters. The section does not reflecting on economic or industrial aspects of the technologies.

3.1 Fuel cell vehicle and fully electric vehicle

As many experts argue that the future of cars is electric and their sales are experiencing a global boom, it seems reasonable to compare different types of powering electric vehicles.[43] Comparing fuel cell driven vehicles and battery powered ones is rather difficult: On the surface, hydrogen seems to be the smarter way of powering a car. It does not require large batteries, offers a greater range and is quickly refillable. However, it falls behind when considering the production process of the hydrogen. With the production, storage and transport of hydrogen, the technology already wastes tremendous amounts of power before it is even used in a car. Electricity on the other side, is widely accessible and loses only a small amount of power to the electrical grid. The same picture continuous on the inside of the vehicle. The electricity of the battery in a BEV only has to be converted from DC to AC current, while the hydrogen energy requires up to four steps of transition until it is transformed to mechanical energy. From end to end, hydrogen vehicles are about 50 % less efficient than battery electric vehicles.[44] This is why many critics of fuel cell vehicles argue that hydrogen cars are simply too inefficient.[45] However, there are also supporters of hydrogen technology, in fact whole countries argue about whether fuel cells are the future or not. [46]

[43] Cf. International Energy Agency, "Global EV Outlook 2019," May 27, 2019, https://www.iea.org/publications/reports/globalevoutlook2019/.
[44] Cf. Sammann, *The Truth about Hydrogen*.
[45] Cf. R Martin and elhoff, "Elektrisch im Straßenverkehr: Batterie vs. Brennstoffzelle vs. Power-to-X » Zukunft Mobilität," accessed December 30, 2019, https://www.zukunft-mobilitaet.net/169895/analyse/elektroauto-brennstoffzelle-synthetische-kraftstoffe-ptx-ptl-kosten-infrastruktur-rohstoffe-energiebedarf-wirkungsgrad/.
[46] Cf. Sammann, *The Truth about Hydrogen*.

Japan made its national goal to become the first hydrogen society and massively supports the growth of hydrogen infrastructure, as on-site production, for example at gas stations, can partially solve the problem of production inefficiencies. Smaller on-site production facilities do not need to transport the hydrogen to the consumer and can use cheap off-peak electricity to produce it.[47]

There are also other attempts trying to solve the problem, for example the idea of Desertec, where electricity and hydrogen are produced in large-scale solar facilities in the North African desert.[48] However, so far none of these concepts have proved to be successful outside of computer simulations, calculations or prototype facilities yet and many have been given up on.

It is difficult to determine which technology is the best, especially because breakthroughs in battery technology and in hydrogen conversion are expected in the near future. [49] For now, BEV's seem to be in a slightly better position, as they are more efficient and electricity infrastructure is widely spread.[50] However, hydrogen powered vehicles could take over in some parts of transport as a multi powertrain future is not unlikely. Due to its high static energy and comparably low weight, hydrogen can be advantageous for trucks and buses, as larger vehicles would require a large battery, which causes it to be less efficient. In this case, the missing refueling infrastructure is not a problem as buses and trucks usually ride on predetermined routes. Thus it is simple to plan fuel stations strategically. Many experts even argue that hydrogen is the future of aviation and railway transport.[51]

However, the most essential point for both technologies is the switch to renewable energy sources since they are directly dependent on electricity. Electric and hydrogen cars in

[47] Cf. Kato, "Japan Draws Support for Global Hydrogen Proposals, Including Refueling Stations."
[48] Cf. "DESERTEC Foundation – Energy for the next Billion," accessed December 7, 2019, https://www.desertec.org/.
[49] Cf. Rathi Akshat, "How We Get to the next Big Battery Breakthrough," *Quartz*, April 8, 2019, https://qz.com/1588236/how-we-get-to-the-next-big-battery-breakthrough/.
[50] Cf. Simonov Alexandr, "Electrolysis Breakthrough Could Solve the Hydrogen Conundrum," September 25, 2019, https://phys.org/news/2019-09-electrolysis-breakthrough-hydrogen-conundrum.html.
[51] Cf. Sammann, *The Truth about Hydrogen*.

Europe and most parts of the United States are already less harmful for the environment than gasoline powered ones, when running on the average national electricity mix. Some countries, China for instance, has such a poor energy mix that hybrids or even gas cars are better for the environment. However, this is not an argument against alternative powertrains, as China is a particularly negative example and has already started to improve energy production systems.[52]

3.2 Hybrid vehicles and internal combustion vehicle

While the majority of experts agree on the electrification of transport in the future, their opinions diverge on the length of the transitional period. It seems unlikely that the world of transport will change overnight. Especially long-distance travel and transport are dependent on internal combustion engines, as the alternatives do not provide the same range and convenience yet.[53]

Until electric vehicles take over outside of cities, in rural areas and on highways, hybrid vehicles promise to be a transitioning solution combining both electric and gasoline powertrain systems. Therefore, it seems reasonable to compare the two hybrid drives and evaluate their potential to replace internal combustion powered cars in the near future, as it is clear that ICE vehicles cannot be used in the same way they are today, even with expected improvements in fuel efficiency.[54] The Plug-in hybrid is clearly more efficient than a full hybrid car, however, it is also more reliant on electricity and therefore on charging infrastructure. That is an issue, as hybrids are meant to take over in fields such as highway driving or in rural areas where electric vehicles are simply not practical enough since charging infrastructure is still missing outside of urban regions and time losses due to recharging are too great when travelling long distances.[55] This is why the plug-in hybrid is an alternative to electric vehicles in the city rather than to ICE powered vehicles on the highway. The full hybrid car seems to be more competitive.

[52] Cf. Univ.-Doz. Dipl.-Ing. Dr.techn. Wolfgang Wachter, "Zukünftige Mobilität."
[53] Cf. Stewart Jack, "Hybrid Cars: Where Do They Perform Most Efficiently?," April 14, 2014, https://www.bbc.com/future/article/20140414-where-hybrid-cars-perform-best.
[54] Cf. Univ.-Doz. Dipl.-Ing. Dr.techn. Wolfgang Wachter , "Zukünftige Mobilität."
[55] Cf. Campbell Peter and Thomas Nathalie, "Switch to Electric Cars Hit by 'Poor' Charging Infrastructure," *Financial Times*, June 11, 2019, https://www.ft.com/content/dfe71424-7c07-11e9-81d2-f785092ab560.

Under most circumstances the driver would not even notice that the driven vehicle is a hybrid, however, it still makes up for some of the inefficiencies of a gasoline car. When recuperating, the electric engine uses the breaking energy instead of losing it.[56] Taking everything into account, full hybrids are more fuel efficient, even in highway use, and emit less environmentally harmful fumes than petrol cars.

Take the Toyota Corolla, for example, one of the newest and most efficient hybrid cars: Comparing the 2020 Corolla Hybrid *(2020 Toyota Corolla Hybrid 1.8 L, 4 cyl, Automatic)* with the regular, gasoline powered 2020 Corolla *(2020 Toyota Corolla 2.0 L, 4 cyl, Automatic [AV-S10] Regular Gasoline)* it is noticeable that there is a significant difference in fuel efficiency between the two models.[57] On the highway the hybrid has a fuel consumption of 4.5 liters on 100 km, while the gasoline versions' mileage uses about 5.6 liters. In the city the difference is even greater.[58]

Hybrid cars can definitely be a great alternative to ICE powered vehicles, their ecological benefit, however, depends heavily on factors like driving style and other variable determinants.[59] If a transitioning solution is necessary, hybrid cars have the potential to change the way we drive. To sum up, using hybrids could help many regions, predominately rural or undeveloped regions, limit their carbon footprint and their dependency on fossil fuels.

3.3 Conclusion

None of the powertrains represent a "perfect solution", they all have their benefits and drawbacks. Fully electric cars do not emit exhaust fumes in use but have heavy batteries that require harmful mining and difficult recycling procedures. The fuel cell vehicle is not as efficient as fully electric cars and there is hardly any infrastructure for hydrogen

[56] Cf. Hofmann, *Hybridfahrzeuge*.
[57] Cf. AT Toyota, "Toyota AT | Alle Toyota Modelle auf einen Blick," 2019, https://www.toyota.at/new-cars/model-filter.json.
[58] Cf. EPA, "Fuel Economy of 2020 Toyota Corolla," 2020, https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=1&year1=2020&year2=2020&make=Toyota&baseModel=Corolla&srchtyp=ymm.
[59] Cf. Stewart, "Hybrid Cars."

supply. Combustion engines themselves are clearly not sustainable and are dependent on fossil fuels.
Hybrids can be advantageous, since they produce less emissions than ICE powered vehicles but at the same time they use heavy batteries with complex and harmful combustion engines.

Considering all the above-mentioned aspects, it is difficult, maybe even impossible to predict the future of individual transport. As for now, a multi powertrain future seems likely, electric or plug-in hybrids in the city, combustion engines or full hybrids for long distance travel and hydrogen powered trucks, trains and planes. It is not so much the drive of our cars that will change, but the way we use cars in general.

We have to rethink the role of the automobile in modern society and it is necessary to improve public transport, in order to make us less dependent on our cars. In some areas, where public transport does not limit car usage effectively, alternative options such as car sharing or carpooling should be taken into account. In addition to that, smaller vehicles for example electrical bikes or scooters are environmentally friendly options for urban traffic systems.

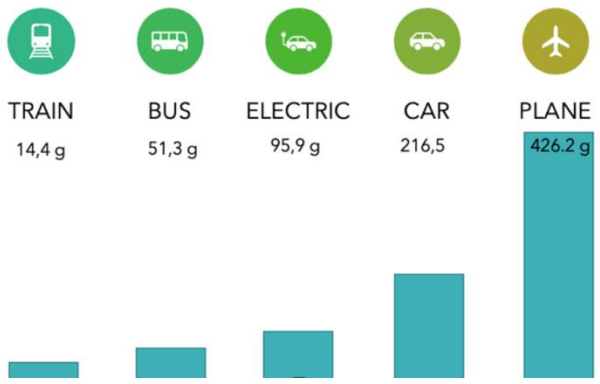


fig. 9: graphical illustration of CO_2 emissions per person per kilometer of traveling*;* calculations based on Austria's energy mix; *own representation based* on Umweltbundesamt [60]

[60] Cf. "EKZ_Fzkm_Verkehrsmittel.Pdf," accessed December 26, 2019, https://www.umweltbundesamt.at/fileadmin/site/umweltthemen/verkehr/1_verkehrsmittel/EKZ_Fzkm_Verkehrsmittel.pdf.

Figure 9 shows how drastically public transport could limit our emissions and how inefficient cars are in general. Trains only take about half of the energy a car uses to transport one passenger, even at high speeds. They also fare better in terms of public health, noise pollution and safety issues. Carbon dioxide emissions vary depending factors such as capacity utilization or energy mix and might affect emissions caused by a person. Especially if trains run on diesel, like they still do in many countries, their carbon footprint can become as high as that of gasoline cars. However, this is an argument for improving our train systems rather than against traveling on rail. [61]

4 Cartopia

This section outlines how an environmentally "perfect" and sustainable model for individual transport with cars could look like in the future. It is based on the "Mobilitätskonzept Vorarlberg 2019", a mobility concept discussing upcoming changes and improvements in Vorarlberg's transport structure in the next 10 - 15 years. Additionally, experts' opinions and other documents such as "public transport in 2040", a paper published by the Dutch government dealing solely with public transport in the Netherlands, are considered. Following these real-life projects, as well as ideas from academics, a "utopian" vision of the future is presented below. Neither economic nor social aspects are discussed, the section covers sustainability issues only and examines their political and personal consequences. All the measure explained below encompass urban centers as well as rural regions. Depending on how small and isolated or large and connected a town is, its transportation needs can be adjusted by taking elements form concepts designed for either urban or rural areas. By combining different ideas and suitable approaches individually for each area, it is possible to improve the situation anywhere in the world.

[61] Cf. Friends of the earth UK, "Why Travelling by Rail Is Better for the Environment," n.d., 2. https://friendsoftheearth.uk/climate-change/ethical-travel-nofly-holiday-ideas

4.1 Urban traffic structure

A green city or urban area could work like this: Public transport plays a major role in inner-city transit. Trains are powered by electricity and run frequently. Furthermore, they are comfortable, reliable and safe.[62] Stations are built close to the consumer, public places, industrial grounds and airports providing taxi services, carsharing, "bike and ride", underground parking for cars and rental places for tourists. Walking, sharing bikes or scooters is environmentally friendly, healthy for the consumer and keeps the people off the roads and consequently, buses, emergency vehicles and regular cars are faster. It is essential that the junctions work well and are accessible by everyone, thus people cannot only travel by train from station to station but also from railway stations to their final destinations. Even more importantly, buses work effectively too, running battery powered or on hydrogen. Electrical buses must be recharged quickly by means of overhead wires, battery switching or through inductive roads and bus stops. If technology allows to charge fast enough, charging them regularly works as well. These means of transport are able to handle peak numbers of passengers during rush hour. As a result, trains run more frequently in the morning and at night and buses use traffic-free bus lanes.[63] The tickets are affordable and cheaper compared to the cost of using a car.

Cars are only used when necessary and are powered electrically. Carpool lanes, charging infrastructure and higher taxes on gasoline and diesel motivate people to change their driving behavior. In addition to a rise in taxes on gasoline and diesel, jet fuel is also heavily taxed. At the same time, more environmentally friendly modes of transport such as trains are promoted by government incentives, thus overall cost for transport remains identical. Emitting carbon dioxide becomes more expensive. Taxpayers' money is refunded through lower fees on environmentally friendly modes of transport.

[62] Cf. Zaken Ministerie van Algemene, "Public Transport in 2040 - Outlines of a vision for the future - Report - Government.nl," rapport, February 1, 2019, https://www.government.nl/documents/reports/2019/05/13/public-transport-in-2040.
[63] Cf. "Mobilitaetskonzept Vorarlberg," accessed December 27, 2019, https://vorarlberg.at/documents/21336/42919/Mobilit%C3%A4tskonzept+Vorarlberg+2019+-+Endbericht/640218bc-18f3-44c8-96d6-e1aae25d7298.

The tax shift is carried out on an international level, e.g. within in the EU, in order to avoid fuel tourism.[64] Governments inform about public transport, carsharing offers close to residential areas and sustainable mobility in general. Tourists and locals are aware of their possibilities and price politics and use more sustainable ways of travel.[65]

4.2 Rural traffic structure

The situation in rural areas and regions with lower population density is far more complicated despite countless attempts to decrease their carbon footprint. It is extremely important for these regions to sustain their quality of life. A green region could work like this: Public transport, mainly buses, play a major role in human transport. They do not require large infrastructure like trains and simultaneously offer flexibility similar to a car. The buses in very small, isolated places do not only rely on routes but also work as an on-demand service that adapts to the peoples' needs. At present, projects of this kind are being tested in Austria, Greece and Spain. In addition to adjustable routes, buses can combine public transport with other services such as postal service or transport of goods. As a result, public transport becomes less dependent on government funding in these regions.[66]

Encouraging tourists to use public transport when visiting rural areas also helps to develop and improve local infrastructure. In Western Europe, mountain villages benefit a great deal from hikers or skiers using public transport instead of their own vehicles. Sharing options may be an additional incentive to reduce the need to own a car. For short distances cycling is also an environmentally friendly option, traditional bikes are suitable as well as e-bikes for faster and effortless travel. At this moment in time, rural areas are unlikely to be completely independent on cars. However, in the long run, there is undoubtedly a lot of potential of making transport more environmentally friendly.[67]

[64] Cf. Todts William, "Climate Benefits from Measure to Stop 'Fuel Tourism' | Transport & Environment," accessed December 26, 2019, https://www.transportenvironment.org/news/climate-benefits-measure-stop-%E2%80%98fuel-tourism%E2%80%99.
[65] Cf. "Mobilitaetskonzept Vorarlberg."
[66] Cf. Zaken, "Public Transport in 2040 - Outlines of a vision for the future - Report - Government.nl."
[67] Cf. "Regierungsprogramm 2019-2024 Vorarlberg," accessed January 16, 2020, https://vorarlberg.at/documents/21336/26927/Arbeitsprogramm+2019+-+2024/66c2fbca-9eb7-444b-8827-acf78b251076.

5 Empirical section

Not only politics is responsible for creating a more sustainable future, the people themselves have to be committed to change. This is why a survey was carried out for this paper. People of different nationalities, social background and age answered questions about climate change and their willingness to do something about it in the near future. Finding out if people are willing to accept trade-offs is important, especially because taking such steps (e. g. driving electric or using public transport) can be seen as a burden. The questionnaire was given to participants from the US, Canada, Australia, Germany, Austria and Switzerland and primarily focuses on younger people as they have to deal with this issue and its consequences more than any other generation.

5.1 Explanation of the questionnaire

Questions 1 - 5
Demographic data

The first five questions gather information about the participant such as gender, age and country of residence. The participants are also asked whether they have a driver´s license (car / motorcycle / moped) and to give an estimate of the distance to their workplace, school or university.

Question 6
How do you get to your workplace / university / school?
Answering system: multi-select multiple choice

- *Public transport / school bus*
- *Car*
- *Bicycle*
- *By foot*
- *Other*

This question intends to find out which means of transport the persons questioned use on a daily basis. The answers have to be put in relation to distance and residence. The answers are expected to vary, depending on where the participant lives. In most parts of North America the legal driving age is 16, lower than in Western Europe. Since many regions in the US and Canada lack public transport, it is quite common for young people to own a car. At the same time schools in the US and in Canada offer free school buses that stop close to every student's house, a service which is usually not offered in Austria, Germany and Switzerland. The option "*Moped/Motorcycle"* was added to the German version of the survey, since these vehicles are far more popular in German speaking countries than in North America.

Question 7
Statement: "Human-made climate change is real."
Answering system: single select multiple choice

- Agree
- Disagree
- Undecided

The statement: *"Human-made climate change is real*." is given and the interviewee has to decide whether he / she agrees with the above-mentioned statement. Depending on the answer to this question other data can be put into context. There is also a third option: *"undecided"* for participants who are not entirely sure, this option is expected to be picked more often by North Americans as the discussion about human climate change is more intense there.[68]

[68] Cf. BBC News, "Trump Says 'Climate Change Goes Both Ways,'" *BBC News*, June 5, 2019, sec. US & Canada, https://www.bbc.com/news/world-us-canada-48531019.

Question 8

Would you be willing to take action for a more sustainable future?

Answering system: single select multiple choice

- *Agree*
- *Disagree*
- *Undecided*

This question provides essential information about the peoples' mindset about changing their behavior. It will be analyzed with respect to previous answers, e.g. if people even believe in human-made climate change.

Questions 9 - 12 (Public Transport)

Statement: "I would be willing to use public transport if it was…

- Question 9 … cheaper than using a car."

- Question 10 … faster than using a car."

- Question 11 … more expensive than using a car."

- Question 12 … slower than using a car."

Answering system: single select multiple choice

- *Strongly agree*
- *Agree*
- *Disagree*
- *Strongly disagree*

The questions try to evaluate how willing people are to compromise when it comes to using public transport instead of their own car. Aspects like costs and time consumption are discussed to see whether people would tolerate trade-offs.

Question 13

Which alternative power sources do you know?

Answering system: multi-select multiple choice

- *Electric*
- *Hybrid*
- *Hydrogen*

Here, the participants are asked about their knowledge of alternative ways of powering cars. It is important to know if alternative powertrains play a role in the responder's life and whether he / she has a general idea of what cars could be like in the future. It is highly probable that the majority of people knows about electric and hybrid cars whereas hydrogen powered cars are widely unknown. A reason for this may be their comparatively low coverage in the media.

Questions 14 - 16

Statement: "I would buy such a car ...

- Question 14 ... in general."

- Question 15 ... if it was cheaper."

- Question 16 ... even if it was more expensive."

Answering systems: multi-select / single select multiple choice

- *Strongly agree*
- *Agree*
- *Disagree*
- *Strongly disagree*

The three questions are about the requirements that have to be met in order to convince people to use cars with alternative powertrains. At first, the survey focuses on finding out whether or not the participants could imagine buying such a car.

The participants then answer questions about pricing, since cars running on alternative sources are still more expensive.

It is important to know whether people are willing to spend more money on such a car since government incentives could be useful in order to promote more environmentally friendly cars.

Question 17
Statement: "I would use a car like that if it took me ... longer."
Answering system: single select multiple choice

- Up to 5 min per hour of traveling
- Up to 10 min per hour of traveling
- Up to 15 min per hour of traveling
- Never

This question is about accepting loss of time due to recharging and refueling. The participants are asked how much time they are willing to „sacrifice". A small amount of loss in time seems inevitable with today's technology.

Question 18
Statement: "I would be willing to carpool."
Answering system: single select multiple choice

- *Strongly agree*
- *Agree*
- *Disagree*
- *Strongly disagree*

Here, the general disposition to carpool is queried as increasing car occupancy rates are an essential step towards more sustainable transport.[69]
The question does not go into detail on how the carpool system works (e.g. carpooling / ridesharing apps / personal agreement).

[69] Cf. European Union, "Increasing Car-Occupancy Rates | CIVITAS," 2020 2016, https://civitas.eu/measure/increasing-car-occupancy-rates.

Question 19

Statement: "I would be willing to use a car-sharing platform instead of having my own car."

Answering systems: single select multiple choice

- *Agree*
- *Disagree*
- *Only if I lived in a city*

The last question deals with car-sharing, a concept particularly important for future cities, which is why there is a third answering option *(Only if I lived in a city)*. It tries to determine whether people are open to use such a system on a daily basis, on condition that a sophisticated and affordable network is in existence.

5.2 Sample description

277 people have filled out the survey, 102 of which live in the US or Canada and 169 in Austria, Switzerland or Germany. 6 people are from the Netherlands or Australia. The relatively high number of participants makes it possible to give at least an overview of the attitudes towards this topic in the western society.

At the same time, the result can only show tendencies, as the sample is too small to be taken as a comprehensive description of the situation or as a basis for estimates on climate action in the future. The focus lies on the opinions of the young people and their views on an issue which will affect them throughout their lives.

For that reason, 75 % of the persons asked were between 16 - 18 years old, many of them attend a high school. About 8 % were aged 19 to 21, 7 % were between 21 and 25 and around 10 % were older than 25.

Despite the fact that the data becomes less reliable when there are only a few participants of a certain age group answering the questions, it is possible to discern at least a rough tendency.

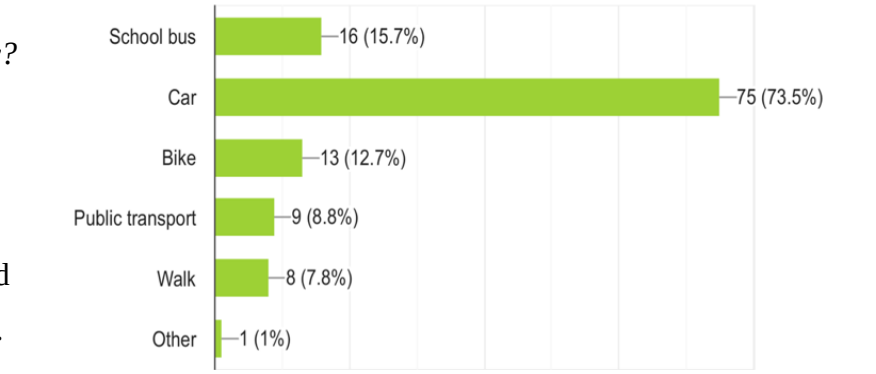
About 49 % of the participants were male, 48 % female and 3 % identified their gender as “different”. The survey was completely anonymous and all participants were asked to answer the questions honestly.
It was conducted during the 2018/19 school year in North America and during 2019/20 in Western Europe.

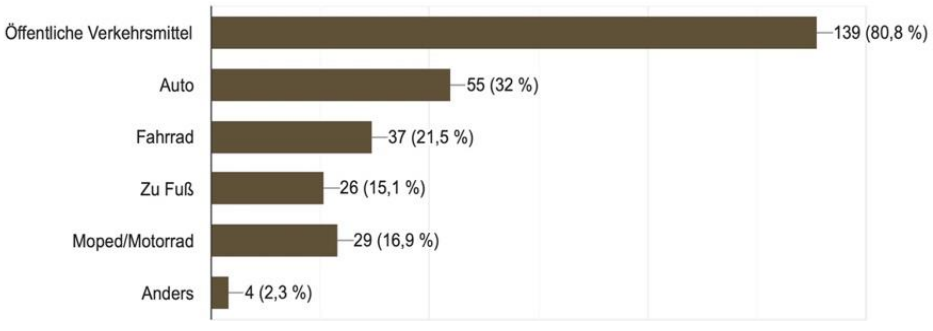
5.3 Analysis of the survey

In a first step the questions 6 - 19 are evaluated individually. Questions 1 – 5 are left out as they solely deal with demographic data. The results are shown in diagrams and the data is discussed and compared.
Secondly, the most important conclusions are drawn and outlined in a separate section.

5.3.1 Individual elevation

Question 6
How do you get to your workplace/school/university?



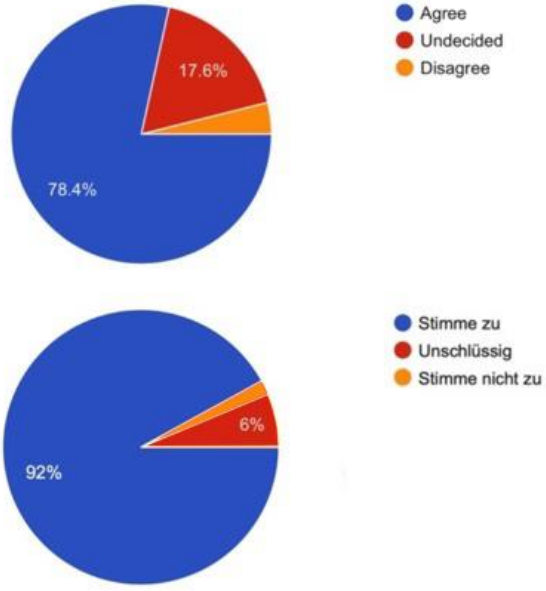


There is a noticeable difference between the answers given in Europe and North America respectively. 80 % of European participants said that they use public transportation to get from and to their daily destinations, less than 9 % of the North Americans use public transport to cover these distances. It is important to add that 15.7 % of the Americans asked claim that they use the school bus. School buses often operate at full capacity, since the routes are planned in advance.

This is why they are comparable to public transport when it comes to their carbon footprint.[70] However, even taking this into account, the difference is immense. 73.3 % of the participants in North America use their cars to get to work / university / school. In Europe only one third go by car and around 17 % by moped or motorcycle. There are also more cyclers and people who walk to school or their working place. This shows a clear and unmistakable tendency that also can be supported by countless reports and newspaper articles - cars are used heavily across US and Canada.[71] However, this does not mean that people living in these countries are not willing to change.
Many parts of the US and Canada unfortunately have poor public service and cycle paths. Much of this can be explained by the size of these countries and their tax systems.[72]
Overall, more than half of participants said that they use their cars to cover their daily distances.

Question 7

Statement: "Human made climate change is real."

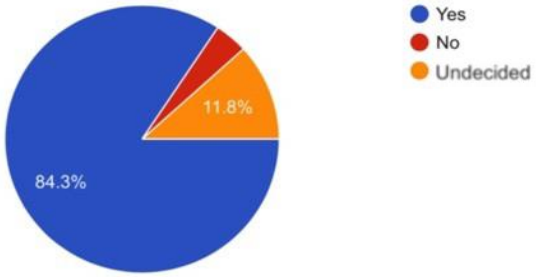


As expected, the number of North American participants choosing to agree is lower. Also, there are no significant differences regarding age. This could be because of the current political situation, as the President of the United States himself often makes critical statements in public and even withdrew from the Paris Agreement in 2017.[73]
Nonetheless, the vast majority in both cases agrees to the statement and is aware of the problem.

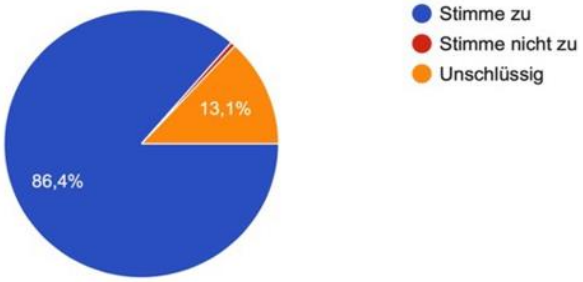
[70] Cf. "Are School Buses Eco-Friendly?," Seventh Generation, accessed January 6, 2020, https://www.seventhgeneration.com/blog/are-school-buses-eco-friendly.
[71] Cf.Humes Edward, "The Absurd Primacy of the Automobile in American Life," The Atlantic, April 12, 2016, https://www.theatlantic.com/business/archive/2016/04/absurd-primacy-of-the-car-in-american-life/476346/.
[72] Cf. English Jonathan, "Why Did America Give Up on Mass Transit?," CityLab, accessed January 6, 2020, https://www.citylab.com/transportation/2018/08/how-america-killed-transit/568825/.
[73] C.f BBC News, "'Regret' as US Begins Exit from UN Climate Accord," *BBC News*, November 5, 2019, sec. US & Canada, https://www.bbc.com/news/world-us-canada-50297029.

Question 8

Would you be willing to take action for a more sustainable future?



Most people claim that they are willing to take action themselves. In North America the number of participants who are reluctant to change their behavior is higher than in Europe. This does not come as a surprise, as it correlates with the higher percentage of people claiming that climate change does not exist.

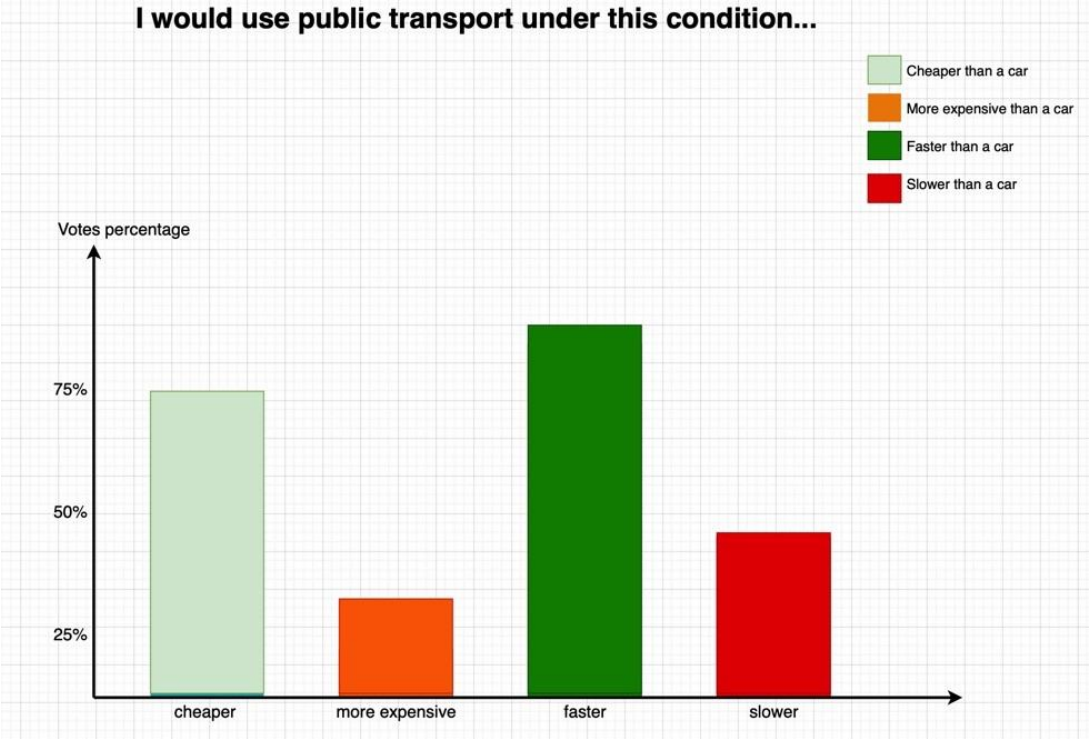


This data clearly shows a tendency. However, considering the rather small sample that was taken, it cannot be seen as a reliable source for an interdisciplinary overview of the situation.

Questions 9 - 12

Statement: "I would be willing to use public transport if it was …"

It is noteworthy that the participants are generally willing to use public transport. However, especially pricing seems to be important to the responders. When asked if they would use public transport, if it was more expensive than using their own cars, the majority in both North America and Europe disagreed.

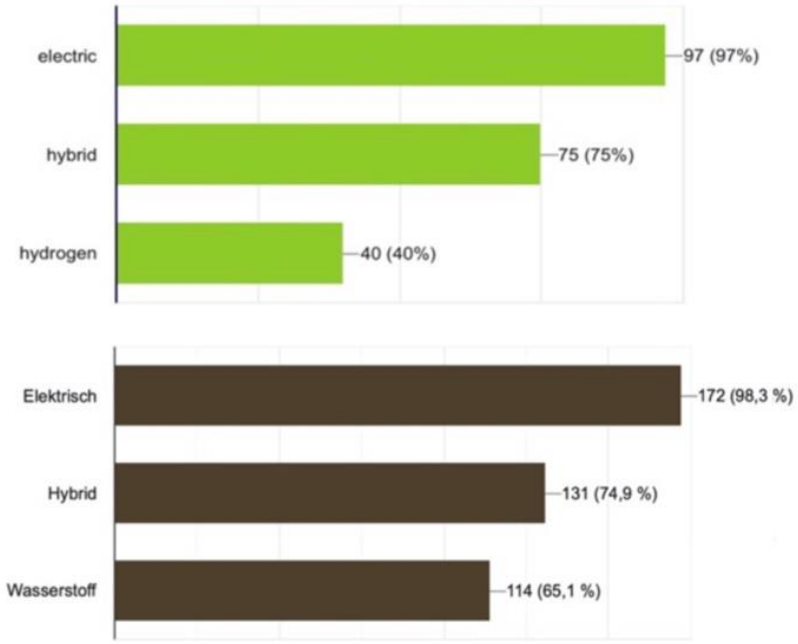


This chart shows to what extent people are ready to accept trade-offs but also that they do not want to spend additional money.

Improving traveling speed is essential in order to make public transport more attractive. While some people would be willing to use public transport even if it was slower, again, the majority disagrees. Both results emphasize the importance of political action in this field, especially when it comes to building the required infrastructure and lowering prices for public services.

Question 13

Which of these alternative power sources do you know?



The answers to this question are not very surprising. Nearly everybody knows about the electric powertrain, many know about hybrids and some have heard of hydrogen powered cars before. While the country of residence has little effect on the results, the age of the participants has to be taken into account. Younger generations seem to have a wider knowledge of this topic. Many youngsters knew about the technologies and, as results of *Question 14* have shown, seem to be willing to use such cars.

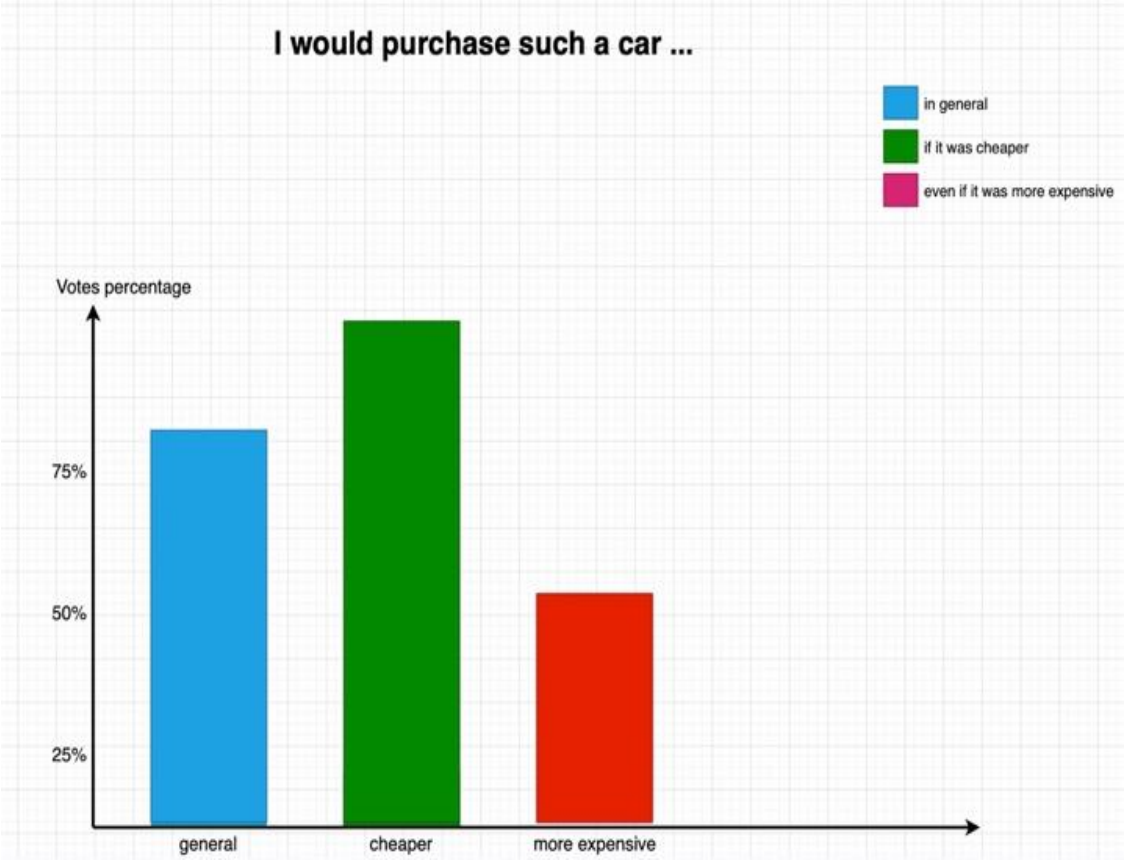
The American youth is even more open to new technology, probably because most of the innovative automotive companies have originated from the US and Canada.[74]

[74] Cf. Wayland Michael, "Tesla, GM and Others Hyped up Emerging Technologies in Autos. Now They Have to Deliver," CNBC, December 19, 2019, https://www.cnbc.com/2019/12/19/tesla-gm-and-others-hyped-up-self-driving-and-electric-vehicles.html.

Questions 14 - 16

Statement: "I would buy a car that runs on alternative sources …"

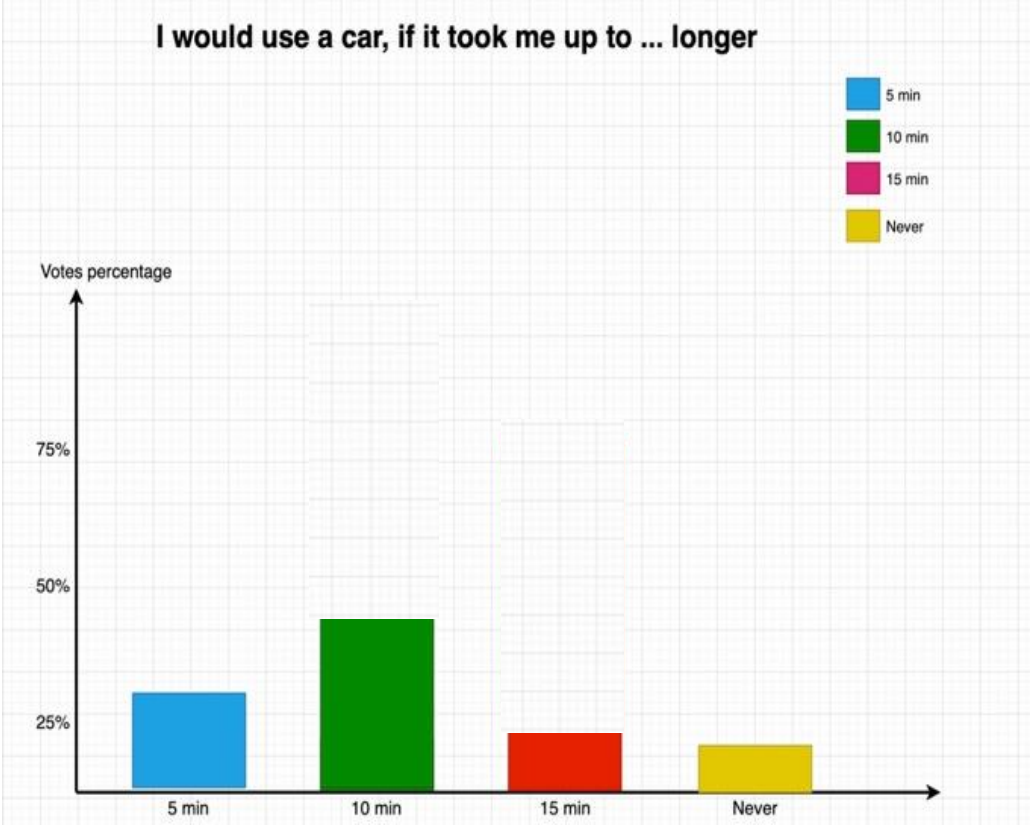
The vast majority of people asked, over 75 % in Europe and more than 90 % in North America, could imagine buying such a car, many of them even if it were more expensive.



Question 17

Statement: "I would use a car like that if it took me ... longer."

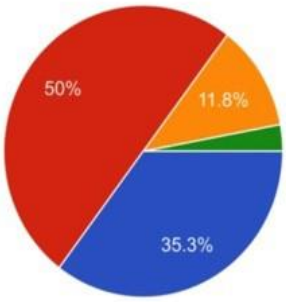
About one third of the participants say that they would accept a delay in travel of up to 5 minutes per hour. For 45 % a delay of up to 10 minutes would be tolerable, for 15 % even up to a quarter of an hour. Only some 15 % would not compromise on this issue. Interestingly enough, younger participants are more open to use such car, even under disadvantageous conditions. 90 % of the participants under 25 years of age are willing to put up with possible delays.

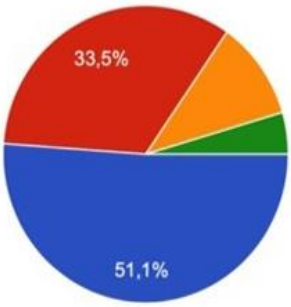


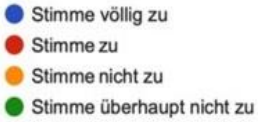
Question 18

Statement: "I would be willing to carpool."

About 85 % of the persons asked are generally willing to carpool. This is a positive sign as carpooling is a highly efficient way reduce one's carbon footprint.



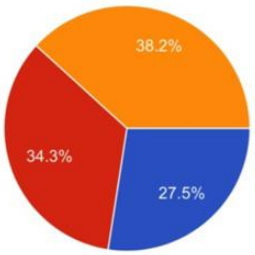


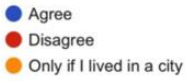


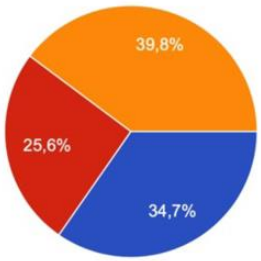
Question 19

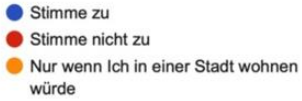
Statement: "I would be willing to use a car-sharing platform instead of owning my own car."

One third of the participants are not willing to use car-sharing as a substitute for their own car. On the other hand, 30 % are ready to use the platform. The remaining 40 % would do likewise if they lived in a city and thus benefit from elaborate infrastructure.









5.3.2 Conclusion of the results

Admittedly, due to the relatively low response rate, the survey cannot claim to be representative. However, it shows a clear tendency, which is that people are generally willing to change and even accept trade-offs, at least to a certain extent. The masses are aware of the problem and its urgency. This tendency can be supported by data from larger survey's results.[75] Young people in particular are well-informed and ready to change. Nevertheless, political action seems inevitable in order to promote a more sustainable lifestyle as a large number of people still has to put their plans into reality.
In order to achieve precise emissions goals and true, factual change, political measures and the masses action have to work mutually.

6 Conclusion and outlook

Concluding the results and research it can be said that the future of automobiles in the western world is complicated and difficult to analyze. Cars will keep playing an indispensable role in transport, especially outside of urban areas. However, automobiles as we know them today are on the verge of a drastic change in the western world. However, the way cars are powered will be different in the future. Internal combustion cars will get replaced by alternatively powered vehicles in the long run. The transition process will be rather slow as alternative powertrains cannot keep up with ICE-powered vehicles yet. Electric cars powered by battery or fuel cells are likely to be a part of the solution, nonetheless, other technologies might be invented and prevail.
Undoubtedly, these changes require a transition to green energy as sustainably produced electricity is the foundation of an environmentally friendly society. In addition, we have to rethink the role of the car, as the majority of automobiles which are on the market at present are still alarmingly inefficient compared to public transport such as trains and buses.
In metropolitan areas and for short-distance travel smaller, one person vehicles are particularly advantageous: Bicycles or e-scooters might, when used efficiently, replace short car rides and reduce emissions and smog.

[75] Cf. Seidl Conrad, "Die Ökoenergie," December 2019.

A multi-powertrain future with smaller, battery-powered vehicles for individual transport, electric railway and fuel-cell driven buses and trucks seems likely. It is this development, in combination with the other points mentioned above, that will help reduce the harm caused to our planet.
In order to turn these ideas into reality, the willingness of political leaders and the people are of vital importance. Western policymakers promise change and improvement.[76] The results of the survey also clearly suggest that the people themselves are ready to change and make ambitious plans come true.

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[76] Cf. "Regierungsprogramm 2020," accessed January 16, 2020, https://www.dieneuevolkspartei.at/Download/Regierungsprogramm_2020.pdf.

8 Bibliography

AT, Toyota Motor Corporation, 2019. Toyota | Alle Toyota Modelle auf einen Blick [WWW Document]. URL https://www.toyota.at/new-cars/model-filter.json (accessed 12.22.19).

Audi AG, 2013. Elektromotoren - Audi Technology Portal [WWW Document]. URL https://www.audi-technology-portal.de/de/mobilitaet-der-zukunft/technikbausteine/elektromotoren (accessed 10.29.19).

BBC, N., 2019. Trump says, “climate change goes both ways.” BBC News.

Benz, Mercedes. “Electric Mobility: Mercedes-Benz Flips the Switch: Generation EQ – Mobility Revisited.” marsMediaSite. https://media.daimler.com/marsMediaSite/en/instance/ko/Electric-mobility-Mercedes-Benz-flips-the-switch-Generation-EQ--mobility-revisited.xhtml?oid=13886650 (accessed 28.01.2020)

Bertram, M., Bongard, S., 2014. Elektromobilität im motorisierten Individualverkehr: Grundlagen, Einflussfaktoren und Wirtschaftlichkeitsvergleich. Springer Verlag.

Campbell, P., Thomas, N., 2019. Switch to electric cars hit by ‘poor’ charging infrastructure. Financial Times.

Canada, H., 2017. Human Health Risk Assessment for Gasoline Exhaust – Summary [WWW Document]. aem. URL https://www.canada.ca/en/health-canada/services/publications/healthy-living/human-health-risk-assessment-gasoline-exhaust-summary.html (accessed 9.18.19).

Climate benefits from measure to stop ‘fuel tourism’ | Transport & Environment [WWW Document], 2007. URL https://www.transportenvironment.org/news/climate-benefits-measure-stop-%E2%80%98fuel-tourism%E2%80%99 (accessed 12.26.19).

Cui, H., 2018. Fuel-efficiency technology trend assessment for LDVs in China: Hybrids and electrification 22.

Czepelczauer, D., 2015. The Invention of The Car I THE INDUSTRIAL REVOLUTION.

Day, E., 2017. Ford believes in Hydrogen and Fuel Cell Future. Connecticut Center for Advanced Technology, Inc. URL https://www.ccat.us/2017/08/ford-believes-in-hydrogen-and-fuel-cell-future/ (accessed 11.4.19).

DESERTEC Foundation – Energy for the next billion [WWW Document], 2019 URL https://www.desertec.org/ (accessed 12.7.19).

Dr. Hoppe, A., n.d. E-Auto | ElektroMobilität NRW [WWW Document]. URL https://www.elektromobilitaet.nrw/infos/e-auto/?L=0 (accessed 9.17.19).

EPA, 2020. Fuel Economy of 2020 Toyota Corolla [WWW Document]. URL https://www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=1&year1=2020&year2=2020&make=Toyota&baseModel=Corolla&srchtyp=ymm (accessed 12.22.19).

European Union, 2016. Increasing car-occupancy rates | CIVITAS [WWW Document]. URL https://civitas.eu/measure/increasing-car-occupancy-rates (accessed 12.30.19).

Ferris, R., 2017. Elon Musk hates hydrogen, but automakers are still investing in it — and for good reason. CNBC.

Friends of the earth, U., n.d. Why travelling by rail is better for the environment. URL https://friendsoftheearth.uk/climate-change/ethical-travel-nofly-holiday-ideas

Gerding, J., 2019. Kobalt: Ein Rohstoff und sein Preis. Die Zeit.

Hanley, S., 2018. Electric Car Myth Buster — Efficiency | CleanTechnica [WWW Document]. URL https://cleantechnica.com/2018/03/10/electric-car-myth-buster-efficiency/ (accessed 9.18.19).

Hofmann, P., 2014. Hybridfahrzeuge: Ein alternatives Antriebssystem für die Zukunft, 2. Aufl. 2014. ed. Springer, Wien.

Humes, E., 2016. The Absurd Primacy of the Automobile in American Life [WWW Document]. The Atlantic. URL https://www.theatlantic.com/business/archive/2016/04/absurd-primacy-of-the-car-in-american-life/476346/ (accessed 1.6.20).

International Energy Agency, 2019. Global EV Outlook 2019 [WWW Document]. URL https://www.iea.org/publications/reports/globalevoutlook2019/ (accessed 11.2.19).

Karle, A., 2018. Elektromobilität: Grundlagen und Praxis. Carl Hanser Verlag GmbH Co KG.

Kato, I., 2019. Japan draws support for global hydrogen proposals, including refueling stations. Reuters.

LaFontsee, G., 2019. Advantages & Disadvantages Of Hybrid Cars | Pros & Cons - ADS Auto. Automotive Diagnostic Specialties. URL https://automotivediagnosticspecialties.com/advantages-disadvantages-of-hybrid-cars/ (accessed 10.31.19).

Matthey, J., 2019. Fuel Cell History - Fuel Cell Today [WWW Document]. URL http://www.fuelcelltoday.com/history (accessed 10.31.19).

Mobilitaetskonzept Vorarlberg, 2019.

Naughton, K., 2019. Prius Sales Are Falling, But Hybrids Are More Popular Than Ever. Bloomberg.com.

ONLINE, Z., 2019. Elektromobilität: Regierung will Förderung von Elektromobilität ausbauen. Die Zeit.

Publishers, H., 2020. Rpm definition and meaning | Collins English Dictionary [WWW Document]. URL https://www.collinsdictionary.com/dictionary/english/rpm (accessed 12.7.19).

Randelhoff, M, 2019. Elektrisch im Straßenverkehr: Batterie vs. Brennstoffzelle vs. Power-to-X » Zukunft Mobilität. URL https://www.zukunft-mobilitaet.net/169895/analyse/elektroauto-brennstoffzelle-synthetische-kraftstoffe-ptx-ptl-kosten-infrastruktur-rohstoffe-energiebedarf-wirkungsgrad/ (accessed 12.30.19).

Rathi, A., 2019. How we get to the next big battery breakthrough. Quartz.

Regierungsprogramm Österreich, "Aus Verantwortung für Österreich", 2020-2024, 2020.

Regierungsprogramm Vorarlberg, 2019-2024, 2020.

Reif, K. (Ed.), 2017. Grundlagen Fahrzeug- und Motorentechnik, Bosch Fachinformation Automobil. Springer Verlag, Wiesbaden.

Sammann, S., 2018. The Truth about Hydrogen.

School Buses Eco-Friendly? [WWW Document], 2014. Seventh Generation. URL https://www.seventhgeneration.com/blog/are-school-buses-eco-friendly (accessed 01.06.20).

Scott, J., 2019. (6) Hydrogen Fuel Cell Cars Aren't The Dumbest Thing. But... | Answers with Joe.

Simonov, A., 2019. Electrolysis breakthrough could solve the hydrogen conundrum.

Stadt Wien. 2015. Das Fachkonzept Mobilität 2025 - Ein Überblick [WWW Document]. URL https://www.wien.gv.at/stadtentwicklung/strategien/step/step2025/fachkonzepte/mobilitaet/ueberblick.html (accessed 12.27.19).

Stewart, J., 2014. Hybrid cars: Where do they perform most efficiently? [WWW Document]. URL https://www.bbc.com/future/article/20140414-where-hybrid-cars-perform-best (accessed 12.21.19).

Thomas, C.E., 2009. Fuel cell and battery electric vehicles compared. International Journal of Hydrogen Energy 34, 6005–6020. https://doi.org/10.1016/j.ijhydene.2009.06.003

Thomas, P. 2019. China's "father of EV" urges more hydrogen infrastructure to develop fuel cell vehicles. Reuters.

Univ.-Doz. Dipl.-Ing. Dr.techn. Wachter, W. 2018. Zukünftige Mobilität.

Wayland, M., 2019. Tesla, GM and others hyped up emerging technologies in autos. Now they have to deliver [WWW Document]. CNBC. URL https://www.cnbc.com/2019/12/19/tesla-gm-and-others-hyped-up-self-driving-and-electric-vehicles.html (accessed 1.12.20).

Wellnitz, J., Subic, A., Leary, M. (Eds.), 2009. Sustainable Automotive Technologies 2010: Proceedings of the 2nd International Conference. Springer-Verlag, Berlin Heidelberg.

What's the greenest way to travel? - YouTube [WWW Document], 2019. URL https://www.youtube.com/watch?v=TkXEU5ng8rE (accessed 12.27.19).

Wie funktioniert eigentlich ein Auto? - YouTube [WWW Document], 2005 URL https://www.youtube.com/watch?v=KeyJKizmslU&t=125s (accessed 9.17.19).

Zaken, M. van A., 2019. Public Transport in 2040 - Outlines of a vision for the future - Report - Government.nl [WWW Document]. URL https://www.government.nl/documents/reports/2019/05/13/public-transport-in-2040 (accessed 12.27.19).

9 List of figures

10 Appendix

10.1 Survey: German version

Autos in der Zukunft

Diese Umfrage dient dem Zweck, das Ausmaß der Bereitschaft der österreichischen Schüler/innen und Arbeitnehmer/innen zu ermitteln, Kompromisse im Bereich des motorisierten Individualverkehres für eine nachhaltigere Zukunft einzugehen. Darüber hinaus wird das Wissen der Teilnehmer/innen im Bereich der alternativen Antriebsmöglichkeiten von PKWs abgefragt.

Geschlecht:

- Weiblich
- Männlich
- Anderes

Alter:

- 16 - 18
- 19 - 21
- 21 - 25
- Älter

Wo ist Ihr Hauptwohnsitz?

- Österreich, Deutschland oder Schweiz
- Vereinigte Staaten oder Kanada
- Anderer Ort

Haben Sie einen Auto- / Moped- oder Motorradführerschein? (Klassen AM / A / A1 / A2 / B)

- Ja
- Nein

Schätzen Sie die Distanz zu Ihrer Schule / zu Ihrem Arbeitsort ein.

- 0 - 5 km
- 5 - 16 km
- 15+ km

Wie bewältigen Sie Ihren Schulweg / Ihren Weg zur Arbeit?

Hier können Sie mehrere Antworten auswählen.

- Öffentliche Verkehrsmittel
- Auto
- Fahrrad
- Zu Fuß
- Moped / Motorrad
- Anders

Aussage: "Der menschengemachte Klimawandel ist real"

- Stimme zu
- Stimme nicht zu
- Unschlüssig

Wären Sie bereit, etwas für eine nachhaltigere Zukunft zu unternehmen?

- Stimme zu
- Stimme nicht zu
- Unschlüssig

Öffentliche Verkehrsmittel

Aussage: "Ich wäre bereit, öffentliche Verkehrsmittel zu verwenden, wenn diese günstiger als ein Auto sind."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich wäre bereit, öffentliche Verkehrsmittel zu verwenden, wenn diese schneller als ein Auto sind."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich wäre bereit, öffentliche Verkehrsmittel zu verwenden, sogar wenn diese teurer als ein Auto sind."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich wäre bereit, öffentliche Verkehrsmittel zu verwenden, sogar wenn diese langsamer als ein Auto sind."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Alternative Antriebsmöglichkeiten

Welche alternativen Antriebsmöglichkeiten kennen Sie?

Hier können Sie mehrere Antworten auswählen.

- Elektrisch
- Hybrid
- Wasserstoff

Aussage: "Ich würde ein Auto mit alternativem Antrieb kaufen."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich würde ein solches Auto kaufen, wenn es günstiger wäre."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich würde ein solches Auto kaufen, auch wenn es teurer wäre."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich würde so ein Auto benutzen, wenn es ... länger dauern würde."
Das Reisen mit einem Auto, das von einem alternativen Antrieb betrieben wird, dauert oft ein wenig länger. Man muss beispielsweise zum Laden stehen bleiben oder bei einem Wasserstoffauto eine spezielle Tankstelle aufsuchen. Sind Sie bereit, dies in Kauf zu nehmen? Wenn ja, wieviel Zeit wären Sie bereit zu investieren?

- bis zu 5 min pro gefahrene Stunde
- bis zu 10 min pro gefahrene Stunde
- bis zu 15 min pro gefahrene Stunde
- Niemals

Effizienteres Fahren

Aussage: "Ich würde grundsätzlich Fahrgemeinschaften nutzen."

- Stimme völlig zu
- Stimme zu
- Stimme nicht zu
- Stimme überhaupt nicht zu

Aussage: "Ich wäre grundsätzlich bereit, eine carsharing Plattform zu nutzen, anstatt mein eigenes Auto zu besitzen."
Bei einer carsharing Plattform können Sie Autos für ein kurzes Zeitintervall ausleihen. Zum Beispiel für einen Einkauf oder einen Wochenendausflug. Die Autos werden von Firmen oder von privaten Personen zur Verfügung gestellt.

- Stimme zu
- Stimme nicht zu
- Nur wenn ich in einer Stadt wohnen würde

10.2 Survey: English version

Cars in the Future

This survey serves the purpose to determine the willingness to change their behavior towards the usage of cars for a more sustainable future. The focus lays on the younger generations.

Gender:

- Female
- Male
- Other

Age:

- 16 - 18
- 19 - 21
- 21 - 25
- Older

What is your country of residence?

- United States or Canada
- Austria, Germany or Switzerland
- Other

Do you have a license? (Car / Motorcycle)

- Yes
- No

Give an estimate of the distance to your workplace / university / school.

- 1 - 3 miles (0 - 5 km)
- 4 - 6 miles (5 - 10 km)
- 7 - 10 miles (11 - 15 km)
- 10+ miles (15+ km)

How do you get to your workplace / university / school?

You can select multiple answers.

- School bus
- Car
- Bike
- Public transport
- Walk
- Other

Statement: "Human-made climate change is real"

- Agree
- Disagree
- Undecided

Would you be willing to take action for a more sustainable future?

- Agree
- Disagree
- Undecided

Public Transport

Statement: "I would be willing to use public transport, if it was cheaper than using a car."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "I would be willing to use public transport, if it was faster than using a car."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "I would be willing to use public transport, even if it was more expensive than using a car."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "I would be willing to use public transport, even if it was slower than using a car."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Alternative types of cars

Which alternative power sources do you know?

You can select multiple answers.

- Electric
- Hybrid
- Hydrogen

Statement: "I would generally buy a car which is running on alternative sources."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "I would buy such a car if it was cheaper."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "I would buy such a car even if it was more expensive."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "I would use such car if it took up to ... longer."

Traveling with a car that runs on alternative sources, often takes a little longer. Refueling or recharging one's car is more complicated and takes more time Are you willing to accept tradeoffs? If yes, how much time are you poised to lose?

- Up to 5 min per hour of traveling
- Up to 10 min per hour of traveling
- Up to 15 min per hour of traveling
- Never

Efficient driving

Statement: "I am willing to carpool."

- Strongly agree
- Agree
- Disagree
- Strongly Disagree

Statement: "Ich am willing to use a carsharing platform instead of owning my own car."

A carsharing platform is an app or a website, which allows you to rent a car for a short period of time (e.g. to run some errands or for a weekend trip.)

- Agree
- Disagree
- Only if I lived in a city

Declaration of Authorship

I hereby declare that this thesis is my own work. All direct and indirect sources used are acknowledged as references.

Christoph Zech 20 February 2020