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ACTIVITY OF PATENTS IN FUEL CELLS AND HYDROGEN PRODUCTION IN THE CONTEXT OF PASSENGER CAR FLEET IN THE V4 COUNTRIES

Abstract. The hydrogen market in the world today is capable ovule and empirical evidence on activity of patents in fuel cells and hydrogen production is limited so far. Patent applications in zero-emission mobility in the aspect of fuel cells include: DAFC/DMFC&DMFC, PEMFC, SOFC, AFC, PAFC. As for the patents relating to the hydrogen production, they concern low carbon, electrolysis and inorganic. The purpose of the study was to investigate certain aspects of the activity of patents in fuel cells and hydrogen production in the context of passenger car fleet in the Visegrad group (V4) countries and to explore the relationship between patent registrations and GDP per capita in V4. The research area relates to the answer to the question of whether a country's involvement in zero-emission patent activity (patents in fuel cells and hydrogen production) could contribute to the renewal of the country's passenger car fleet. The theses were formulated as follows: 1) activity of patents in fuel cells and hydrogen production in the V4 countries doesn't depend on the car fleet in these countries, 2) the level of GDP per capita in the V4 countries is not followed by the number of patents registrations in hydrogen technology, 3) the highest patent activity in fuel cells and hydrogen production doesn't mean that the car fleet in these country will be zero-emission in coming years. The method used in this article is a comparative analysis, but also the relationships between patent registrations, GDP per capita and passenger car fleet in V4 are considered

Keywords: patents; zero-emission mobility, fuel cells, hydrogen production, V4, passenger car fleet.

Introduction

Innovation in zero-emission mobility and alternatively-powered passenger cars is of particular importance. Patents, and innovations as a result of them, in fuel cell and hydrogen technology can develop a zero-emission public transportation solution. Hydrogen and fuel cell technologies are crucial in specifications for the safe and efficient use and production of hydrogen. Transport exhaust emissions are among the largest single sources of air pollution. Important role, in line with the European Green Deal, the European Climate Law (Hydrogen Europe..., 2021), is played by zero-emission passenger cars. As hydrogen could be the future of transport fuel, hydrogen technology patents could be essential.

In the pursuit of low-carbon or zero-emission mobility alternatively-powered vehicles (APVs) play a significant role (Garrett Motion, 2020). APVs include electrically-chargeable vehicles (ECVs), fuel cell electric vehicles (FCEVs), gas-electric hybrids (HEVs), plug-in hybrid electric vehicles (PHEV), vehicles battery electric vehicles (BEVs), flexible-fuel vehicles (FFVs) and natural gas vehicles (NGV), that use CNG or LNG and shouldn't be confused with LPG as alternative fuel (ACEA, Making the transition..., 2021). Patents concerning low-carbon energy technologies play an important role in forecasting new technology (EPO and OECD/IEA, 2021), especially when it comes to zero-emission mobility.

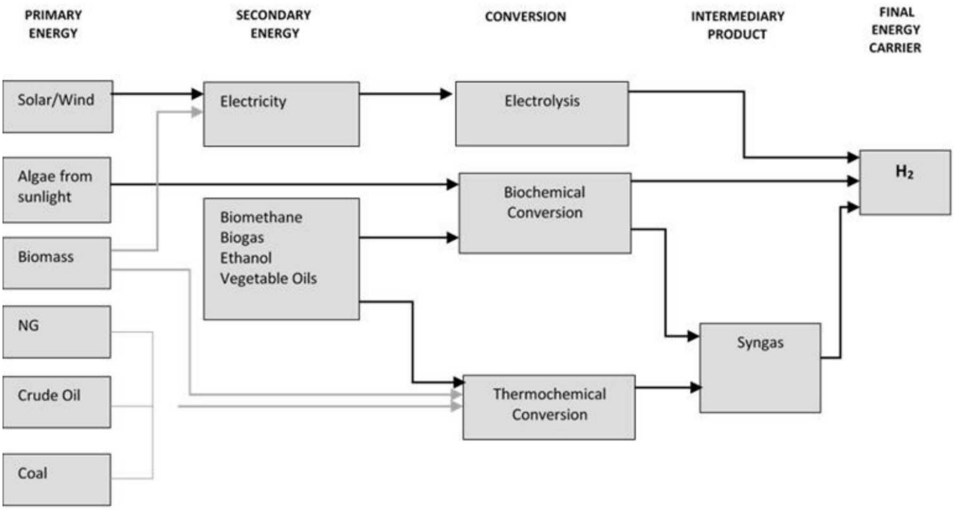
1. Literature review

1.1. The role of hydrogen in zero-emission mobility

The global movement towards low-carbon economy and zero-emission mobility has started. These activities include the deployment of alternative energy towards zero-emission vehicles and increase in the efficiency of the transport (European Commission, 2016). The use of low-emission alternative energy, such as hydrogen is crucial in this process of energy transformation. Hydrogen as a kind of clean energy (Pudukudy et al., 2014) could be used in fuel cells, but this technology is still new and ipso facto expensive (Castonguay, 2009). At the same time hydrogen is pivotal to achieve zero-emission mobility. Hydrogen can be used to power cars and is generated from several renewable sources through different conversion techniques like electrolysis, biochemical and thermochemical conversion, as it is also given in the next figure 1.

Figure 1

Hydrogen production



Source: Adolf et al., 2021; Pangsy-Kania, Flouros, 2021.

Hydrogen is renewable, highly efficient and produces no pollution. But next to the benefits it also has disadvantages. From the economical point of view, the production is expensive and requires expensive hydrogen infrastructure (Wen, He, 2018). The problem is achieving acceptable producing cost of the hydrogen, and it should be possible by 2030 (Staffell et al., 2019). Hydrogen energy will certainly be important in the energy transition, especially in the context of the development of mobility and electricity supply. To this end, it will be necessary to develop cheap, fast and efficient methods for the production and the storage (NREL, 2019). As a side note, hydrogen could be used also in industry and at heat homes. Benefits of hydrogen need holistic consideration in hydrogen supply chain (The Royal Society, 2018).

The hydrogen market in the world today is capable ovule. To the most advanced countries on the way to the "hydrogen economy" include, among others United States, Japan, China, Germany, and Australia. A similar situation applies to the market for powered cars hydrogen fuel cells (Dorociak, Tomecki, 2019). Hydrogen-powered transport can be a rescue to reduce gas emissions and reduce smog. For customers, the barrier to the widespread introduction of such cars is their price and the lack of charging stations (U.S. Energy Information Administration, 2021).

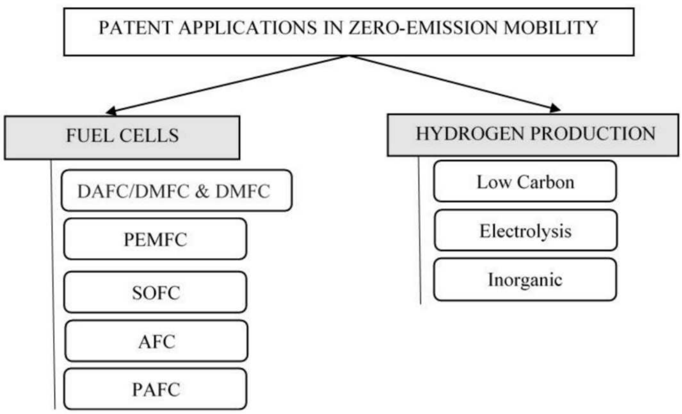
Developing a clean hydrogen economy will be instrumental in making the Fit for 55 Package (Hydrogen Europe, 2021). The use of hydrogen in energy systems is very complex (Hanley et al., 2018). In ambitious roadmap aims, to achieve carbon neutrality by 2050, hydrogen has to be taken into account. Renewable "green" hydrogen could be a future transport fuel toward a low-carbon economy (Pangsy-Kania, Flouros, 2021). In the initiatory stage of new technology, the results of research are visible in the activity of patents (Wen, He, 2018). It can be concluded, that patents in fuel cells and hydrogen production set directions in innovation passenger car fleet.

1.2. Patents by technology – fuel cells and hydrogen production

Patents are path for studying technology developments. However sometimes innovations may occur outside of the patent's system (Cohen et al., 2000). Patent applications concerning transition to zero-emission mobility (figure 2) provide new trends in economy. Technological development in hydrogen economy are reflected in patents (Sinigaglia et al., 2019). Patent applications in zero-emission mobility can be divided into technology concerning fuel cells and hydrogen production.

Figure 2

Patent applications is zero-emission mobility



Source: own elaboration based on FCHO Fuel Cells & Hydrogen Observatory, 2020.

Fuel cells for vehicles remain one of the most high-profile applications of fuel cells (Moore et al., 2021). Hydrogen fuel and an oxidant, by a chemical reaction at the electrodes, are converted into electricity and this way they are generating electric power for vehicles and also for other electric devices (Busby, Nguyen, 2010; Garrison, 2012). Vehicles with hydrogen fuel cells emit steam while they are running, and this way zero or near-zero-emission of harmful exhaust gas (JHFC..., 2015).

Three groups of technologies play a significant role in hydrogen production in the context of zero-emission mobility: low carbon, electrolysis and inorganic. Patent applications in zero-emission mobility in the aspect of fuel cells include: DAFC/DMFC&DMFC (Zhao, Chen, 2009; Scott, Xing, 2012), PEMFC (Weber et al., 2012), SOFC (Sanson, Gondolini, 2021), AFC (Gulzow, Schulze, 2008; Murahashi, 2009), PAFC (Weber et al., 2012; Sudhakar et al., 2018). As the article concerns the patent activity in the V4 countries a short description of the Visegrad Group was presented below.

2. Passenger car fleet in the V4 countries

2.1. Brief characteristics of V4 countries

All the activities of the Visegrad Group (Visegrad Four or simply V4), which includes Poland, the Czech Republic, Hungary, and the Slovak Republic are aimed at strengthening stability in the Central European region (Visegrad Group, 2018). The Visegrad countries' entranced into the EU in 2004. The population of the Visegrad Group countries is almost 64 million citizens, and the total area is 533,613 square kilometers. Almost 38 m. citizens live in Poland, almost 11 m. in the Czech Republic, almost 10 m. in Hungary, and 5.5 m. in the Slovak Republic. Czech Republic has the highest GDP per capita. In Poland, Hungary, and the Slovak Republic it is about USD 34,000 PPP (table 1).

Table 1

Main indicators of the V4 countries, 2019

	Total population (m.)	Total area (km²)	GDP (current USD, billions)	GDP per capita (PPP USD)	GDP growth 2019 (annual %)	Unemployment (%)	Inflation (%)	Public debt (% GDP)
Poland	37.97	312,683	595.9	34,431.2	4.5	2.3	2.9	46.0
Czech Republic	10.63	78,867	250.7	43,299.6	2.3	2.0	2.9	30.2
Hungary	9.78	93,028	163.5	34,507.1	4.6	3.4	3.4	66.3
Slovak Republic	5.45	49,035	105.1	34,066.9	2.3	5.8	2.8	48.0

Source: own elaboration based on The World Bank, 2020; International Monetary Fund, 2020.

The highest share of GDP occurs in the Slovak Republic, and the lowest in the case of Poland. The same is true with merchandise trade as a share of GDP (Slovak Republic 176%, Poland 91%). In all analyzed countries, GDP growth in 2019 was lower than in 2018. This was a sign of the beginning of the crisis connected with the economic cycle, which in 2020 was aggravated by the announcement of the coronavirus pandemic [Blake, Wadhwa, 2020].

Among the Visegrad Group countries, the highest unemployment rate is in the Slovak Republic (5.8%), and the lowest is in the Czech Republic (2.0%). Inflation in all the V4 countries reaches around 2%. The highest public debt is observed in Hungary (66.3%) and the lowest in the Czech Republic (30.2%) (Pangsy-Kania, 2021). Only the Slovak Republic has the euro, the rest of the V4 countries have national currencies.

In all V4 countries there are 36.5 m. passenger cars (table 2). Number of cars per capita is the highest in Hungary – one car is for 2.6 inhabitants (it means 0.39 cars per capita), and the lowest rate is in Poland (1.6 inhabitants per one car, that is 0.64 cars per capita).

Table 2

Total number of passenger cars in the V4 countries

	Total number of cars	Number of cars per capita	Number of inhabitants per one car
Poland	24,360,166	0.64	1.56
Czech Republic	5,924,995	0.56	1.79
Hungary	3,812,013	0.39	2.57
Slovak Republic	2,393,577	0.44	2.28

Source: own elaboration based on Eurostat, 2021.

The largest car fleet is therefore in Poland, then in the Czech Republic, the Slovak Republic and Hungary. It should be emphasized that the role of the automotive industry in the V4 countries is much greater than in the other EU countries and is of key importance for the development of these countries' economies (Frelichowski, 2019). Simultaneously, the presence of low-emission vehicles in all V4 countries is low, which may be surprising given the extent to which the economies of all four countries are dependent on the automotive industry. Poland is distinguished by a large share of the automotive component production sector, while in the Czech Republic, the Slovak Republic and Hungary the most important role is played by vehicle and main component factories (engines) (Forum Energii..., 2021). The countries of Visegrad Group also share some structural problems, such as low purchasing power and low R&D expenditure. Moreover, Poland and the Czech Republic have ambitious plans to produce their own electric cars (Zgut et al., 2019) Now, let's analyze the passenger car fleet in the Visegrad Group countries.

2.2. Passenger car fleet

The European Union counts 569 passenger cars per 1.000 inhabitants (Gourtsilidou, 2021). In reference to the data contained in the table 2, the highest car density among the V4 countries is in Poland – 642 passenger cars per 1,000 inhabitants, and Hungary, where half of all households don't have an own car, has the lowest – 390 passenger cars per 1,000 inhabitants. In the Slovak Republic the passenger car density counts 439 cars per 1,000 people and in the Czech Republic it is 557 cars.

In the aspect of new registered passenger cars in V4 (table 3), as in all countries in 2020 compared to 2019, declines were recorded – as a result of the announcement of the Covid pandemic. The largest decrease was recorded in Croatia (– 42.8%), and the smallest was recorded in Norway (– 0.7%).

Table 3

New registered cars in the V4

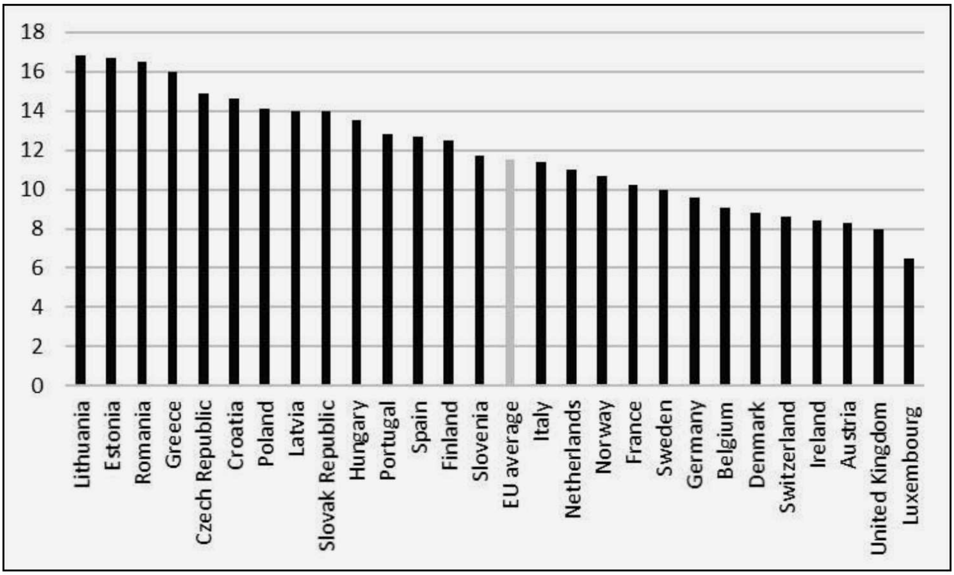
	2020	2019	Change (%)
Poland	428,347	555,598	– 22.9
Czech Republic	202,971	249,915	– 18.8
Hungary	128,021	157,900	– 18.9
Slovak Republic	76,305	101,568	– 24.9

Source: own elaboration based on Finnish Information Centre of Automobile Sector, New registered cars..., 2021.

The oldest passenger car fleet is in Lithuania, Estonia and Romania (more than 16 years), while Luxembourg, United Kingdom, Austria, Ireland, Switzerland and Denmark have the youngest (less than 9 years). Passenger cars are now on average 11.5 years old in the European Union. The newest cars are in Luxembourg (6.5 years) (ACEA, Average age of..., 2021).

Average age of passenger cars in the V4 countries are as follows (from the youngest to the oldest): Hungary – 13.5 years, the Slovak Republic – 14.0 years, Poland – 14.1 years, the Czech Republic – 14.9 years. If we analyze the passenger car fleet according to the age of cars (table 4), it turns out that the oldest fleet is in Poland and Hungary. However, data for the Slovak Republic are lacking. 77.97% of total passenger cars in Poland counts more than 10 years. In Hungary it is 72.62%. At the same time the smallest share of the newest cars can be found in Poland – only 6% of total passenger car fleet have less than 2 years. Cars by age between 2 and 5 years represent 10% of total passenger vehicles in the Czech Republic, in Hungary 7.19%, and in Poland 5.43%. The share of cars aged 5–10 is similar in Poland and Hungary (about 11%), while in the Czech Republic it is 16.78%.

Figure 3
Average age (in years) of passenger cars in the V4 countries compared to some European countries, 2019



Source: own elaboration based on ACEA, Average age of..., 2021; Finnish Information Centre of Automobile Sector, Average age of..., 2021.

Table 4
Passenger car fleet in the V4 countries by age of cars, % share, 2019

	Number of cars by age				
	0–2 years	2–5 years	5–10 years	10–20 years	over 20 years
Hungary	8.60	7.19	11.59	57.67	14.95
Slovak Republic	data not available				
Poland	5.80	5.43	10.80	40.08	37.89
Czech Republic	11.84	10.00	16.78	61.38	0.00

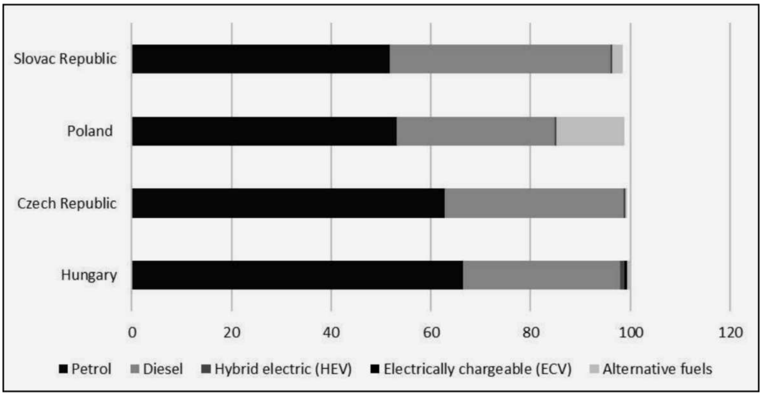
Source: own elaboration based on Eurostat, 2021.

The dominant fuels are still petroleum and diesel. Hungary has the largest share of gasoline – 66.4% of the total and the Slovak Republic has the largest share of diesel (44.3%). At the same time the Slovak Republic has the lowest share of petroleum among other V4 countries (51.7%). The share of hybrid electric (HEV) and electrically chargeable (ECV), which include battery electric and plug-in hybrid, is negligible in all analyzed countries (ACEA, Vehicles in use..., 2021).

Data concerning vehicle passenger car fleet in the V4 countries from the point of view of fuel type was presented in figure 4. Alternatively-powered cars exceed just 4.6% of the total EU car fleet (ACEA, Passenger car fleet..., 2021). In Poland it is 15.2%, in the Slovak Republic 3.9%, in Hungary 2.2%, in the Czech Republic 1.3%. Surprising is the high share of alternatively fueled cars in Poland. It must be underlined that 13.6% of passenger car fleet are LPG fueled. No country in the EU has such a high share of LPG in vehicles in use, by fuel type. The average of the EU is 0.1%. In the Czech Republic LPG as fuel of passenger cars counts 0.1%, in Hungary 0.7% and in the Slovak Republic 2.0%.

Figure 4

Passenger cars in use, by fuel type, % share, 2019



Source: own elaboration based on ACEA, Passenger car fleet..., 2021.

On Europe's roads only 0.8% of all cars are hybrid electric, while in Hungary it is 1.0%, in the Slovak Republic 0.4%, and both in Poland and the Czech Republic each account for only 0.3% of the total. Battery electric cars count 0.2% of all passenger car fleet in Hungary, in the Slovak Republic 0.1%, in Poland 0.0% and in the Czech Republic 0.0%. When it comes to plug-in hybrid powered cars – in Hungary it is 0.2% of all passenger car fleet, in Poland, the Czech Republic and the Slovak Republic it is 0.0%. But 0.0% does not mean that there are no battery electric or plug-in hybrid cars in these countries at all. Although the share of electric cars in the fleet is growing month by month, but in general statistics it is still a small percentage. For example, by the end of April 2021, 25,438 electric cars were registered in Poland, of which 11,761 were battery electric (46.2% of ECV), and 13,677 were plug-in hybrids (53.8% of ECV). Although the pace of growth of the electric car segment is very dynamic, but the figures themselves are not particularly impressive – they are still small (below 1% of new car registrations).

It should be assumed that because the majority of the passenger car fleet are over 10 years old, in the coming years they will not be replaced so quickly with battery electric or plug-in hybrid cars, and even more so with hydrogen-powered ones, because the main problem is the low income of inhabitants in the V4 countries vs. high price of innovative cars and poorly developed charging infrastructure.

For comparison, almost 48% of all new cars registered in the EU run on petrol. Diesel accounts 28%. Hybrids account for 11.9%, while 5.4% battery electric and 5.1% plug-in hybrids, of total car sales. There is a visible growing trend in the use of "new fuels" [ACEA, Passenger car fleet..., 2021; ACEA, Fuel types of new passenger cars..., 2021; ACEA, Fuel types of new cars..., 2021; OICA, 2021]. Sweden represents a market share of 32.2% of all electric car in the EU, Netherlands: 25%, Finland: 18.1%, Denmark: 16.4%, Germany: 13.5% [ACEA, Interactive map..., 2021]. In Poland, the Czech Republic, the Slovak Republic and Hungary, electromobility is at an early stage of development. In the last three years, however, the Visegrad Group countries have recorded a stable and dynamic growth in both the number of electric vehicles used and their charging points [Mizak, 2021], although, as it was mentioned before, in the statistics it is still not much.

3. Materials and Methods

Patents are monopoly rights granted by Patent Offices in respect of inventions which are new, inventive and industrially applicable. For many inventions patents are the only source of published technical information relating to the underlying principles upon which an invention is founded. The universally accepted patent classification system is the International Patent Classification (IPC). During the process of seeking granted patent rights, the disclosed invention is assessed by patent examiners (Moore et al., 2021).

Patent data used in this article was obtained from Fuel Cell and Hydrogen Observatory (FCHO, 2021). Raw data was extracted from the PatBase database on 15–17 February 2021 by project partner HGF. Global patent activity data was obtained from the World Intellectual Property Organization (WIPO). The global data on patents for the period 2014–2020 provides an indication of the evolution of research and development activities in the fuel cells sector, as well as of hydrogen deployment and comparable technology patent applications. Patent applications for mobile fuel cells out-pace those for stationary and portable fuel cells. Also data for comparable technologies are included (batteries, battery accumulators, alternative fuel sources) (FCHO, 2021).

The number of published PCT applications concerning renewable energy is divided into four sectors: solar power, wind energy, geothermal and fuel cells (Nurton, 2020). This article examines the state of recent patent activity in zero-emission mobility in Poland, the Czech Republic, Hungary and the Slovak Republic. Patents were divided into two main groups: fuel cells and hydrogen production. The method used in the work is a comparative analysis, but also the relationships between patent registrations, GDP per capita and passenger car fleet in V4 are considered.

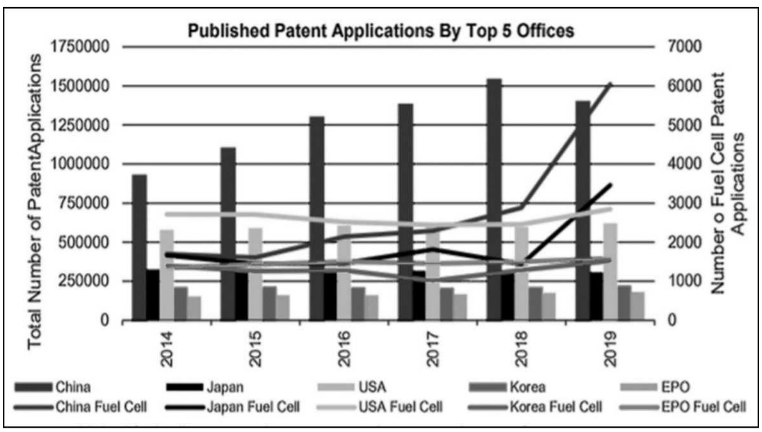
4. Results

4.1. Activity of patent registrations in technology of fuel cells and hydrogen production in the V4 countries

It's worth starting with the fact that China is consistently the leading filer of overall patent applications in recent years, with the number of filings increasing annually (figure 5). In terms of the rankings of the top 5 offices, the United States Patent and Trademark Office had the largest number of published fuel cell patent applications between 2014 and 2017, and China recorded the greatest number of filings in 2018 and 2019 (Moore et al., 2021).

Figure 5

Published fuel cell patent applications vs total patent applications in years 2014–2019 at Top 5 Patent Offices

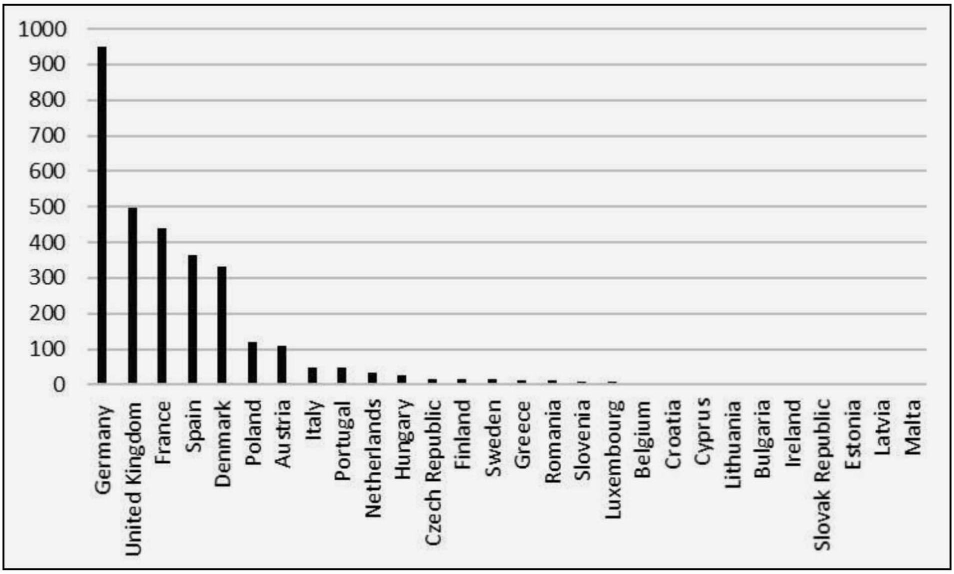


Source: Moore et al., 2021.

In years 2014–2020 the highest total number of patents in fuel cell and hydrogen production technology was in China – 11,231, then in USA – 9,817, Canada – 1,543, Germany – 951 and Australia – 880 (FCHO, 2021). The number of patent registrations in technology of fuel cells and hydrogen production in the V4 countries in terms of other European countries was presented on figure 6.

Figure 6

The number of patent registrations in technology of fuel cells and hydrogen production in European countries



Source: own elaboration based on FCHO, 2021.

Among the V4 countries, most of patent registrations in technology of fuel cells and hydrogen production are in Poland. In the Slovak Republic they are negligible. Detailed data on this subject are included in the tables 5, 6, 7 and 8. Based on the figure 2 patent applications in zero-emission mobility were divided into technology concerning fuel cells and hydrogen production.

Patent activity understood as the sum of patents in fuel cell technology and hydrogen production in years 2014–2020 is presented in the figure 7a. In addition, the activity per 1 million inhabitants in individual V4 countries was presented in figure 7b.

Table 5

Patent registrations in technology of fuel cells and hydrogen production in Poland

Sector	Technology	2014	2015	2016	2017	2018	2019	2020
Fuel cells	DAFC/DMFC & DMFC					1		
	PEMFC		1	1			2	
	SOFC	2	3	4	1	4	2	4
	AFC				1	1		
	PAFC		1					1
Hydrogen production	Low Carbon	4	1			5	5	20
	Electrolysis	3	1		6	7	10	14
	Inorganic			2	1	4	6	3

Source: own elaboration based on FCHO, 2021.

Table 6

Patent registrations in technology of fuel cells and hydrogen production in the Czech Republic

Sector	Technology	2014	2015	2016	2017	2018	2019	2020
Hydrogen production	Low Carbon	2	3				2	4
	Electrolysis						1	4

Source: own elaboration based on FCHO, 2021.

Table 7

Patent registrations in technology of fuel cells and hydrogen production in Hungary

Sector	Technology	2014	2015	2016	2017	2018	2019	2020
Fuel cells	DAFC/DMFC & DMFC						1	
	PEMFC			1				
	SOFC				1	3	2	
Hydrogen production	Low Carbon		1		1	2	2	2
	Electrolysis	1		1	1	2	3	2
	Inorganic			1			1	

Source: own elaboration based on FCHO, 2021.

Table 8

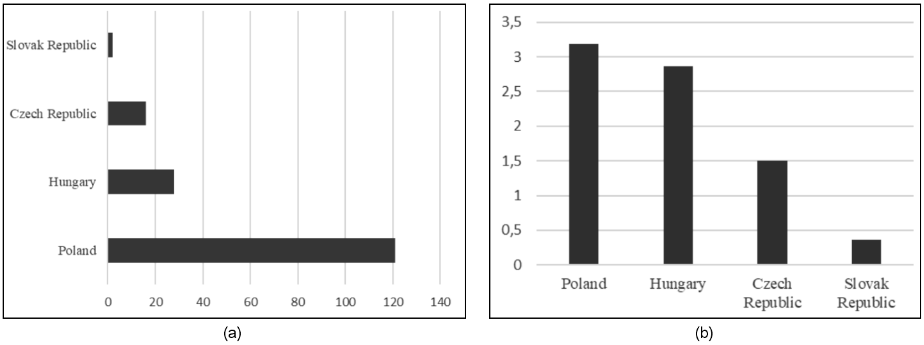
Patent registrations in technology of fuel cells and hydrogen production in Slovak Republic

Sector	Technology	2014	2015	2016	2017	2018	2019	2020
Hydrogen production	Low Carbon	1						
	Electrolysis	1						

Source: own elaboration based on FCHO, 2021.

Figure 7

Patents in fuel cell technology and hydrogen production in years 2014–2020 in the V4 countries: (a) sum of patents; (b) number of patents per 1 million inhabitants

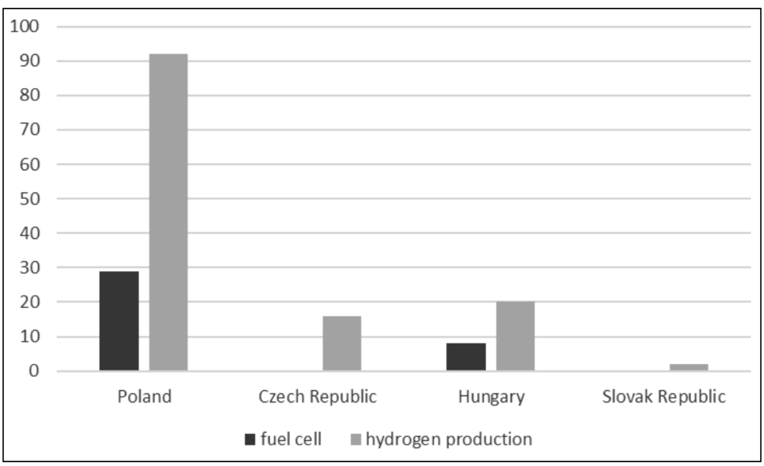


Source: own elaboration based on FCHO, 2021.

The leader among the V4 countries is Poland. The number of all patents in fuel cell technology and hydrogen production in years 2014–2020 counted 121 in Poland and 76% of them were concentrated in hydrogen production, what means 92 patent applications. In the V4 countries, there is dominance of patents in the field of hydrogen production over fuel cell technology (figure 8). And in the case of the Czech Republic and the Slovak Republic there is no patent activity in fuel cell technology.

Figure 8

Activity of patents in technology of fuel cells and hydrogen production in the V4 countries

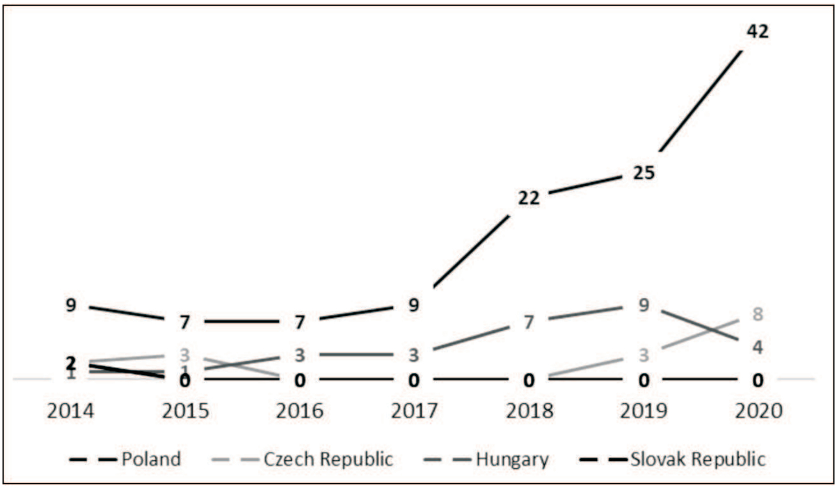


Source: own elaboration based on FCHO, 2021.

In the case of Poland most of patents in hydrogen technology were in 2020 (Finnish Information Centre..., New registered cars..., 2021), and in the case of Hungary in 2019 (Wen, He, 2018). In the Czech Republic 8 were in 2020 and it was the most from the point of view of the activity analysis in 2014–2020. There is practically no activity concerning hydrogen technology in the Slovak Republic. Activity of patent in hydrogen technology in the V4 countries in years 2014–2020 was presented in figure 9.

Figure 9

Activity of patent in hydrogen technology in the V4 countries in years 2014–2020



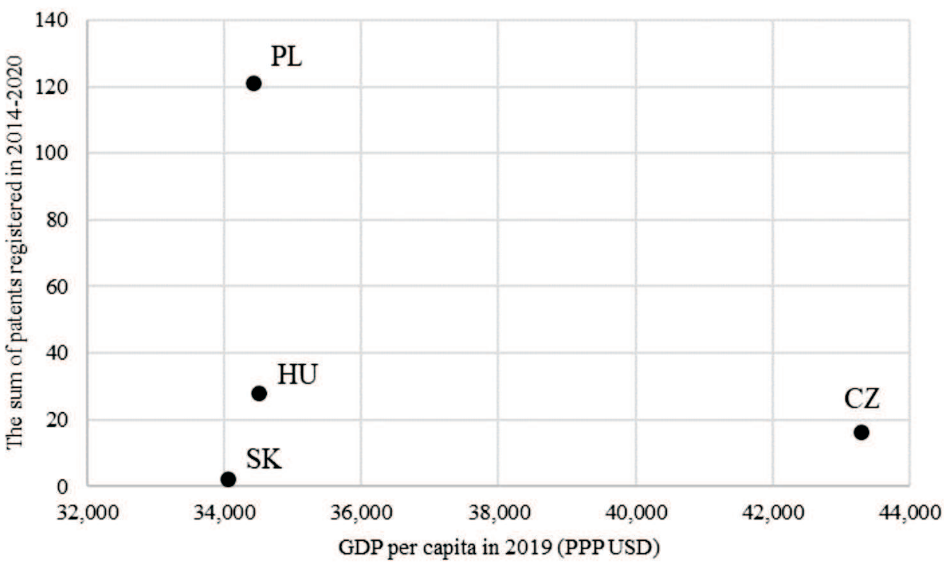
Source: own elaboration based on FCHO, 2021.

To sum up, Poland stands out from the background of the V4 countries when analyzing patent activity in technology of fuel cells and hydrogen production. In fuel cells sector, there is activity in the field of patents related to SOFC, and in the aspect of hydrogen production prevails technology of electrolysis. In the Czech Republic, where in years 2014–2020 were 16 patents, the most of them refers to technology in low carbon. In Hungary, as in the case of Poland, the most patents in refers to SOFC and technology of electrolysis. The Slovak Republic's low activity relates only to technology of low carbon and electrolysis. It should be emphasized that the activity of the V4 countries in the field of patents in hydrogen technology is low and only the activity of Poland is increased year by year. At the same time, it should be added that in the world this activity is high only in the case of a few countries.

4.2. Relationship between patent registrations and GDP per capita in V4

Figure 10 describes the relationship between GDP per capita and the sum of patents registrations between 2014 and 2020 in V4 countries. Despite that the Czech Republic had the highest GDP per capita among V4 group in 2020, the number of patents registered by the country is relatively low. Other members of V4 have a comparable level of GDP per capita, but the number of patent registrations differs among these countries. Poland significantly outstands from the others with the highest number of patents registered in 2014–2020.

Figure 10
Relation between GDP per capita in 2019 and the sum of patents registered in 2014–2020

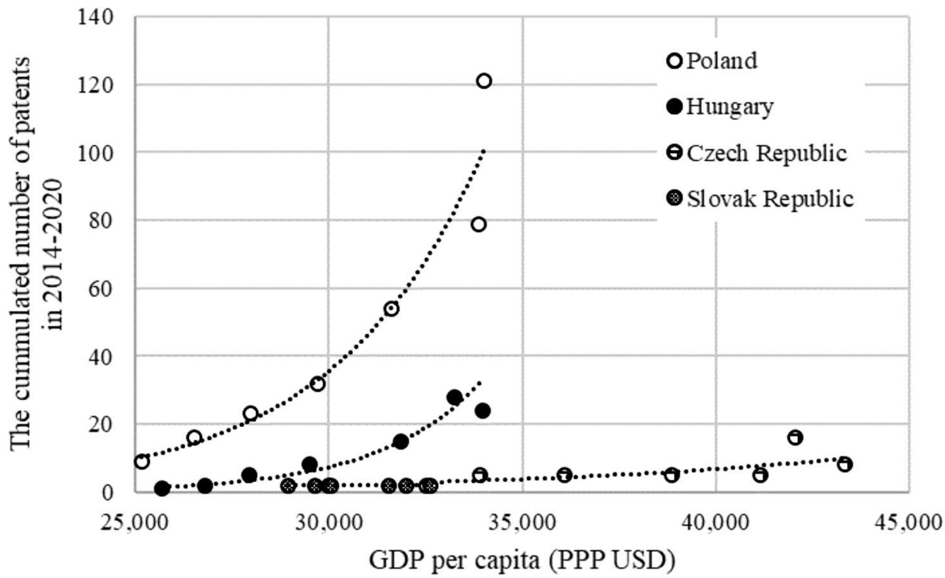


Source: own elaboration based on table 1 and tables 5–8.

The activity of V4 in patents registrations was compared to the GDP per capita in 2014–2020 taking into account yearly data. Figure 11 demonstrates the pace of increase in new patents registrations in each country. While in Poland and Hungary GDP per capita increase was almost identical through the analyzed period, the pace of increase in new patents registrations in Poland which was 17.3 new patents a year on average was much faster than in Hungary where, on average, 4 new patents were registered annually.

Figure 11

Relation between GDP per capita and the cumulated number of patents in 2014–2020



Source: own elaboration based on The World Bank, 2020 and tables 5–8.

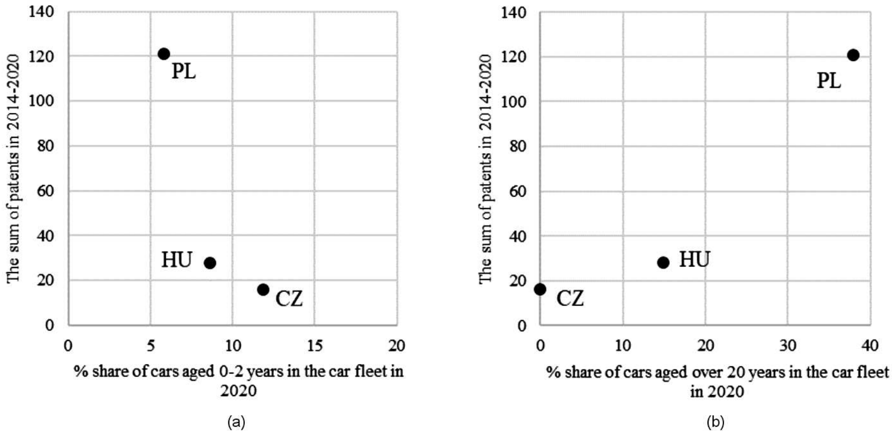
4.3. Relationship between patent registrations and passenger car fleet in V4

Since the activity in patents registrations is not to be related to the level of welfare in V4 countries, we decided to look at the relationship between the patents registrations and passenger car fleet characteristics. Figures 12a and 12b demonstrate the share of new cars (aged 0–2 years) and the share of the oldest cars (aged over 20 years) in relation to the activity in patents registrations. Pearson correlation coefficient was calculated showing that there is no significant relation between the data. The share of new cars is negatively correlated to the sum of patents ($r = -.90$, $p = .29$), while the share of old cars is positively correlated to the sum of patents ($r = .96$, $p = .19$).

We also looked at the relationship between the sum of patents and the share of cars powered by alternative fuels (which means other than diesel and petroleum powered cars). Figure 13 demonstrates that Poland stands out from other V4 in terms of both the number of patents and share of alternatively powered cars, which are significantly higher. There seems to be a positive relationship between both, however, not proved to be significant ($r = .94$, $p = .06$).

Figure 12

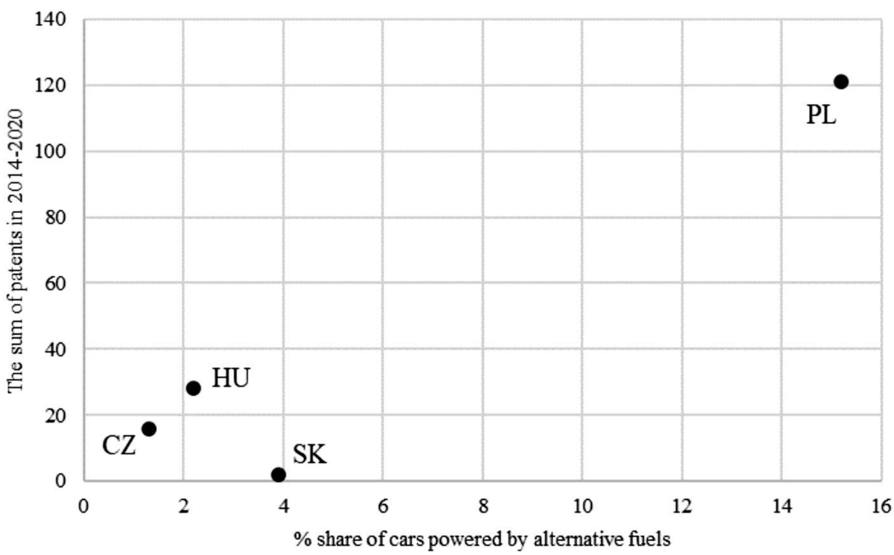
Relation between the sum of patents registered in 2014–2020 and % share of cars by age in 2020: (a) cars aged 0–2 years old, (b) cars aged over 20 years old



Source: own elaboration based on tables 4–8.

Figure 13

Relation between the sum of patents registered in 2014–2020 and % share of cars powered by alternative fuels



Source: own elaboration based on figure 4 and tables 5–8.

Conclusions

The results of our analyses show that the level of GDP per capita in V4 countries is not followed by the number of patents registrations in hydrogen technology. Poland significantly stands out from other V4 with the highest number of patents registered between 2014 and 2020 (121 patents) and the highest pace of increase in patents registrations (on average 17.3 patents a year), while in the much wealthier Czech Republic the number of patents was 16 only with average increase of 2.3 patents a year. This shows that there must be other factors behind patent activity in V4 than economic welfare.

In similar, the activity in patents registration was not proved to be related to the passenger car fleet in terms of cars age distribution. Both the highest share of new cars and the lowest share of old cars were observed in the Czech Republic where the activity in patents registrations was much lower than in Poland or Hungary. In Poland, where the number of patents is the highest, a large proportion of cars (almost 40%) is aged above 20 years old. Moreover, it can be predicted that if electric cars become dominant in Western Europe, Poland will receive old gasoline and diesel cars, which will be imported, for example, from Germany, France, Italy or Spain.

However, V4 is composed of four countries, and thus, statistical analyses are based on limited number of data points. Therefore, we must be careful with drawing conclusions on the relationships between activity in patents registrations and countries' characteristics.

To sum up, activity of patents in fuel cells and hydrogen production in V4 countries doesn't depend on the car fleet in these countries. The level of GDP per capita in V4 countries is not followed by the number of patents registrations in hydrogen technology. Patent activity in fuel cells and hydrogen production is the highest in Poland. Based on the analysis, the theses were confirmed. But the subject of patent activity in the field of hydrogen technologies requires constant observation and research, because it is a new topic and future-oriented problem. The challenges that will be faced in the coming years by car manufacturers and their suppliers, as well as customers, will be related to megatrends that change mobility (electro-mobility) and may bring tangible benefits to the economies of the V4 countries.

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