Green Hydrogen Production in Slovakia as Part of the Circular Economy

Pavol Štuller[1] – Peter Drábik[2] – Dominika Vernerová[3]
ORCID: 0000-0002-3683-1143[1], 0000-0002-2740-4756[2], 0000-0002-3636-6659[3]
pavol.stuller@euba.sk, peter.drabik@euba.sk, dominika.vernerova@euba.sk
University of Economics in Bratislava, Faculty of Commerce, Department of Marketing, Bratislava, Slovakia

Abstract: The global energy system needs to perform a profound transformation to achieve the targets set by the Paris Agreement. In this context, low carbon electricity production from renewable sources, embedded with then global and national circulation economies, may become the preferred energy source. The share of electricity in all the energy consumed by end users worldwide will need to increase by 40% in 2050 to achieve the decarbonized energy world envisaged by the Paris agreement. However, the total decarbonization of specific industrial sectors, such as transport, production industry that require high-grade heat, may be difficult only be means of electrification. This challenge could be addressed by hydrogen from renewable that allows large amounts of renewable energy to be channeled from the power sector to end users. Even though Slovakia has relatively low-carbon electricity production structure, hydrogen production may represent the solution to such pressing issues as shutting down of coal power plants and mining in the Upper Nitra region and can also be the missing link in the energy transition of Slovakia and become the integrated part of the circular economy focused, among others, on decarbonization.

Keywords: Circular economy, Decarbonization, Hydrogen, Value chain.

JEL Classification codes: Q42, Q410

INTRODUCTION

The Paris Agreement aims to limit the increase in average global temperature by "below 2°C" in this century as compared to pre – industrial levels, which can be only achieved by substantial reduction of emissions in all sectors. To achieve the targets in the Paris Agreement, the global energy system must undergo a profound transformation from one largely based on fossil fuels to an efficient and renewable low-carbon energy system. According to analysis by the International Renewable Energy Agency (IRENA, 2018), over 90% of the necessary global CO2 emission reductions could come from these measures; renewable energy is expected to contribute 41 % of the required emission reductions directly and an additional 13% through electrification. To meet this objective, renewable energy's share of global final energy consumption needs to increase from 18% today to 65% in 2050. Variable renewable energy in the power system, in particular wind and solar, will make up the vast majority of generation capacity and ca. 60% of all electricity generation. The power system needs to become more flexible to economically integrate such large shares of variable generation.

Today, one-third of global energy-related emissions come from economic sectors for which there is presently no economic alternative to fossil fuels (IRENA, 2018). These emissions originate mostly from the energy- intensive industry sectors and freight transport (Figure 1).

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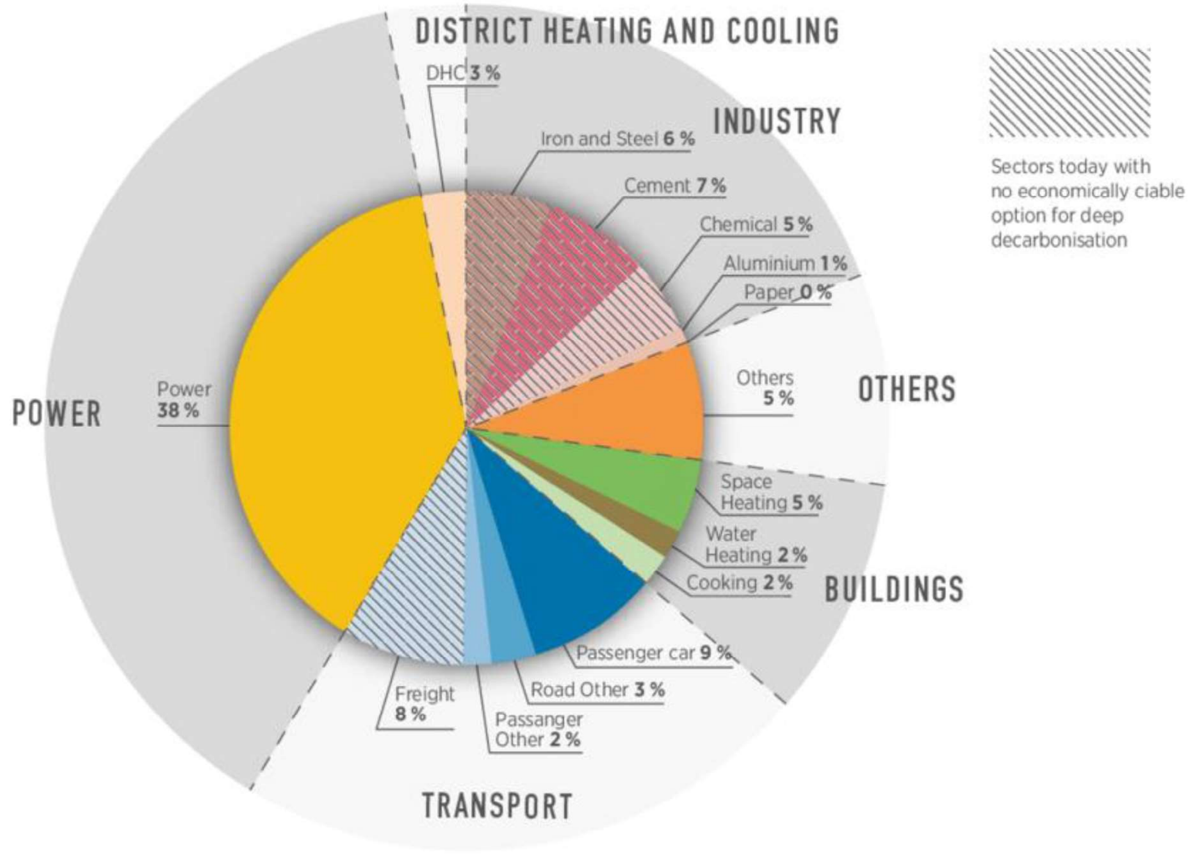
Figure 1 Breakdown of global energy related CO_2 emissions by sector in 2015



Source: Irena, 2018

In the context of Slovakia that also faces significant challenges associated with decarbonization goals, hydrogen could be the "missing link" in the energy transition from a technical perspective: hydrogen from renewable electricity allows large amounts of renewable energy to be channeled from the power sector into sectors for which electrification (and hence decarbonization) is otherwise difficult, such as transport, buildings, and industry.

Hydrogen could thus play a key role in facilitating three positive outcomes: the decarbonization of main CO2 producing sectors; the integration of large amounts of variable renewable energy and the decoupling of variable renewable energy generation and consumption through the production of transportable hydrogen.

Within an electrochemical classification, the most utilized industrial process for hydrogen production today is water electrolysis. Hydrogen is produced through water electrolysis by splitting water molecules into hydrogen (H2) and oxygen (O2). The process takes places within an electrolytic cell where two partial reactions occur at two separate electrodes.

There are high energy requirements for electrolysis in the form of electric power, therefore high production rates of hydrogen can become economically unfeasible due to the elevated cost of electricity based on fossil fuels, such as coal or diesel to generate such power. However, the alternative of powering massive electrolysis arrangements with a combination of renewable energy sources such as solar and wind is possibly an economical alternative for hydrogen production (Silveira, 2017), which provide an ideal alternative for diversification and utilization of renewable energy for hydrogen production in Slovakia.

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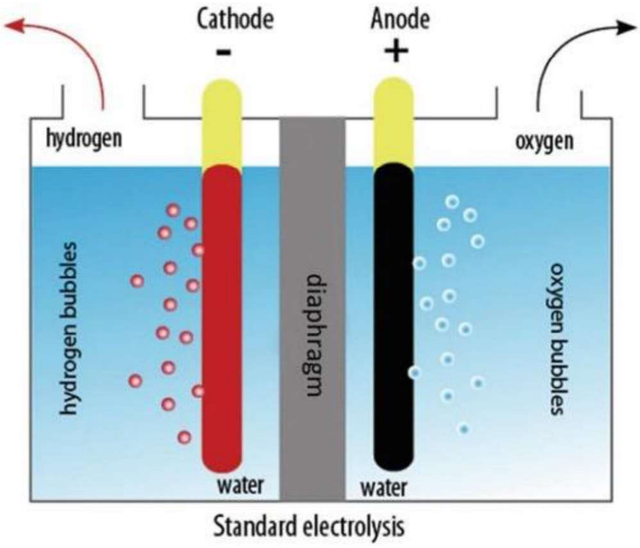
Figure 2 Water electrolysis for hydrogen production



Source: Silveira, 2017

1. LITERATURE REVIEW

The energy demand has increased exponentially worldwide owing to the continuously growing population and urbanization. The conventional fossil fuels are unable to satiate this requirement causing price inflation and significant environmental damage due to unrestrained emission of greenhouse gases. The focus now has shifted towards alternative, economical, renewable and green sources of energy such as hydrogen to deal with this bottle-neck. Hydrogen is a clean energy-source having high energy content (122 kJ/g) (Sharma, Surbhi et al. 2020).

Hydrogen production from renewable sources has become one of the fastest developing topics for decarbonization of industry sectors and transportation in developed countries. As part of the research, we have reviewed available sources with recent research results focused on green hydrogen production, current official documents and plans of the Slovak republic, mainly in connection with the Generation EU (Plán obnovy, 2021) as well as presentations and proceedings from the hydrogen focused conferences.

Today, around 120 Mt of hydrogen are produced globally each year, of which two-thirds is pure hydrogen and one-third is in mixture with other gases. This equals 14.4 exajoules (EJ, equivalent of 4000TWh or 102 Mt), about 4% of global final energy and non-energy use, according to International Energy Agency (IEA, 2019) statistics. Around 95% of all hydrogen is generated from natural gas and coal. Around 5% is generated as a by-product from chlorine production through electrolysis. In the iron and steel industry, coke oven gas also contains a high hydrogen share, some of which is recovered. Currently there is no significant hydrogen production from renewable sources (IRENA, 2018). To achieve a net-zero greenhouse gas economy, the increase of GDP invested in energy system to 2.8% (or around € 520-575 billion annually) will be needed (European Commission, 2018).

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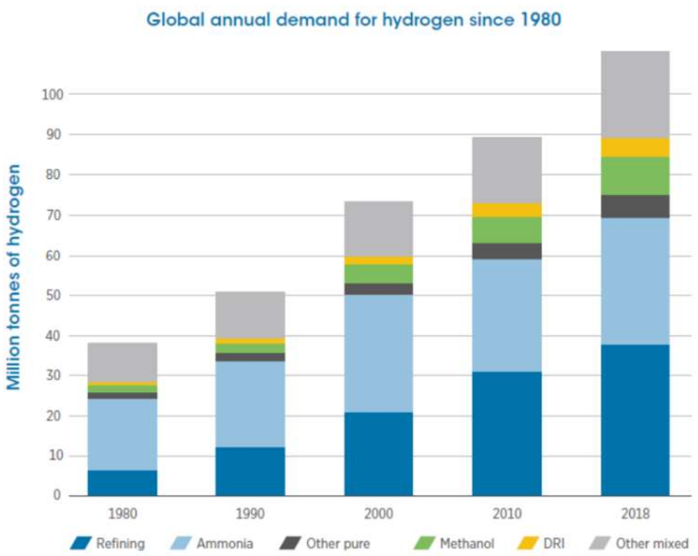
Figure 3 Global annual demand for hydrogen since 1980



Source: IEA, 2019

The increasing ambition of climate targets creates a major role for hydrogen especially in achieving carbon-neutrality in sectors presently difficult to decarbonize. In late 2019, the European Commission (EC) presented the European Green Deal, outlining the main policy initiatives for reaching net-zero greenhouse gas (GHG) emissions by 2050 (European Commission, 2021). The Green Deal identifies clean hydrogen as a priority area for achieving carbon neutrality.

There are two aspects:

1. First, the European Union (EU) currently uses approximately 9,7 million tons (Mt) of hydrogen annually and this needs to be decarbonized (Kakoulaki, 2020). Most of the hydrogen consumption is associated with two industries – oil refineries (ca. 52%) and ammonia production (ca. 43%) (European Hydrogen Infrastructure, 2007), the rest is other industrial use (ca. 2%). Together with methanol production (ca. 5%) and use in metal industries (ca. 3%), these four sectors correspond to 90% of the total hydrogen consumption in Europe. Today hydrogen accounts for less than 1% of Europe's energy consumption and is mainly produced through highly carbon-emitting pathways ('grey' hydrogen) and used as feedstock in sectors such as fertilizers and refineries. Because of this, H2 production is responsible for release of 70 to 100 million tons CO2 annually in the EU (Maisonnier, 2007).
2. Second, hydrogen is considered a key input to the future energy system as a flexible energy carrier for industry and transport, helping to reduce GHG and particle emissions. At least 6 GW (of electrolysers powered by renewable energy) should be installed between 2020 and 2024. Depending on its utilization, such capacity could produce up to 0.8 Mt of clean hydrogen, annually. Another 40 GW should be added by 2030 with aim to produce up to 10 million tons of renewable hydrogen in the EU (A hydrogen strategy for climate, 2020. By 2025, about 1 million public recharging and refueling stations will be needed for the 13 million zero- and low-emission vehicles expected on European roads (European Commission, 2021).

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By 2030, the hydrogen demand in EU + UK according to the 2019 Hydrogen Roadmap Europe's ambitious scenario will be 665 TWh or 16,9 Mt. Analysts estimate clean hydrogen could meet 24% of energy world demand by 2050 (corresponding to ~2251 TWh of energy) (Kakoulaki, 2020) and value chain could employ up to 1 million people, directly or indirectly. Green and blue (not clean, but low carbon) hydrogen demand in sectors, where hydrogen is primarily used as feedstock, can be expected to increase to 238 TWh in 2030, 692 TWh in 2040 and 983 TWh in 2050 (Wang, 2021).

2. METHODOLOGY

The main goal of the paper is analysis of the existing framework for the hydrogen production as integrated part of the circular economy both in context of international requirements of achieving decarbonization targets of the Slovak economy as well as local needs and opportunities in the light of industry structure and energy demands as projected for upcoming decades and expected major investments into the renewable sources from the Next Generation EU from, which Slovakia is planning to use 2.201M EUR (Plan obnovy, 2021). In order to meet these goals, we have performed comparation, analysis and synthesis of the current state of the hydrogen production data worldwide and in the context of the Slovak republic. As part of this process, we have analyzed the conditions for the hydrogen production from renewable sources on the background of international and EU requirements and performed analysis of the economic and financial conditions for hydrogen production.

3. RESULTS AND DISCUSSION

3.1 Description of existing H2 value chain

World and EU

Hydrogen is not new to the energy system. Supplying hydrogen to industrial users is a major business globally and there are companies with extensive experience of producing and handling hydrogen. The scope of the hydrogen discussion has expanded beyond an initial focus on road transport and the stakeholder community has broadened to include renewable electricity suppliers, electricity and gas network operators, automakers, oil and gas companies and major engineering firms. Among governments, there is increasing attention from both energy exporting and importing countries, as well as city and regional authorities around the world.

Demand for hydrogen in its pure form is currently around 70 million tonnes (Mt) per year, equivalent to around 330 Mtoe. This hydrogen is almost entirely supplied from fossil fuels: 6% of global natural gas consumption and 2% of global coal consumption goes to hydrogen production today. Most of this is used for oil refining and chemicals production. A further 45 Mt of hydrogen is used without prior separation from other gases in the industry sector (IEA 2019).

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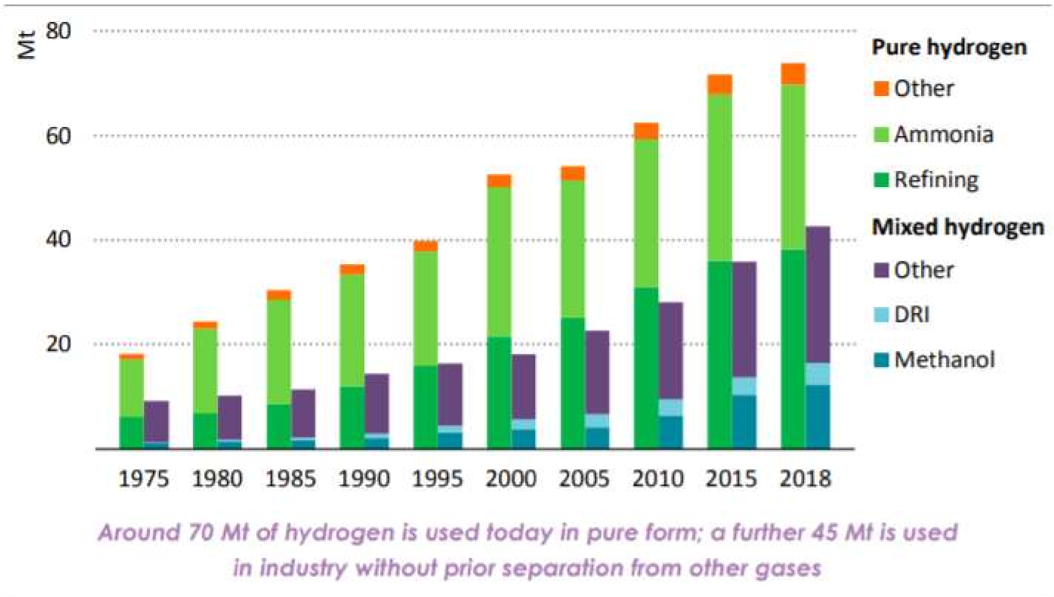
Figure 4 Historic global annual demand for hydrogen



Notes: DRI = direct reduced iron steel production. Methanol, DRI and "other mixed" represent demand for applications that use hydrogen as part of a mixture of gases, such as synthesis gas, for fuel or feedstock.
Source: IEA, 2019

Hydrogen has also been used extensively in the past in gas networks. In 1950, the United Kingdom had over 1 000 facilities producing "town gas", which was a mixture of gases produced from coal or oil that had a hydrogen content of around 50%. Over 100 000 kilometres (km) of distribution pipelines were built to transport it to end-use sectors. Many of these pipelines were replaced after the discovery of natural gas in the North Sea but some are still in use. Other countries, including the United States, Canada and many northern European countries such as Austria, France and Germany, also underwent government-led transitions from town gas to natural gas from the 1950s to 1970s (European Hydrogen Infrastructure, 2007). The hydrogen market comprises three main players: merchant companies which trade hydrogen, captive producers who produce hydrogen for their direct customer or their own use and by-product hydrogen resulting from chemical processes (Maisonnier, 2007). In 2007, 80% of the total hydrogen in Western Europe was consumed by mainly two industrial sectors: the refinery (50%) and the ammonia industry (32%), which are both captive users. If one adds hydrogen consumption by methanol and metal industries, those four sectors cover 90% of the total (Maisonnier, 2007).

By 2050, hydrogen demand in industry grows further and is expected to be spread across Europe and total demand is estimated to reach 1,200 TWh per year (Kakoulaki, 2020). As a result of this trend, several new innovative projects are starting around the world:

• group of regions – led by California, Germany, Japan, and South Korea – is driving developments, spending more than $850 million annually to advance hydrogen and fuel-cell technology (Heid, 2017).

• the world's largest green-hydrogen plant currently has been inaugurated in Quebec, Canada, by industrial gases giant Air Liquide. The Bécancour facility, which is powered by local hydroelectricity, is now producing up to 8.2 tonnes of green H2 per day – close to 3,000 tonnes annually (Collins, 2021).

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• the undisputed leader in the world hydrogen market is Ballard Power Systems. The company was founded in 1979 and was focused on the development of lithium filters. In 1989, their focus switched on PEM fuel cell technology.

• Nel ASA, also known as Nel Hydrogen, is a Norwegian company based in Oslo that offers solutions for the production, storage and distribution of hydrogen from renewable energy sources. The company is also currently working on the launch of the new RotoLyzer product, which is considered a revolution in hydrogen production.

• the "Energiepark Mainz" in Germany is the world largest producer of hydrogen by electrolyzers - they use it to store extra electricity made by wind and water turbines for later use (Energie-Park Mainz, 2021)

• New start-ups with business models connected to hydrogen were founded, including HyPoint, Hydra, Ways2H or Lavo.

• Interest is visible in international organization membership as well – number of companies joining the International Hydrogen Council has grown from 13 in 2017 to 81 today (Maisonnier, 2007). Above that, the European Clean Hydrogen Alliance was announced as part of the new industrial strategy for Europe in March 2020. It is part of efforts to accelerate the decarbonisation of industry and maintain industrial leadership in Europe.

Slovakia

According to its NECP (Integrated National Energy and Climate Plan), Slovakia considers the use of decarbonised gases and hydrogen as a way to "ensure environmental sustainability", "very promising fuel" and a good option (also regarding air quality) to replace natural gas on the one hand and fossil fuels in the transport sector on the other hand. Slovakia estimates that by 2030 around 1% of its RES target for the transport sector will be covered by the direct use of hydrogen (2 ktoe hydrogen out of a total of 229 ktoe renewable fuels). By 2040, this share could be multiplied by more than 20. Slovakia addresses the entire value chain from generation, over underground storage, delivery infrastructure to end uses mainly in the transport sector and the industry (FCH Slovakia, 2020). There are currently 2 major hydrogen producers – Duslo Šaľa and Fortischem Nováky, both using H2 mostly for internal purposes (TASR, 2020).

In Slovakia, the opportunities relating to hydrogen demand occur most strongly in industry and the built environment. In industry, existing hydrogen use as a feedstock exists, but is limited. Therefore, hydrogen deployment will likely primarily contribute to the decarbonisation of the gas supply in industry and act as a low-emission solution for the provision of high temperature process heat. In the built environment, where direct and indirect use of natural gas is a very dominant application for heat generation (natural gas accounts for almost half of the final energy demand in households and services and for over 60%), hydrogen can be deployed to decarbonise the gas supply. In Slovakia's transport sector, the largest opportunities for hydrogen relate to its deployment in road transport, where it can play a role in the decarbonisation of trucks, buses and vans. Additionally, together with electrification, hydrogen can be deployed to replace fossil fuel use in the passenger car sector (FCH Slovakia, 2020).

Hydrogen demand in the year 2030 has been estimated in a low and a high scenario covering the range of uncertainty. Today, conventional hydrogen mainly used in industry is produced from fossil fuels (e.g. through steam methane reforming) or is a by-product from other chemical processes. Both scenarios assume that in 2030 renewable hydrogen will be provided to partially substitute current conventional production and to cover additional demand (e.g. from transport sector). According to the estimations, the hydrogen refuelling station network

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will by 2030 encompass between 20-30 stations for 8 000-17 000 fuel cell vehicles on the road. In addition, the analysis estimates substitutions of up to 1% of the conventional steel production by renewable hydrogen-based steelmaking. Further use of renewable hydrogen is foreseen in ammonia production (up to 5%). Finally, the introduction of 980-4 290 stationary fuel cells for combined power and heat production is estimated.

Analyses shows that in the years 2020-2030 around 20 million EUR can be retained annually in the domestic economy as value added in the low scenario, and over 50 million EUR in the high scenario (value added is defined here as sum of wages for employees, margins for companies and taxes). If the indirect effects induced by the investment in and operation of hydrogen technologies are also taken into account, around 60 million EUR (low scenario) and over 160 million EUR (high scenario) of value added can be created in the Slovak economy annually, which is almost equivalent to the amount of annual investment needed. Most of this value added is expected to be created by building and operating dedicated renewable electricity sources and electrolysers for hydrogen production, and by building and

operating hydrogen transport networks and storage facilities. The hydrogen-related expenditures in 2020-2030 are estimated to generate employment of 360 – 1 000 direct jobs (in production and operations & maintenance) and contribute to a further 920 – 2 600 indirectly related jobs, depending

on the scenario. Most of these jobs are expected to be created in the by building and operating renewable electricity sources, electrolysers and hydrogen transport infrastructure (FCH Slovakia, 2020).

Spill-over by a contribution to green deal investment

For climate experts, green or renewable hydrogen is indispensable to climate neutrality. It features in all eight of the European Commission's net zero emissions scenarios for 2050 (European Commission, 2018). In theory, it can do three things: store surplus renewables power when the grid cannot absorb it, help decarbonize hard-to-electrify sectors such as long-distance transport and heavy industry and replace fossil fuels as a zero-carbon feedstock in chemicals and fuel production.

The Hydrogen Council, a global industry group, estimates that by 2050 hydrogen will represent 18 percent of the energy delivered to end users, avoid six gigatons of carbon emissions annually, enable US$2.5 trillion in annual sales and create 30 million jobs globally (Hydrogen Council, 2017).

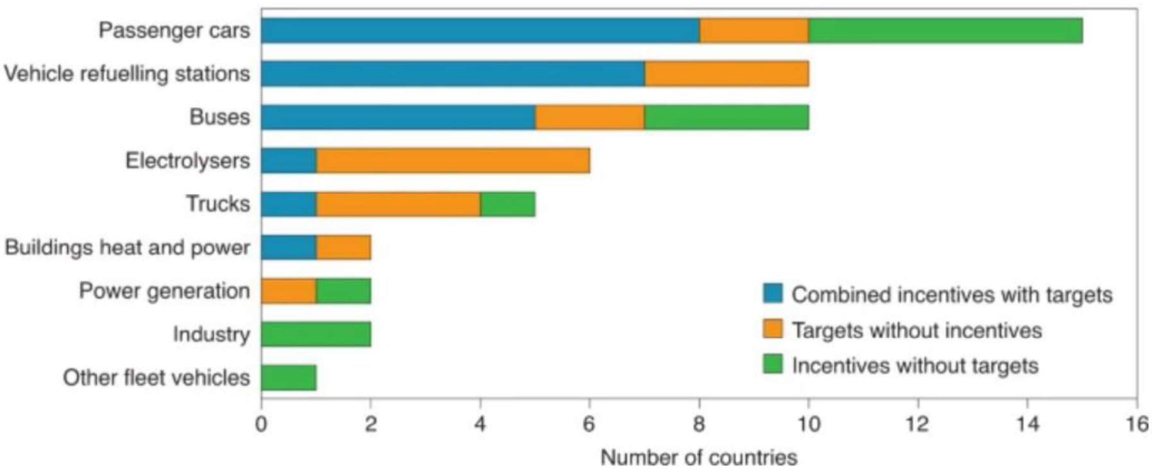

Figure 5 Policies directly supporting hydrogen deployment by target application

Source: IEA, 2019

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The hydrogen economy is a priority for the EU's post-COVID-19 economic recovery package (European Commission, 2020). The emergence of a clean hydrogen economy depends on regulation (see table of policies directly supporting hydrogen deployment by target application):

There is important industrial dimension – Europe is the global leader in electrolysis technology. It has filed about twice as many patents and publications as its nearest competitors — the US, China and Japan — over the last 10–15 years (Biebuyck, 2019). But green hydrogen economy needs tailored support. Eurogas, representing the European gas industry, wants policymakers to set targets for renewable and decarbonized gas and let the market decide what works best for a variety of end-uses. Other stakeholders such as Agora Energiewende and ECF believe that hydrogen support should reflect the need to prioritize specific sectors. It must, after all, remain supplementary to energy efficiency, renewables and direct electrification.

3.2 Green Certificates

In order to support decarbonisation in commercial trade relations, institute of green certificates was established – terminology predominantly used in Europe, but now becoming more widespread globally, which is a tradable asset proving that certain electricity is generated using renewable energy sources. Typically, one certificate represents the generation of one Megawatthour of electricity. What is defined as "renewable" varies from certificate trading scheme to trading scheme, but in general we understand it as wind, solar, geothermal, hydro or biomass energy sources. Several countries use green certificates as a means to make the support of green electricity generation closer to a market economy instead of more bureaucratic investment support and feed-in tariffs. Such national trading schemes are in use in e.g. Poland, Sweden, the UK, Italy, Belgium and some US states. More recently certificates (tradable white certificates (TWCs)) for the electricity saved by demand-side energy efficiency measures (EEMs) have been introduced in some European countries, such as UK, Italy or France.

Energy attribute certificates (EAC) have been around since the late 1990s and the market has developed significantly. While these markets were initiated in Europe and the US, in many countries around the world EAC markets are now emerging and evolving. Regulation and procedures may differ between these EAC systems, but at their core these systems have one common function, to trace the attributes of a given megawatt-hour of electricity from a producer to a consumer.

At its most basic level, the Energy attribute certificates work as follows:

1. A producer of (renewable) electricity generates 1 unit of electricity (generally this is 1 megawatt-hour (MWh))
2. For each MWh of power they inject into the grid the producer requests an EAC from the issuing entity; the EAC, which is an electronic certificate, contains factual information attributes about the specific unit of electricity such as the technology used to generate the power and where it is located.
3. The EAC can be traded between market participants through registries with the ultimate aim of selling it to a consumer (also known as an end-user).
4. The end-user or their representative consumes the EAC by cancelling it so that it cannot be used again – without cancellation, there is a risk that one EAC can be used twice (known as double counting)

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5. The consumer can then claim to have consumed the unit of power that was represented by the EAC (RECS, 2021).

Green certificates are traded for compliance reasons or on a voluntarily basis. They are issued and traded in compliance markets because of governmental policies which require suppliers to have a certain percentage of renewable production in their supply portfolio. With green certificates, governments can set exact targets as to the level of renewable production in a country, while the market finds the most efficient way to meet these targets. It is an alternative to other policy mechanisms, such as renewable investment subsidies, renewable production subsidies, fiscal benefits and feed-in tariffs. For corporates, this has commercial benefits, as it improves their reputation and provides a competitive edge in a society in which awareness and the importance of environmental impacts are ever increasing. For individuals, it can be tool to reduce own CO2 footprint (KYOS, 2021).

The price of the green certificates depends on the scarcity in the market. The price is higher when the green certificates scheme is driven by tight targets of government policies. Certificates cannot be transferred between the European markets, as opposed to emission certificates, so the total market size is often small and trading rather illiquid.

Standards are required for the successful development of EAC markets around the world. The importance of standards is seen clearly in Europe with the development of the Guarantee of Origin system (GO or GoO). The creation of the EECS (European Energy Certificate Standard) for GOs allowed for the development of a robust and reliable EAC market in Europe that is now adhered to by most EU Member States, as well as some other EEA/EFTA countries. On an annual basis, we see more than 600-TWh of voluntary trade with 15% growth year-over-year in the use of EECS-GOs in Europe (RECS, 2021).

Slovak national authority for Guarantee of Origin certificates is OKTE - Short-term electricity Market Operator (OKTE, 2021). The Guarantee of origin is issued for the amount of electricity corresponding to 1 MWh of electricity supplied to the system and is active for a period of 12 months from the date of production. In this period it is possible to trade and/or transfer it between account holders. Guarantees of origin that enter the auction will be automatically generated three months after the production of electricity after the final settlement. Only guarantees of origin of electricity from RES will be included in the process of automatic generation, last such auction happened August 6, 2021 Tariff for issuing a guarantee of origin is 0,005 €/MWh, annual fixed account management fee is 120 EUR (OKTE, 2021).

CONCLUSION

Slovakia is facing number of challenges associated both with ensuring its energy security, mainly connected to diversification of its energy sources (gas, nuclear fuel, crude oil) but is also bound to fulfill its international commitments associated with decarbonization and reduction of CO2 production and development of the circular economy. Despite a relative low-carbon electricity production base (mainly nuclear and water power plants), it still lacks sufficient investments into the renewable energy production base that would both diversify existing production assets but would also further improve our position as low emission economy. Recent spikes in the energy prices, especially in Europe, are creating further incentives for countries and electricity producer to invest into localized, renewable sources that would decrease dependency on international commodity prices, would provide a more stabile base for the industry and most importantly would provide the country with means to meet its international environmental obligations.

Green hydrogen production (Slovakia can also further extend production of Blue Hydrogen from nuclear power plants once Mochove 3.4 units will be put into operation in 2022 and 2024

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and Slovakia will become a net exporter of electricity) provides an opportunity to invest into a diversified, flexible energy carrier infrastructure ideal for both industry as well as transportation. Implementation of the Generation EU (Plán obnovy, 2019) plan provides a significant milestone that can enable investments into building the complete infrastructure of hydrogen generation (e.g. planned JESS company at Bohunice site – solar park combined with hydrogen electrolyser) , storage and delivery with involvement of industry, research capacities of Slovak universities, municipalities and government. Analyses shows that in the years 2020-2030 around 20 million EUR can be retained annually in the domestic economy as value added in the low scenario, and over 50 million EUR in the high scenario (value added is defined here as sum of wages for employees, margins for companies and taxes). If the indirect effects induced by the investment in and operation of hydrogen technologies are also taken into account, around 60 million EUR (low scenario) and over 160 million EUR (high scenario) of value added can be created in the Slovak economy annually, which is almost equivalent to the amount of annual investment needed. Most of this value added is expected to be created by building and operating dedicated renewable electricity sources and electrolysers for hydrogen production, and by building and operating hydrogen transport networks and storage facilities. The hydrogen-related expenditures in 2020-2030 are estimated to generate employment of 360 – 1 000 direct jobs (in production and operations & maintenance) and contribute to a further 920 – 2 600 indirectly related jobs, depending on the scenario.

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