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An overview about the feasibility of the hydrogen power plants

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Abstract. *In order to make the decision to implement a project from any domain, several aspects must be analyzed in the preliminary stage, leading to the justification of the practical realization of the project. Feasibility is based on technical-economic criteria but also involves other impact factors, such as social and ecological. In the case of hydrogen, there are not many countries with experience in the field, but in the future it is expected that hydrogen technologies will expand, from production, transport, storage, distribution and use. There are more and more factors that encourage the development of hydrogen projects and the funding proposed through European environmental agreements is a real challenge for specialists. Therefore, the authors of the paper aimed to analyze several aspects of the feasibility of hydrogen production and storage projects with the identification of implementation conditions: benefits, efficiency, costs, sources of funding, entities involved, constraints or legislative framework.*

Keywords*: hydrogen projects, feasibility, economic criteria, funding*

1. Introduction

As it follows from the strategy and documents of the European Union (EU) administration and legislature, on the road to a climate-neutral Europe and a cleaner planet in general, it is important to rethink energy supply and create a fully integrated energy system under the European Green Pact [12]. The green transition of the EU economy should provide access to clean, safe and affordable energy for companies and final consumers. But it is not an easy task because as energy production and consumption generated 75% of EU greenhouse gas emissions in 2018, and it still depends on imports for 58% of total energy, especially oil and gas [17]. Beyond supporting the implementation of renewable energy sources at European level, a new challenge has appeared, due to several advantages: the hydrogen.

Hydrogen can contribute to the storage of electricity and can be used as fuel in transportation or building heating as it is non-polluting. However, for the most part, obtaining it today is generally done through polluting processes.These processes must be eliminated by gradually moving to comprehensive ecological processes for the production of "green" hydrogen. Green hydrogen, produced from renewable energy resources, is considered one of the solutions for countries around the world to achieve climate neutrality by 2050, the main challenges for its production being high costs and resource availability. In Romania, the hydrogen is currently used mainly in the chemical industry, in refineries and for ammonia production. It is also used in welding processes. Given the need to reduce the harmful environmental impact, it is important that countries around the world start developing projects quickly to implement the necessary hydrogen infrastructure. Future projects require high material, human or financial investment and public-private partnerships and non-reimbursable financing must be used, which are available to EU countries, and a significant number of legislation acts are being developed to support hydrogen production and storage facilities. As in other economic sectors, before obtaining funding, the technical-economic possibilities for practical implementation of projects must be identified, through a preliminary feasibility study by applying specific analysis criteria and impact factors on human society and the natural environment.

2. Hydrogen properties. Hydrogen storage problems

Hydrogen is the lightest of all gases. It is very often found in nature in compounds with other elements and is the most abundant element in the universe. Hydrogen is a component of water, minerals and acids, as well as an essential part of all hydrocarbons and essentially all other organic substances being the third element of compounds to spread in the earth's crust. In fact, 98% of the known universe - especially the sun and stars - are made of hydrogen. Hydrogen cannot be found in nature in its pure state, so it cannot be mined in the same way as oil or coal. Hydrogen must be extracted from chemical compounds [18].

Hydrogen is a substance that comes in gaseous form at normal atmospheric temperature and pressure. In fact, hydrogen is found in solid form up to about 14 K (-259 ^{o}C) when it passes into the liquid phase and at about 20 K (- 253 ^{o}C) it vaporizes and passes into the gas phase. Under normal conditions of pressure and temperature, hydrogen has a very low density of about 0.08988 kg / Nm^3 [18].

At present, hydrogen is produced in large quantities from fossil fuels by steam reforming of natural gas and partial oxidation of coal or heavy hydrocarbons. These methods can take advantage of economies of scale and are currently the cheapest and most established techniques for the large-scale production of hydrogen [3]. They can be used in the short to middle term to meet hydrogen fuel demand and enable the proving and testing of technologies related to hydrogen production, storage, distribution, safety and use. However, in the long term, it is clearly unsustainable that the hydrogen economy is driven by hydrogen derived from hydrocarbons. The manufacture of hydrogen from fossil fuels using reformation and gasification processes always yields carbon dioxide as a by-product [3]. A more promising route of hydrogen production without carbon dioxide release is the high-temperature pyrolysis (decomposition in the absence of oxygen) of ydrocarbons, biomass and municipal solid waste into hydrogen and (solid) carbon black accompanied by its industrial use and/or easy sequestration. At present, the cost of this process is significantly higher than that of steam reforming of natural gas [3].

Nuclear hydrogen production can be made by lowtemperature electrolysis, high-temperature electrolysis, thermochemical, and hybrid processes. Low temperature electrolysis is simply splitting water into hydrogen and oxygen using electrical power which possesses a high amount of electricity consumption (~1,23 V/mol H_2O)[4]. High-temperature electrolysis, which can also be called steam electrolysis, is a method to split steam into hydrogen and oxygen. Electrical energy requirement for splitting steam is lower than that of liquid water, and higher efficiencies can be obtained by using heat as a part of energy source [4].

Regardless of the source from which hydrogen is extracted, a production process is needed and it involves energy consumption. The great advantage, however, is that for the generation of hydrogen it is not strictly necessary to use energy from fossil fuels, but you can use electricity from renewable sources (RES): hydraulic, solar, wind, geothermal, biomass [1]. The scheme of a production system based on electrolysis and storage of hydrogen energy from RES, through fuel cells, is shown in Figure 1[5].

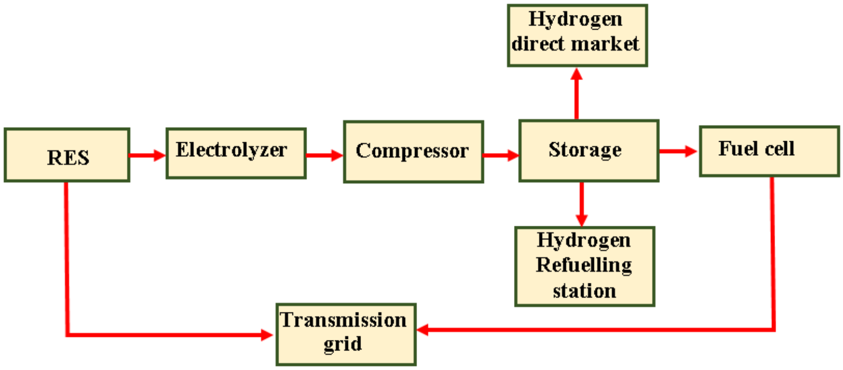

Figure 1. Scheme of a renewable hydrogen storage system

Hydrogen can be stored in all forms of aggregation but problems can occur when an explosive mixture occurs in the presence of air, because hydrogen, mixed with oxygen in a proportion of 5–85%, is flammable and therefore dangerous [1]. When stored under pressure in metal containers, special care must be taken to remove leaks.

A means of storing hydrogen is ammonia (NH_3), from which it can be released by a catalytic reforming process.

In recent years, other storage techniques have been developed, using graphite nanotubes. Hydrogen is stored between layers of nanotubes with diameters of 5–10 nm. Thus, about 30 liters of hydrogen are stored for every gram of graphite. The disadvantage is that the charging time of a 25 liter tank is 4÷24 hours and can only be done 4-5 times [1]. Hydrogen can be stored in metal-organic networks using a series of synthetic porous materials, polymers with attached titanium atoms, glass microspheres of 10–300 m [1]. The storage capacity of hydrogen by different methods is shown in Table 1.

Table 1. Hydrogen storage capacity by different methods

Storage type	Moles of hydrogen/cm^3
H_2 gas at 100 bar	0,81
Liquid H_2	7,0
Hidride MgH_2	11,1

Table 2 shows some of the solid storage properties of hydrogen in magnesium compounds called hydrides. Mg. Other hydrides are sodium, lithium or calcium and aluminum or boron.

Table2. Hydrogen storage properties in Mg-based alloys

Material type	Minimum mass storage capacity H_2[%]	Bearing pressure at 300°C [atm]	Temperature [°C]	Reaction kinetiks [min]	Reaction Enthalpy [kJ/mol H_2]
$Mg_{75}Ti_{12}Fe_4Ni_8$	4,75	Abs 1,5 desorb.1,5	300÷360	1,36,6	73,67
$Mg_{75}Ti_{12}Fe_8Ni_4$	5,33	Abs 1,4 desorb.1,2	300÷360	1,14,5	71,79

One form of intense hydrogen storage discussed by specialists in the last period is that in gaseous form in underground caverns and especially in disused salt mines. A research project in this sense is being developed in partnership and in Europe, in which Romania also participates and which is called HyUnder [10]. The project will be briefly presented in Chapter 4 of this paper.

3. Cost of hydrogen. Technical and economic criteria of analysis

The feasibility analysis of hydrogen projects aims to identify potential constraints and appropriate solutions in terms of technical, economic, regulatory and managerial aspects. Typical feasibility reports for major infrastructure should include information on: demand analysis, available technology, production plan, staffing requirements, project size, location, physical inputs, timing and implementation, deployment and financial planning phases etc [13].

There are many decision-support instruments in the scientific literature that can perform an impact assessment of an hydrogen energy system. The most widely financial applied decision support methods are life-cycle assessment (LCA), cost-benefit analysis (CBA) and multi-criteria decision analysis (MCDA)[2].

From a technical point of view, for the first time in electrolysis processes, the specific energy consumption on component terms must be analyzed in order to determine the yield of the transformation of the detected substance into hydrogen. Thus, the financial criterion will be linked by evaluating the costs of incoming electricity with the amount of hydrogen at the exit from the electrolysis plant. This will establish the profitability of this process. In most electrochemical reactions, the amount of electricity consumed in electrolysis is higher than the theoretical one (corresponding to Faraday's law, which defines them) because the losses in the process must be covered [9].

The specific energy consumptions are obtained by reporting the amount of energy actually used in the mass, respectively the volume of product obtained in electrolysis and can be expressed with the formulas [9]:

$$CSE_{mass} = \frac{U_{pr} \cdot I \cdot t}{m} \quad (1)$$

and

$$CSE_{volume} = \frac{U_{pr} \cdot I \cdot t}{V} \quad (2)$$

where: m – practical mass of product obtained; V – the volume of hydrogen released.

In order to be able to appreciate the degree of discrepancy between the theoretical and practical values (there are losses and secondary reaction substances), the notion of transformation yield was introduced, with several components one being the electrical current yield η_c, which is calculated with the relationship [9]:

$$\eta_c = \frac{Q_t}{Q_p} \cdot 100,\ \% \quad (3)$$

In which: Q_t – theoretical Quantity of electricity; Q_p – the Quantity of electricity practically consumed.

The electricity yield can also be calculated depending on the amount of transformed substance:

$$\eta_c = \frac{m_p}{m_p} \cdot 100,\ \% \quad (4)$$

where: m_p – the mass of product practically obtained; m_t – theoretical mass of product.

It is still possible to calculate the energy, noted with simbo η_W, which expresses the ratio between the quantity of theoretically required electricity, W_t and of electric energy practically consumed, W_p, in an electrochemical reaction:

$$\eta_W = \frac{W_t}{W_p} \cdot 100,\ \% \quad (5)$$

Replacind with W = V · I · t = W·Q , results:

$$\eta_W = \frac{V_t \cdot Q_t}{V_p \cdot Q_p} \cdot 100 = \frac{Q_t}{Q_p} \cdot 100,\ \% \quad (6)$$

In which: V_t – theoretical electrolysis voltage (decomposition voltage); V_p – work voltage (terminal voltage).

The third type of yield is the voltage yield, which can be calculated with the formula:

$$\eta_W = \frac{U_{min}}{U_{pr}} \cdot 100 = \frac{E}{U_{pr}} \cdot 100,\ \% \quad (7)$$

where: U_{min} – minimum electrolysis voltage; U_{pr} – practical working voltage;
E – the electromotive voltage of the considered system.

The main financial indicators specific to investments in hydrogen project achievement, are [7]:

a). Total costs of investments. As a first step in financial evaluation of project, the total costs of investments(I) included direct(I_d) and indirect costs(I_i):

$$I = I_d + I_i \quad (8)$$

Where, I_d reprezented the cost of materials and equipments and I_i is related to design, authorization, project's check, unforeseable expenses etc;
b).Yearly total cost: Can be calculated using the following relationship:

$$C_{tot} = \frac{I}{D_a} + C_p \quad (9)$$

In which D_a is analysis period, in years and C_p – the cost of production;
In the energy domain, the yearly costs of production can be assessed using the next formula:

$$C_p = C_{comb,t} + C_{EE} + C_{OM\&R} \quad (10)$$

Where, $C_{comb,t}$ represents the early expenses with fuel; CEE- are the yearly expenses with electric energy; $C_{OM\&R}$ – The costs of operating, maintnance and repairs whitout fuel involvment;
c). Total costs C, are expressed with the following formula:

$$C = I = C_p \cdot D_a \quad (11)$$

d). Costs of hydrogen, is calculated as a ratio between the yearly total costs and the production capacity in physical measuring units, namely[7]:

$$C_H = \frac{C_{tot}}{Q_f} \tag{12}$$

Where, C_H reperesents the yearly costs of Hydrogen and Qf – the production capacity in physical measuring units;

e). Specific investment. Is calculated as a ratio between total investment and the production capacity in prhisical measuring units, namely[7]:

$$i_s = \frac{I}{Q_f} \tag{13}$$

in which, i_s represent the specific investment .

To assess the cash flow resulting from hydrogen production, the Hydrogen Levelized Cost indicator is used - $PC_{Leverized}$ - which is a measure of the current average net cost of hydrogen production for a plant. It is used to plan investments and to compare different methods of hydrogen production. It is calculated as the ratio of all costs updated over the analysis period of a plant divided by a weighted amount of hydrogen delivered.

For the calculation of the levelized production costs of hydrogen, can use the next standard formula, given in [6]:

$$PC_{Leverized} = \frac{\sum_{t=1}^{n} \frac{C_{CapEx,t}+C_{OpEx,t}+C_{Elec,t}}{(1+d)^t}}{\sum_{t=1}^{n} \frac{m_t}{(1+d)^t}} \tag{14}$$

The terms from Equation (1) have the following meanings:

n- analysis period(years), t – year index, $C_{CapEx,t}$ – Costs of capital expeditures in year t; $C_{OpEx,t}$ – Costs of operation expeditures in year t; $C_{Elec,t}$ – Costs of electricity in year t; m_t – Mass of produced hydrogen in year t; d – Asumed discounting factor(5%).

Once the investment costs, revenues and operating costs and sources of funding have been determined, it is possible and useful to determine the financial sustainability of the project [13]. A hydrogen project is financially sustainable when it does not involve the risk of running out of money in the future. Project beneficiaries must closely monitor how, over the time horizon of the project, the sources of funding (including income and any cash transfers) will consistently correspond to the required periodic payments. Sustainability occurs if the cumulative net flow of cash receipts and payments generated is positive for all considered years.

The indicators needed to test the financial performance of the hydrogen project are:

- The Financial Net Present Value of project (FNPV),
- Financial Internal Rate of Return (FIRR).

FNPV is defined as the amount that results when the planned investment and operating costs of the project (updated as appropriate) are deducted from the present value of the expected revenue. [13]:

$$FNPV = \sum_{t=0}^{n} a_t \cdot S_t = \frac{S_0}{(1+i)^0} + \frac{S_1}{(1+i)^1} + \cdots + \frac{S_n}{(1+i)^n} \quad (15)$$

Where S_t is the cash flow balance at time t, a_t - the financial factor chosen for the update at time moment t and i -the reference discount rate.

4. Hydrogen projects at national level. Funding sources

If they meet the conditions for eligibility and financial score, hydrogen-based projects can be funded from several non-reimbursable sources. Hydrogen plants can be included in the infrastructure, environmental protection, energy efficient and renewable energy program. At the same time, the financing of the project on hydrogen can be done through guaranteed bank funds or through public-private partnerships.

The European Commission (EC) launched on 8 July 2020 the strategy for integrating hydrogen production, storage and use into the energy system, as part of Green Deal [11]. Through "Hydrogen strategy for a climate-neutral Europe", EC targets 38 actions on an integrated energy system, in which hydrogen contributes to the decarbonisation of industry, transport, electricity production and buildings across countries of EU.

Also, through the European Hydrogen Strategy, the European Commission has set certain targets for the use of hydrogen, funded and achieved in stages, as follows [11]:

• From 2020 to 2024, support the installation of at least 6 gigawatts of renewable electricity electrolysis plants in the EU and the production of up to one million tonnes of renewable hydrogen;

• From 2025 to 2030, hydrogen must become an intrinsic part of the integrated European energy system, with at least 40 gigawatts of electrolysis plants generated by RES in hydrogen and the production of up to ten million tonnes of renewable hydrogen in the EU;

• In the period 2030-2050, renewable hydrogen technologies are encouraged to reach maturity and to be widely implemented in all sectors difficult to decarbonise.Through the project called „HyUnder", worth 2 million euros, carried out over a period of 2 years and in which Romania participated along with France, Germany, Romania, Spain, Netherlands and England, it was aimed to identify the possibilities of underground storage of hydrogen. In our country, four points with old salt mines were identified located in Ocnele Mari, Ocna Mureș, Târgu Ocna and Cacica. In Spain also, four good locations have been found as mentioned in [8]. All locations are old brown coal mines and since the beginning all sites were defined as interesting options for hydrogen storage due to its good location near wind resources and also vicinity to the electric and natural gas grids.

In line with the hydrogen strategy [11], the JTM (Just Transition Mechanism) was created, which is the transition mechanism to green energy provided in the European Green Deal for the period 2020 ÷ 2030, with allocated funds. on three distinctive pillar.

A synthesis of future funding for projects, studies and research in the field of green hydrogen, for 10 EU countries, with the largest budget allocations in the period 2021 ÷ 2027, is presented in Table 3.

Table 3. Just Transition Machanism allocation(EUR million)

Country	Proposed JTF allocation	Total estimated funding under pillar 1	Estimated expected investments to be mobilized under pillars 1,2,3
Poland	2000	7692	27344
Germany	877	4614	13387
Romania	**757**	**2704**	**10116**
Czech Rep.	581	2074	7761
Bulgaria	458	1710	6205
France	402	1825	5807
Italy	364	1301	4868
Spain	307	1397	4445
Estonia	294	1049	3923
Nederlands	220	1045	3174
Finland	165	749	2383
Slovakia	162	580	2170
Ireland	125	569	1.811

With a number of 1350 pages, the new proposal document prepared by the Romanian government for PNRR (National Recovery and Resilience Plan) which supports the recovery from the economic crisis caused by the COVID 19 pandemic, provides for the allocation of 29.2 billion eruo funds by the European Commission for interval 2021 ÷ 2026. Approved on September 27 , 2021, PNRR has a lot of green hydrogen-based projects in addition to other renewable energy projects. Among the hydrogen projects we mention: hydrogen networks combined with natural gas, 420 hybrid buses with electricity(together with fast and slow charging stations) / hydrogen in the county residences, 240 electric/hydrogen buses in other types of localities, 1000 minibuses electric/ hydrogen minibuses purchased for Community purposes, two railways with hydrogen trains (12 trains), RES hydrogen generation and capture facilities, etc.

The "HyLaw" project - "Hydrogen Law and removal of legal barriers to the deployment of fuel cells and hydrogen applications", is a report that brings together a package of laws and regulations on hydrogen and the removal of legal barriers to the use of fuel cells and applications hydrogen-based [14]. This is a pilot project that aims to stimulate the market uptake of hydrogen and fuel cell technologies, giving market developers a clear view of the applicable regulations, while drawing the attention of decision makers to the legal barriers that need to be removed. . The project is the result of the cooperation of 23 partners from: Austria, Belgium, Bulgaria, Denmark, Finland, France, Germany, Hungary, Italy, Latvia, Norway, Poland, Romania, Spain, Sweden, Portugal, Netherlands and the UK, being coordinated by Hydrogen Europe.

5. Electricity RES-based Market impact on Hydrogen production

One of the most important factors which has influence about the technical and economic feasibility of hydrogen projects is the cost of energy. It should be noted that the electricity in the RES is attractive for powering the electrolyzers only if the installations are owned by the hydrogen producer. In this situation, after the amortization of the investment in renewable energy power plants, the cost of electricity generated can be considered close to zero, if operating and maintenance costs are excluded. Instead, the purchase of electric energy(EE) from certified RES producers that sell on the energy exchange, electricity is no longer attractive even if it is cheaper than electricity from fossil fuel power plants.

In the context of the economic crisis triggered by the COVID 19 pandemic, the EE prices from the RES have risen sharply and the energy market is fluctuating. This is also due to the fact that, on the one hand, there is demand and on the other hand, the purchasing power of consumers decreases or there are increased precautions and interest in financial savings, with a more careful analysis of the Energy Market.

Table 4. Transactions results

Day number	Mean price of transaction for EE[RON/MWh]		
	Month1	Month 2	Month 3
	July	August	September
Day1	257,70	402,00	441,25
Day 2	300,05	288,00	363,75
Day 3	289,30	212,50	365,03
Day 4	365,25	400,75	365,04
Day 5	402,39	411,05	548,10
Total period	322,94	342,86	416,63

In order to observe the fluctuations of the electricity prices on the market, it is sufficient to follow the evolution of the transactions with EE coming from RES on the energy exchange managed by the Commercial Operator from Romania [19].

The results of the RES market investigation of electricity for trading periods consisting of five days in three consecutive months, July August and September, 2021, are presented in the the Table 4.

The graphics evolution of EE transactions results from RES analyzed market is shown in Figure 2.

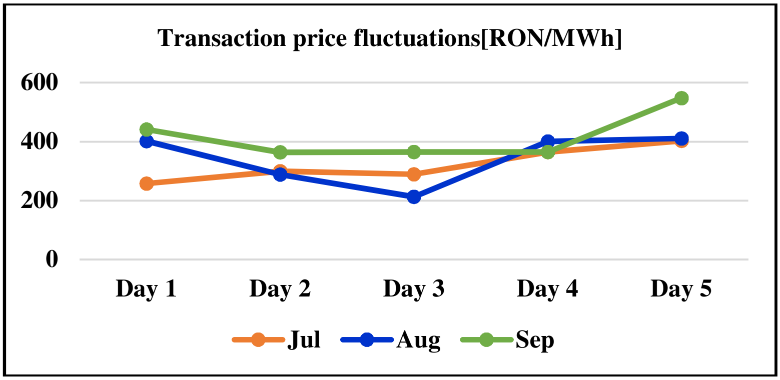

Figure 2. Results of EE transactions from the RES dedicated market

The chart shows significant fluctuations in trading prices, with average percentage increases for the periods analyzed as follows: August compared to July recorded an average price increase of 5.81% and September compared to August of recorded an average increase in the trading price of 17.71%. Thus, between September and July there was an increase of 23.52% in the average trading price of EE in RES, which is a significant value. But, the most spectacular jump of the EE price in RES occurred on the stock exchange on 11.10.2021, the first trading day of the month when it was traded with the price of 820,01 RON / MWh with an increase of 96, 82% compared to the mean price in September [19].

The research carried out by the authors is important especially in view of the fact that large energy companies in Romania, which operate in the field of renewable energy sources, such as Enel Green Power [15] or Hidroelectrica [16], have shown interest in entering the market for hydrogen from renewable energies. In partnership with the Austrian company Verbund AH, the Romanian company Hidroelectrca S.A., wants to produce ecological hydrogen through the "Green Hydrogen & Blue Danube" project and to transport it by river to the riparian countries in Europe.

Beyond the ecological aspect and the continuous restoration, RES are also important because they are rewarded by the state with green certificates that are traded separately and increase the profitability of EE production.

6. Discussion

RES as well as the cheap electricity produced from them allow the creation of electrical networks interconnected with hydrogen networks obtained by electrolysis and fuel cells. This creates facilities that allow the storage and use of energy at flashes or peak loads. The conversion efficiency of several RES categories has continuously improved.

About the photovoltaic panels it can be said that they have evolved a lot lately with an increasing efficiency due to new technologies and high-performance materials used in the manufacture of solar cells, which leads to an increase in electricity generated on a smaller area. However, electrolysis processes are high consumers of electricity, which makes the large-scale production of hydrogen in this way still quite expensive. Then, in the absence of hydrogen transmission infrastructure, it is necessary that the electrolysis stations be located near the RES or the electric discharge stations from the RES plants in order to keep the costs low. Last but not least, the problem of efficient storage of large quantities of hydrogen and easy to evacuate must be solved for easy integration into the transmission and distribution.

7. Conclusions

Romania is a country that has been producing hydrogen for a long time for various industrial uses. An energy industry or an entire hydrogen-based economy is a solution to a number of problems, but especially to those related to energy supply and security. Hydrogen must be seen as an alternative energy vector that relaxes the problem of critical infrastructure and helps reduce risks and improve the resilience of the energy sector. It offers long-term potential for a sustainable energy system that can operate without emissions of greenhouse gases and gases, based on commonly available sources. A future hydrogen infrastructure will be developed in years to come, but scientific, technical and commercial studies conducted so far have already highlighted the role of hydrogen in the future energy system based on renewable energy in Romania. The energy and raw materials used to produce hydrogen are preferably local.

Although hydrogen is already an increasingly used fuel on the transport side and its future as a fuel is certified by many specialists, the problem of switching to an extended energy system with storage and conversion to hydrogen is a highly technical problem. whose solution appeals to multiple disciplines covering several fields, from engineering research to social and economic sciences.

Planning the development of hydrogen networks throughout the chain from production to consumption is an essential part of the decision-making process of integration into national energy systems with which they must be associated with the sustainable development of energy. However, it is often difficult to compare different feasibility criteria that may be contradictory, uncertain and heterogeneous and therefore their careful evaluation and analysis is required to make objective recommendations.

References

[1] Badea G, Feiseghi R.A, *Hydrogen role in the background of technical-economic current directions*, Conference Paper, May 2012, DOI: 10.13140/RG.2.1.1397.8720

[2] Bandaru S.A., Beccera V., et.al, A General Framework for Multi-Criteria Based Feasibility Studies for Solar Energy Projects: Application to a Real-World Solar Farm, *Energies Journal*, 14(2204) 2021, pp.1-34 https://doi.org/10.3390/en14082204

[3] Edwards P.P., Kuznetsov V.L., David W.I.F., *Hydrogen energy*, Phil. Trans. Of Royal Soc. A), 365, 2007, pp. 1043–1056, DOI:10.1098/rsta.2006.1965

[4] El-Eman S.R, Ozcan H., Dincer I., Comparative cost evaluation of nuclear hydrogen production methods with the Hydrogen Economy Evaluation Program, *International Journal of Hydrogen Energy* (40), 2015, pp.11168-11177, DOI: 10.1016/j.ijhydene.2014.12.098

[5] Garcia D.A., Barbanera F., et al, Expert Opinion Analysis on Renewable Hydrogen Storage Systems Potential in Europe, *Energies Journal of Science and Technology*, 9(963), 2016, pp. 1-22., DOI:10.3390/en9110963

[6] Jovan D.J., Dolanc G., Can Green Hydrogen Production Be Economically Viable under Current Market Conditions, *Energies Journal of Science and Technology*, 13(6599), 2020, pp. 1-16., DOI: 10.3390/en13246599

[7] Naghiu G.S., Giurca I. et. al, *Comparative Analysis on the Solutions of Hydrogen Production Using Solar Energy with and without Connection to the Power Network*, The 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, 8-9 October 2015, Târgu Mureș, Romania, Procedia Technology, 22, 2016, pp. 781 – 788

[8] Simon J., Ferriz A.M., Correas L.C., *HyUnder – Hydrogen Underground Storage at Large Scale: Case Study Spain*, The 9th International Renewable Energy Storage Conference, IRES 2015, Energy Procedia No.73, 2015, pp. 136–144, doi: 10.1016/j.egypro.2015.07.661

[9] Randamente electrochimice/Chimie fizică și electrochimie, https://alili2001.files.wordpress.com/2014/12/m08_chimfiz.pdf/ (downloaded at September 10rd, 2021)

[10] Proiectul international HyUnder/Scurtă prezentare, https://mfe.gov.ro/wp-content/uploads/2021/01/31e1b03347c949e0e023e510346507ea.pdf (downloaded at September 8rd, 2021)
[11] European Commission, A Hydrogen strategy for a climate neutral Europe , adopted on 8 july, 2020, https://www.hydrogeneurope.eu/
[12] European Commission, The European Green Deal, 13 December 2019 https://ec.europa.eu/clima/policies/eu-climate-action_ro
[13] European Commission, *Guide to Cost-Benefit Analysis of investment projects,* http://ec.europa.eu/regional_policy/sources/docgener/ guides/cost/guide2008_en.pdf;
[14] Proiectul HyLaw, Topic: FCH-04-2-2016, Identification of legal-administrative barriers for the installation and operation of key FCH technologies Tip de proiect: "Supporting action", Grant nr. 735977 , Data de început: 1 ianuarie 2017, www.hylaw, www.hydrogeneurope.eu
[15] https://www.enelgreenpower.com/learning-hub/renewable-energies/hydro-gen
[16] https://cdn.hidroelectrica.ro/cdn/aga/2021/2903/ nota_aprobare_memorandum_verbund.pdf
[17] https://www.europarl.europa.eu/news/ro/headlines/society/ 20210512STO04004/energie-din-hidrogen-care-sunt-beneficiile-pentru-ue
[18] http://dezvoltaredurabila.gov.ro/web/wp-content/uploads/2020/06/RAPORT-Prof.-Tudor-Prisecaru.pdf
[19] www.opcom.ro

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