Hydrogen Production Possibilities in Slovak Republic

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Abstract: Slovak Republic is a member of the European Union and is a part of the European energy market. Although Slovakia contributes only marginally to global emissions, there is an effort to meet obligations from the Paris climate agreement to reduce greenhouse gases. As in many countries, power industry emissions dominate Slovakia’s emissions output but are partly affected and lowered by the share of nuclear energy. The transition from fossil fuels to renewables is supported by the government, and practical steps have been taken to promote the wide use of renewable resources, such as biomass or solar energy. Another step in this transition process is the support of new technologies that use hydrogen as the primary energy source. The European Union widely supports this effort and is looking for possible sources for hydrogen generation. One of the main renewable resources is hydropower, which is already used in the Slovak Republic. This article presents the current situation of the energy market in Slovakia and possible developments for future hydrogen generation.

Keywords: hydrogen; power generation; hydropower

1. Energy Production in Slovak Republic

Slovakia belongs to a group of vulnerable countries in terms of energy security; therefore, for the benefit of stability, development of the national economy, and for the benefit of the customer and their protection, Slovakia supports energy architecture that will create conditions for increased energy self-sufficiency, expand electricity export capacity, increase transparency, and optimise energy efficiency via the inclusion of low-carbon technologies. In recent years, the support of renewables was extended not only for industrial and state sectors, but also for individual consumers. The framework for all measures to reduce energy consumption is defined in the document, “Energy policy of Slovak Republic” (EP). This framework is part of the national economic strategy, which is oriented towards ensuring sustainable economic growth and the reliable supply of affordable energy with a low carbon footprint [1]. The goal is to contribute to the sustainable growth of the national economy and to enhance competitiveness by ensuring sustainable energy resources are available at optimal costs and to ensure environmental protection. The implementation of the European regulations in the national energy policy should expand and strengthen a well-functioning energy market with a competitive environment. The role of the energy policy is to create a stable framework for the secure functioning of the energy market, thus motivating investment into energy utilisation, with a primary focus on renewable resources. It pursues the interests of customers and end users who will reap the full benefits of a liberalised and secure energy market. New measures align with the main goals of the Lisbon Treaty and are based on the basic European goals of the Europe 2030 energy strategy [1,2].

The dominant renewable resource in Slovakia is biomass, especially in the form of wood, due to the high percentage of forests in the total country area. The main biomass producers in Slovakia for energy purposes are sectors of the forestry industry, agriculture, and the wood processing industry [1]. There are also some possibilities in maintaining
fast-growing plants. The method of obtaining energy from biomass depends upon the physical and chemical properties of the biomass. The amount of water and dry matter in biomass has a major impact on biomass processing. It is on this basis that wet and dry biomass processing methods are distinguished, with the approximate limit between wet and dry processes. A summary of biomass resources is outlined in Table 1.

Table 1. Biomass resources in Slovak Republic—summary [2].

| Source                        | Technical Potential (TJ) | Present Usage (TJ) |
|-------------------------------|--------------------------|--------------------|
| Forest biomass                | 20,242                   | 1778               |
| Energy crop                   | 5006                     | 372                |
| Wood processing industry      | 17,570                   | 9497               |
| Agricultural biomass          | 32,708                   | 216                |

The easiest way to obtain thermal energy from biomass is its direct combustion. It is possible to burn wood in the form of logs, wood chips, briquettes, and pellets, but also the straw of cereals and oilseeds, and energy plants in the form of bales and briquettes. The processing of organic substances with a higher water content, where the simultaneous formation of biogas occurs, is called anaerobic fermentation. Possible use of these biomass resources can contribute to a reduction in fossil fuel dependence, but emissions are still created [3].

The second most important renewable energy source is hydropower. Hydropower, as well as most other RESs, is created by solar activity. The energy that water offers us in this way can be used to produce electricity in hydroelectric power plants. The clear advantage of these sources is their flexibility, as well as the fact that they do not produce harmful emissions in the production of electricity. However, large hydropower plants and waterworks have also been shown to have negative effects on the environment and on local ecosystems. From this point of view, hydroelectric power plants with lower installed capacity, so-called small hydropower plants (SHPP), are preferred due to their lower environmental impact [4]. Present conditions of energy production in the Slovak Republic are summarized in Table 2.

Table 2. Present electric energy power plants in Slovak Republic [5].

| Primary Energy Resources | Power (MW) | Share (%) | Category  |
|-------------------------|------------|-----------|-----------|
| Nuclear                 | 1940       | 25.1      | Nuclear   |
| Hydro                   | 2543       | 33.0      | RES       |
| Lignite                  | 320        | 4.1       | Fossil fuel|
| Hard coal               | 221        | 2.9       | Fossil fuel|
| Natural gas             | 1153       | 14.9      | Fossil fuel|
| Oil                     | 257        | 3.3       | Fossil fuel|
| Mixed fuels             | 399        | 5.2       | Fossil fuel|
| Solar                   | 531        | 6.9       | RES       |
| Biomass                 | 214        | 2.8       | RES       |
| Biogas                  | 104        | 1.3       | RES       |
| Wind                    | 3          | -         | RES       |
| Other RES               | 12         | 0.2       | RES       |

Electricity is generated in Slovakia partly from renewables, but there is also a huge share of power stations that use fossil fuels. On a closer look, for example, per day
with yearly peak electricity consumption, as is presented in Table 3, the situation is even more different.

**Table 3.** Share of electricity generation on day of yearly peak [5].

| Primary Energy Resources | Share (%) |
|--------------------------|-----------|
| Nuclear                  | 46.6      |
| Hydro                    | 11.1      |
| Fossil fuels             | 21.5      |
| Solar                    | 1.0       |
| Other                    | 8.7       |
| Import                   | 9.8       |

To have complete image of electricity production, usage, and transportation, it is advantageous to use graphical visualisations. Figure 1 shows the metered cross-border flow of electricity in 2020.

![Metered (physical) Cross-Border Flows of Electricity in the year 2020 in GWh](image)

**Figure 1.** Metered cross-border electricity flow [5].

As shown in Figure 1, a huge amount of electricity is transported through the country, with only a small percentage being used for domestic consumption. A significant share of electricity production in Slovakia, more than 22% of all generated electricity, is from fossil fuels. To lower this share, there is a need to develop a wider use of renewable resources, adjusted to local conditions and natural resources. In combination with energy conservation, for example, emerging hydrogen technologies, this could be the best solution to establish a low-carbon economy in the Slovak Republic [3,6].

2. Hydrogen as a Natural Resource

The hydrogen atom is the lightest and simplest of all elements [7]. The H₂ molecule is a colourless, non-toxic, highly combustible gas with no odours and with a low density, one-fourteenth of the density of air. To condensate gas hydrogen to liquid form at atmospheric pressure, the temperature has to be reduced to 20.3 K [7]. Released hydrogen disperses rapidly. Compared with other fuels, hydrogen has the highest combustion energy per unit mass [7]. Hydrogen is used in gaseous, liquid, or slush forms. Liquid hydrogen is transparent, with a subtle light blue tint. Slush hydrogen is a mixture of liquid and solid
hydrogen at triple-point temperature. The conditions to create triple-point hydrogen are a temperature of 13.8 K and pressure of 7200 Pa [8]. The highest possible temperature at which hydrogen vapour can be liquefied is 33.145 K, which is critical temperature. The corresponding critical pressure is 1300 kPa; the density at this critical point is 31.263 kg/m$^3$. Above this temperature, it is impossible to condense hydrogen into its liquid phase just by increasing the pressure [7]. At normal conditions, temperature, pressure, etc., hydrogen is not a very reactive substance; to accelerate the reaction, a catalyst or spark is needed, which causes a violent explosion [7]. Hydrogen is an extremely flammable gas. It burns in air and oxygen to produce water. In an air chlorine mixture, it can explode spontaneously just from exposure to a spark, heat, or even sunlight [8]. The flammability range of hydrogen is from 4% to 75% by volume in air at NTP (normal temperature and pressure). Hydrogen’s flammability range expands with temperature; the flammability limit of hydrogen lowers to 3% at a temperature of 100 °C at NTP [6]. Hydrogen’s adiabatic premixed flame temperature for stoichiometric mixture in air is higher compared to other fuels, at 2403 K. Stoichiometric hydrogen-oxygen is composed of 66.66% of hydrogen and 33.33% of oxygen volume.

Hydrogen can be produced in several different ways. Thermochemical processes use thermal and chemical reactions to release hydrogen from organic materials such as fossil fuels and biomass, or from materials such as water. Microorganisms, such as bacteria and algae, can produce hydrogen through biological processes. Some thermal processes use energy from various sources such as natural gas, coal, or biomass that release hydrogen from their molecular structures [9]. In other processes, heat in combination with closed chemical cycles produces hydrogen from raw materials such as water. Natural gas reforming is an advanced production process, where hydrogen is produced by reforming natural gas in large chemical plants. Biomass gasification is a technological path that uses controlled processes involving heat, steam, and oxygen to convert biomass to hydrogen and other products, without combustion [9].

The production costs for various hydrogen production methods are shown in Table 4. The table shows methods that are currently available, with specified hydrogen production mode and efficiencies. All of these methods use electrolysis as the basic process of hydrogen production.

**Table 4.** Some hydrogen production methods and costs.

| Energy Source          | Production Route | Plant Efficiency | H$_2$ Cost (USD/kg) | Reference          |
|------------------------|------------------|------------------|----------------------|--------------------|
| Wind                   | PEM electrolysis | 52               | 5                    | Bertuccioli et al. [10] |
| Nuclear (VHTR)         | SOEC electrolysis| 55.8             | 2.47                 | Yang et al. [11]    |
| Solar PV + grid        | PEM electrolysis | 9.76             | 6.1                  | Shanner et al. [12] |
| Solar PV               | PEM electrolysis | 9.76             | 12.1                 | Shanner et al. [12] |
| Biogas                 | PEM electrolysis | 65               | 3.43                 | Abusoglu et al. [13] |
| Off-peak grid electricity | HTSE            | 52               | 2.25                 | Harvego et al. [14] |

These technologies are well-developed and commercially available, and systems are being developed that can efficiently use intermittent renewable energy. Electrolysis is a promising option for the production of carbon-free hydrogen from renewable and nuclear sources. Electrolysers can vary in size, from small plant sizes that are suitable for small-scale distributed hydrogen production, to large-scale central plants that can be directly linked to renewable or other non-greenhouse-gas-generating forms of electricity generation.

3. Possible Energy Production Expansion

Securing hydrogen production and storing surplus energy from renewable sources is not very advantageous in the current situation in the Slovak Republic. To ensure a continu-
ous supply of energy to electrolysers for hydrogen production, it is necessary to expand existing energy sources or add new energy sources, which would use potential low-carbon sources available in Slovakia [3]. The completion and expansion of the nuclear power plant in Mochovce is currently underway, where the number of reactors will increase twofold, and the total output capacity of the power plant will increase by 942 MW [3]. Compared to fossil fuel power plants, the new Mochovce units will prevent the release of approx. 5.2 million tons of CO$_2$ emissions into the atmosphere every year. That is, the equivalent of more than two million cars and trucks will have disappeared from Slovak roads [15]. The new units will replace the capacity shortage of the Novaky brown coal-fired power plant, which will be in operation until the end of 2023, as well as Slovakia’s negative balance in electricity imports and exports [3]. Slovakia will thus become self-sufficient again in supplying the country with electricity and will be prepared for higher electricity consumption in the future, which will come with the development of electromobility [15–17]. However, the biggest problem of nuclear power plants remains spent nuclear fuel, which needs to be processed and then stored for a long time at considerable cost, which will be reflected in the final price of electricity.

The second energy source that is currently in use is hydropower. This source does not burden the environment as much, and some water structures can also be used for recreational purposes, such as the Orava dam. In comparison to other European countries, as can be seen in Table 5, there are still options to enhance use of hydropower in Slovakia [18,19].

Table 5. Utilisation of primary hydroelectric potential [6].

| Country | Utilisation (%) | Installed Capacity (MW) |
|---------|-----------------|-------------------------|
| France  | 96.7            | 25,508                  |
| Great Britain | 75.2 | 4712                   |
| Germany | 74.4            | 11,022                  |
| Austria | 67.3            | 14,597                  |
| Finnland| 63.9            | 3263                    |
| Slovakia| 56.7            | 2522                    |
| Romania | 43.3            | 6313                    |
| Bulgaria| 30.7            | 3129                    |

In Slovakia, several hydroelectric power plants have been built on the largest rivers, Vah and Danube, in recent decades. Their purpose is not only to generate electricity, but also to regulate the flow of rivers to prevent floods, which often cause property damage. On the river Vah, which is Slovakia’s longest river, there is a system of dams called Vah cascade. The largest hydroelectric power plant is built on the Danube River, where flow regulation allows shipping even during periods of lower water flow in the river. An overview of the most important hydropower plants is given in the following Table 6.

The Energy Security Strategy of the Slovak Republic states that hydropower is the most widely used renewable energy source for electricity generation in the Slovak Republic. The technically usable potential for hydropower generation is 6683 GWh (24 PJ). This use is mainly due to the construction of large hydroelectric power plants, the total installed capacity of which is 1531 MW. However, only 25% of the potential suitable for small hydropower plants is used [6]. Given the suitability of connecting all hydropower plants to the electricity system, there is a need to order their construction in order to maximize the technical potential, not only for direct use, but also for hydrogen production via electrolytic process. The hydropower potential of Slovakia’s most important rivers is described in Table 7.
Table 6. Important hydroelectric power stations [6].

| Name         | Location       | Capacity (MW) | Notes                  |
|--------------|----------------|---------------|------------------------|
| Cierny Vah   | Cierny Vah     | 735           | Pumping hydropower     |
| Gabcikovo    | Gabcikovo      | 720           |                        |
| Liptovska Mara | Liptovska Mara | 198           | Pumping hydropower     |
| Miksova      | Miksova        | 94            |                        |
| Zilina       | Zilina         | 72            |                        |
| Nosice       | Nosice         | 68            |                        |
| Ruzin        | Ruzin          | 60            | Pumping hydropower     |
| Povazska Bystrica | Povazska Bystrica | 55           |                        |
| Kralova      | Kralova nad Vahom | 45         |                        |

Table 7. Hydropower potential of important rivers [6].

| Hydrological Basin | Total Theoretical Hydropower Potential (GWh/a) | Technical Hydropower Potential (GWh/a) | Current Utilisation (%) |
|--------------------|-----------------------------------------------|---------------------------------------|------------------------|
| Morava             | 113                                           | 29                                    | -                      |
| Dunaj              | 3394                                          | 2511                                  | 63                     |
| Váh a Malý Dunaj    | 5953                                          | 2985                                  | 62                     |
| Nitra              | 320                                           | 72                                    | -                      |
| Hron               | 1406                                          | 427                                   | 14                     |
| Ipeľ                | 157                                           | 34                                    | -                      |
| Slaná              | 314                                           | 96                                    | -                      |
| Bodva              | 65                                            | 3                                     | -                      |
| Hornád             | 807                                           | 262                                   | 16                     |
| Bodrog             | 692                                           | 138                                   | 17                     |
| Poprad a Dunajec    | 461                                           | 143                                   | -                      |

The table shows the amount of the total theoretical hydropower potential of watercourses in the Slovak Republic and the amount of technical hydropower potential of watercourses in the Slovak Republic, broken down by river basin. To map the hydropower potential of watercourses in the Slovak Republic, the current state of its use and the prospective possibilities of its further use, the database of the Research Institute of Water Management in Bratislava was used as a starting technical basis. The output of this review is an inventory of the hydropower potential of watercourses in the Slovak Republic, the current state of its use, and the possibilities of its further use, along with a design of technically usable sites for the location of hydroelectric power plants. The results are presented in Table 8. These hydroelectric power stations can be used as a main source of possible hydrogen production.

Harnessing the hydropower potential of rivers for electricity generation is a highly positive, global, long-term measure to reduce significant negative impacts on the environment and health, as it is one of the most environmentally friendly ways of obtaining electricity. In combination with other renewable resources, this electrical energy can be used to generate hydrogen [20,21]. As mentioned in Table 4, in second chapter, one of the possibilities is the use of so-called off-peak grid electricity, where energy is used when it is available and is not in demand. This grid-based production is considered a base model for future hydrogen generation. There is also a need to distinguish between total electricity costs and costs for different sources. The electricity costs of different sources are shown in Table 9.
Table 8. Technically usable hydropower potential [1,6].

| Hydroelectric Power Station Output | Amount Planned | Planned Total Power Output (MW) | Power Output (GWh/annum) |
|-----------------------------------|----------------|---------------------------------|--------------------------|
| LHPP over 10 MW                   | 4              | 241                             | 1159.2                   |
| SHPP from 1 MW to 10 MW           | 69             | 116.22                          | 587.45                   |
| SHPP from 0.1 MW to 1 MW          | 125            | 36.75                           | 179.00                   |
| SHPP to 0.1 MW                    | 174            | 6.90                            | 30.80                    |
| Total                             | 372            | 400.87                          | 1956.45                  |

Table 9. Costs of electricity [9].

| Category | Type                    | LCOE (USD/kWh) |
|----------|-------------------------|----------------|
| Coal     | Partly CO₂ capture      | 0.140          |
| Natural gas | Combined cycle       | 0.057          |
| nuclear  |                         | 0.099          |
| biomass  |                         | 0.102          |
| Solar    | photovoltaics           | 0.085          |
| hydroelectric |                   | 0.066          |

With different electricity sources coupled to the grid, it is possible to calculate some average electricity costs and final hydrogen production costs. If the electrolyzers can be coupled directly with chosen renewable resources, they can produce cheap, green hydrogen [21]. When there is surplus energy in the grid, it is possible to produce hydrogen using electricity from the grid. The use of hydrogen in Slovakia is still confined to the chemical industry. Using hydrogen as a fuel additive for CNG-powered vehicles is currently being considered, where a mixture of CNG and hydrogen would be formed, with a hydrogen content of up to 20% [22]. The increased output of hydropower plants, according to Table 8, would make it possible to produce up to 42,531 tonnes of hydrogen per year at an electrolyzer efficiency of 73%. This could be, according to the diagram in Figure 2, stored in storage tanks as an energy supply for later use, and some could be used in a mixture with natural gas for household use and for CNG-powered vehicles [23]. It is also envisaged to mix hydrogen into the existing pipeline network, not supplying natural gas to the end user, but its mixture [24,25]. These projects are part of the European power to gas projects.

By gradually building the proposed hydropower plants and gradually increasing the use of river potential, it would be possible to achieve the production of a certain amount of green hydrogen from renewable sources by 2050. Figure 3 presents the possibilities of hydrogen production. The negative scenario considers the construction of new power plants and the decommissioning of unsatisfactory ones. The real situation represents an annual increase in the use of hydropotential by 1% while the existing power plants are being renewed. The positive scenario assumes an annual increase in the use of hydropotentiality by 1.5%.
4. Conclusions

To use the potential of small rivers, so-called small hydropower plants (SHPP) can be utilized. Most small hydropower plants serve as a seasonal resource. The flows of streams on which SHPPs are set up fluctuate and often depend on the weather and the season. They are, therefore, not ideal for year-round electricity production, but if the electricity can be converted to hydrogen, the surplus energy from the river can be stored for use later in the year. Small hydropower plants are also characterised by the fact that their construction and operation are not usually associated with negative impacts on the environment. Like large hydropower plants, SHPPs are characterized by high efficiency of hydropower use. In addition, they have the advantage of being a decentralised energy source. By being able to be installed in remote areas, they provide opportunities for development and offer energy self-sufficiency, especially in rural areas. This also provides an opportunity for Slovakia to capitalise on the potential of the smaller rivers that flow through its undeveloped regions, and if this opportunity is taken advantage of, it can provide new jobs and accelerate the economic development of these regions, where a significant amount of the population lives.
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References
1. Energy Policy Draft of the Slovak Republic; Ministry of Economy of the Slovak Republic: Bratislava, Slovakia, 2021.
2. Low-Carbon Growth for Slovakia: Implementation of the EU Framework of Climate and Energy Policies until 2030; Ministry of Economy of the Slovak Republic: Bratislava, Slovakia, 2019.
3. National Energy Action Plan from Renewable Sources; Ministry of Economy of the Slovak Republic: Bratislava, Slovakia, 2010.
4. The Concept of Using the Hydropower Potential of Watercourses in the Slovak Republic until 2030; Ministry of Economy of the Slovak Republic: Bratislava, Slovakia, 2020.
5. Ročensky SED. Available online: https://www.sepsas.sk/sk/dispecing/rocne-udaje-o-prevadzke/rocenky-sed/ (accessed on 4 January 2022).
6. Low Carbon Development Strategy of the Slovak Republic to 2030 with a View to 2050; Ministry of Economy of the Slovak Republic: Bratislava, Slovakia, 2021.
7. Subramani, B.V. Compendium of Hydrogen Energy Volume 1: Hydrogen Production and Purification; Woodhead Publishing: Cambridge, UK, 2015.
8. Sorensen, B. Hydrogen and Fuel Cells: Emerging Technologies and Applications; Elsevier Academic Press: Cambridge, MA, USA, 2005.
9. El-Emam, R.S.; Özcan, H. Comprehensive review on the techno-economics of sustainable large-scale clean hydrogen production. J. Clean. Prod. 2019, 220, 593–609. [CrossRef]
10. Bertuccioli, L.; Chan, A.; Hart, D.; Lehner, F.; Madden, B.; Standen, E. Development of water electrolysis in the European Union. Fuel Cells Hydrog. Jt. Undertaking 2014. Available online: https://www.fch.europa.eu/node/783 (accessed on 4 January 2022).
11. Yang, K.J.; Lee, K.Y.; Lee, T.H. Preliminary Cost Estimates for Nuclear Hydrogen Production: HTSE System. In Proceedings of the 2008 Spring Meeting of the Korean Nuclear Society, Kyeongju, Korea, 29–30 May 2008.
12. Shaner, M.R.; Atwater, H.A.; Lewis, N.S.; McFarland, E.W. A comparative technoeconomic analysis of renewable hydrogen production using solar energy. Energy Environ. Sci. 2016, 9, 2354–2371. [CrossRef]
13. Abusoglu, A.; Demir, S.; Ozahi, E. Energy and economic analyses of models developed for sustainable hydrogen production from biogas-based electricity and sewage sludge. Int. J. Hydrog. Energy 2016, 41, 13426–13435. [CrossRef]
14. Harvego, E.A.; McKellar, M.G.; Sohal, M.S.; O’Brien, J.E.; Herring, J.S. Economic Analysis of the Reference Design for a Nuclear-Driven High-Temperature- Electrolysis Hydrogen Production Plant.; Idaho National Laboratory: Idaho Falls, ID, USA, 2008.
15. The Concept of Using the Hydropower Potential of Watercourses in the Slovak Republic until 2030; Adopted by the Resolution of the Government of the Slovak Republic No.178/2011; Ministry of Economy of the Slovak Republic: Bratislava, Slovakia, January 2011.
16. Brestovič, T.; Carnogurska, M.; Prihoda, M.; Lukac, P.; Lázár, M.; Jasminska, N.; Dobaková, R. Diagnostics of hydrogen-containing mixture compression by a two-stage piston compressor with cooling demand prediction. Appl. Sci. 2018, 8, 625. [CrossRef]
17. DOE Technical Targets for Hydrogen Production from Electrolysis. Available online: https://www.energy.gov/eere/fuelcells/doe-technical-targets-hydrogen-production-electrolysis (accessed on 4 January 2022).
18. Hanley, E.S.; Deane, J.P.; Gallachoir, B.P.O. The role of hydrogen in low carbon energy futures—A review of existing perspectives. Renew. Sustain. Energy Rev. 2017, 82, 3027–3045. [CrossRef]
19. Kakoulaki, G.; Kougias, I.; Taylor, N.; Dolci, F.; Moya, J.; Jager-Waldau, A. Green hydrogen in Europe—A regional assessment: Substituting existing production with electrolysis powered by renewables. Energy Convers. Manag. 2021, 228, 113649. [CrossRef]
20. Dincer, I.; Acar, C. Review and evaluation of hydrogen production methods for better sustainability. Int. J. Hydrog. Energy 2015, 40, 11094–11111. [CrossRef]
21. Abad, A.V.; Dodds, P.E. Green hydrogen characterisation initiatives: Definitions, standards, guarantees of origin, and challenges. Energy Policy 2020, 138, 111300. [CrossRef]
22. Kouchachvili, L.; Entchev, E. Power to gas and H-2/NG blend in SMART energy networks concept. Renew. Energy 2018, 125, 456–464. [CrossRef]
23. Lo Basso, G.; Nastasi, B.; Garcia, D.; Cumo, F. How to handle the Hydrogen enriched Natural Gas blends in combustion efficiency measurement procedure of conventional and condensing boilers. Energy 2017, 123, 615–636. [CrossRef]
24. Vodík v Sieti SPP-D. Available online: http://svse-aem.cz/wp-content/uploads/2021/02/Vodik-v-sieti-SPP-D.pdf (accessed on 10 January 2022).

25. De Santoli, L.; Lo Basso, G.; Nastasi, B. The Potential of Hydrogen Enriched Natural Gas deriving from Power-to-Gas option in Building Energy Retrofitting. *Energy Build.* 2017, 149, 424–436. [CrossRef]