energies

Review

Research and Prospects for the Development of Alternative Fuels in the Transport Sector in Poland: A Review

Dorota Burchart-Korol [1,*], Magdalena Gazda-Grzywacz [2] and Katarzyna Zarębska [2]

1 Faculty of Transport and Aviation Engineering, Silesian University of Technology, ul. Krasińskiego 8, 40-019 Katowice, Poland
2 Faculty of Energy and Fuels, AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Krakow, Poland; magdago@agh.edu.pl (M.G.-G.); zarebska@agh.edu.pl (K.Z.)
* Correspondence: dorota.burchart-korol@polsl.pl

Received: 13 May 2020; Accepted: 8 June 2020; Published: 10 June 2020

Abstract: The aim of this publication is to review the current state and possibilities of developing electromobility and alternative fuels in Poland. It was found that the current market for alternative fuels in Poland is insufficiently developed. At the end of 2019 in Poland, liquefied petroleum gas-powered cars accounted for approximately 3.3 million pieces, which amounts to 14.3% all passenger vehicles up to 3.5 tonnes of gross vehicle weight. There were over 9000 electric cars on the road, the share of which accounted for 0.04% of domestic passenger transport. The lack of a sufficient number of charging points, inhibiting the development of electromobility, was also noted. There were approximately 4000 (0.02%) passenger cars powered by compressed natural gas. Liquefied gas-powered vehicles were exclusively public transport vehicles or trucks. The share of biofuels in the Polish transport sector stands at 4%, while European Union requirements are at a level of 10%. Although there is huge potential for the use of hydrogen as an alternative to conventional transport fuels in Poland, just one hydrogen-powered vehicle has been registered in the country so far, with no filling station in existence for this fuel. The synthetic fuel sector is in the planning stage.

Keywords: alternative fuels; electromobility; transport sector; development of alternative fuels in Poland

1. Introduction

The dynamic development of civilization requires both increased energy supplies and the development of a widely understood transport infrastructure. The transport sector is one of the key elements that determines a country's competitiveness in the international market, both economically and socially. Transport is an integral part of every society and is determined by the extent and location of the activities, goods and services that are available [1].

The growing transport sector has made it possible to reorganize the lives of societies and has thus had a huge impact on their present character. In highly developed countries, a significant proportion of people travel for work, life or leisure. However, it should be remembered that transport consumes many natural resources, such as materials, raw materials, minerals, metals, earth and fuels. In addition, conventional hydrocarbon-based fuels are being rapidly exhausted [2]. The evolution of transport infrastructure contributes to the degradation of the natural environment. The negative environmental effects of the use of oil and oil derivatives are mainly related to greenhouse gas (GHG) emissions [3]. The EU requires its Member States to reduce greenhouse gas emissions from the transport sector, particularly by minimising oil imports. In 2017, total oil imports to the EU amounted to 565.7 million tons. The largest contributions came from Russia (163.1 million tons), Norway (61.4 million tons), Iraq (44.0 million tons), Kazakhstan (39.7 million tons) and Saudi Arabia (35.6 million tons). In 2017, the transport sector was the main consumer of petroleum products—especially road transport, which consumed 48.0% [4].

Atmospheric air pollution is a major problem that affects the quality of human life. Measures to protect and improve the state of ambient air are a key focus of the work of the European Commission. In EU countries, efforts to reduce GHG emissions have been stepped up and developed in recent years. In 2017, EU GHG emissions declined by 22% in comparison with 1990 levels, representing approximately 1240 million Mg of CO_2 equivalents. Such a significant reduction in emissions is the result of an objective to reduce GHG by 20% by 2020, with a 40% reduction from the base year by 2030. The European Commission launched a public consultation in March 2020 on tightening the 2030 greenhouse gas emission reduction target. The draft climate law presented by the European Commission assumes that the objective of reducing CO_2 emissions by 2030 will be increased to 50–55% compared to 1990 levels. Fuel combustion technologies (without transport) accounted for 54% of total GHG emissions and the transport sector (including international aviation) was the second largest source of emissions, accounting for 25% in 2017 [5]. In 2019, transport contributed to almost 30% of the total EU GHG emissions, 72% of which come from road transport. The EU has set itself the objective of reducing these emissions by 90% by the year 2050, in addition to becoming less dependent on oil. In the strategy, concrete actions are planned, leading to significant structural and technological changes in passenger and freight transport. Urban transport will also be affected by these ambitious objectives [6–8]. It should be noted here how difficult it is to estimate GHG emissions and to minimise them without damaging the economy. There is no final assumption as to what method should be decisive in shaping climate policy. Research has been carried out on uncertainty in the economic assessment of carbon dioxide emissions from transport. The outcomes of the various approaches were often contradictory because each method frames the problem differently. In 2018, Nocera et al. [9] concluded that, as long as GHG emissions do not vary from sector to sector, a fair assessment of CO_2 emissions from transport cannot be provided. The authors proposed a mesoscopic approach to determine the political consequences. It was found that, beyond the numerical values, insight gained from the process of working through different methods may be a primary benefit for carbon policy. Through the adoption of an uncertainty assessment, decision makers can reach a fairer final unitary price.

The current dependence of the European economy on imported oil is burdensome, both economically and environmentally. This calls for the development and implementation of new technological solutions in the transport sector, aimed at the gradual replacement of oil by alternative fuels and the development of the necessary infrastructure for this purpose. In 2013, the European Commission published a communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions entitled, "Clean Power for Transport: A European alternative fuels strategy". The document sets out a comprehensive strategy for alternative fuels and how they should be implemented, covering all modes of transport. The aim of the strategy was to create a long-term policy framework to guide the technological and investment development of alternative fuels. EU member states have been given a certain degree of freedom in shaping a policy framework for the development of the alternative fuel sector in accordance with national requirements [10]. The final Directive 2014/94/EU of the European Parliament and of the Council, adopted on 22 October 2014, aimed to promote the use of alternative fuels in transport. The Directive required member states, including Poland, to initiate national policy frameworks for the development of the market for alternative fuels and their infrastructure. Therefore, the Polish Ministry of Energy, referring to Directive 2014/94/EU, published the required document in March 2017 [11]. The most important tasks of the team included the preparation and development of a concept for electromobility development. The Electromobility Development Programme was the basis for the creation of the regulatory package, which included, among others: Electromobility Development Plan for Poland "Energy to the Future" [12], National Policy Framework for Alternative Fuel Infrastructure

Development [11], Act on Electromobility and Alternative Fuels [13] and the Act Establishing the Low-Emission Transport Fund [14].

The National Act on Electromobility and Alternative Fuels was created to stimulate the development of electromobility and the application of such fuels in the transport sector in Poland, by defining the legal framework for the development of the charging infrastructure for electric cars and the refueling of such fuels. The increased use of alternative fuels in transport is projected to reduce the sector's dependence on oil and oil derivatives. This would reduce oil imports, ultimately improving air quality and the state budget. The law provides for the construction of refueling or recharging networks, especially in urban and densely populated areas, which will allow the movement of such vehicles without fear of a possible lack of fuel. The strategic approach of Poland as a member of the European Union in meeting the needs of various national transport modes should be to use the entire spectrum of available alternative fuels, while also taking into account the specificity of the country, raw material resources and environmental and economic considerations.

The aim of the publication is to review the current state and possibilities for the development of electromobility and alternative fuels in Poland. It will present the current state of infrastructure, number of alternative vehicles and technologies, discuss opportunities and barriers to development and present research and initiatives related to the development of alternative fuels, including electromobility.

There are more and more frequent works on the transport sector in Poland, in various aspects. However, there are still very few works that synthetically and critically describe the current state of Polish transport in terms of its transition from conventional to low-emission fuels. This very aspect is crucial because of Poland's membership in the European Union and the need to adapt domestic transport to the EU requirements for reducing greenhouse gas emissions.

2. Current and Developing Market of Alternative Fuels Used in Transport in Poland

Polish institutions and organizations are conducting research on different types of alternative fuels that are or can be used in transport. Figure 1 presents the current and developed domestic market for alternative fuels, in relation to the number of cars on Polish roads. Currently, in Polish transport, mainly liquefied petroleum gas (LPG), electricity and natural gas in the form of compressed natural gas (CNG) and liquefied natural gas (LNG) are used as substitutes for conventional fuels. According to the report of the Ministry of Energy on the implementation of the national policy framework for the Development of Alternative Fuel Infrastructure, there were only 290 charging points for electric vehicles with standard power (≤22 kW) in 2016 and 32 charging points for vehicles with high power (≥22 kW). At the end of 2019, the number of charging points for standard power was 529 and 308 for high power. This represents an increase of 82.4% for standard power charging points and 862.5% for high power charging points. In the case of natural gas filling stations (CNG), there were 26 in 2016, an increase of 7.69% [15]. Alternative fuels within the scope of the EU Directive also include synthetic and paraffinic fuels; however, these fuels are not used at all in Poland and their development stopped at the planning stage in 2018, when the Jastrzębska Coal Company (JCC, Jastrzębie-Zdrój, Poland) was looking for opportunities to collaborate with the Global Integrated Chemicals and Energy Company (SASOL). JCC planned to produce synthetic fuel based on domestic coal. Within the framework of cooperation with SASOL, the necessary investigations were to be carried out on the profitability of investments, related to the industrial processing of hard coal into fuels, gas and chemicals [16].

Figure 1 illustrates the current state of development of the alternative fuel market in Poland by type and indicates the share of alternative vehicles amongst the total number of passenger cars (up to 3.5 tonnes of gross vehicle weight) in the country. These values were calculated on the basis of information provided by the Automotive Market Research Institute SAMAR, the Polish Association of Alternative Fuels (PAAF) and the Polish Liquid Gas Organization (PLGO).

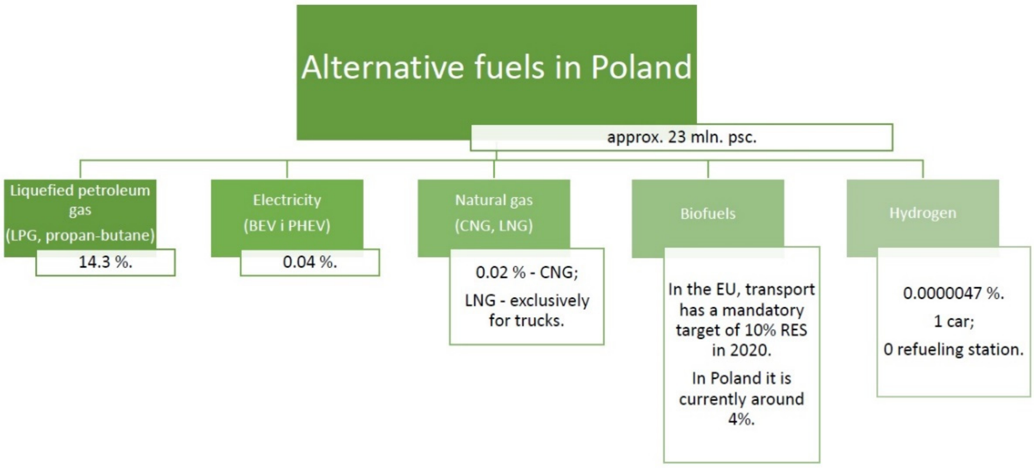

Figure 1. Current and developing alternative fuel technologies in operation. Own development based on [17–20].

2.1. Electric Cars

An increasingly popular alternative to hydrocarbon fuels as a means of transport in Poland is electric propulsion. Vehicles powered by electric motors, registered in Poland, are mainly passenger cars. At the end of 2019, there were over nine thousand electric cars, 5700 Battery Electric Vehicles (BEV) and 4103 Plug-in Hybrid Electric Vehicles (PHEV) in Poland [19,21]. According to analysts from the Automotive Market Research Institute Samar [17], in the first half of 2019, 945 BEV passenger cars were registered in Poland, which equates to approximately 0.3% of all new vehicles registered and approximately 46% more than in 2017. In the first half of 2019, 379 PHEVs were also registered in Poland. Most of the BEVs and PHEVs registered in 2019 (over 96%) were owned by companies. It can therefore be assumed that the domestic market for electric cars might not have existed without so-called "car sharing". The reason for this may be the high purchase and operating costs of such vehicles in Poland.

According to the European Automobile Manufacturers Association (ACEA) (Figure 2), the EU-wide market share of electric passenger cars in 2018 was around 1%, 0.3% for light commercial vehicles and 0.6% for buses [22]. ACEA statistics on electric vehicles cover different types of electric or battery electric vehicles (BEV), mains-powered hybrid electric vehicles (PHEV), fuel cell electric vehicles (FCEV) and extended range electric vehicles (REEV). In the case of electric buses, there are programs in the EU to support the development of this sector, mainly in pilot form, (e.g., the Zero Emission Urban Bus System project (ZeEUS)) [23]. The main investment in electric buses is made by city carriers. The increased interest in so-called e-buses, despite their high price in relation to conventional buses, is due to their low or zero emissions from the propulsion system. Additionally, such buses are characterized by a much lower noise level, which is particularly important on congested and polluted Polish roads. Data from the National Central Register of Vehicles (NCRV) show that 85 hybrid buses and 63 electro-buses were registered in 2017. Since the beginning of 2019, the number of registrations of new e-buses has decreased to 13 hybrid units and 30 purely electric units [24]. Electric vehicles can be powered from the power grid, which, in Poland, still has a significant carbon footprint (CF) [25–27]. Electric vehicles do not directly and locally emit pollutants and noise. Hybrid cars, in turn, make it possible to reduce oil consumption [28,29]. These technologies, although well-known and used in transportation for years, are still at the development stage in Poland and are perceived as uneconomic and harmful to the environment, especially when the national energy mix is based on hard coal and lignite. In 2018, in Poland, the first studies on the whole life cycle of electric vehicles were carried out, which showed that if the coal-based electricity grid was used to recharge the batteries, the impact on greenhouse gas emissions would be higher than for vehicles with internal combustion engines [30]. Unfortunately, the development of electromobility in Poland is hampered by the lack of a sufficient number of vehicle charging points. According to the European Alternative Fuels Observatory [31], by mid-2019, across the European Union, there were approximately 158,000 charging points for BEV and PHEV electric cars, of which approximately 132,000 were points with power up to 22 kW (standard charge) and another 24,000 were points with power above 22 kW (fast charge). In Poland (Figure 3), there are currently 976 charging points, 584 standard charges and 392 fast charges.

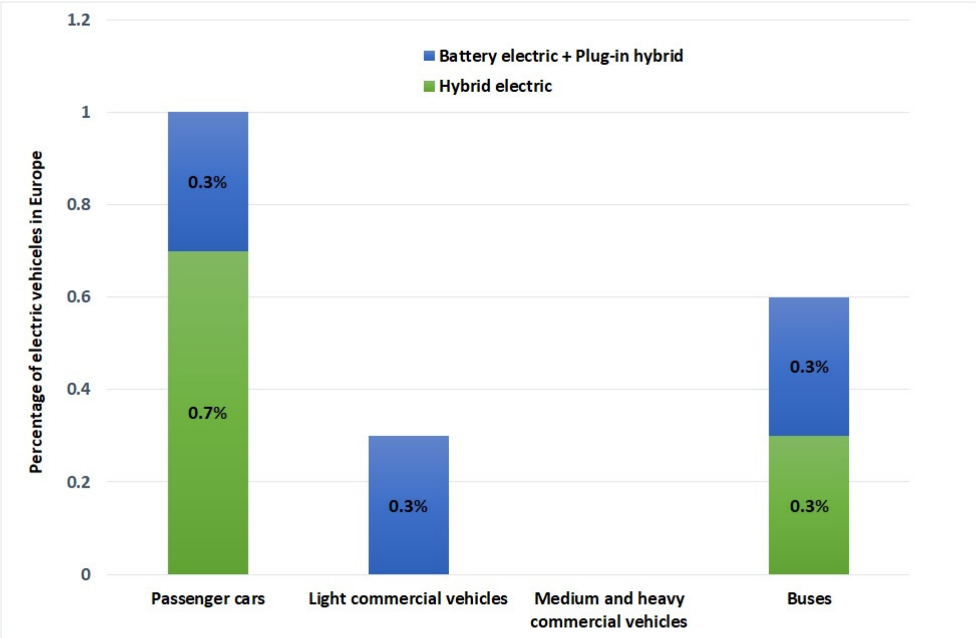

Figure 2. EU-wide market share of electric cars, by purpose and type of power supply in 2018 [22].

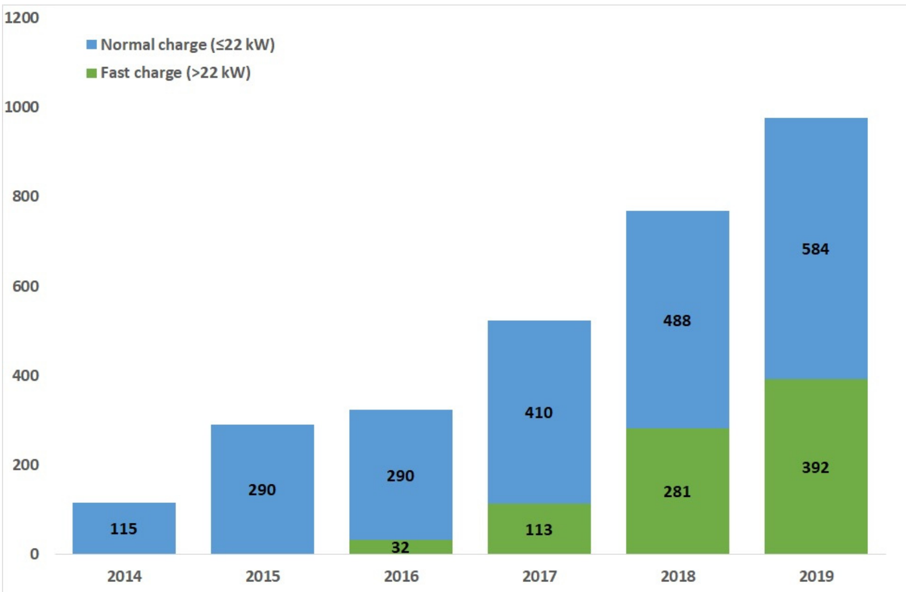

Figure 3. Development of infrastructure of electric car charging points in Poland [31].

According to Statista [32] analysts, in the European Union, Norway has the highest penetration of plug-in electric vehicles (PEV). Despite population, geopolitical, raw material and infrastructural differences, a huge dissonance can be observed when comparing the two countries. Compared to Norway, where there are approximately 17,000 BEV and PHEV charging stations, Poland is less attractive from the point of view of users of alternative electric vehicles. Figure 4 compares the number of Polish charging points for electric cars with Norway. The graph represents the last three years and shows that the total number of standard and fast chargers for BEV and PHEV is 21 times lower in Poland than in Norway. Buying an electric car in Poland involves not only higher costs but also problems with regard to its charging.

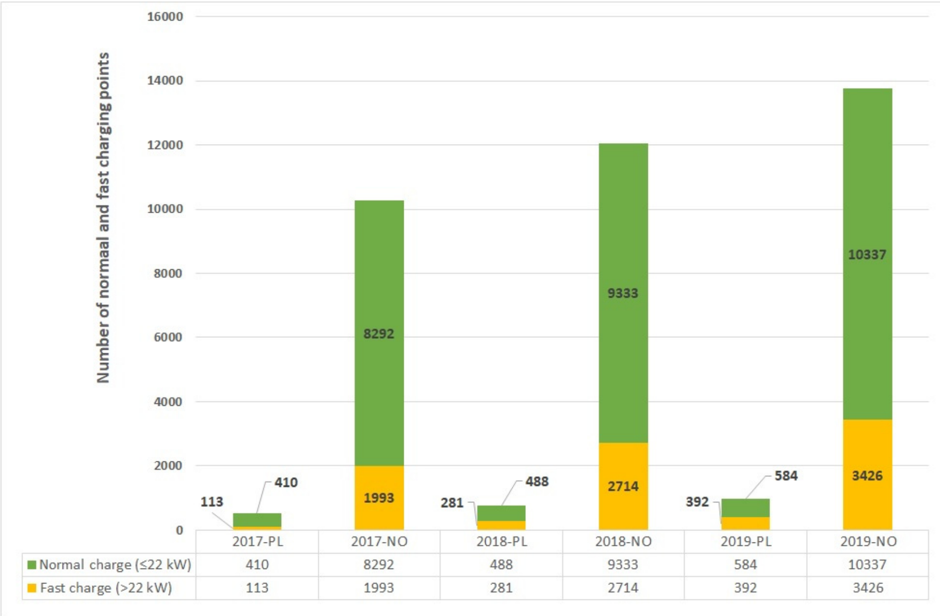

Figure 4. Number of Polish and Norwegian electric car charging points [31].

Many countries promote a policy of subsidizing the purchase of electric vehicles. On 5 November 2019, the Ministries of Energy and Finance, Investment and Development signed a regulation relating to the conditions for supporting the purchase of new vehicles from the funds of the Low Emissions Transport Fund for Natural Persons. The main purpose of this regulation was to define the rules of support for the purchase of cars, powered by electricity or hydrogen. Individuals would be able to receive a subsidy of 30% of the purchase price of an electric or hydrogen-powered vehicle. The subsidy would be available for the purchase of an electric or hydrogen vehicle, the price of which should not exceed 29,000 or 70,000 EUR, respectively. The subsidies announced by the government for electricians could be applied for from the beginning of 2020. Unfortunately, the submission of applications was postponed, which is connected with the inventory of development programs. Verifications of existing assumptions and amounts of support for the development of electromobility in Poland were also announced. Moreover, the government has announced that subsidies will be reduced by at least 50%. The Polish electric transport sector requires solutions that will allow the economical use of such vehicles and their faster recharging. As a result, potential buyers are moving away from purchasing electric vehicles and some current users are returning to vehicles with conventional engines.

Environmental aspects should not be overlooked when it comes to the legitimacy of subsidies for the purchase of electric cars. In 2018, Cavallaro et al. [33] assessed whether the subsidies to BEV are justified in UE countries. To answer this question, a simulation model was developed, based on the most reliable data available. These results have been compared with alternative fuel policies adopted by individual EU countries and, in some cases, it has been suggested that such incentives should be reconsidered. One of the conclusions of the cited paper indicates in which cases subsidies to BEV can be justified in terms of carbon reduction. In this case, the energy mix plays an important role. In those countries where the energy mix is based on renewable or alternative primary sources, incentives to purchase BEV are fully justified in terms of carbon savings. In other cases, where power generation still relies on traditional sources (such as Poland), the adoption of subsidies for BEV does not make a real contribution to reducing CO_2 emissions. It should be stressed that CO_2 emissions are one of many elements that contribute to the definition of national incentive and taxation policies. There are other external transport-related factors that should be taken into account in defining the most appropriate policy. Noel et al. [34], in his work, reported on the benefits of using electric vehicles in terms of noise reduction, both at the individual level of the driver and passengers of such a vehicle and non-users such as cyclists and pedestrians. The author concluded that the use of electromobility can improve the safety and efficiency of public transport, as drivers will have less headaches caused by noise and better reactivity during acceleration and stopping. This is why the secondary advantages of electrification of mobility, although difficult to quantify, should not be overlooked when making transport policies.

2.2. CNG and LNG-Fueled Natural Gas Vehicles

Another popular alternative fuel is CNG. It is a gas compressed to 20 MPa, which consists of approximately 97% methane. CNG is known as a bridging fuel between petroleum-based fuels and hydrogen. CNG is used in Polish transport on a large scale, mainly in the sectors of public transport, municipal services or large logistics fleets. Current laws strongly support the development of the CNG sector for passenger cars. The European and, therefore, the Polish Act on Electromobility and Alternative Drives [13] provides for the creation of special environmental zones in cities, which will be accessible free of charge to electric and CNG vehicles, among others. The act also assumes the creation of a wide infrastructure for refueling natural gas. The Polish CNG market is constantly developing, the number of vehicles fueled exclusively with methane is increasing. However, due to the high cost of purchasing a new vehicle that is factory fitted with CNG power and the fact that there are too few filling stations, the potential for methane fuels seems underutilized. There are approximately 23 CNG filling stations in Poland [35,36]; therefore, some users of cars with compressed gas use home filling stations. The installation of such a device is possible, but very cumbersome from a conventional perspective. However, the Act on Electromobility and Alternative Drives assumes that, in the coming years, the number of CNG refueling points will increase to 104. In 2017, 12 CNG-powered eco-buses were registered in Poland, while, in 2019, the number of such units was 29 [24].

LNG, as an engine fuel, has similar performance characteristics to CNG. However, its storage and transport necessitate the use of cryogenic tanks to maintain the required low temperature. The development of the LNG bus and truck segment in Poland is hampering the high cost of building the necessary infrastructure of the refueling stations; the construction of gas filling stations costs about 350,836.98 EUR. Construction of the first publicly accessible LNG station for trucks in Poland was completed in late 2019 thanks to Shell. In total, Shell already operates 14 public LNG stations across Europe (10 in the Netherlands, three in Belgium and one in Germany) and plans to build 39 more in the next three to four years. In Poland, the target is to have 11 refueling points. For the time being in Poland, LNG is used to fuel buses. These LNG-powered buses, of which there are 35 [37], only currently operate in the capital city, Warsaw, and use a non-public filling station belonging to a municipal carrier. The situation regarding gas-fueled cars in Poland is much more complicated than in other European countries, where governments support the CNG and LNG market. Currently, in Poland, apart from the lower excise duty on gas, drivers have no other benefits or infrastructural facilities.

2.3. Liquefied Petroleum Gas Vehicles

At European level, liquefied propane–butane, or liquefied petroleum gas (LPG), has been recognized as an alternative fuel and an efficient, low-carbon energy carrier. LPG is a gaseous petroleum product, the main components of which are propane, butane, propylene, butenes and mining additives. LPG is a gaseous fuel for the propulsion of spark ignition engines, with a fuel supply system specially adapted for this fuel. LPG comes from two sources: it is extracted during the extraction of natural gas and crude oil from the ground and is produced by refining crude oil [38]. LPG is the leading alternative fuel for automotive transport, with more than 26 million vehicles in the world running on this fuel. According to the 2019 report of the Polish Liquid Gas Organization

(PLGO) [20], 78% of LPG sold in the country was used in the automotive sector as autogas. In 2018, approximately 1835 thousand Mg of autogas was sold in Poland. With the exception of the quantity of autogas sold, the PLGO report also highlights the approximate number of LPG filling stations according to the Energy Regulatory Office records (URE), as well as the number of LPG-fueled cars. According to the URE, at the end of 2018, there were 7432 autogas stations or refueling points in Poland. According to the Central Statistical Office (CSO), there were an estimated 3,135,000 LPG vehicles in Poland at the end of 2018 [17,20,39]. In fact, the data of the CSO and that of the Central Register of Vehicles and Drivers (CRVD) may be outdated and do not indicate the actual number of vehicles operated with LPG propulsion. In 2019, the Polish Association of Automotive Industry (PAIA) prepared and published a report "Automotive Industry" [19], using data on the vehicle fleet developed by the Analysis and Statistics Department of the Polish Automotive Industry Association. In 2017, as a result of the earlier applications of PAIA, the Ministry of Digitization resolved to make the number of vehicles realistic and to define archived vehicles, i.e., vehicles that are more than 10 years old (from the date of first registration) and have not been updated in NCRV databases in the last six years, provided that they are not historic vehicles. According to the PAIA report, interest in cars with factory LPG propulsion is decreasing, with the number of registrations at the end of 2018 totaling approximately 7.5 thousand.

2.4. Vehicles Powered by Biofuels

In December 2008, the Commission and Parliament of the European Union agreed on the content of the Renewable Energy Act. One of its elements was the introduction of a mandatory threshold of 10% for the blending of biofuels and fossil fuels in transport from 2020. This requirement is part of the European Climate Change Package, called '3 × 20', namely the action "National targets—Increasing the share of energy from renewable sources" [40]. Currently, the EU average share of renewable energy sources (RES) in transport is more than 7%, while in Poland it is over 4% [41]. In addition, old fuel markings, i.e., Pb95 (petrol type of fuel) and ON (diesel type of fuel), disappeared from Polish stations. They have been replaced by new symbols referring, among other things, to the biocomponents they contain. According to EU Directive 2014/94/EU of the European Parliament and Council on the Development of Alternative Fuel Infrastructure, the method of marking a given fuel type at EU stations had to be changed by 12 October 2018. Petrol was categorized depending on the amount of ethanol (as biocomponent) contained in the fuel: E5—petrol with a maximum ethanol content of 5% or less, E10—petrol with 10% ethanol (rare in Poland) and E85—petrol consisting mainly of biocomponents (not in Poland). Designations for diesel were: B7—diesel with 7% bio-components, B10 diesel with 10% bio-components (for certain engines only) and XTL (diesel produced without the use of crude oil), which is paraffinic diesel, used as a clean fuel and containing up to 7% biodiesel.

Sustainable energy sources are divided into natural ones such as sun or wind and those derived from biomass [42]. Energy from natural phenomena is valued for its prevalence, but its big disadvantage is its variability and discontinuity. Biomass, in turn, is the third primary energy source after coal and oil [43]. Biomass can be processed into biofuel by biological or biochemical processes, i.e., fermentation [44], physico-chemical processes such as extraction [45] or thermochemical processes such as gasification [46]. Biofuels are green alternative fuels and are classified into four generations: I, II, III and IV. The first generation is conventional biofuels [42], produced from sugar, starch or vegetable oil; this includes biodiesel [47], bioalcohols [48], pure vegetable oils [49] or biogas [50]. Second-generation biofuels are produced from cellulosic raw materials such as wood, straw and wood industry waste. These include lignocellulose bioethanol [51] or biohydrogen [52]. Third-generation fuels are produced from algae and other microorganisms [53]. They are obtained by similar methods to the second generation of fuels but the raw material for their production is biomass, modified to improve the process of transformation of biomass into biofuel. The literature also describes fourth-generation biofuels [54], the technologies for producing such fuels include carbon capture and storage (CCS) processes at the stage of their manufacture. In addition, raw materials for the production of fourth-generation fuels, by means of genetic modification, are intended to assimilate larger amounts of carbon dioxide during cultivation. The use of biomass for biofuel production depends on many factors, i.e., the geographical region or economic conditions of the country. Poland is one of the largest agricultural countries in the EU, so, theoretically, it has the potential for biofuel production [55]. The national share of energy from renewable sources in terms of total energy consumption is 11.8% (10.6 Mtoe) and energy from liquid biofuels, including bioethanol, is only 10.8% of that value (1.1 Mtoe) [39]. Bioethanol plays an important role in this structure. The transport biofuel market in Poland is based on the use of fuel blends, which are a combination of conventional fuels and biocomponents (gasoline mixed with bioethanol and diesel with methyl esters, so-called biodiesel) [55,56]. In the transport sector in Poland, bioethanol is mainly used in accordance with the Act on Biocomponents and Liquid Biofuels, i.e., ethyl alcohol obtained from biomass [57]. According to the regulations in force in Poland, business activity related to the production, storage or marketing of bio-components requires an entry in the register of manufacturers, kept by the President of the Agricultural Market Agency (AMA). Until 17 November 2017, 24 entities had been recorded in the register [58], of which 14 are bioethanol plants. The situation on the biofuel market in Poland in terms of legislative processes is complicated and dynamic. New methods are being developed to produce biocomponents that meet EU requirements, primarily in environmental terms. The availability of brand new vehicles running on biofuels is also a problem, mainly due to their price. Although there are solutions to install a necessary biofuel combustion plant, vehicle users are concerned about the possible future effects on engines. Additionally, at the end of 2018, new key regulations regarding the new EU energy and climate policy in 2030 were published. Among the published documents is the new Renewable Energy Directive (RED II). They replace the previous directive from 2009. The regulations are to apply to 2021–2030 and will focus on reducing the share of first-generation biofuels in use. Therefore, subsidies and support from European and national institutions are to focus on supporting environmentally friendly second- and third-generation biofuels. First generation biofuels with a high risk of "indirect land use change" from 2030 will no longer be included in the EU's renewable energy targets [59].

2.5. Hydrogen-Powered Cars

The chemical energy of hydrogen (39.4 kWh/kg) is three times greater than that of other fuels, such as liquid hydrocarbons (13.1 kWh/kg) [60]. Interest in hydrogen as an energy carrier [61,62] results from its particularly favorable features: hydrogen reacts with oxygen and releases a significant amount of energy—143.1 MJ/kg—and the only product of the reaction is water; therefore, no pollutants are released into the environment [63]. Although hydrogen is the most common element in the universe, it does not exist in large quantities and concentrations on earth [64]. It is produced, inter alia, from biomass, water and fossil fuels, due to their widespread availability [65]. The most popular ways of obtaining hydrogen are the conversion of natural gas and light hydrocarbons [66], coal gasification [67] and biomass [68], recovery from coke oven gas [69,70], as well as water electrolysis [71], photo-electrolysis [72] and photo-biological processes [73]. The growing interest in and demand for hydrogen, which is called the 'fuel of the future', is due to its increasing use in transport. Hydrogen used in transport is seen as a low-carbon fuel and an alternative to oil and gas products. Fuel Cell Electric Vehicles (FCEVs) could reduce air pollution because they do not have direct exhaust emissions, as BEVs can. The FCEV is powered by an electric motor, but the difference is in the way it is stored and generated [74,75]. In FCEV, the batteries are replaced by hydrogen tanks which, as a result of the chemical reaction in fuel cells, are converted into electricity and steam. Theoretically, this is the ideal solution for cars, but the potential of hydrogen technology is effectively inhibited by the high production costs of FCEV [76] and poor infrastructure, especially in Poland. Currently, there are 11,200 FCEVs in operation worldwide, mainly in the USA and Japan. In Europe, FCEV cars can be found mainly in Germany and France [77]. The number of hydrogen refill installations is small. Hydrogen refueling stations for road transport, both public and private, account for a total of 381 points worldwide [78]. Japan has the largest number, with 100 refueling points, Germany has 69 and the United States has 63. In 2018, in Poland, the first vehicle powered by a fuel cell was registered. After several months of difficulties, Toyota Motor Poland introduced the Toyota Mirai to the Polish market, a passenger car powered by hydrogen [79]. However, there is still not a single station in the country where such a car can be refueled [31].

On 18 July 2018, the parliamentary team "Polska Wodorowa" was established [80], which discussed agreements and production activities for the development of hydrogen transport in Poland during meetings. At the end of October 2018, the first meeting of the "Hydrogen Poland" parliamentary team was held, which was attended by representatives of companies from the coal, fuel, chemical and automotive sectors. Poland, wishing to reduce its dependence on coal and perceiving hydrogen as an opportunity to achieve this, has 'observer' status in the International Partnership for Hydrogen and Fuel Cell Technology [81]. In addition, the Ministry of Energy established a working group for the Strategic Analysis of the Development of the Hydrogen Economy in Poland. The task of the team is to identify the factors causing changes in hydrogen regulations, i.e., vehicle approval, distribution, filling stations, safety regulations.

Since 2018, Jastrzębska Coal Company (JCC) Innovation has been working on adapting the technology of hydrogen separation from coke oven gas, which enables a high quality product intended for electro-mobility to be obtained, consistent with the purity requirements set by fuel cells. The Company was the first in Poland to announce its accession to the European Hydrogen and Fuel Cell Association, "Hydrogen Europe". The association includes the world's most advanced companies in the development of hydrogen technologies, such as 3M, Airbus and BMW GROUP [16].

Hydrogen issues in the area of "zero-emissions" have been investigated in Poland. In 2016, Burmistrz [27] and colleagues analyzed the carbon footprint of the hydrogen production process, by gasifying hard coal and lignite, using Shell and Texaco technologies in Poland. The aim of the study was to analyze the CF of the hydrogen production process with zero emissions, the "fuel of the future". Calculations and evaluations of CO_2 emission factors were carried out for the whole hydrogen production cycle, such as coal extraction, mechanical processing, transport of coal to the gasification plant, gasification and the sequestration process of captured CO_2. A CF of 1 kg of hydrogen, calculated according to the life cycle assessment (LCA) methodology, was (i) 19,423 kg $CO_{2\text{-e}}$/kg H_2 for the Shell hard coal gasification technology, (ii) 21,703 kg $CO_{2\text{-e}}$/kg H_2 for the GE/Texaco hard coal gasification technology and (iii) 25,279 kg $CO_{2\text{-e}}$/kg H_2 for the Shell lignite gasification technology. The application of the sequestration of captured $CO_{2\text{-e}}$ reduced the 1-kg CF of the hydrogen produced from 72% (lignite gasification according to Shell technology) to 79% (hard coal gasification according to Shell technology) by comparison with the variants without sequestration. It should be noted that the gasification technologies in question do not operate in Poland like they do in other countries; research and pilot projects were carried out on a small scale and consisted mainly of underground and laboratory gasification.

There are currently many international projects underway, in conjunction with Poland, concerning hydrogen energy, e.g., HydrogenLAW [82], which is a two-year international project financed by the European Commission under the Fuel Cells and Hydrogen Joint Undertaking (FCH JU). It concerns legislative and regulatory issues in the energy and transport sector, based on hydrogen technologies. The project consortium includes 23 partners, including European companies, associations and research centers, representing a total of 18 countries. The project is coordinated by Hydrogen Europe, an organization of 108 companies involved in hydrogen technologies.

Poland sees a huge potential for hydrogen as a source of energy and heating or an alternative to conventional transport fuels. Therefore, our country actively supports all national and international initiatives for the production, storage and use of hydrogen, in the fields of research, science and industry. Poland is committed and interested in the development of various methods of obtaining hydrogen, which will have positive economic and ecological effects in the future.

3. Summary

This article presents the current legal and infrastructural situation, planned activities for the next years and research in the field of alternative fuels used in transport in Poland. According to the assumptions within the national policy framework for the Development of Alternative Fuel Infrastructure adopted by the Council of Ministers, by 2025, one million electric cars will be driving on Polish roads and, in three years' time, over 6000 publicly available charging points for such cars will be operating. The objectives relating to the development of the natural gas market in transport are equally ambitious: 70 CNG filling stations are to be built in 32 Polish agglomerations by 2020. By 2025, 54,000 compressed gas-powered vehicles will be on Polish roads. It has been assumed that, by this time, the number of vehicles powered by liquefied natural gas will be 3000. According to the PAAF Report [16,17], there are currently 26 CNG stations in Poland and one publicly available LNG station. Currently, there are more than 9000 electric vehicles in operation in the country, with about a thousand charging stations at their disposal. The market for hydrogen-powered vehicles is underdeveloped, both in terms of vehicles and infrastructure. In the current national energy and economic situation, there are fears that the development of alternative fuels will be held back. There is a lack of multi-faceted analysis of the market and infrastructure for alternative fuels, for example, in terms of public readiness for change. Analyses of the social benefits of alternative technologies in transport will emerge worldwide. Lee et al. [83] demonstrated the willingness of Korean society to pay (a surcharge) for flour imports on board LNG-powered ships. Flour is a product that is mostly imported into Korea. Studies have shown that the surcharge was 571 KRW (0.48 USD) per kg of flour. This is about 36% of the current market price of the product. It was found that South Korean households are willing to pay a premium of this amount for flour imports on board LNG ships. Similar analyses, in the current year 2020, were carried out by Lopez [84], which calculated the ownership savings and social benefits of various alternative vehicle technologies compared to their base vehicle technology (e.g., petrol or diesel). This assessment was conducted for the Philippines. The results of such analyses should serve as an example for governments of other countries (including Poland) to shape the policy of implementing alternative fuels. In Poland, studies on the impact of electromobility and alternative fuels on society and its financial possibilities have not yet been carried out or made public. In 2017, analyses were made of the impact of the development of electromobility on electricity consumption in the country [85], with a time horizon of 2025. The analysis showed that the expected value of electricity consumption resulting from the development of electromobility in Poland is about 1.33 TWh per year, which is about 0.8% of the national electricity consumption for 2016. The increase in electricity consumption resulting from the development of electromobility in Poland should not (even in extreme scenarios) exceed approx. 3.27 TWh/year in 2025 (approximately 2.0% of Poland's national electricity consumption in 2016). Poland's current situation seems to be unfavourable for the development of alternative fuels, particularly electric vehicles. At the beginning of 2020, the free charging of e-cars at stations belonging to the national oil company ended, and charges were introduced. Analysts indicate that assuming the consumption of electricity at the level of 20 kWh/100 km, we will pay between 0.26 (alternating current) and 0.58 EUR (direct current) when driving a distance such as this for each 1 kWh. This costs about 5.11–11.60 EUR [86]. Ultra-fast chargers will have an even higher price—0.78 EUR/kWh. According to the PAAF, the problem of the Polish market is the high distribution fees charged to operators, regardless of actual energy consumption. A key element in this disadvantage is the continuous increase in tariff charges. With the current trend, the cost of driving 100 km by electric vehicle, with the abovementioned assumptions, can reach up to 15.67 EUR. The PAAF made an appeal to the Minister of Energy to change the distribution tariffs for electricity. The analyses conducted by PAAF clearly indicate that the system of the calculation and application of distribution tariffs is a significant additional barrier to the development of electromobility in Poland. As the PAAF emphasizes, no other Central European country applies such a high tariff differentiation as Poland (separate tariffs are in place for power up to 40 kW and over 40 kW for public stations). Consequently, the development of charging infrastructure in our country, especially in the area of fast charging stations, encounters greater barriers than in the neighbouring countries [87].

It was found that, in Poland, it is necessary to invest in infrastructure to develop the market of alternative fuels in the transport sector. The development of the alternative fuel market will reduce greenhouse gas emissions and improve the security of energy supply, and will also support economic growth and strengthen the competitiveness of the industry. So far, the alternative fuel market in Poland has been insufficiently developed and the objectives set out in the Directive and defined in the National Policy Framework for the Development of Alternative Fuel Infrastructure can only be achieved with the support of the state, especially the introduction of support instruments and incentives for buyers of vehicles using alternative fuels. The use of alternative fuels, in addition to the obvious environmental benefits, must pay off. There is no clear and conclusive research as to whether a Polish citizen can afford subsidies for both electricity and infrastructure, as well as the price of an alternative vehicle and its operation.

Author Contributions: Conceptualization, D.B.-K. and M.G.-G.; data collection and analysis D.B.-K., M.G.-G. and K.Z.; writing—original draft preparation, D.B.-K. and M.G.-G.; writing editing, K.Z. and M.G.-G; review and supervision, D.B.-K. and K.Z.; funding acquisition, D.B.-K. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the project no. 12/020/RGP19/0145 (Silesian University of Technology, Poland).

Acknowledgments: The authors would like to thank the AGH University of Science and Technology, Krakow, Poland for financial support (No. 16.16.210.476) and Silesian University of Technology, Katowice, Poland for financial support (No. 12/020/RGP19/0145).

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

ACEA	European Automobile Manufacturers Association
AMA	Agricultural Market Agency
BEV	Battery electric vehicles
CCS	Carbon capture and storage
CEF	Connecting Europe Facility
CF	Carbon footprint
CNG	Compressed natural gas
CRVD	Central Register of Vehicles and Drivers
CSO	Central Statistical Office
DOE	American Department of Energy
EAFO	European Alternative Fuels Observatory
EHA	European Hydrogen Association
EU	European Union
FCEV	Fuel cell electric vehicles
GHG	Greenhouse gas
JCC	Jastrzębska Coal Company
LCA	Life cycle assessment
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
m-CHP	Micro-combined heat and power
NCBiR	National Centre for Research and Development
NCRV	National Central Register of Vehicles
PAAF	Polish Association of Alternative Fuels
PAIA	Polish Association of Automotive Industry
PAS	Polish Academy of Sciences
PATH	Partnership for Advancing the Transition to Hydrogen
PHEV	Plug-in hybrid electric vehicles
PLGO	Polish Liquid Gas Organization

POC	Orlen Polish Oil Company
POGC	Polish Oil and Gas Company
REEV	Extended range electric vehicles
RES	Renewable energy sources
SAMAR	Automotive Market Research Institute
URE	Energy Regulatory Office
USDM	Upper Silesian Depth Metropolis
ZeEUS	Zero Emission Urban Bus System

References

1. Mathew, T.V.; Rao, K.V.K. Introduction to Transportation Engineering, NPTEL Web Course, Transportation Systems Engineering Civil Engineering Department, Indian Institute of Technology, 2006. Available online: https://nptel.ac.in/courses/105/101/105101087/ (accessed on 29 January 2020).
2. Erdiwansyah, M.R.; Sani, M.S.M.; Sudhakar, K.; Kadarohman, A.; Sardjono, R.E. An overview of Higher alcohol and biodiesel as alternative fuels in engines. *Energy Rep.* **2019**, *5*, 467–479. [CrossRef]
3. Awad, O.I.; Mamat, R.; Ali, O.M.; Sidik, N.A.C.; Yusaf, T.; Kettner, M. Alcohol and ether as alternative fuels in spark ignition engine: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 2586–2605. [CrossRef]
4. Eurostat, European Environment Agency, Imports of Crude Oli. Available online: https://ec.europa.eu/energy/data-analysis/eu-crude-oil-imports_en (accessed on 14 December 2019).
5. Eurostat, European Environment Agency, GHG Emission—Sectors. Available online: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge&lang=en (accessed on 29 December 2019).
6. Transportation in, UE. Available online: https://europa.eu/european-union/topics/transport_en (accessed on 12 December 2019).
7. White Paper on the Future of Europe. Available online: https://ec.europa.eu/commission/sites/beta-political/files/white_paper_on_the_future_of_europe_en.pdf (accessed on 10 October 2019).
8. The European Green Deal. Available online: https://ec.europa.eu/transport/themes/sustainable_en (accessed on 29 May 2020).
9. Nocera, O.; Irranca Galati, F.; Cavallaro. On the Uncertainty in the Economic Evaluation of Carbon Emissions from Transport. *J. Trans. Econ. Policy* **2018**, *51*, 68–94.
10. EC, European Commission, Communication from the Commission to the European Earliament, the Council, the European Economic and Social Committee and the Committee of the Regions, Clean Power for Transport: A European Alternative Fuels Strategy. Available online: https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A52013PC0017 (accessed on 20 December 2019).
11. ME, Ministry of Energy, Ministerstwo Energii, National Policy Framework for Developing Alternative Fuel Infrastructure. Available online: https://www.gov.pl/web/energia/elektromobilnosc-w-polsce (accessed on 12 August 2019).
12. ME, Ministry of Energy, Ministerstwo Energii, Electromobility Development Plan for Poland "Energy to the Future". Available online: https://www.gov.pl/documents/33372/436746/DIT_PRE_PL.pdf/ebdf4105-ef77-91df-0ace-8fbb2dd18140 (accessed on 12 October 2019).
13. CM, The Council of Ministers, Rada Ministrów, Act on Electromobility and Alternative Fuels. Available online: https://www.infor.pl/akt-prawny/DZU.2018.027.0000317,ustawa-o-elektromobilnosci-i-paliwach-alternatywnych.html (accessed on 1 February 2020).
14. ME, Ministry of Energy, Ministerstwo Energii, Act Establishing the Low-Emission Transport Fund, on Amending the Act on Biocomponents and Liquid Biofuels and Certain other Acts. Available online: https://www.gov.pl/web/energia/fundusz-niskoemisyjnego-transportu (accessed on 15 October 2019).
15. ME, Ministry of Energy, Ministerstwo Energii, Report on the implementation of the National Policy Framework for the Development of Alternative Fuel Infrastructure. Available online: https://www.gov.pl/attachment/d8178ee2-cbdf-4290-8b2b-d34205715ead (accessed on 10 December 2019).
16. JCC Innovation, Jastrzębska Coal Company—Innovation, Jastrzębska Spółka Węglowa—JSW Innowacje. Available online: https://www.jsw.pl/odpowiedzialny-biznes/jsw-na-rzecz-srodowiska-naturalnego/eko-projekty-jsw/produkcja-wodoru/ (accessed on 2 January 2020).

17. SAMAR, Automotive Market Research Institute. Available online: https://www.samar.pl/ (accessed on 20 October 2019).
18. PAAF, Polish Association of Alternative Fuels, Polskie Stowarzyszenie Paliw Alterantywnych PSPA, Report 2017 and 2019. Available online: http://pspa.com.pl/ (accessed on 10 December 2019).
19. PAIA, Polish Automotive Industry Association, Polski Związek Przemysłu Motoryzacyjnego PZPM, Report 2019/2020. Available online: https://www.pzpm.org.pl/Publikacje/Raporty (accessed on 15 December 2019).
20. PLGO, Polish Liquid Gas Organization—Report, Polska Organizacja Gazu Płynnego POGP. Available online: http://pogp.pl/wp-content/uploads/2019/04/POGP_2019-RAPORT_420x297_internet.pdf (accessed on 1 December 2019).
21. ACEA, European Automobile Manufacturers Assosiation, Passenger car registrations in 2017. Available online: https://www.acea.be/statistics/tag/category/registrations-and-press-release-calendar/P40 (accessed on 15 December 2019).
22. ACEA, European Automobile Manufacturers Assosiation, Report Vehicles in use Europe 2019. Available online: https://www.acea.be/publications/article/report-vehicles-in-use-europe-2019 (accessed on 20 December 2019).
23. ZeEus, Zero Emission Urban Bus System. Available online: https://zeeus.eu/ (accessed on 22 December 2019).
24. CRVD, Central Register of Vehicles and Drivers, Centralna Ewidencja Pojazdów i Kierowców CEPiK, Vehicles Registered in 2019. Available online: http://www.cepik.gov.pl/statystyki/ (accessed on 22 February 2020).
25. Kaszyński, P.; Kamiński, J. Coal Demand and Environmental Regulations: A Case Study of the Polish Power Sector. *Energies* **2020**, *13*, 1521. [CrossRef]
26. Lelek, Ł.; Kulczycka, J. Life Cycle Modelling of the Impact of Coal Quality on Emissions from Energy Generation. *Energies* **2020**, *13*, 1515. [CrossRef]
27. Burmistrz, P.; Chmielniak, T.; Czepirski, L.; Gazda-Grzywacz, M. Carbon footprint of the hydrogen production process utilizing subbituminous coal and lignite gasification. *J. Clean. Prod.* **2016**, *139*, 858–865. [CrossRef]
28. Huang, Y.; Surawski, N.C.; Organ, B.; Zhou, J.L. Consumption and emissions performance under real driving—Comparison between hybrid and conventional vehicles. *Sci. Total Environ.* **2019**, *659*, 275–282. [CrossRef] [PubMed]
29. Suarez-Bertoa, R.; Astorga, C. Unregulated emissions from light-duty hybrid electric vehicles. *Atmos. Environ.* **2016**, *136*, 134–143. [CrossRef]
30. Burchart-Korol, D.; Jursova, S.; Folęga, P.; Korol, J.; Pustejovska, P.; Blaut, A. Environmental life cycle assessment of electric vehicles in Poland and the Czech Republic. *J. Clean. Prod.* **2019**, *202*, 476–487. [CrossRef]
31. EAFO, European Alternative Fuels Observatory. Available online: https://www.eafo.eu/countries/european-union/23640/infrastructure/electricity/compare (accessed on 23 December 2019).
32. STATISTA. Available online: https://www.statista.com/statistics/625795/eu-electric-vehicle-market-share-by-country/ (accessed on 25 May 2020).
33. Cavallaro, F.; Danielis, R.; Nocera, S.; Rotaris, L. Should BEVs be subsidized or taxed? A European perspective based on the economic value of CO_2 emissions. *Trans. Res. Part D Trans. Environ.* **2018**, *64*, 70–89. [CrossRef]
34. Noel, L.; Zarazua de Rubens, G.; Kester, J.; Sovacool, B.K. Beyond emissions and economics: Rethinking the co-benefits of electric vehicles (EVs) and vehicle-to-grid (V2G). *Trans. Policy* **2018**, *71*, 130–137. [CrossRef]
35. CNG EUROPE. Available online: http://cngeurope.com/countries/poland/ (accessed on 19 December 2019).
36. NGVA EU, The Natural & bio Gas Vehicle Association. Available online: https://www.ngva.eu/ (accessed on 19 December 2019).
37. PCAF, Polish Congress of Alternative Fuels, Polski Kongres Paliw Alterantywnych PKPA, Alternative Fuels in Urban Transport 2018/2019. Available online: http://pspa.com.pl/assets/uploads/2018/11/PKPA_raport_wydanie_II_2018.pdf/ (accessed on 1 December 2019).
38. WLPGA, The World LPG Association. Available online: https://www.wlpga.org/ (accessed on 2 December 2019).
39. CSO, Central Statistical Office, Główny Urząd Statystyczny GUS, Report—Energy 2018. Available online: https://stat.gov.pl/en/topics/environment-energy/ (accessed on 28 December 2019).
40. EU Action, European Commission/Energy, Climate Change and Environment/Climate Action. Available online: https://ec.europa.eu/clima/policies/strategies/2020_pl (accessed on 2 January 2019).

41. Eurostat, Statistics on Energy from Renewable Sources. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics/pl (accessed on 2 December 2019).
42. Li, P.; Sakuragi, K.; Makino, H. Extraction techniques in sustainable biofuel production: A concise review. *Fuel Process. Technol.* **2019**, *193*, 295–303. [CrossRef]
43. Lisý, M.; Lisá, H.; Jecha, D.; Baláš, M.; Križan, P. Characteristic Properties of Alternative Biomass Fuels. *Energies* **2020**, *13*, 1448. [CrossRef]
44. Guo, W.; Li, G.; Zheng, Y.; Wang, S. Simulation study of thermochemical process from biomass to higher alcohols. *Energy Fuel* **2016**, *30*, 9440–9450. [CrossRef]
45. Li, P.; Makino, H. Liquefied Dimethyl Ether: An Energy-Saving, Green Extraction Solvent. In *Alternative Solvents for Natural Products, Extraction*; Chemat, F., Abert, V.M., Eds.; Springer: Berlin/Heidelberg, Germany, 2014; pp. 91–106.
46. Tamoši, A.; Gimžauskait, D.; Aikas, M.; Uscila, R.; Praspaliauskas, M.; Eimontas, J. Gasification of Waste Cooking Oil to Syngas by Thermal Arc Plasma. *Energies* **2019**, *12*, 2612. [CrossRef]
47. Sánchez-Arreola, E.; Bach, H.; Hernández Luis, R. Biodiesel production from Cascabela ovata seed oil. *Bioresour. Technol. Rep.* **2019**, *7*, 100220. [CrossRef]
48. Cho, S.; Kim, J.; Han, J.; Lee, D.; Kim, H.J.; Kim, Y.T.; Cheng, X.; Xu, Y.; Lee, J.; Kwon, E.E. Bioalcohol production from acidogenic products via a two-step process: A case study of butyric acid to butanol. *Appl. Energy* **2019**, *252*, 113482. [CrossRef]
49. Emberger, P.; Hebecker, D.; Pickel, P.; Remmele, E.; Thuneke, K. Emission behaviour of vegetable oil fuel compatible tractors fuelled with different pure vegetable oils. *Fuel* **2016**, *167*, 257–270. [CrossRef]
50. Winquist, E.; Rikkonen, P.; Pyysiäinen, J.; Varho, V. Is biogas an energy or a sustainability product?—Business opportunities in the Finnish biogas branch. *J. Clean. Prod.* **2019**, *233*, 1344–1354. [CrossRef]
51. Sadhukhan, J.; Martinez-Hernandez, E.; Amezcua-Allieri, M.A.; Aburto, J.; Amador Honorato, J.S. Economic and environmental impact evaluation of various biomass feedstock for bioethanol production and correlations to lignocellulosic composition. *Bioresour. Technol. Rep.* **2019**, *7*, 100230. [CrossRef]
52. Preethi; Usman, T.M.M.; Banu, J.R.; Gunasekaran, M.; Kumar, G. Biohydrogen production from industrial wastewater: An overview. *Bioresour. Technol. Rep.* **2019**, *7*, 100287. [CrossRef]
53. Leong, W.; Lim, J.; Lam, M.; Uemura, Y.; Ho, Y. Third generation biofuels: A nutritional perspective in enhancing microbial lipid production. *Renew. Sustain. Energy Rev.* **2018**, *91*, 950–961. [CrossRef]
54. Moravvej, Z.; Makarem, M.A.; Rahimpour, M.R. The Fourth Generation of Biofuel. In *Second and Third Generation of Feedstocks*; Basile, A., Dalena, F., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 557–597.
55. Mączyńska, J.; Krzywonos, M.; Kupczyk, A.; Tucki, K.; Sikora, M.; Pińkowska, H.; Bączyk, A.; Wielewska, I. Production and use of biofuels for transport in Poland and Brazil—The case of bioethanol. *Fuel* **2019**, *241*, 989–996. [CrossRef]
56. Izdebski, W.; Skudlarski, J.; Zajac, S. Use of raw materials of agricultural origin for production of transport biofuels in Poland. *Sci. Yearb. Assoc. Agric. Agribus. Econ.* **2014**, *16*, 93–97.
57. CM, The Council of Ministers, Rada Ministrów, Act on Biocomponents and Liquid Biofuels. Available online: http://prawo.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20061691199 (accessed on 3 January 2020).
58. NASC, National Agricultural Support Centre, Krajowy Ośrodek Wsparcia Rolnictwa. Available online: http://www.arr.gov.pl/data/01670/1_kw_2017_wyt.pdf (accessed on 5 January 2020).
59. Renewable Energy Directive, RED II. Available online: https://eur-lex.europa.eu/legal-content/PL/TXT/PDF/?uri=CELEX:32018L2001&from=EN (accessed on 29 May 2020).
60. Züttel, A. Hydrogen storage methods. *Naturwissenschaften* **2004**, *91*, 157–172.
61. Behera, B.K.; Balasundaram, R.; Gadgil, K.; Sharma, D.K. Photobiological production of hydrogen from Spirulina for Fueling Fuel Cells. *Energy Sources Part A* **2007**, *29*, 761–767. [CrossRef]
62. Kovács, K.L.; Maroti, G.; Rákhely, G. A novel approach for biohydrogen production. *Int. J. Hydrogen Energy* **2006**, *31*, 1460–1468. [CrossRef]
63. Kapdan, I.K.; Kargi, F. Bio-hydrogen production from waste materials. *Enzym. Microb. Technol.* **2006**, *38*, 569–582. [CrossRef]
64. Stiegel, J.G.; Ramezan, M. Hydrogen from coal gasification: An economical pathway to a sustainable energy future. *Int. J. Coal Geol.* **2006**, *65*, 173–190. [CrossRef]
65. Turner, J.A. Sustainable hydrogen production. *Science* **2004**, *305*, 972–974. [CrossRef] [PubMed]

66. Wiltowski, T.; Mondal, K.; Campen, A.; Dasgupta, D.; Konieczny, A. Reaction swing approach for hydrogen production from carbonaceous fuels. *Int. J. Hydrogen Energy* **2008**, *33*, 293–302. [CrossRef]
67. Minchener, A.J. Coal gasification for advanced power generation. *Fuel* **2005**, *84*, 2222–2233. [CrossRef]
68. Shen, L.; Gao, Y.; Xiao, J. Simulation of hydrogen production from biomass gasification in interconnected fluidized beds. *Biomass Bioenergy* **2008**, *32*, 120–127. [CrossRef]
69. Karcz, A. Gaz koksowniczy jako surowiec do produkcji wodoru. *Polityka Energ.* **2009**, *12*, 111–117.
70. Sun, Q.; Dong, J.; Guo, X.; Liu, A.; Zhang, J. Recovery of hydrogen from coke-oven gas by forming hydrate. *Ind. Eng. Chem. Res.* **2012**, *51*, 6205–6211. [CrossRef]
71. Take, T.; Tsurutani, K.; Umeda, M. Hydrogen production by methanol–water solution electrolysis. *J. Power Sources* **2007**, *164*, 9–16. [CrossRef]
72. Siripala, W.P. Hydrogen energy and photoelectrolysis of water. *Proc. Tech. Sess.* **2004**, *20*, 67–73.
73. Zhang, W.; Chen, Z.A. Photo-biological hydrogen production system by green microalgae: Theoretical analysis for constraints and prospects. *J. Biotechnol.* **2010**, *150*, 33. [CrossRef]
74. Pollet, B.G.; Kocha, S.S.; Staffell, I. Current status of automotive fuel cells for sustainable transport. *Curr. Opin. Electrochem.* **2019**, *16*, 90–95. [CrossRef]
75. Garland, N.L.; Papageorgopoulos, D.C.; Stanford, J.M. Hydrogen and Fuel Cell Technology: Progress, Challenges, and Future Directions. *Energy Procedia* **2012**, *28*, 2–11. [CrossRef]
76. Apostolou, D.; Xydis, G.; A literature review on hydrogen refuelling stations and infrastructure. Current status and future prospects. *Renew. Sustain. Energy Rev.* **2019**, *113*, 109292. [CrossRef]
77. IEA, International Energy Agency. The Future of Hydrogen. 2019. Available online: https://webstore.iea.org/download/summary/2803?fileName=English-Future-Hydrogen-ES.pdf (accessed on 7 January 2020).
78. AFC TCP, Advanced Fuel Cells, Survey on the Number of Fuel Cell Electric Vehicles, Hydrogen Refuelling Stations and Targets. Available online: https://www.ieafuelcell.com/fileadmin/publications/2019-04_AFC_TCP_survey_status_FCEV_2018.pdf (accessed on 2 December 2019).
79. Toyota. Available online: https://www.toyota.pl/new-cars/mirai/ (accessed on 27 November 2019).
80. Hydrogen Poland, Polska Wodorowa. Available online: http://www.sejm.gov.pl/Sejm8.nsf/agent.xsp?symbol=POSIEDZENIAZESP&Zesp=538 (accessed on 20 December 2019).
81. Musiał, D. Ministry of Energy of the Republic of Poland, Innovation and Technology Development Department, www.me.gov.pl. Available online: https://ec.europa.eu/energy/sites/ener/files/documents/3-4_poland_musial.pdf (accessed on 20 November 2019).
82. DE, Department of Energy, Instytut Energetyki. Available online: https://www.ien.com.pl/aktualnosc/items/seminarium-projektu-hylaw (accessed on 19 December 2019).
83. Lee, H.-J.; Yoo, S.-H.; Huh, S.-Y. Economic benefits of introducing LNG-fuelled ships for imported flour in South Korea. *Trans. Res. Part D Trans. Environ.* **2020**, *78*, 102220. [CrossRef]
84. Lopez, N.S.; Soliman, J.; Bienvenido, M.B.J.; Fulton, L. Cost-benefit analysis of alternative vehicles in the Philippines using immediate and distant future scenarios. *Trans. Res. Part D Trans. Environ.* **2020**, *82*, 102308. [CrossRef]
85. Krupa, K.; Kamiński, J. Analiza wpływu rozwoju elektromobilności na zużycie energii elektrycznej w Polsce. *Rynek Energii Energy Market* **2017**, *6*, 8–13.
86. Electricity Rises in Poland. Available online: https://energia.rp.pl/nowa-energia/elektromobilnosc/20074-podwyzki-pradu-dobija-program-elektromobilnosci (accessed on 24 May 2020).
87. Tariffs for Electromobility in Poland. Available online: https://orpa.pl/pspa-potrzebna-nowa-e-taryfa-dla-elektromobilnosci/ (accessed on 24 May 2020).