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Review

Analysis of the Implementation of Functional Hydrogen Assumptions in Poland and Germany

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Abstract: The use of hydrogen exists in various sectors in Poland and Germany. Hydrogen can be used in industry, transport, decarbonisation of the Polish steel industry and as one of the low-emission alternatives to the existing coal applications in this sector. Limiting climate change requires efforts on a global scale from all countries of the world. Significant economic benefits will be realized by stimulating the development of new technologies to deal with climate change. The scenarios show an increasing demand for industrial hydrogen in the future. The key is to replace gray hydrogen with green, and to convert industrial processes, which will create additional hydrogen demand. The condition for the development of a green hydrogen economy is access to adequate installed capacity in renewable energy. Germany will become the leading market in the era of energy transformation in the coming years. The implementation of the hydrogen assumptions in Poland is possible, to a greater extent, by the efforts of entrepreneurs.

Keywords: hydrogen; green energy; renewable energy; transport; decarbonization; Poland; Germany; individuals; enterprises

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1. Introduction

In Poland, possibilities for using hydrogen exist in all sectors, particularly in industry and the transport sector. In industry, the use of renewable or low-carbon hydrogen in ammonia production and refineries can help reduce greenhouse gas emissions associated with existing hydrogen use [1–3].

The deployment of hydrogen can contribute to the decarbonisation of gas supplies in industry and, in the long term, can be used as a low-carbon solution for supplying high-temperature process heat [4–8].

Hydrogen may be a solution for the decarbonisation of the Polish steel industry, which is currently still dependent on the carbon-based steel production process. In the transport sector, the greatest chances for the implementation of hydrogen lie in the Polish road and rail sector. In the built environment, hydrogen can decarbonise the existing use of natural gas, but it can also be used as a low-carbon alternative to existing coal uses in this sector [9–11].

In Poland, the possibilities for using hydrogen in industry are significant. First of all, the Polish industry has a significant market share in the production of ammonia and refining capacity in Europe. These industries already consume hydrogen from fossil fuels, which can be replaced with renewable or low-carbon hydrogen. In addition, natural gas accounts for almost a quarter of the industry's energy mix, and the use of renewable or low-carbon hydrogen is one way to decarbonise gas supplies [12].

Hydrogen is a low-carbon energy carrier that is well suited to decarbonising this part of the energy demand. Finally, the Polish steel sector accounts for 6% of the EU's primary steel production and can be decarbonised by switching from conventional fossil fuel-based steel production processes to a process where iron in direct reduction is produced using hydrogen [13–15].

The assessment shows that although Poland has included hydrogen as a key transport decarbonisation solution in its National Action Plan to reduce carbon dioxide emissions with several supportive measures, there is still scope to develop a comprehensive framework for the deployment and use of hydrogen in other sectors (construction and industry) [16,17].

Poland considers hydrogen a key area to be explored as part of its R&D activities to support investments in hydrogen-related production assets, storage and distribution infrastructure, final application, and in the development of materials for energy storage [18,19].

Poland is the main beneficiary of the Modernization Fund and believes that this funding should be allocated to investments in line with climate policy, to support the implementation of the NECP (National Contact Point—European partnership for clean hydrogen) measures for investments related to hydrogen and fuel cells [20].

Under its NECP, Poland will support national research on clean coal technology (CCT), including the production of hydrogen from coal gasification, to generate electricity using the IGCC (gas combination cycle), or for use in fuel cells [21,22].

Poland acknowledged that additional measures may be needed to deploy hydrogen refueling stations and encourage the use of hydrogen cars. The NECP also pointed out that the power system faces increasing risks due to the increasing generation of variable power generation, and that there is a need to pay more attention to technologies, such as the use of hydrogen, that allow the integration of these transform sources [23,24].

Poland treats Germany as a model for the introduction of hydrogen. Details of hydrogen planning in Germany are presented in chapter 4.

2. Materials and Methods

2.1. Research Background

The authors jointly decided to carry out an analysis of entrepreneurs' opinions. The analysis responds to climate action and social, economic, ethical and political challenges. The drastic reduction of negative climate change relies on the cooperation of all countries around the world. Activity towards the development of new technologies in connection with climate change should bring economic benefits.

2.2. Research Methodology

The research analysis was carried out through the use of descriptive statistics and statistical tests: the sample randomness test and the chi-square test of independence.

The sample randomness test was used to verify the null hypothesis [25]:

The randomness was presented in the form of a random sample or not, where, respectively, H0 and H1 are indicated.

1. The verification of the hypothesis is based on the generation of the median Me, then mapping occurs,
2. xi, we consider the order where xi < Me, goes to the symbol b, if xi > Me. In turn xi = Me can be downplayed,
3. it shows k, which includes a and b, related to all the elements [26].
4. by constructing that the null hypothesis is authentic, the number of series k has a known and stable distribution,
5. the rejection area is two-sided. From the tables of the distribution of the number of series for the previously determined significance level α i n1 and n2 (numbers a and b) we verify the critical symbols $k1$ and $k2$ in the direction of the relationship P ($k \leq k\_1$) = $\alpha/2$ and P ($k \leq k\_2$) = $1 - \alpha/2$,
6. therefore, if $k \leq k\_1$ or $k \geq k\_2$ we reject the sample randomness hypothesis, but when $k\_1 < k < k\_2$ we accept the sample randomness hypothesis (we do not reject) [27].

The verification is based on the formula below:

$$\chi^2 = \sum_{i=1}^{l} \sum_{j=1}^{k} \frac{\left(n_{ij} - \hat{n}_{ij}\right)^2}{\hat{n}_{ij}} \quad (1)$$

where:

- n_{ij}—real results
- $\hat{n}_{ij}$—results based on the formula $\hat{n}_{ij} = \frac{n_i n_j}{n}$

Given the status showing that the null hypothesis is confirmed, then the test statistic has a score χ^2 o $(k-1)(l-1)$ degrees of freedom, where k is the number of options for the first feature of the analyzed crosstab, and l is the number of variants of the second feature. A critical area for is $[\chi^2_\alpha; \infty]$, gdzie χ^2_α, this is the critical result, as shown in the table χ^2 for the top-down level of significance α.

The group of respondents comprised natural persons (not conducting business activity) and entrepreneurs. The research area covered the Mazowieckie Voivodeship. The research period was from March 2021 to May 2022. During this time, interviews were conducted with 644 people (natural persons (not conducting business activity) and entrepreneurs). The questionnaire was intentionally designed in such a way as to capture the respondents' ability to select answers consciously. Forty questionnaires were rejected due to incomplete information. The number of correctly completed questionnaires included in the study was 604.

3. Hydrogen Planning in Poland

Poland is preparing a hydrogen technology development program aimed at introducing hydrogen applications in the electricity, transport and gas industries, while reducing the consumption of traditional fossil fuels [28].

The program covers hydrogen production, transport, storage, distribution and final use, taking into account the EU and Polish legal framework. Hydrogen can become an important area of economic development in Poland [29].

The program covers all possible uses of hydrogen, from large factories to homes, and the introduction of hydrogen would fulfill three main objectives: to increase the competitiveness of energy companies; increase the security of the energy supply and benefit the Polish economy as part of the energy transition [30–32].

Hydrogen produced from electricity can be sent to the natural gas network and combined with carbon dioxide to produce synthetic methane, thereby improving the quality of biogas.

The share of renewable electricity in total electricity consumption will increase from the current 1% to 32% by 2030 [33].

Gas-based generation capacity is being developed to support variable generation. Backup power plants are powered by imported gas and domestic resources, including hydrogen.

Energy conservation options are also being developed, especially in the field of renewable energy conservation (Figure 1) [34].

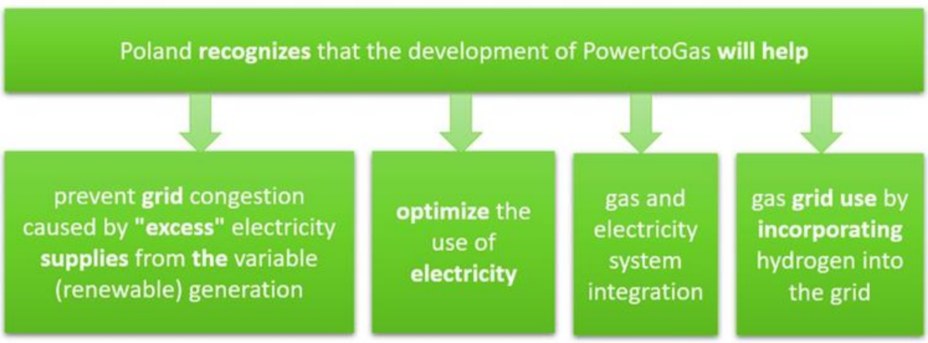

Figure 1. Poland recognizes that the development of PowertoGas will help [35].

According to the NECP, Poland will encourage the use of alternative fuels in transport, including hydrogen, in accordance with the law on "alternative fuel and electric capabilities". Poland plans to reduce its dependence on oil imports through the increased use of cars powered by alternative fuels and the implementation of the necessary infrastructure [36].

Electricity significantly reduces carbon dioxide emissions. Efforts to fully decarbonise the transport sector are key: promoting other zero-emission vehicles, including hydrogen-powered vehicles.

Hydrogen will also be considered for decarbonisation in the rail, aviation and maritime sectors. Among the policies and measures to achieve low-emission mobility, Poland plans to promote environmentally friendly modes of transport, such as the use of fuel cell vehicles by cities to refuel and deploy hydrogen refueling stations in densely populated areas [37].

The Low Emissions Transportation Fund aims to support the rollout of alternative fuel infrastructures and begin rolling them out in the marketplace [38].

Poland has established a fund for the period 2018–2027, which supports investments for: renewable fuel production; the deployment of hydrogen delivery and delivery infrastructure; manufacturing transport equipment related to the hydrogen value chain; and purchasing hydrogen-powered vehicles and boats [39].

Poland plans to use its salt cave geological formations as underground gas storage facilities for hydrogen storage [40].

Poland plans to increase the GDP energy and climate budget to 2.5% in 2030. Poland also plans to cooperate more closely with organizations of the European Organization and other EU Member States in the field of the Strategic Energy Technology Plan.

Poland considers hydrogen a key area to be explored as part of its R&D activities to support investments in hydrogen-related production assets, storage and distribution infrastructure, final application and in the development of materials for energy storage (e.g., carbon cells and nanostructures) [41].

Poland has significant potential for the use of hydrogen in road transport. A total of 43% of the energy used in the sector is consumed by trucks, buses and light trucks [42].

Electrification of this segment of the trucking sector remains challenging. There is a significant opportunity for the deployment of hydrogen to decarbonize this part of the trucking industry. The Polish railway industry is still dependent on fossil fuels for a quarter of total energy consumption [43].

Combined with electrification, the deployment of low-carbon or renewable hydrogen could replace the use of diesel trains. In the medium and long term, hydrogen and derived fuels can also play a role in the decarbonization of the Polish aviation industry, which still accounts for a relatively small share of the world's energy needs. Similarly, hydrogen and hydrogen-derived fuels could be deployed to decarbonize the energy used to power international ships. Although international transport and aeronautics are not currently regulated by the EU or international climate law, EU countries will need a collective effort to support decarbonisation in these areas [44].

4. Hydrogen Planning in Germany

Potential applications for hydrogen include rail, road, aviation, shipping and other industries, and many projects have already begun or are being seriously considered [45].

In rail traffic, hydrogen is particularly attractive for rails that do not have a catenary. In general road and freight transport, hydrogen would also be cheaper compared to electric vehicles, as the charging times and weight of batteries required in electric vehicles are not always economically viable [46].

Road transport currently has only 87 hydrogen fueling stations across the country. The German automobile club ADAC estimates that approximately 1000 stations are needed to ensure nationwide delivery [47].

Hydrogen can be transported in a number of ways, including pipelines, tankers and trucks. NRW has a hydrogen pipeline of 240 km, which is already suitable for transporting longer distances. Several industrial partners plan to build a 130 km long hydrogen pipeline from Lingen to Gelsenkirchen NRW (Get H2 Nucleus). Germany's transmission system operators also recently announced plans to introduce a hydrogen start network (H2-Startnetz) by 2030 to link the demand priorities of NRW and Lower Saxony with hydrogen-related green gas projects in northern Germany. By the end of 2030, the introduction of the network will require investments of approximately 660 million euros. Of the planned 1200 km, about 1100 km should be used for hydrogen transport by changing the existing natural gas pipelines, so only about 100 km remain unbuilt [48–50].

Salt caverns allow for the storage of more hydrogen, and Germany has cavern storage facilities with a base gas volume of approximately 11 billion cubic meters of hydrogen, where approximately 4 billion standard cubic meters are contained in NRW (Figure 2).

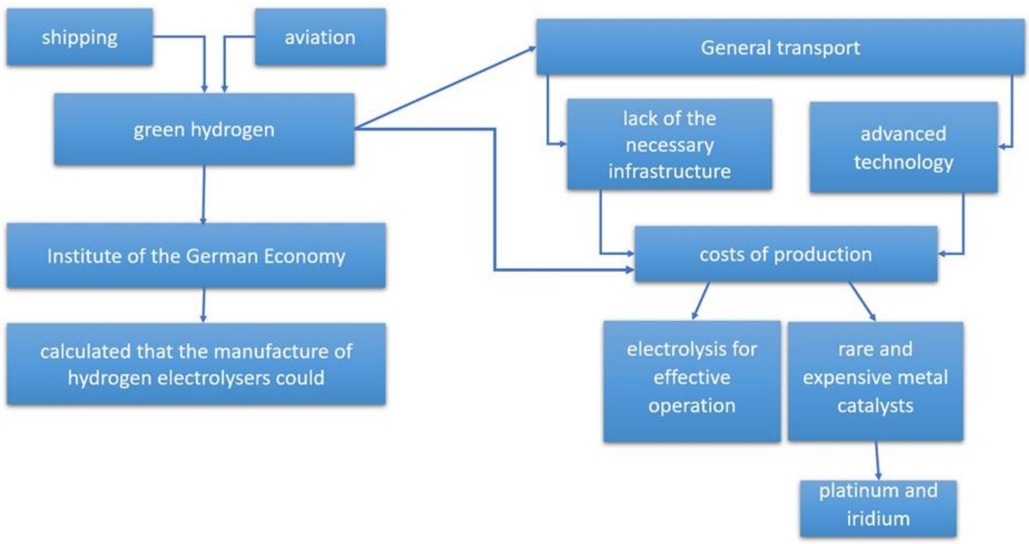

Figure 2. Green hydrogen in Germany [51].

At €10 per kg, hydrogen is still too expensive to use in general transport, especially due to the lack of necessary infrastructure (i.e., network of filling stations) and the very technology used. Production costs appear to be around €6 per kg. The electrolysis of also requires rare and expensive metal catalysts such as platinum and iridium to work effectively [52].

5. Results

Given the large overall potential for hydrogen use, hydrogen in the entire Polish energy sector should be included in the Hydrogen Technology Development Program to address the challenges of decarbonisation in all energy end-use sectors, preferably in cooperation with neighboring countries, and taking into account initiatives and policies at the EU level. Regulatory barriers could also be addressed under this Program [53].

5.1. Characteristics of Hydrogen

5.1.1. Hydrogen as the Fuel of the Future

Hydrogen is poised to drive the energy of the future—from transport, through energy storage and gas networks, to heavy industry. The European Commission has started work on a hydrogen strategy that will set the directions for development, and EU countries are already planning solid financial support [54].

Figure 3 below presents the optimistic hydrogen performance data for 2050.

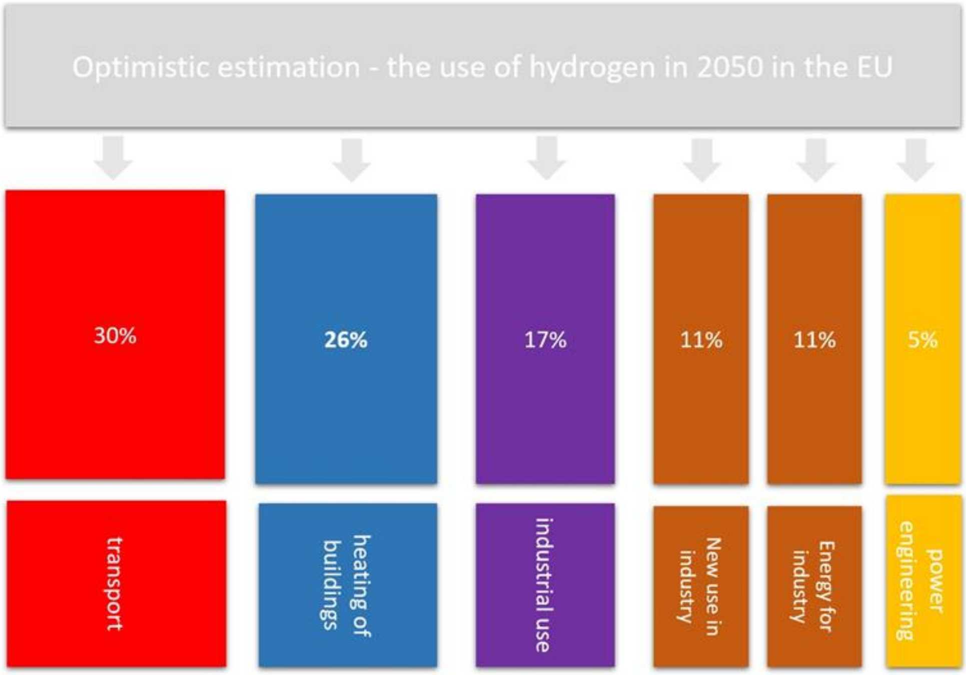

Figure 3. Optimistic hydrogen performance data in 2050 [55].

Hydrogen demand in 2030 has been estimated in the low and high scenarios covering a range of uncertainty. Today, conventional hydrogen, mainly used in industry, is produced from fossil fuels. Scenarios A and B, indicated below, assume that in 2030, hydrogen from renewable sources will partially replace the existing conventional production and cover additional demand from the transport sector (Figure 4).

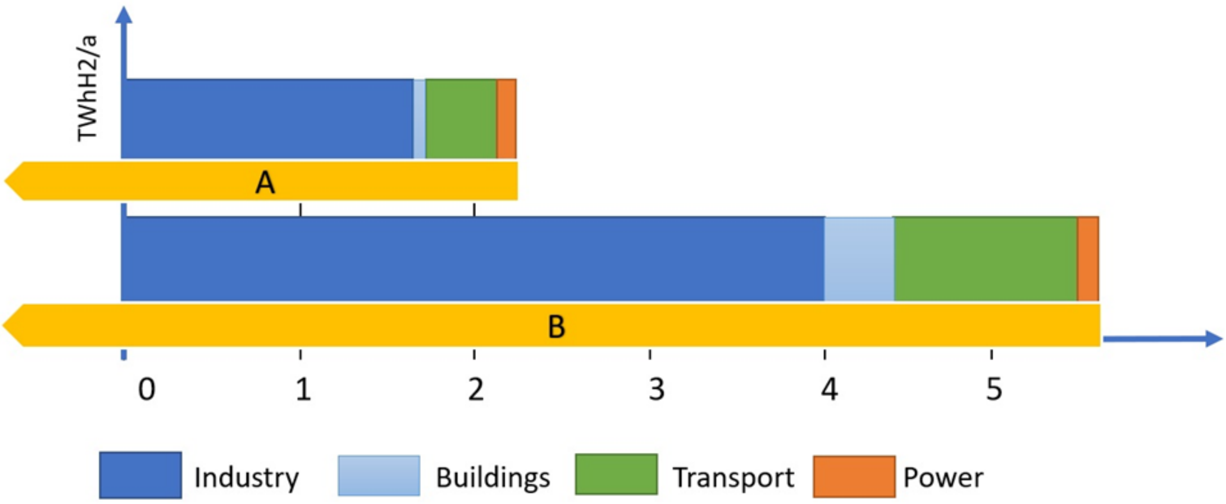

Figure 4. Scenario with low and high range of uncertainty [56].

5.1.2. Assessment of Hydrogen Production Potential and Its Role in the Flexibility of the Energy System

The evaluation of the hydrogen production potential is presented in Table 1, as follows.

Table 1. Assessment of hydrogen production potential.

Assessment of Hydrogen Production Potential	Result
The technical variable is renewable Electricity potential (TWh/year)	1085
Technical renewable electricity generation comparing the potential to the forecast	539%
Estimation of the NECP variable renewable Electricity production in 2030 (TWh/year)	45.05
Estimation of the NECP variable renewable Electricity production in the 2030 comparison to its technical potential	4%
The relationship between variable power Generation of capacity in 2030 and average load based on the NECP	109%
Ready for Carbon dioxide storage	short

The final energy demand from hydrogen in TWh is presented in the diagram below Figure 5.

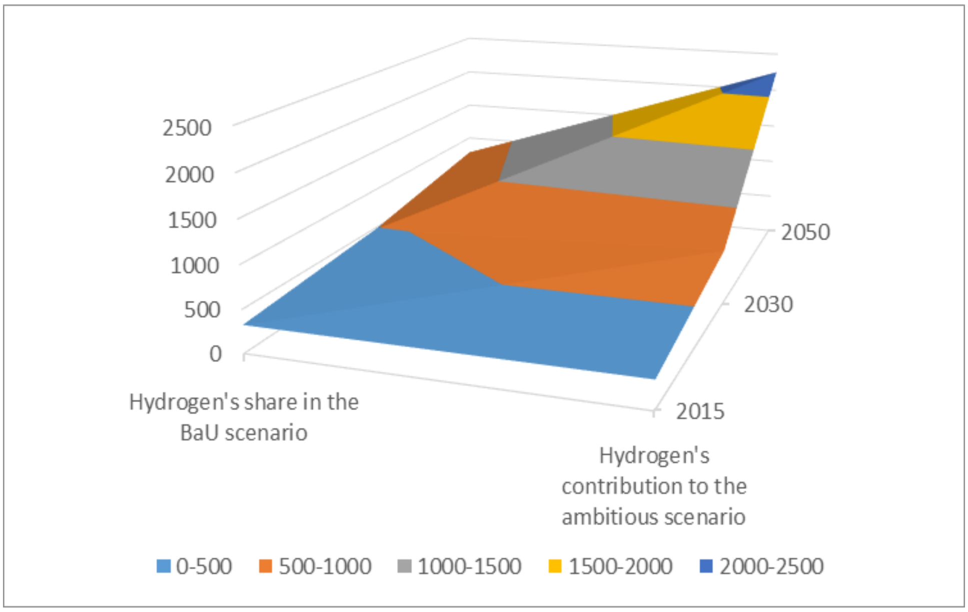

Figure 5. Final energy requirement from hydrogen in TWh [57].

Presentation of the use of hydrogen in 2050 in an ambitious scenario.

The zero emissions path to 2050 requires much more use of hydrogen in existing applications and significant use of hydrogen and hydrogen-based fuels in new applications in heavy industry, heavy road transport, shipping and aviation (Figure 6).

Under the zero emissions scenario, hydrogen demand will increase to almost 530 million tons of H2 by 2050. Half of the demand will come from industry and transport. In fact, industrial demand will almost triple, from about 50 and a half million tons in 2020 to about 10 million tons in 2050. Transport demand will increase, and in some segments, will reach below 20,000 tons.

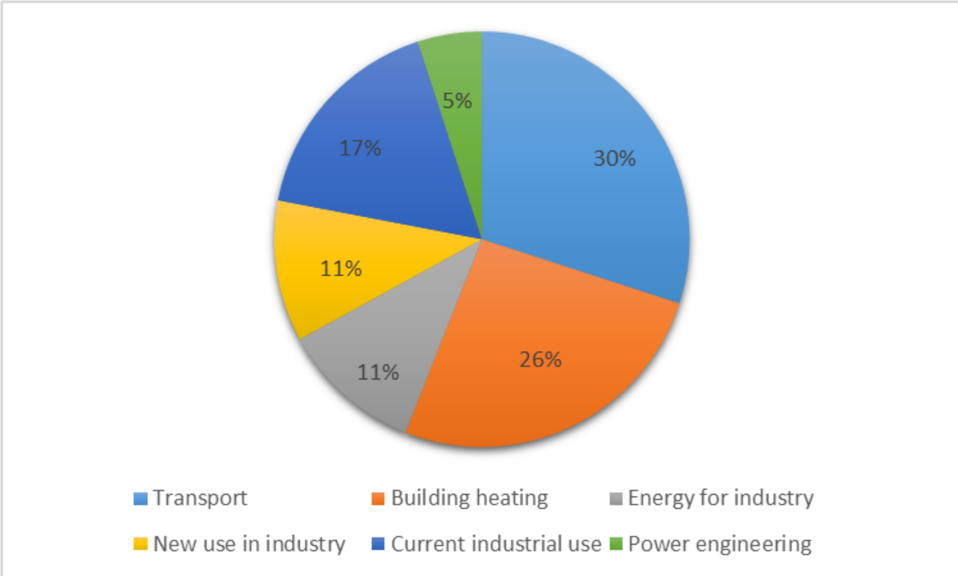

Figure 6. The use of hydrogen in 2050 in an ambitious scenario [58].

5.1.3. Hydrogen Demand by Sector in Announced Pledges

The Figure 7 below shows Hydrogen Demand by sector in the promised commitments.

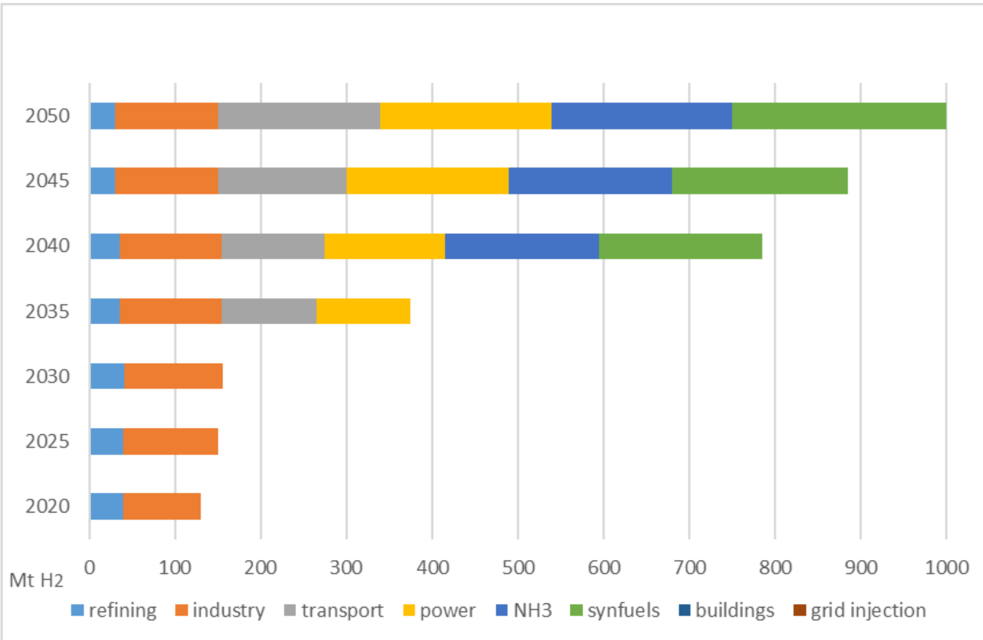

Figure 7. Announced Pledges Scenario [59].

5.1.4. Hydrogen Demand by Sector in the Net Zero Emissions Scenarios, 2020–2050

By 2050, about one third of the hydrogen demand in the net zero emissions scenario will be used to produce hydrogen-based fuels, such as ammonia, synthetic kerosene and synthetic methane. The use of ammonia will go beyond its existing uses (mainly nitrogen fertilizers) to be used as fuel.

The Figure 8 below shows Net Zero Emissions by 2050.

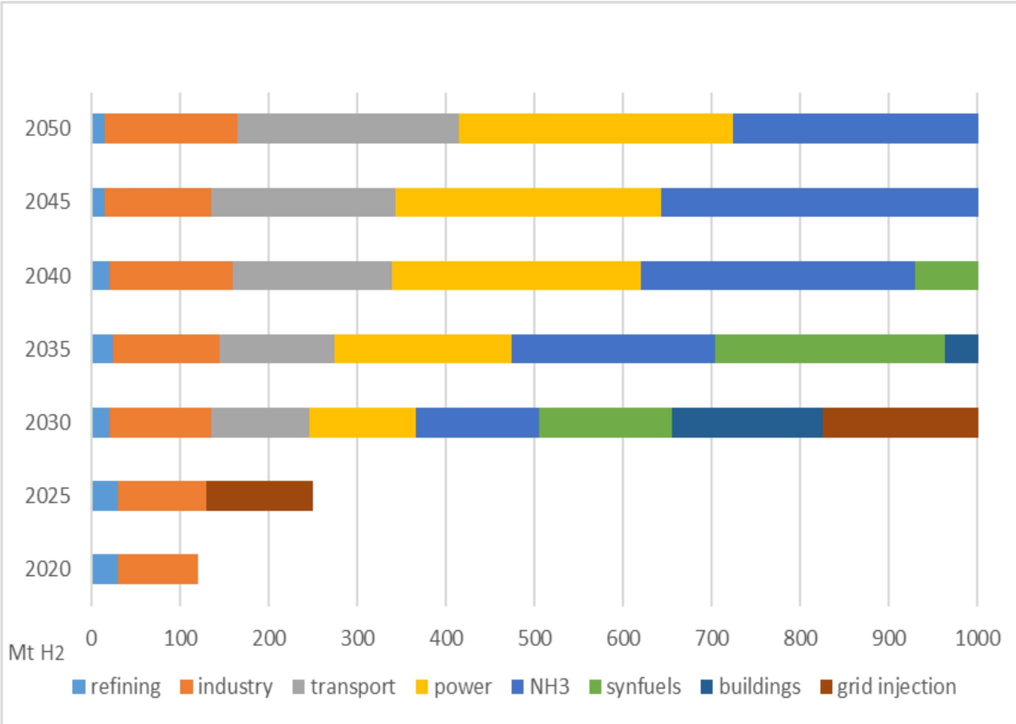

Figure 8. Net Zero Emissions by 2050 [60].

Ammonia has an advantage over the direct use of hydrogen in long-distance shipping, as it covers approximately 50% of global transport fuel demand in a zero emission scenario. Ammonia is increasingly used in existing coal-fired power plants to reduce carbon dioxide emissions in energy production, and some former coal-fired power plants are being completely upgraded to use 100% ammonia to provide low-carbon power.

6. Hydrogen Analysis of Germany and Poland

6.1. Hydrogen Key Lessons until 2040—Poland

The annual demand for hydrogen in Poland in 2040 will exceed 100 TWh.

Figure 9 below presents the production of hydrogen in Poland.

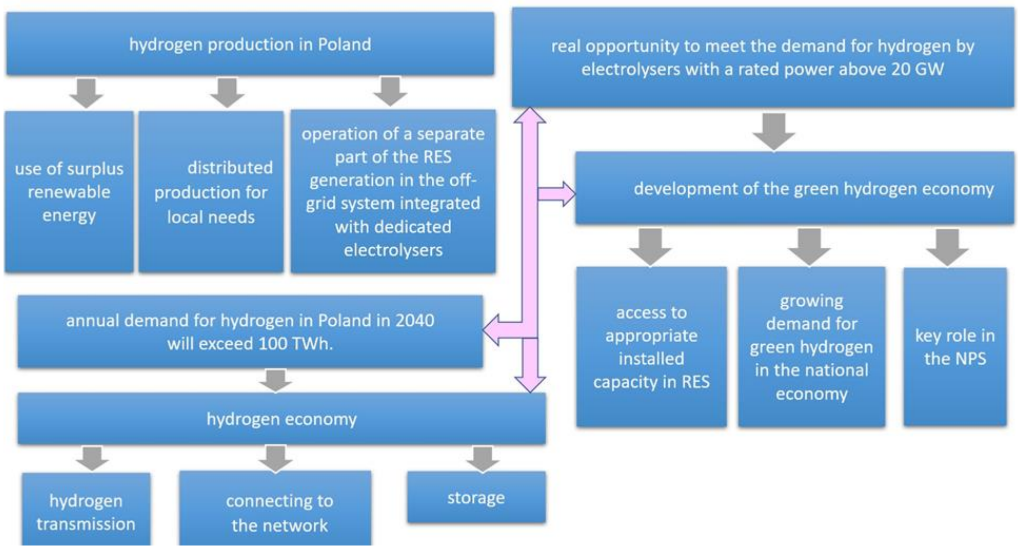

Figure 9. Hydrogen production in Poland [61].

Hydrogen production in Poland should be carried out within three paths, i.e., the use of surplus RES, the operation of a separate part of RES generation in an off-grid system integrated with dedicated electrolysers and distributed production for local needs [62].

By 2040, there will be a real opportunity to meet the demand for hydrogen by electrolysers with a rated power above 20 GW [63].

Rapid action is needed to meet the requirements of the hydrogen economy, in particular, in terms of hydrogen transfer, storage and grid connection.

A necessary condition for the development of the green hydrogen economy is access to appropriate installed capacity in renewable energy. To make this possible, in 2040, the generation of RES should be over 60 GW. Planned transformation of the Polish energy sector should take into account the growing demand for green hydrogen in the domestic economy and its key role in the Polish Power System [64].

The energy transformation requires the withdrawal of conventional coal-fired units from the NPS and the cessation of construction of new ones. In the future, the NPS must operate on the basis of renewable sources (mainly onshore and offshore wind farms and photovoltaics), as well as energy storage systems [65].

Among the key findings were that achieving climate neutrality requires profound changes in all sectors of the economy, as well as in cross-cutting areas, such as the governance and lifestyle of individual EU citizens. The document states that almost all regions of the European Community are working towards achieving climate neutrality, but are at different levels of advancement in this process.

A key role in the transformation process is played by the regional or local administration, which is responsible for coordinating and implementing the initiative, usually together with other stakeholders (such as municipalities, businesses, NGOs and civil society). The private sector also plays an important role here—assessed in the content of the publication [66].

The greatest obstacles to achieving climate neutrality were considered to be insufficient citizen involvement, as well as a lack of clear objectives, monitoring systems and experts. The weakness of the initiatives undertaken is also visible in the context of financial dependence on external sources of support.

In April 2019, the agreement on the just transformation of Eastern Wielkopolska was concluded in Poland. As a result of the involvement of local government officials from the region, non-governmental organizations, trade unions and associations of entrepreneurs, working groups were formed, which developed a strategy for the pursuit of climate neutrality [67,68].

In order to replace the energy derived from lignite combustion, in Eastern Wielkopolska, emphasis has been placed on three modern technologies: renewable sources, electromobility and hydrogen technologies.

The Figure 10 shows the replacement of energy from brown coal combustion.

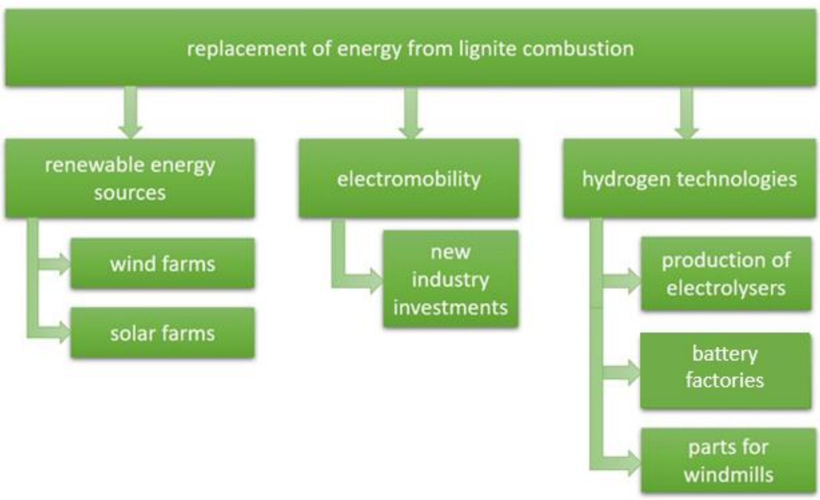

Figure 10. Replacement of energy from lignite combustion [69].

The goals are to reduce CO_2 emissions from energy and heating by 90–95% by 2030, close all mines, and implement climate-neutral public transport by 2040.

The European Commission has published a list of European cities that will participate in the mission for Climate Neutral and Smart Cities by 2030. 12% of the European population lives in selected cities. Additionally, 12 cities from countries associated or potentially associated with the Horizon Europe program (2021–2027) in the field of research and innovation were invited to participate in the mission. Among the selected cities, there are both larger and smaller urban centers—currently located in different places on the road to achieving climate neutrality [70].

As the European Commission explains, European cities play a key role in achieving climate neutrality by 2050, which is the main goal of the European Green Deal. Cities cover only 4% of the EU's land area, but are home to 75% of EU citizens. In addition, cities consume over 65% of the world's energy and are responsible for over 70% of global CO_2 emissions, explains the European Commission. Part of the mission will relate to research and innovation in the field of sustainable mobility, energy efficiency and urban planning, and will also enable the creation of joint initiatives and strengthening cooperation with other EU programs.

The mission of the cities will involve citizens as well as businesses, investors and regional and national authorities, so that by 2030 there are 100 climate-neutral and smart cities in Europe. In addition, the mission aims to "ensure that these cities act as centers of experimentation and innovation to enable all European cities to follow suit by 2050". Thanks to the EU support, the best solutions for climate protection will be sought. As part of the mission of the European Commission, we will create, among others, an ecological and citizen-friendly heating system based on renewable energy. The developed solutions will be able to serve as a model to be used in other Polish and EU cities [71].

6.2. Green Hydrogen in Germany

Green hydrogen is expected to be one of the key factors positively influencing Germany's energy transition. Generating carbon-neutral energy should lead to Germany meeting its climate goals.

In 2020, Germany gained the National Hydrogen Strategy (NWS) award presented by the Ministry of Economy and Energy. Germany has gained recognition for its acknowledgement of the importance of green hydrogen in achieving climate protection and mitigation goals [72].

Being a recognizable country focused on the implementation of the postulates of renewable energy, they have a chance to become a key market in the era of energy transformation. Germany engages in international activities based on improving their energy status [73].

Germany currently generates more than 40% of its electricity from renewable energy sources. Forecasts indicate an upward trend to 80% already by 2050. Green hydrogen plays a fundamental role in the energy efficiency challenge. Green hydrogen is essential in decarbonising the industry [74].

The targeting of hydrogen activities in industrial cases will show an upward trend from over 50 TWh to over 100 TWh already by 2030. The measures taken towards green hydrogen will require large-scale financial investments.

The Figure 11 below shows Hydrogen utilization in Germany.

National Hydrogen Strategy envisages the creation of a generation capacity of 5 GW by 2030 and an additional 5 GW by 2035 and by 2040 at the latest. Government funding programs for companies that implement hydrogen operations are expected in the near future [75].

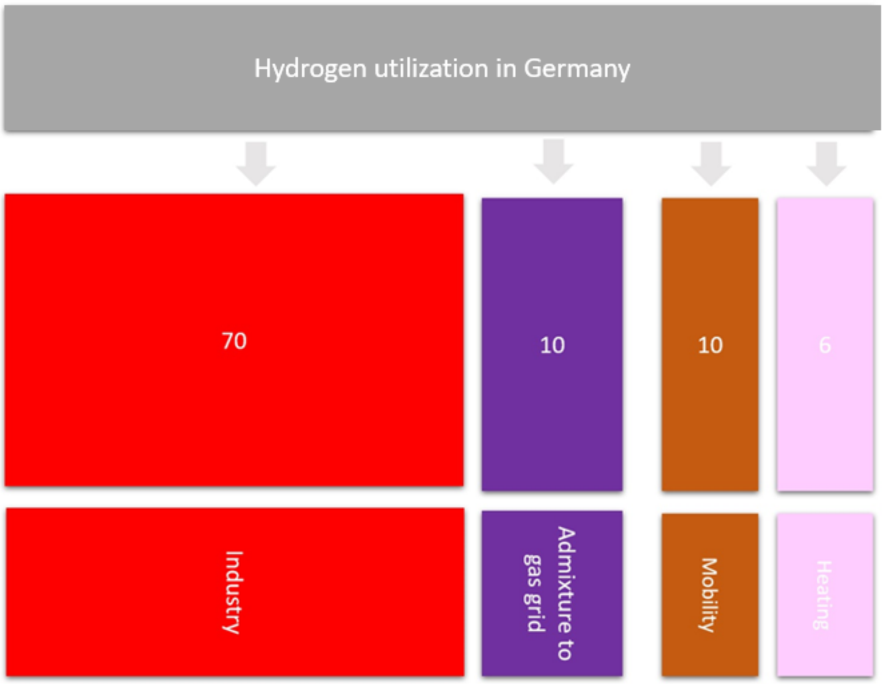

Figure 11. Hydrogen utilization in Germany (in TWh) [75].

Power-to-gas (P2G) technologies will play a fundamental role in Germany's energy transformation. This is due to increased seasonal and geographic fluctuations in energy production as a result of the greater share of energy from renewable sources. Power-to-gas technologies provide a method of dealing with these fluctuations by stabilizing the grid frequency and optimizing grid utilization. Thanks to electrolysis, surplus energy from variable renewable sources can be stored as hydrogen gas in Germany's extensive gas grid. The expansion of P2G facilities throughout Germany is inevitable as the German government aims to meet its climate goals and reduce the primary energy demand in the transport sector [76].

There is investment potential throughout the supply chain: from long-term storage, production and trading to electrolyser production, gas compression and smart gas metering. In Europe, Germany itself has most of the European demonstration projects for fuel cell and hydrogen technology. With internationally recognized certification bodies and a large number of actors and regional and international activities, Germany is developing and setting global technical frameworks and standards for tomorrow.

Hydrogen will play a key role in the energy transition in Germany and Europe. The German government is committed to supporting both the development of hydrogen infrastructure in Germany and throughout Europe, but the German legal framework has yet to fully reflect this commitment. Decarbonising the German energy mix is also costly and the government will want to ensure that the right incentives for investors are created.

Currently, approximately 20 billion standard cubic meters of hydrogen are produced annually in Germany. Only 5% of this is green hydrogen and the remaining 95% is mainly produced from fossil fuels, such as natural gas or coal. Industry players are striving to change this, in particular, by building the required installations (power plants, electrolysis, hydrogen condensers) in the coming years [77].

The Figure 12 below shows the possibilities of using hydrogen in Germany.

In public road and freight transport, hydrogen would also prove to be advantageous over electric vehicles, as the charging times and weight of batteries needed for electric vehicles are not always economically viable.

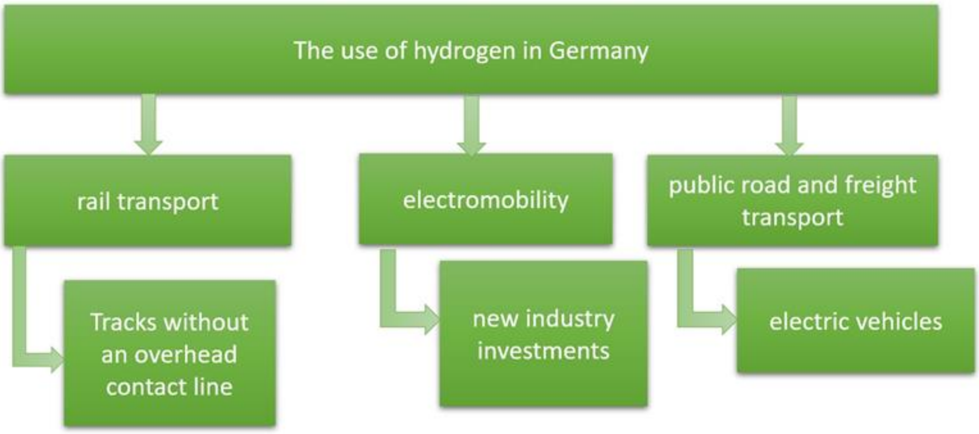

Figure 12. Utilization of hydrogen in Germany [78].

Converting excess green electricity into energy-rich hydrogen and methane, which can be stored and then used to power fuel cells, can help transform energy [79].

The Figure 13 below shows the national hydrogen strategy.

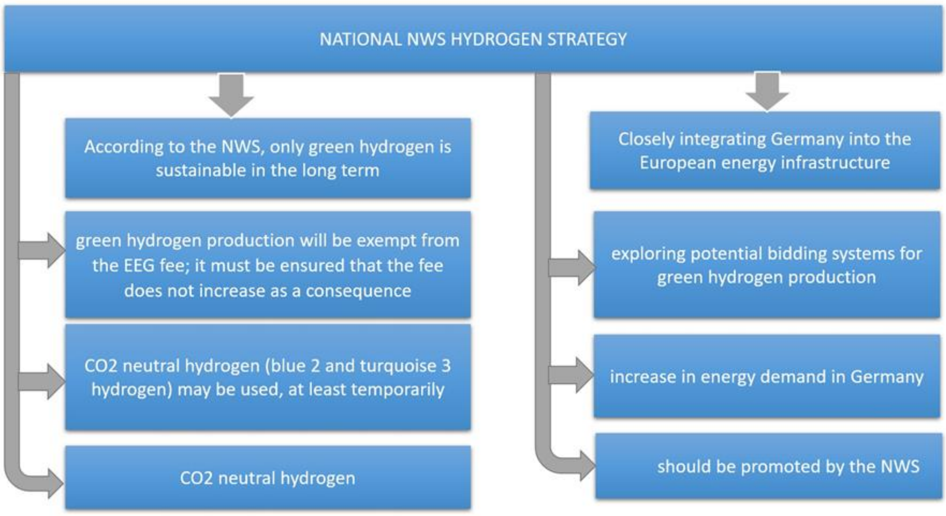

Figure 13. National hydrogen strategy in Germany [80].

Green hydrogen is sustainable in the long term and should, therefore, be promoted. The integration of Germany into the European energy infrastructure, and due to the growing energy demand in Germany, allows the possibility of hydrogen neutrality in terms of CO_2 emissions in blue and turquoise.

By 2030, installations for the production of hydrogen with a total capacity of up to 5 GW are to be built. By 2035, and by 2040 at the latest, 10 GW should be installed.

In 2020, Germany passed a draft act on offshore wind energy, which provides for the possibility of building offshore wind farms that do not require connection to the power grid. Instead, the electricity generated from these offshore wind farms is to be used directly at sea without using the grid, e.g., by operating offshore electrolysis to produce green hydrogen [81].

Although the construction and operation of offshore electrolysers is significantly more expensive compared to onshore facilities, the additional cost is offset by savings in investment costs associated with connecting to the electricity grid. Such electrolysers can also be operated using other facilities, including oil and gas platforms.

The strategy says Germany intends to build 5 gigawatt (GW) industrial hydrogen production facilities by 2030, including the necessary onshore and offshore renewable energy supplies, roughly equivalent to five nuclear power plants or large coal-fired power plants. This is to be increased by another 5 GW by 2035 or by 2040 at the latest.

Germany intends to import large amounts of green hydrogen in the future because the country simply does not have enough space to install the huge amounts of renewable energy needed to produce it [82].

6.3. Scenario German

Hydrogen demand is expected to increases significantly over time between 2020 and 2050. The amount of hydrogen required by 2050 will be slightly less 370 TWh and many times higher than the current demand, 43 TWh.

In 2050, industry and transport with a share of 26% (94 TWh) and 38% (140 TWh) will be among the most important consumers of hydrogen. In 2050, hydrogen will be used in transportation in a wide range of applications, including cars, vans, trucks, trains and buses. Due to the growing demand from cars, vans and trucks, the demand in transportation is especially growing from that side [83].

The year 2025, and from 2035 onwards, will constitute the largest share (approx. 35%) of the total demand for hydrogen.

Total industrial demand will remain stable until 2040, as the existing hydrogen demand for ammonia and methanol will first be shifted to green hydrogen. This will double in 10 years, as the demand in the industrial sector grows due to additional demand in the production of steel and cement and in the process of heat generation [84].

The proportion of hydrogen consumption in the conversion sector in 2050 will be approximately 31%. Hydrogen, here, will be mainly used for conversion in gas turbines and fuel cells. Moreover, in the initial stages of the transformation, hydrogen will be mainly used for the production of syngas, which will account for 30% to 50% of the demand transformation sector in the years until 2030. The use of hydrogen in the construction sector will be small, with a share of 5%, and will be mainly used for condensing boilers, among others, to cover the peak performance of bivalent heat pumps [85].

Figure 14 below shows the development of annual hydrogen demand by sector in the baseline scenario.

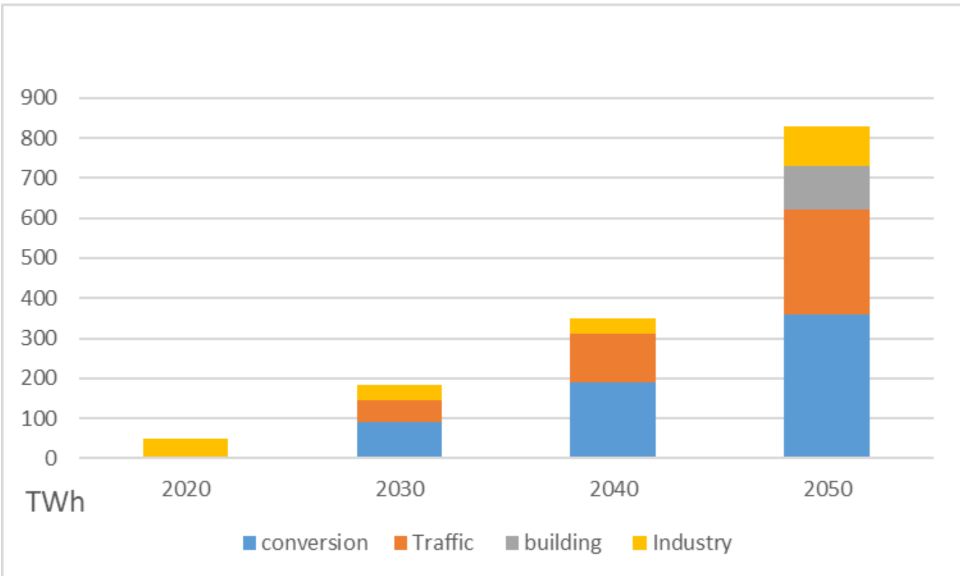

Figure 14. Development of the annual hydrogen demand by sector in the baseline scenario [86].

To cover hydrogen demand by 2030, conventional plants (gray hydrogen or natural gas), electrolysis and imports will be used. Domestic production will increase from 2020 to 2030; it will be driven by electrolysis expansion, while conventional power plants will only be expanded by around 1 GW. The planned electrolysis capacity is reflected in the national hydrogen strategy. The electrolysis expansion will increase in 2040 and 2050, the total production may be around 28 GWe or around 70 GWe.

Over the same period, the importance of conventional power plants will rapidly decline, where by 2050, only currently existing plants will be found, without significant production.

The results of the international hydrogen infrastructure, as well the resulting renewable hydrogen import paths to Germany up to one year, will be clarified in 2050. It is assumed that hydrogen gas could be obtained via pipelines from the Netherlands, while distant imports could be discharged in Germany in the form of liquid hydrogen.

Hydrogen in Germany for 2050 is calculated as 191 TWh or 5.7 MtH2 using the demand-dependent import cost curve. According to the model calculations, this demand is calculated taking into account the global allocation of renewable energy supply of hydrogen from the windy Northern European preferred regions of Iceland, Norway and the British Isles, which are covered with green hydrogen [87].

7. Survey Research Analysis

The following charts inclusively show the data obtained from the record, prepared on the basis of a questionnaire by natural persons and entrepreneurs.

Most of the surveyed employees are women (48% of responses) and men (2% less than women) in the age range of 36 to 45 years. Later, women almost proportionately ranged in age from 18 to 25 and from 26 to 35 years old. For men, the age structure from 18 to 25 is almost two times smaller than the age group from 26–35 (Figures 15–17).

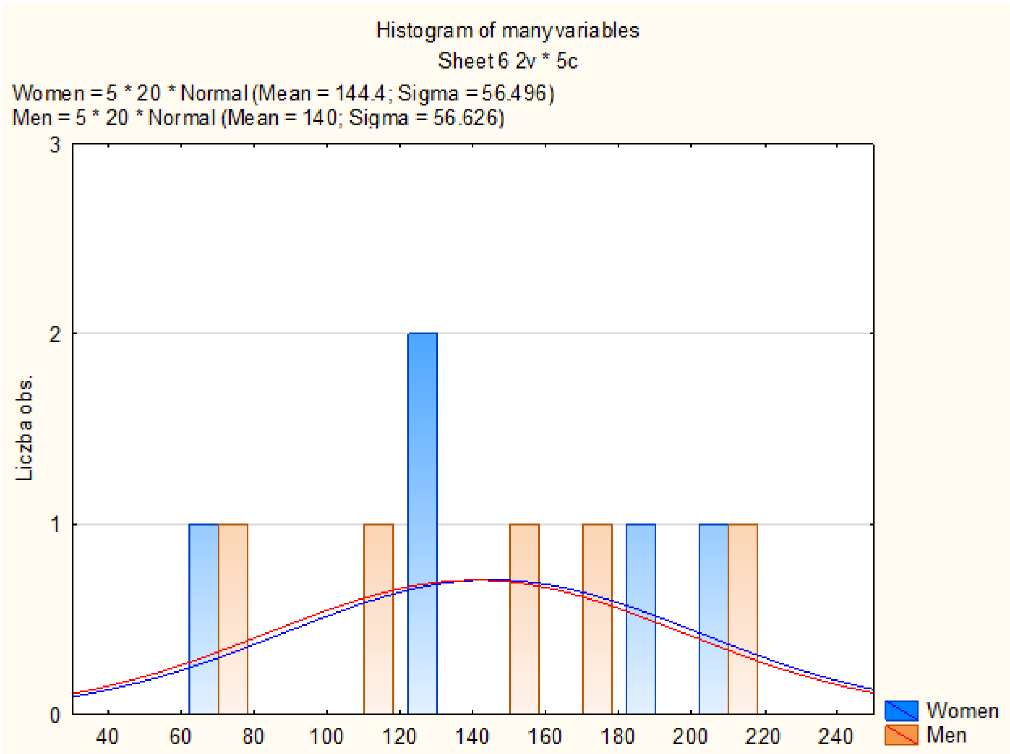

Figure 15. Employee structure by gender.

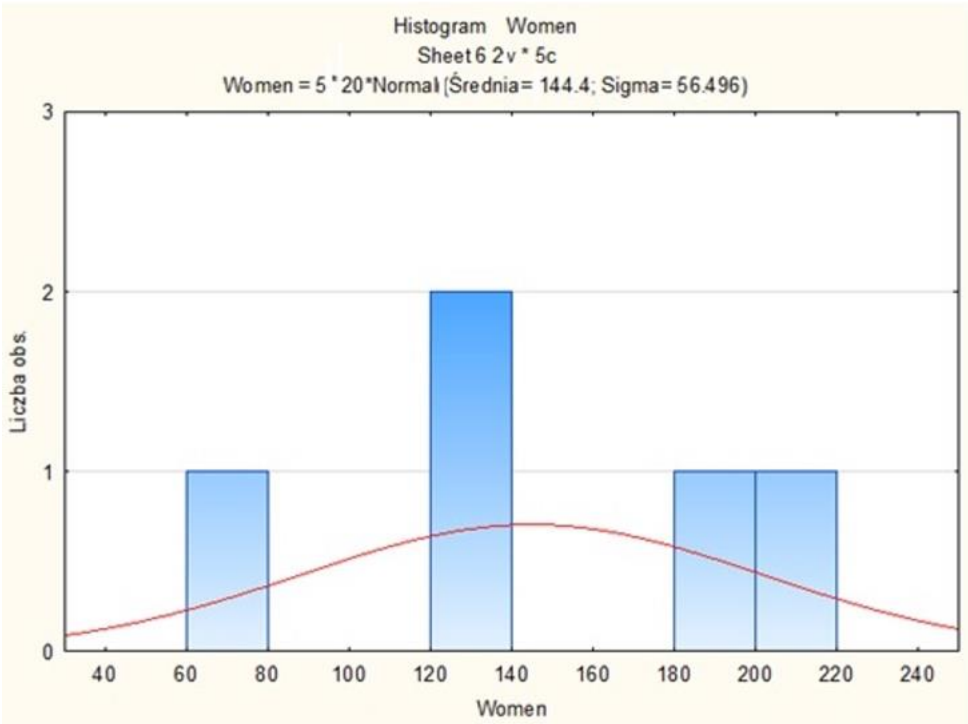

Figure 16. Structure of employees by women.

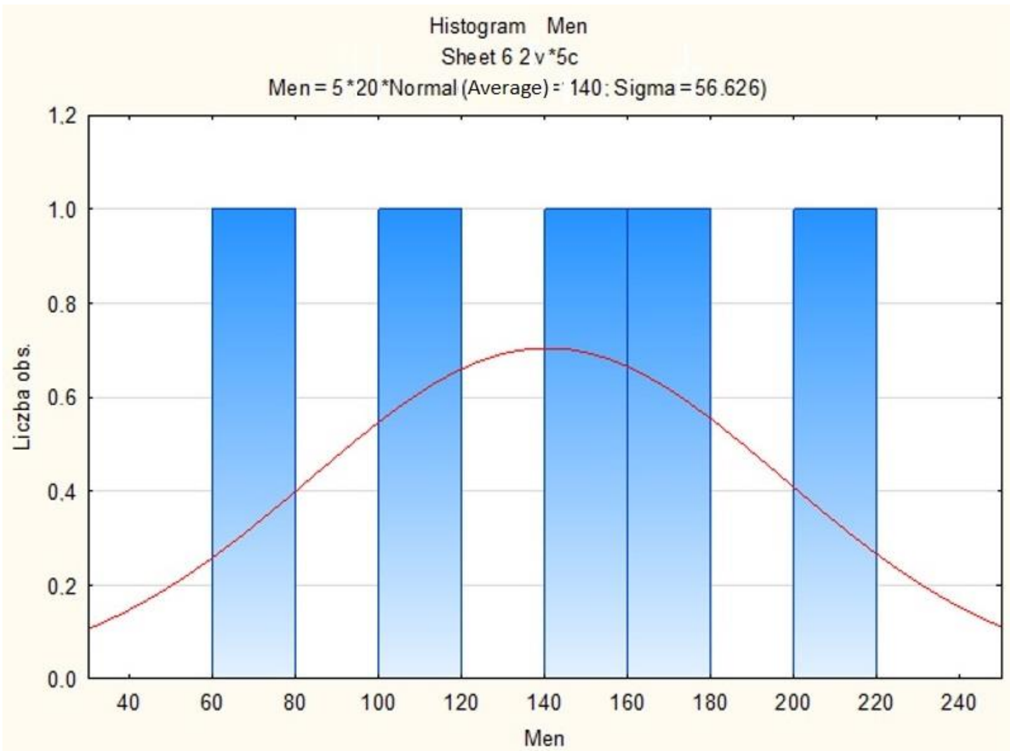

Figure 17. Structure of employees by men.

The research sample consists of both natural persons and entrepreneurs, and includes both women and men. There are almost 10% more people qualified as natural persons (in relation to women to men). There are slightly more than 15% more entrepreneurs (men) than entrepreneurs (women) (Figures 18 and 19).

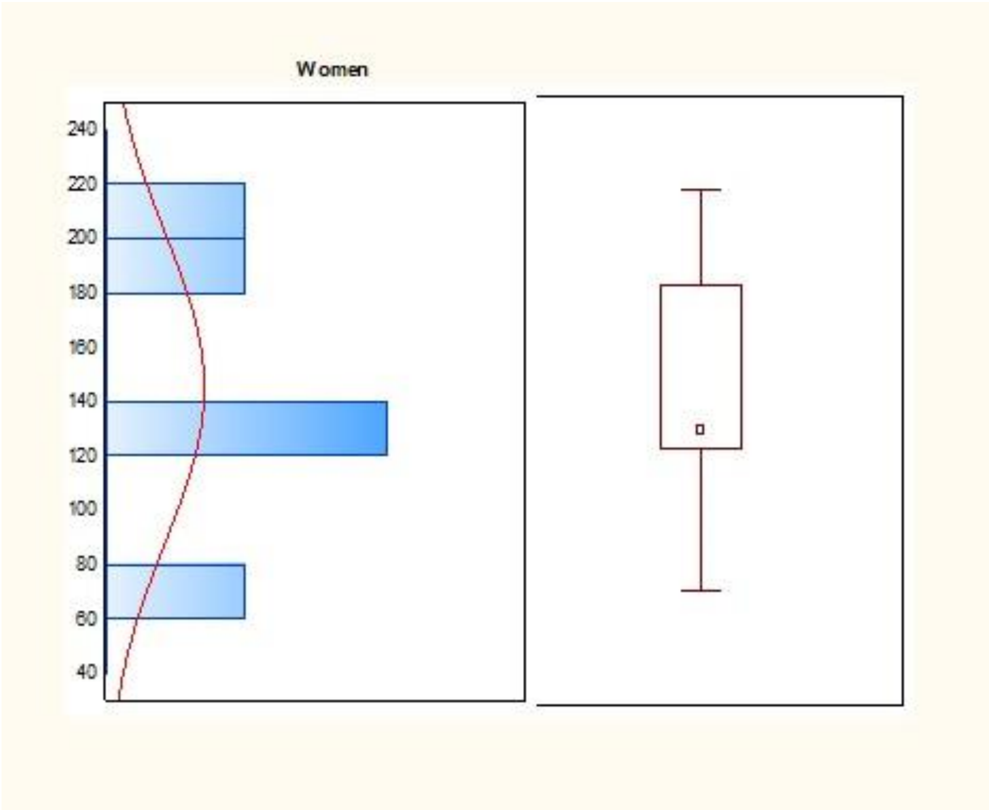

Figure 18. Employee structure by gender and performance data.

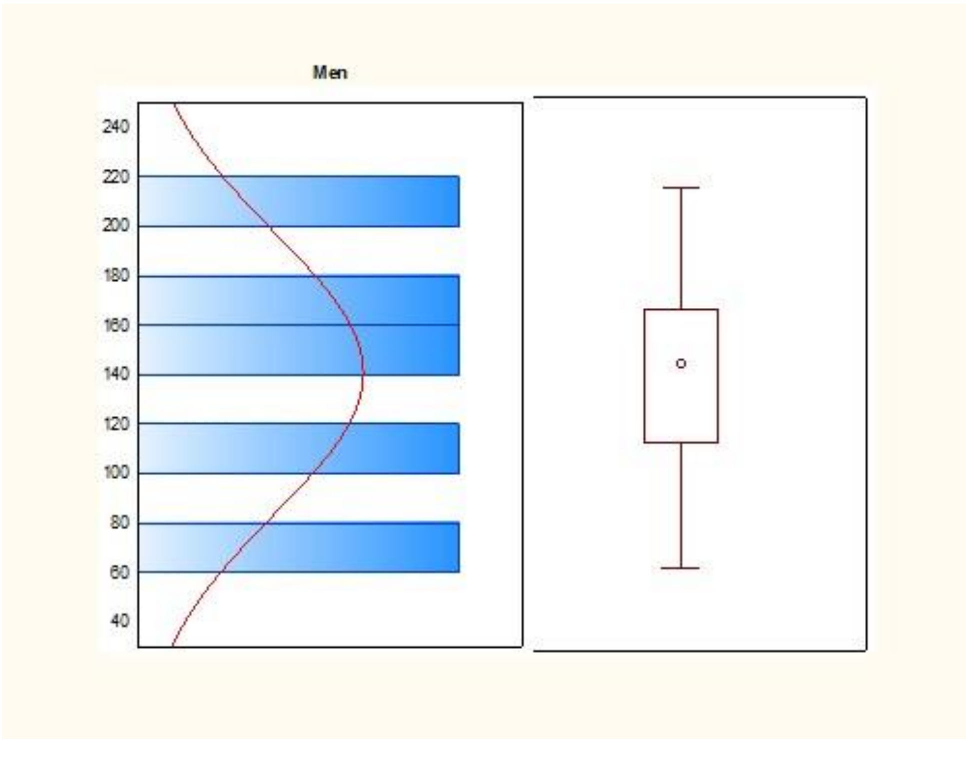

Figure 19. Employee structure by gender and performance data.

There was no significant correlation between women's education and their age, nor between men's education and age. The comparison of all variables influencing individual parameters significantly included in the specification shows the similarity of the results (final), without significant statistical differences (Table 2).

Table 2. Result analysis (Figures 18 and 19).

N	5	5
Average	144	140
Median	129	144
Slightly	71.00	63.00
Maximal	217	214
25%	123	113
75%	182	166
Variance	3192	3207
Standard deviation	56.50	56.63
Standard error	25.27	25.31
Skewness	0.0622	−0.122
Kurtosis	−0.752	0.0396
Confidentiality o.s		
Bottom	33.85	33.93
Top	162	163
Average confidentiality		
Bottom	74.25	69.69
Top	215	210

The research sample consists of both natural persons and entrepreneurs, which includes both women and men. The structure of the participation of entrepreneurs in the study indicates the correct selection for the research sample, as does the structure of natural persons participating in the study (Figures 20 and 21).

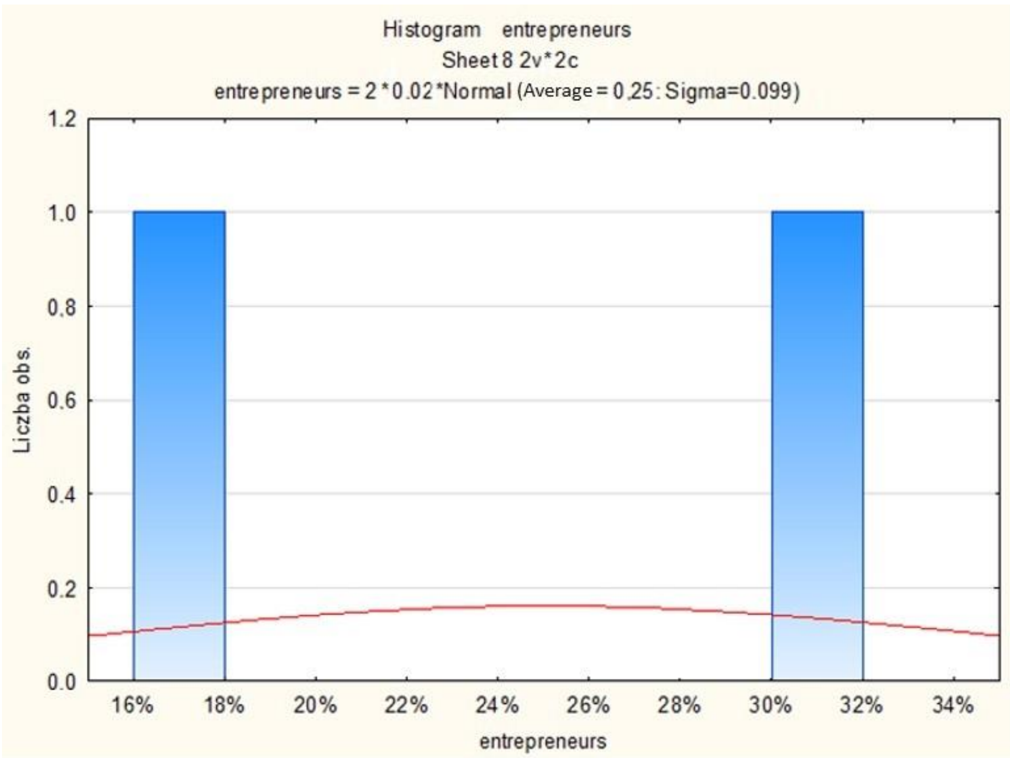

Figure 20. Structure of the participation of entrepreneurs in the survey.

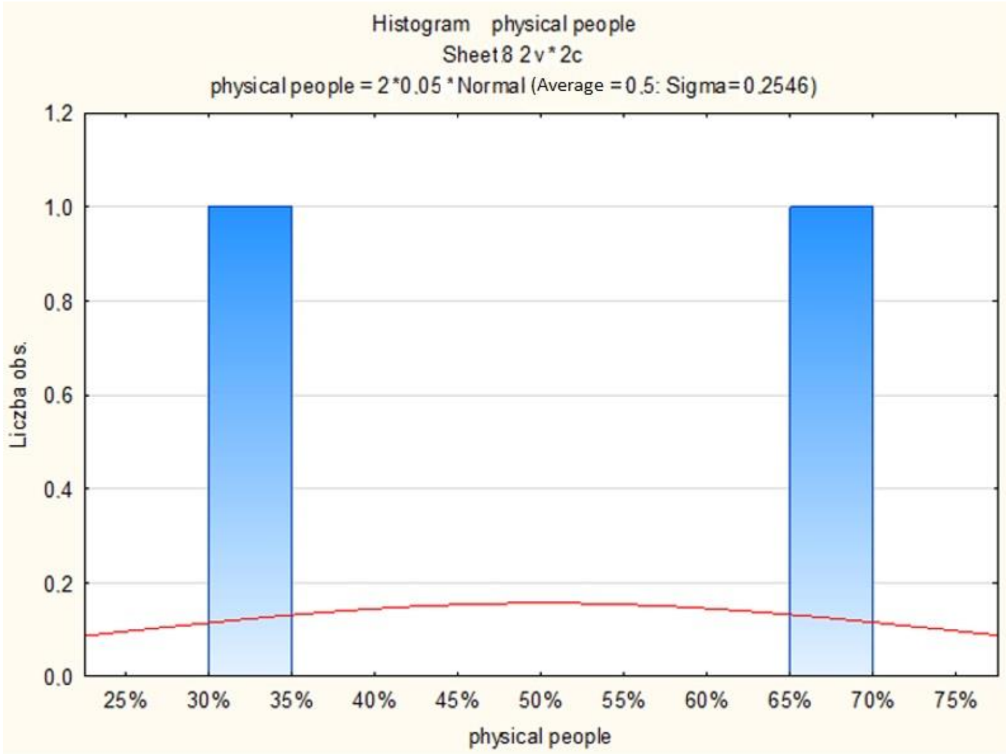

Figure 21. Structure of the participation of physical people in the survey.

By making an analysis on the basis of a contour chart, an analysis of Poland's chances of meeting the hydrogen assumptions was made (Figure 22).

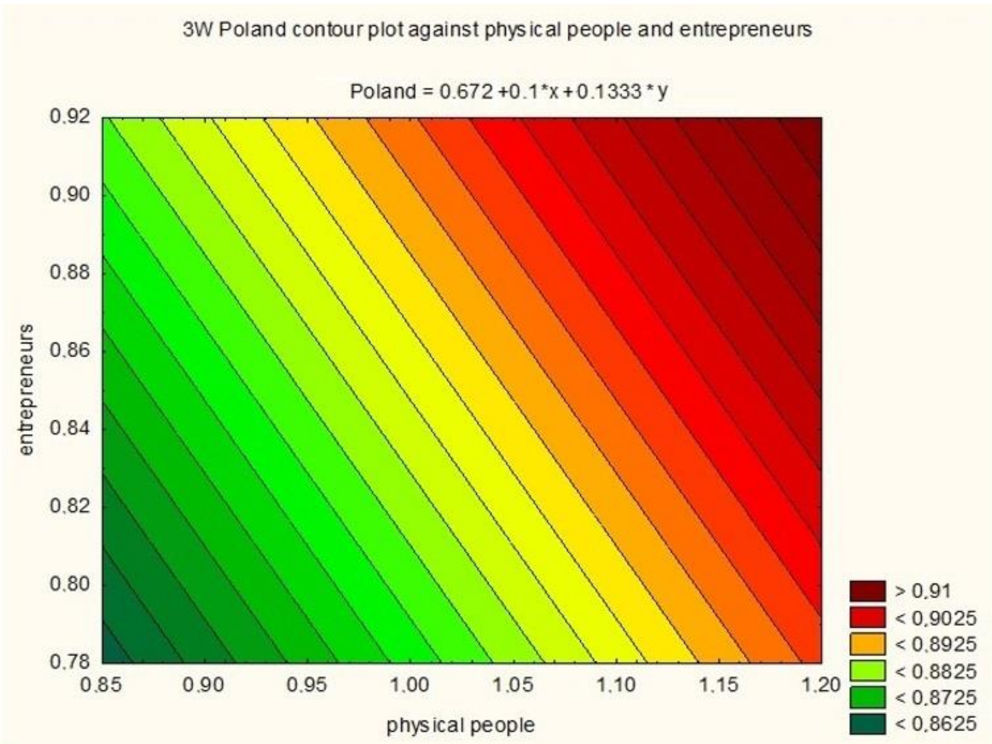

Figure 22. Contour chart verifying Poland's chances of meeting the hydrogen assumptions.

Poland's chances of meeting the hydrogen targets are less perceived. Entrepreneurs have better chances than natural persons (who are not entrepreneurs).

The chart below presents the ratio of the difference.

By making an analysis on the basis of a contour plot, an analysis of Germany's chances of meeting the hydrogen assumptions was made (Figure 23).

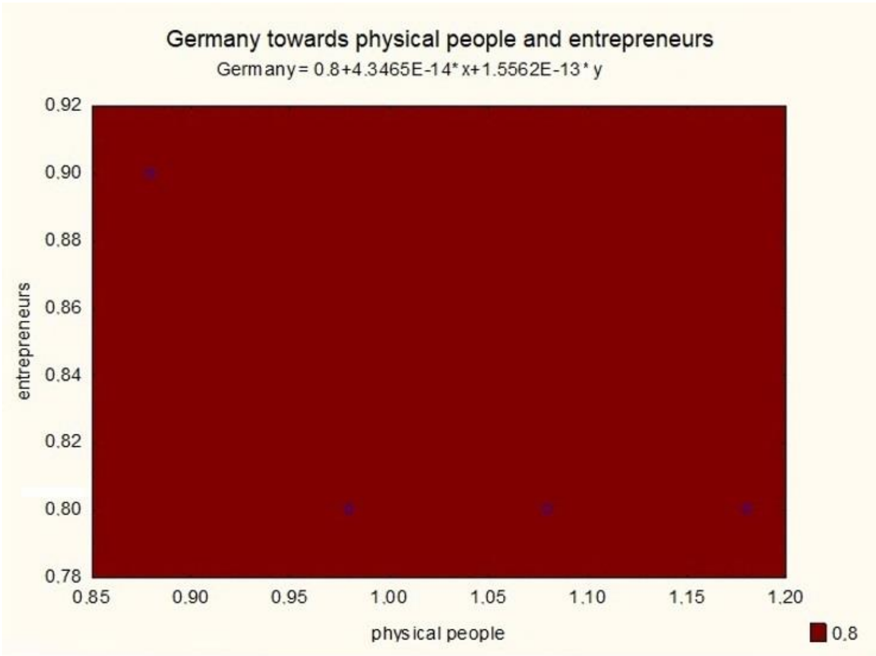

Figure 23. Contour chart to verify Germany's chances of achieving its assumptions.

Hydrogen

An analysis of the chances of Germany to implement the hydrogen assumptions was made by analyzing the contour chart. Opportunities, both in the opinion of individuals and entrepreneurs, indicate high opportunities (Figure 24).

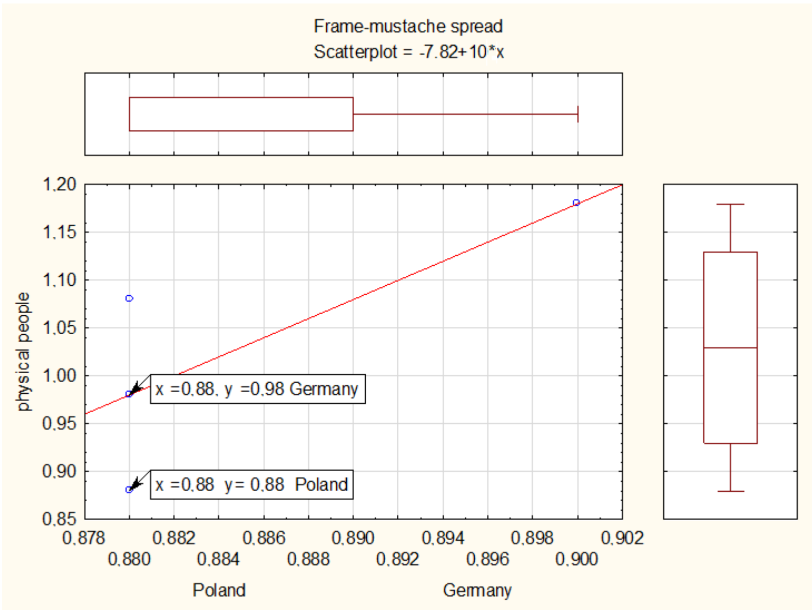

Figure 24. Chart showing the effectiveness of the implementation of the hydrogen assumptions in Poland and Germany based on the opinions of the respondents.

In the opinion of entrepreneurs, Poland has the best chance for obtaining hydrogen assumptions, but it is much smaller than in Germany (Figures 25 and 26).

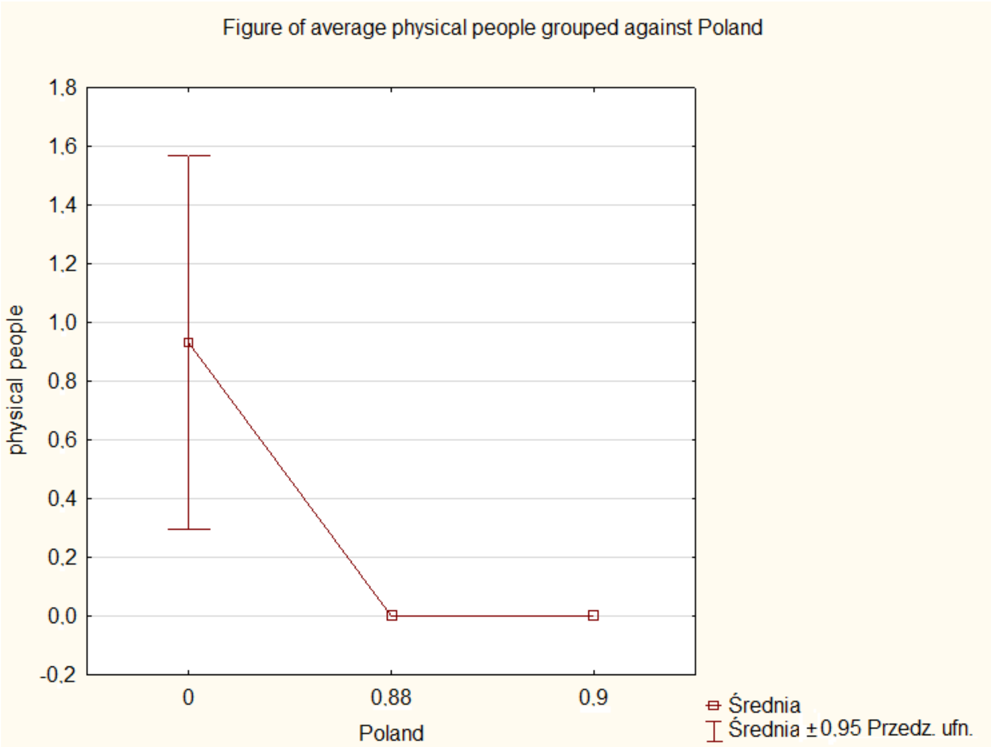

Figure 25. Poland in the opinion of entrepreneurs (hydrogen activities).

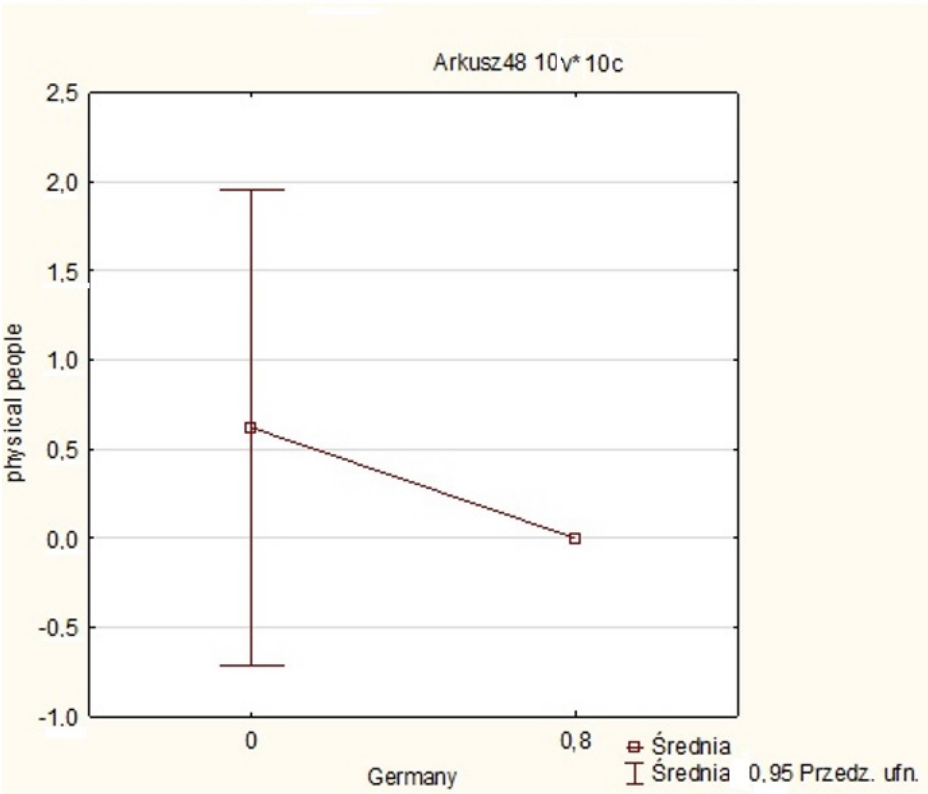

Figure 26. German in the opinion of entrepreneurs (hydrogen activities).

8. Discussion and Conclusions

The use of hydrogen exists in various sectors in Poland and Germany. Hydrogen can be used in industry, transport, decarbonisation of the Polish steel industry and as one of the low-emission alternatives to the existing coal applications in this sector. Limiting climate change requires efforts on a global scale from all countries of the world. There will be significant economic benefits brought about by stimulating the development of new technologies to deal with climate change.

The scenarios indicate an increasing demand for industrial hydrogen in the future. The key is to replace gray hydrogen with green, and to promote the conversion of industrial processes that create additional hydrogen demand. About half of the currently sought hydrogen will be used in industrial settings in the future.

A necessary condition for the development of a green hydrogen economy is access to adequate installed capacity in renewable energy.

Germany will become the market leader in the energy transformation era in the coming years. Poland's chances of meeting the hydrogen assumptions are less perceived by individuals compared to enterprises.

Germany's likelihood of meeting the hydrogen targets, both in the opinion of private individuals and entrepreneurs, shows great opportunities.

According to entrepreneurs, Poland has a high chance for achieving the hydrogen assumptions, but much less than Germany.

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