energies

MDPI

Review

Analysis of the Existing Barriers for the Market Development of Power to Hydrogen (P2H) in Italy

Cesare Saccani [1], Marco Pellegrini [2,3] and Alessandro Guzzini [3,*]

1 Department of Industrial Engineering (DIN), University of Bologna, Viale Risorgimento, 2-40136 Bologna, Italy; cesare.saccani@unibo.it
2 Department of Industrial Engineering (DIN), University of Bologna, Via Fontanelle 40, 47121 Forlì, Italy; marco.pellegrini3@unibo.it
3 CIRI FRAME, University of Bologna, via Sant'Alberto 163, 48123 Ravenna, Italy
* Correspondence: alessandro.guzzini2@unibo.it

Received: 4 August 2020; Accepted: 11 September 2020; Published: 16 September 2020

Abstract: New technological solutions are required to control the impact of the increasing presence of renewable energy sources connected to the electric grid that are characterized by unpredictable production (i.e., wind and solar energy). Energy storage is becoming essential to stabilize the grid when a mismatch between production and demand occurs. Among the available solutions, Power to Hydrogen (P2H) is one of the most attractive options. However, despite the potential, many barriers currently hinder P2H market development. The literature reports general barriers and strategies to overcome them, but a specific analysis is fundamental to identifying how these barriers concretely arise in national and regional frameworks, since tailored solutions are needed to foster the development of P2H local market. The paper aims to identify and to analyze the existing barriers for P2H market uptake in Italy. The paper shows how several technical, regulatory and economic issues are still unsolved, resulting in a source of uncertainty for P2H investment. The paper also suggests possible approaches and solutions to address the Italian barriers and to support politics and decision-makers in the definition and implementation of the national hydrogen strategy.

Keywords: hydrogen; power to hydrogen; smart grid; electrolysis; hydrogen grid; green hydrogen

1. Introduction

Among energy systems, the electrical one can lead the transition between fossil and renewable energy sources agreed in the Paris Agreement [1], even if only a few of the signatory countries have put into practice very ambitious plans [2]. However, something changed in the last two decades. As reported by data, in fact, world renewable energy production has rapidly grown since 2003 [3]. Particularly, focusing on the European energy market, renewable energy accounted for almost 25% of the total production in 2016, while it represented 10% at the beginning of the 1990s [4].

Italian renewable electricity production reached 30% in 2016, i.e., doubling with respect to 1990 [5]. In addition, further progress in renewable energies are expected in the near future. In fact, according to the European energy strategy, in 2019, the Italian government approved the Energy and Climate Plan [6] in which three main targets were defined: (i) a reduction of the primary energy consumption, i.e., -43% compared to the European reference scenario [7], (ii) an increase in renewable production up to 30% of the gross final energy consumption and (iii) a reduction of 40% of greenhouse gas emission. Almost 55.4% of the estimated electricity consumption in 2030, i.e., 16.1 Mtoe, is planned to be covered by renewable sources, in particular, 6.3 Mtoe (39.9%) and 3.4 Mtoe (21.5%) should be produced, respectively, by photovoltaics and wind turbines.

As a result, the already achieved increase in renewable power sources connected to the grid is moving towards a "renewable electrical network". Such a huge transformation should be accompanied by the development of challenging strategies and new tools for Italian grid management and operation to ensure the grid's stability despite the rising unpredictability of power production [8,9]. Otherwise, detrimental damage can occur to the electrical devices and to generators.

Since the management of grids characterized by a high percentage of unpredictable renewable power generation is critical for the renewable scenario's success, solutions are required as soon as possible. For example, a first approach may focus on the improvement of the forecasting tools to predict non-programmable renewable energy production with a greater accuracy, but it was too complex to be effectively realized [10]. A second approach involves the introduction of an intermediate element between power generation and consumption, i.e., the energy storage. The need for an improvement of the Italian grid was firstly and implicitly introduced by the Italian Regulatory Authority's Act n° 344/2012/R/EEL in 2012 [11], which lays down in law that the Transmission System Operator (TSO) could disconnect renewable energy plants to solve grid congestion or grid instabilities [12]. In fact, since steam and combined cycle power plants accounted for almost 50% of national installed capacity [13] and a long time is required to regulate their instantaneous power production [14,15], renewable power plant disconnection was considered the preferred solution. A different approach is required to not waste the increase in national renewable capacity. For this purpose, a storage capacity of 1 TWh/day was estimated in 2019 to ensure Italian daily needs [6]. Nevertheless, no final decision was still taken about how to store the excess electrical energy.

A wide literature exists about available electric storage technologies [16–20], but the selection of the best solution is highly influenced by local frameworks. However, among the different solutions for the Italian grid, electrical batteries attracted great attention over time. Terna S.p.A., the Italian electrical TSO, performed two experimental research projects, i.e., the Storage Lab and the Large Scale Energy Storage, aiming to test and to validate the performances of different electrical batteries connected to the Italian transmission grid [21]. However, although electrical batteries are considered a mature and reliable technology, several issues have to be considered for a wide application in Italy. First of all, the Italian manufacturing capacity of batteries in 2017 was limited to 67 companies with 90,000 devices produced, with a turnover of EUR 1.39 billion and approximately 2900 employers, as reported in [22]. In addition, almost 2/3 of the world battery manufacturing currently takes place in China and only 3% in Europe [23]. Secondly, raw material availability, i.e., lithium, cobalt and nickel for lithium batteries, is a very critical issue [24]. For example, [0.114, 1.38] kg of lithium [25], [0.143, 0.394] kg of cobalt [26] and about 0.68 kg of nickel [27] are required to produce a 1 kWh lithium battery. None of these materials is present in Italy or in Europe more generally; only small amounts of cobalt are present in Finland. Therefore, since their presence is restricted to a few areas of the world [28], possible complications in accessing raw materials could occur in the future. Thirdly, economic and environmental barriers related to batteries recycling also have to be accounted for [29]. In particular, considering lithium battery technology, almost 0.3 kWh of energy and 800 L of water are consumed for 1 kWh of storage capacity [30]. In addition, 40–340 kg/kWh of greenhouse gas emissions are estimated to be emitted during the whole manufacturing process [31]. From these data, 0.3 GWh of energy, 0.8 billion of m^3 of water and greenhouse gas emissions between $[4 \times 10^7, 3.4 \times 10^8]$ tons, i.e., equivalent to the emissions of the generation of up to 1100 TWh by the national park, would completely satisfy the reported national storage demand. Based on 2019 Italian electrical consumption [32], i.e., 320 TWh/year, more than three years of energy production would be required to emit the same amount of greenhouse gases. Moreover, recovery processes are currently responsible for costs and emissions greater than those obtained in the case of the purchase of new materials, as reported in [33] and [34]. In addition to these reflections, it should be noted that hazardous wastes are contained in exhausted batteries and so they have to be properly treated in accordance with existing regulations [33].

For the abovementioned reasons, the adoption of electrical batteries as the national storage solution does not appear the best choice for the Italian case and other energy storage strategies should be considered. Compressed Air Energy Storage (CAES) has received greater attention over time [35]. The CAES system principle consists in the use of a compressor during off-peak periods to compress air into underground or aboveground storage systems such as, for example, caverns, and then expand such air through turbines for electricity generation during high demand periods [36]. Despite the great potential of the technology, key technical challenges still hinder its development such as, for example, the presence of caverns or other dedicated storage structures able to store a large amount of air pressurized at high pressure (100 bar) and at temperatures up 650 °C, avoiding perturbations to the surface and subsurface environment [37]. Pumped Storage Hydropower (PSH) is a well-exploited technology since Italy accounts for the greatest installed capacity in the European framework [38]. As for CAES, PHS systems exploit water energy potential. In fact, during off-peak periods, water is pumped from a lower reservoir and stored in an upper one, waiting to convert this energy potential into electricity during high demand periods [39]. Even if the technology is characterized by a long lifetime and a huge installed capacity, geographical constraints such as, for example, the need for a relatively large water reservoir and reservoir level differences and the potential impact on the local environment, often discourage the realization of new plants [40]. The Power to Gas (P2G) solution, based on chemical energy storage, is a very interesting alternative to power storage in batteries [41]. Figure 1 shows a schematization of the P2G concept. As is shown, several purposes can be considered for hydrogen that is produced by water electrolysis [42]. For example, it can be (i) converted back into electricity and heat through the use of fuel cells [43]; (ii) directly used as a raw material for industrial processes [44] (industrial hydrogen demand is estimated to equal 560,000 tons/year in Italy [45]); (iii) used as fuel in the transport sector [46], i.e., in spark ignition fuel engines [47] and in fuel cell vehicles [48]; (iv) converted into Synthetic Natural Gas (SNG) through chemical or biological reactions, i.e., Power to Methane (P2M) [49,50]; (v) injected into the natural gas network [51].

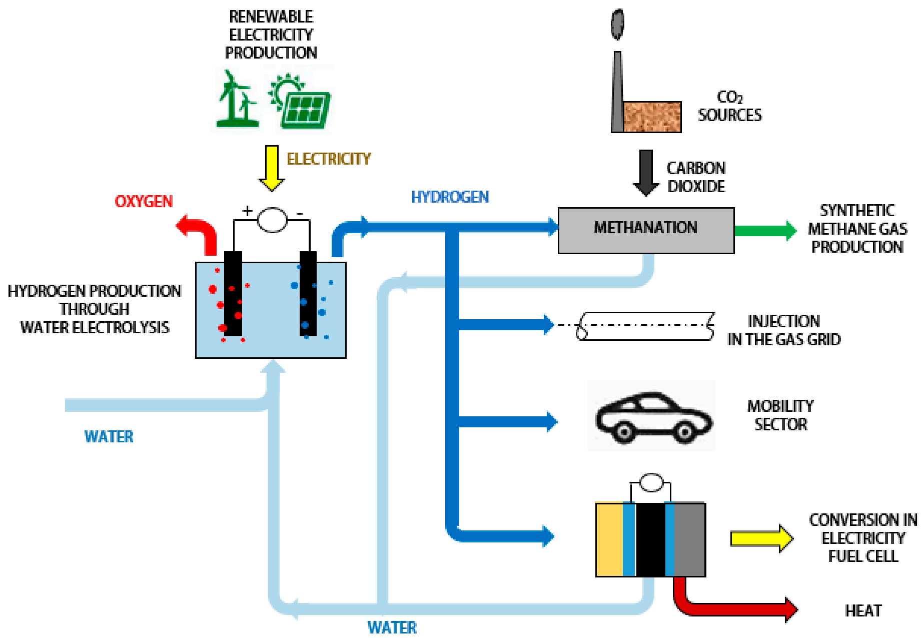

Figure 1. Schematization of Power to Gas (P2G) concept.

Among possible P2G configurations, Power to Hydrogen (P2H) is the simplest and most reliable. Moreover, renewable hydrogen (also called "green hydrogen") production is a crucial element in the recent "hydrogen strategy for a climate-neutral Europe" promoted in 2020 by the European Commission [52], and so the adoption of P2H as the key element for Italian power grid storage can play a relevant role in the rising European hydrogen strategy. Furthermore, if compared to other P2G configurations, P2H is the one with the highest Technology Readiness Level (TRL), and thus is easier to be designed and realized as an effective and reliable solution. However, despite the potential, only 84 P2H plants with a nominal capacity from a few kW up to 6 MW have been realized in the world since 2019 [53], and four are active plants in Italy. Nevertheless, despite the small number of plants, the hydrogen topic has attracted funds and interest in recent years. Based on (i) the Fuel Cells and Hydrogen Joint Undertaking (FCHJU), (ii) the Hydrogen Europe and (iii) CORDIS databases [54–56], 152 projects with at least one Italian participant were funded within the Horizon 2020 research program (63 projects), the Eranet program (two projects), and the 7th Framework Program (FP7) (87 projects). Among these, 29 projects (19% of the 152) were coordinated by Italian partners [57–85].

So, the question is "why is P2H Italian potential still unexploited?" The simplest answer is linked to the presence of barriers that currently hinder its deployment. Unfortunately, since different countries have different barriers, no common solution can be proposed and dedicated analysis of national frameworks is required to propose an effective approach to tackle the barriers. Therefore, based on the activities of the "*Synergies Utilising renewable Power REgionally by means of Power To Gas*" (SuperP2G) project, this paper aims to show the results of the barrier analysis for P2H development in Italy. In fact, the analysis is necessary since several technical, economic and regulatory barriers are now limiting P2H development in Italy and result in a very limited realization of industrial-sized plants. Therefore, the final goal of this paper is to define how the barriers that have already been identified in the literature can be specifically lowered in the Italian framework to better address them through tailored strategies.

2. Classification and Review of the Main Barriers Against P2H Development

The methodology to classify and to lower the main barriers to the Italian case for P2H development is described in this section of the paper. A review of the internationally recognized barriers is given. Since the aim of the paper is not to rank the identified barriers on the basis of qualitative or quantitative criteria, the methodology description refers only (i) to the identification of barriers as found in the literature, (ii) to the splitting into typologies (economic, technical, normative/operational, social) and into P2H value chains and (iii) to the barrier contextualization by considering the Italian framework. Further development of the analysis will include the weighting of the different identified barriers at present and under future scenarios (for example, through an analytical hierarchical process).

2.1. Classification of the P2H Barriers

The P2H supply chain was divided into three steps to classify P2H barriers. As shown in Figure 2, the three steps are: (i) production and storage, (ii) transportation and (iii) utilization. A similar hydrogen market classification was also suggested by [86,87], but in this paper, hydrogen production and storage are considered in the same section since P2H production plants usually account for both sections.

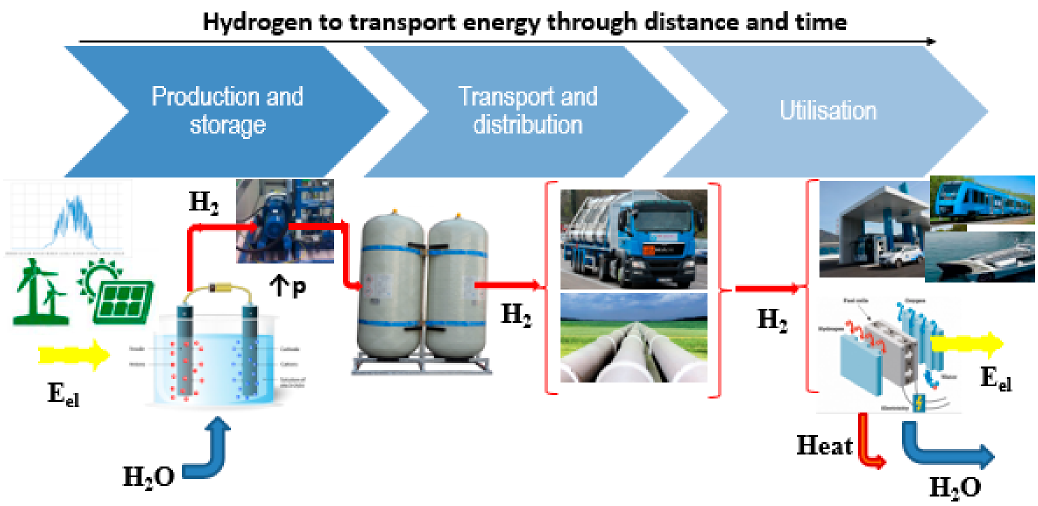

Figure 2. Power to Hydrogen (P2H) chain: (1) hydrogen production by water electrolysis and renewable energy, hydrogen storage, hydrogen distribution and hydrogen final consumption.

The following assumptions are also considered for the purpose of the paper:

- Hydrogen may be produced through a variety of processes. However, only fully or partially decarbonized hydrogen produced by water electrolysis is considered in the paper. Therefore, fossil-based hydrogen, produced from fossil fuels such as, for example, methane and coal, is not considered in the analysis.
- The amount of carbon dioxide emitted during hydrogen production depends on the electrical source used to supply the process. Two possible integration schemes in the Italian energy context are considered:
    - The P2H production and storage plant is installed close to the renewable power plant. Hydrogen production is simultaneous with renewable power production and no carbon dioxide is emitted.
    - The P2H production and storage plant is installed away from the renewable power plant and the electrical energy is supplied by the national grid. In this case, since both renewable and traditional fossil fuels plants contribute to the Italian energy mix, hydrogen production is not fully decarbonized.
- All the proposed storage technologies reviewed by [88] are considered in the analysis. However, since it is characterized by a TRL adequate for market applications, only compressed gaseous storage is represented in Figure 2.
- Concerning hydrogen transportation from P2H plant to final utilization, transport by means of trucks, trains and ships, the injection into natural gas pipelines or the realization of a dedicated infrastructure for hydrogen transport are considered.

Recognizing the main steps of the P2H chain, a literature review was performed. For this purpose, barriers were classified into four categories in accordance with the following:

1. Economic barriers: those barriers that affect P2H market penetration due to their negative impact on economic sustainability.
2. Technical barriers: those barriers related to each component and/or to the process as a whole that limit P2H efficiency, effectiveness, reliability and safety.
3. Normative and operational barriers: those barriers that derive from a non-adapted legislative and/or standard framework or a lack thereof which prevents, seriously hinders or lengthens the duration of the realization of P2H projects.
4. Social barriers: those barriers that are related to the lack of awareness, familiarity and general acceptance of P2H by citizens and end users.

2.2. Review of the Main Barriers Against P2H Development

Coherently with the methodology described in the previous section, the literature review gave the following result:

2.2.1. Economic Barriers

The literature agrees with the fact that the main economic barriers concern (i) investments (CAPEX), (ii) operative costs (OPEX) and (iii) final hydrogen production cost, which includes hydrogen generation, storage and transport. Table 1 reports a comparison between CAPEX and OPEX for the most common hydrogen production technologies. For this purpose, P2H is compared with methane steam reforming with and without Carbon Capture, Utilization and Storage (CCUS). Coal and oil reforming are not considered in accordance with the Italian energy plan that aims to decarbonize the national energy sector. As is shown, P2H currently shows greater CAPEX and OPEX, discouraging investments. Table 2, however, shows the same comparison between hydrogen and reference technologies for energy storage. In this case, fuel cell or turbine technologies are considered when integrated with the P2H plant in order to convert the hydrogen produced into electricity. As shown from a preliminary analysis, P2H currently represents the worst solution for the energy storage target from an economic point of view. The absence of appropriate incentive strategies and of the application of tax breaks, subsidies or penalties on conventional alternatives to encourage market uptake are included in the literature as further relevant economic barriers [89].

Table 1. Economic barriers. Capital Expenditure (CAPEX) and Operative Expenditure (OPEX) are referred to by the unit of hydrogen produced (kg).

Economic Barriers			
Technologies (*)	**CAPEX (€/kW)**	**OPEX (€/(MWh)) (**)**	**Hydrogen Production Cost (€/kg) [90]**
P2H	750–1200 [91]	75–85	2.5–6.4
Steam methane reforming with Carbon Capture and Utilization (CCUS)	575–625 [92]	35–41	1.3–2.5
Steam methane reforming without CCUS	420–520 [92]	33–40	0.8–2.7

(*) Coal reforming is not considered in accordance with the decarbonization plan defined by the Italian government. (**) OPEX was calculated with the following assumptions: Average electricity purchase cost in the Italian market: EUR 50/MWh [93]; Gas purchase cost in the Italian market: EUR 26.40/MWh [94]; P2H: 60–70%. [42] Only hydrogen production and compression are considered; Steam methane reforming efficiency: 70–85% [95] (a reduction of 5% is assumed in the case of CCUS to take into account additional consumption); Fixed Operative and Maintenance (O&M) costs: conservatively assumed to be equal to 4% both for P2H and for steam methane reforming options.

Table 2. Economic barriers. CAPEX and OPEX are referred to by the unit of power (kW) stored. Data from [96].

Economic Barriers			
Technologies	**CAPEX (€/kW)**	**OPEX (€/(MWh)) (****)**	**Levelized Cost of Storage (€/MWh)**
P2H (*)	1360–4674	140–170	250–370 (*****)
Electric battery (**)	874–4182	65–125	150–750
PSH plants	1030–1675	75–85	50–250
CAES plants (***)	774–1338	68–80	75–325

(*) P2H is assumed to convert hydrogen into electricity. In particular, fuel cells and gas turbines are considered. (**) Different technologies are included in the range: lead acid, NaS, Ni-Cd, ZEBRA, Li-Ion, VRFB, Zn-Br, PSB, Fe-Cr, Zn-air. (***) Aboveground and underground CAES are considered. (****) OPEX was calculated with the following assumptions: Average electricity purchase cost in the Italian market: EUR 50/MWh [93]; Fixed O&M costs: assumed 4% both for P2H and for steam methane reforming options; P2H efficiency: 33–42%. Hydrogen conversion into electricity is considered; Battery efficiency: 60–88%; PSH efficiency: 70–82%; CAES efficiency: 70–90%. (*****) The LCOS for P2H was calculated assuming an average electricity purchase cost of EUR 50/MWh and working hours equal to 3500 h/year. LCOS for other technologies are in accordance with [96].

2.2.2. Technical Barriers

Among technical barriers, several authors agree that the main one is the relatively low efficiency of water electrolysis in comparison with other storage competitors [97]. Furthermore, a low hydrogen energy density is required for high compression work, which further reduces the whole cycle efficiency and puts relatively high pressure on the operation for effective storage and transport and on application in the mobility sector [98]. Table 3 compares P2H efficiency with other technologies. As for the previous tables, P2H is compared with steam reforming and with electrical storage technologies separately. As is shown, improvements are required in order to improve state-of-the-art performances. In Table 4, energy density is reported only for storage technologies since, in the case of hydrogen production for direct utilization, storage should not represent a crucial requirement since hydrogen production would be controlled in accordance with the processes' demands. On the other hand, storage is crucial for energy storage applications. As is shown, P2H seems to be the best solution in accordance with hydrogen LHV, i.e., 120.000 kJ/kg. However, due to its density, i.e., 0.0899 kg/Nm^3, great volumes or pressures are required in order to store a defined amount of energy. The same concept also applies for CAES. Even if it represents the only way to increase gas density, compression represents an additional energy loss, in accordance with the isentropic compressor's efficiency. For example, commercial hydrogen compressors declare efficiencies in the range 65–85% up to 70 bar, while values down to 52% can be reached in the case of higher pressure, i.e., up to 350 bar. Other issues are the limitations to hydrogen injection into the natural gas networks. The current allowed blending percentage of hydrogen into the natural gas network may vary from 1% in Finland to 6% in France [99]. Moreover, very severe requirements have to be respected in terms of safety, fuel quality control [100] and possible negative impacts on existing network components [101], like compressors, turbines or end-user equipment (i.e., burners or furnaces). In addition, some authors also suggested considering the low number of large-scale applications (in the period 2015–2019, the mean size of P2H projects was 0.64 MW [102]) and the inadequate competence of involved stakeholders in P2H technologies [103].

Table 3. Technological barriers. Technologies' performances.

Technological Barriers	
Technologies	**Efficiency**
P2H (only hydrogen production)	60–70% [42]
Steam reforming	70–85% [95]
P2H (conversion of hydrogen into electricity)	33–42% [96]
Electric battery	60–88% [96]
CAES	70–90% [96]
PSH	70–82% [96]

Table 4. Technological barriers. Energy density data from [104] except for P2H, which was preliminarily calculated.

Technological Barriers	
Technologies	**Energy Density (kWh/m^3)**
P2H (conversion of hydrogen into electricity) (*)	6–9 @5bar 85–125 @70 bar 360–540 @ 300 bar
Electric battery	4.20–957
CAES	0.40–20.0
PSH	0.50–1.33

(*) P2H energy density has been calculated at different pressures assuming a fuel cell efficiency in the range of 40–60% in order to take into account the losses during hydrogen conversion [105].

2.2.3. Normative and Operational Barriers

The HyLaw project [106], the International Energy Agency (IEA) report [44] and the Store&Go project [107] identified normative and operational barriers in terms of classification, unbundling rules and authorization procedures. Therefore, an enabling regulatory market is required to drive hydrogen development, but no or very few efforts were taken to change or to correct the existing frameworks to consider hydrogen devices. On the other hand, as reported by the European Commission, the implementation of ambitious structural reforms, fiscal policies and well-targeted investments is needed to support the digital and sustainable Italian transformation [108]. Therefore, without specific actions aiming to cover the recognized normative lacks, P2H projects and, more generally, all power sector investments appear less attractive, as reported by the World Bank [109]. In fact, as already reported by IEA for the Italian case [109], a simplification of the national energy framework is needed to push stakeholders' investments in terms of: (i) a minimization of regulatory uncertainty by vesting clear responsibility for the implementation of the energy solutions with the most appropriate institutions and (ii) a reduction of the overlapping authorities.

2.2.4. Social Barriers

In the past, the low interest of policy-makers in hydrogen potential was recognized [97]. Nevertheless, in recent years, something changed, but policy and public support are still required to support hydrogen development [110], including dedicated strategies able to ensure social acceptance of the final users [111].

3. Results and Discussion

In the next section, the barriers are specifically analyzed for the Italian framework. The results of the analysis are reported and discussed. Furthermore, some suggestions are proposed by the authors to tackle them.

3.1. Classification and Analysis of the Barriers to P2H Development in Italy

A total of 20 barriers to the development of P2H in Italy were identified. Referring to Table 5, economic (**E**.X), technical (**T**.X), normative and operational (**N**.X) and social (**S**.X) barriers are reported. In particular, the four categories are further classified as "H_2 Production and storage" (X.**1**), "H_2 Transport and distribution" (X.**2**) and "H_2 Utilization" (X.**3**). For each one of the four categories, subcategories are identified and listed in the table to improve the detail of the analysis. For example, the code E1.1. indicates the economic barrier (E) that occurs in "H2 production and storage section" (1) as the first subcategory (1). Therefore, E1.1 represents "Unsustainable CAPEX or OPEX". The code T1.1, indicates the technical barrier (T) that occurs in "H2 production and storage section" (1) as the first subcategory (1). Therefore, T1.1 represents a technical barrier and, specifically, "Energy performances".

Table 5. Classification of the main barriers to P2G development in Italy.

		P2H Chain Sections		
		H_2 Production and Storage	**H_2 Transport**	**H_2 Utilization**
Barriers		**1**	**2**	**3**
Economic barriers (E)		**E.1**	**E.2**	**E3**
Unsustainable CAPEX or OPEX	1	E1.1	E2.1	E3.1
Lack of incentives	2	E1.2	E2.2	E3.2
Technical barriers (T)		**T.1**	**T.2**	**T.3**
Energy performances	1	T1.1	T2.1	T3.1
Safety performances	2	T1.2	T2.2	T3.2
New skills and competencies	3	T1.3	T2.3	-
Normative barriers (N)		**N.1**	**N.2**	**N.3**
Existing legislative and standard frameworks	1	N1.1	N2.1	N3.1
Social barriers (S)		**S.1**	**S.2**	**S3**
Public awareness and social acceptance	1	S.1.1	S.2.1	S3.1

3.1.1. Economic Barriers

As reported in a previous section, several economic barriers currently hinder P2H development. Focusing on hydrogen and production, two barriers were recognized in the Italian framework:

1. **E1.1**. The CAPEX for P2H production and storage is relatively high (see Table 3). Payback time for P2H production and storage plants depends on the specific business case. However, the payback time of the best European business cases calculated by the Fuel Cells and Hydrogen Joint Undertaking (FCHJU) varies from 3 to 11 years depending on the primary application, conditional on a gas grid injection tariff of EUR 90/MWh [112]. In the same report, Italy is not recognized as a region in which profitable business cases can be found. The high CAPEX negatively influences Italian decision-makers about hydrogen investment. Italy is characterized by a relatively low level of public investment compared with the other EU member states [113]: public Italian investment in 2018 was 2.1% of the gross domestic product (GDP), while the euro area is characterized by a mean value of 2.4% (i.e., France 3.4%, Germany 2.4%, the Netherlands 3.3%, Sweden 4.9%). Since P2H development cannot be supported only by private investors, the existing trend in public investment in Italy represents a serious barrier to long-term investment in P2H. Additionally, OPEX could represent a critical barrier: electricity is consumed for water electrolysis, hydrogen storage processes and to supply plant auxiliaries (i.e., compressors). Moreover, electrolyzers and other equipment need ordinary and extraordinary maintenance. A specific barrier that can be identified about OPEX in Italy is that no distinction exists for electricity consumption in P2H plants with respect to other industrial consumers. So, electricity is purchased at a market price that, in the case of Italian non-household consumers, is the highest in Europe, as shown by the data from the first half of 2019, i.e., 16.61 c€/kWh [114]. An average price equal to 10.75 c€/kWh occurs in the same period in EU-27. As a consequence, the operative cost to store the same amount of energy in Italy is almost 35.3% greater with respect to the European average.
2. **E1.2**. Incentives, tax breaks, subsidies or penalties for conventional alternatives to encourage market uptake cannot be applied for hydrogen production and storage, since P2H is not currently considered as a storage energy solution in the Italian regulatory framework. Instead, a different scenario occurs for batteries. For example, the Italian Energy Authority (ARERA) recognized a reward policy for research energy storage projects as defined in art. 24 of Annex A of 199-11-TIT [115], i.e., "*removable*" energy storage systems that are able to store at least the 50% of the renewable surplus energy that would otherwise have been lost. Two of Terna's pilot energy storage plants were rewarded in accordance with Directive 169/2019/R/EEL [116]. Furthermore, incentives for batteries are also recognized by the national agency responsible for the promotion of renewable energy sources and efficiency (GSE) [117]. In addition to the lack of regulation that will be examined in the normative section, the application of a supporting mechanism to P2H operation could negatively influence the energy market, as also reported by [118]. For example, in accordance with D.M. 04/07/2019 [119], renewable energy production is already incentivized. Therefore, a risk of double incentivizing the same amount of energy exists.

Economic barriers are also recognized in hydrogen transport:

1. **E2.1**. Economic barriers also influence decisions concerning hydrogen transport from production to utilization areas. Concerning CAPEX, several options have to be taken into account. In the first development phase, hydrogen injection into natural gas networks could be considered as sustainable and reliable. No particular investments to improve the existing grids should be required for hydrogen concentrations up to about 10% since no negative effects were observed and reported in the literature. However, in the second phase, characterized by higher hydrogen production and concentration, a different approach should be planned, including the conversion of existing natural gas pipelines and/or the realization of new pipelines dedicated to hydrogen transport. Assuming a cost of up to EUR 100,000/km for new distribution pipelines [120],

the distance between production and utilization could become a very stringent condition for the sustainability of the investment. Therefore, to revamp steel and cast-iron distribution pipelines for “100% hydrogen” transport, an investment of up to EUR 26 billion (= EUR 100,000 × 260,000 km × 79%) could be required to substitute all pipelines except those made of polyethylene. In addition to pipelines, other components have to be converted in transportation networks, requiring higher investment. In particular, as shown in the “European Hydrogen Backbone” report [121], a part of the existing natural gas transportation network is likely to be retrofitted by 2040 for the delivery of “pure” hydrogen from the renewable energy plants located in the south of Italy to the existing industrial clusters in the north. Assuming a total pipeline route of 1000 km, a total investment of EUR 2.5–7.4 billion would be required to convey up to 13 GW, i.e., 1200 Nm^3/s. The existing Italian lack of public investment already mentioned in E1.1 represents a serious bottleneck in the transition to a hydrogen grid. Regarding OPEX applied to hydrogen blending, a relevant aspect is the higher risk in case of hydrogen leakage from pipelines, with a potential increase in maintenance and inspection costs for gas Transportation and Distribution System Operators (respectively, TSOs and DSOs) for existing natural gas networks. Since these costs are included in the purchase price of natural gas (i.e., 23% for domestic customers [122]), a greater expense would result for final customers if a supporting mechanism is not applied. Trucks, railways and ships can be seen as alternatives to the realization of a fully developed hydrogen infrastructure. Although a detailed analysis should be performed, high CAPEX could be expected in Italy since the investments needed would be not only apply to the purchase of such fleets, but also to the completion/renovation of the existing transport infrastructures, including roads, rails, waterways and ports. In fact, Italy has structural barriers regarding rails and ports: on the EU Transport Scoreboard [123], the efficiency of Italian railway services achieves 3.90 out of 7 points, with 21 European countries doing better, while for the efficiency of port services, the score is 4.54 out of 7, with 14 countries with a better score.

2. **E2.2**. Can a supporting mechanism be incisive for hydrogen transport? In the case of hydrogen injection into the natural gas grid, since gas contracts between Italian DSOs and municipalities do not account for hydrogen transportation, legal disputes could occur to assess to whom the expenses for adapting the network belong. Policies for Italian gas networks could be avoided by concessionaries, i.e., the TSOs and DSOs, that are responsible for grid operation but are not the owners [124].

As for hydrogen production, storage and transport, economic obstacles hinder hydrogen utilization.

1. **E3.1**. What is the economic impact of the “hydrogen economy” for Italian end users? The answer is not so simple and it depends on the specific category of end-user that is analyzed. A list of the main elements is reported as follows:

    a. *Industrial purposes—hydrogen as feedstock for industrial processes*. In this case, if the purchase cost of hydrogen produced by P2H is competitive with respect to other traditional processes including, but not limited to, methane reforming, no other specific economic barriers seem to be present in the Italian framework.
    b. *Industrial purposes—hydrogen as energy carrier*. In this case, depending on the percentage of hydrogen mixed with natural gas, the industrial equipment (i.e., furnaces, boilers, internal combustion engines) should be adapted or substituted. Private investments (CAPEX) will be needed, while an increase in OPEX due to safety issues could be expected with the increasing hydrogen percentage mixed with natural gas.
    c. *Residential customers*. No household/domestic device revamping is required if natural gas is substituted by hydrogen up to a defined threshold (i.e., about 10%). On the other hand, for higher concentrations, a revamping strategy will be required to assure safety performance. This could imply the allocation of economic resources since Italy accounts

for the highest number of gas customers in Europe, i.e., more than 23 million [125]. In fact, natural gas is the primary source of energy for Italian residential and commercial sectors [126]. In accordance with the value calculated by [127] for a 12% hydrogen blending in the Netherlands, characterized by a modern network and a low-pressure final distribution similar to Italy, and taking into account the inflation throughout the year, less than EUR 40 for each customer should be considered for domestic appliances, resulting in a total national effort of up to EUR 0.9 billion. From the reported data, the complete substitution of natural gas by hydrogen seems to be currently unrealistic without supporting actions due to the high CAPEX needed for both private and public sectors.

d. *Mobility sector*. The private mobility sector has not demonstrated an interest in hydrogen in Italy to date, probably because in 2016 only three hydrogen refueling stations were in operation [45]. Moreover, the price of hydrogen vehicles is more than double with respect to a traditional diesel engine vehicle. Furthermore, higher refueling costs are calculated in the case of hydrogen with respect to traditional vehicles. Nevertheless, the use of methane is quite diffused in the private mobility sector in Italy (1,004,982 vehicles in 2017 [128], 2.3% of the circulating park), so in the first phase of hydrogen development, it may be used in a low percentage to feed existing methane vehicles with relatively low CAPEX and OPEX. Conversely, Italian public transport showed a lot of interest in hydrogen mobility: in particular, several local experimental activities have been carried out in urban transport in the northern regions of Italy [129], i.e., buses with fuel cells or "traditional" buses with a mixture of hydrogen and methane. The Italian Hydrogen Mobility Plan, released in 2016, foresees the realization of 10 bus and 10 car hydrogen stations by 2020 and future actions to be implemented up to 2050 [130]. Since the executive plan is still missing [131], the 2016 estimates now seem more ambitious compared to the current situation.

2. **E3.2**. In Italy, GSE managed incentives of up to EUR 14.7 billion in 2019 [132] to support Italian energy renovation, but none of them was available for hydrogen devices. Incentive schemes for renewable and low-carbon hydrogen mobility are much needed to make them affordable [133]. In fact, from a preliminary estimation of the Hydrogen Europe Association, almost EUR 22 billion are identified as a subsidy for European hydrogen mobility [134]. Despite the goals, no supporting scheme has yet been introduced in Italy. For example, economic incentives were approved in the "Decreto Rilancio" by the Italian government to stimulate the renovation of the Italian car fleet with low greenhouse gas emission vehicles, i.e., up to 110 gCO_2/km for diesel cars, but hydrogen mobility is not included [135].

3.1.2. Technical Barriers

Technical barriers are present in all the P2H supply chains from production to final utilization. The analysis will be structured as was performed for the economic barriers:

1. **T1.1**. The technological limits of P2H production and storage are well known (see Tables 3 and 4) and are not related specifically to the Italian framework.
2. **T1.2**. Safety is one of the most debated topics in the literature due to the high flammability range of hydrogen in air, i.e., [4%–75.6%] by volume. Therefore, dedicated measures have to be taken to reduce hydrogen leakage risks. In accordance with the Italian Safety Code D.Lgs. 81/08, specific protective actions must be designed and applied for the safety and the health of workers that could be exposed to explosive atmospheres [136]. In accordance with international safety rules, work areas have to be classified in accordance with ATEX Directive 94/9/CE [137]. Components and plant assembly have to be certified in accordance with the ATEX Directive [138]. Therefore, P2H production and storage plants could result in complex designs due to safety limitations and countermeasures.

3. **T1.3**. New skills and competencies are required to design and to operate P2H plants. Despite the potential in terms of occupational sector growth [139], it should be noted that no Italian P2H market currently exists. In fact, even though four electrolyser manufacturers operate in the Italian market [140], no Italian company is specialized in the design and realization of P2H plants.

Specific technical barriers are also present for hydrogen transportation in Italy.

1. **T.2.1**. Hydrogen blending has a great potential in Italy since natural gas transportation and distribution networks reach a total length of almost 300,000 km [141,142]. Concerning transport efficiency, the addition of hydrogen into the natural gas grid will be responsible for variation in the gas conveyed to properties. This change would be responsible for several issues that have to be solved:

    a. *The increase in the operative flowrates in the network to convey the same amount of energy*. Due to the lower density, the injection of hydrogen into the natural gas grid will be responsible for a reduction of energy transportation capacity. For example, assuming a hydrogen concentration of up to 5% by volume, the gas flowrate has to be increased up to 3.6% to convey the same amount of energy as the baseline situation, i.e., assuming a gas composition in accordance with existing Italian standards [143]. Since no revamping of existing infrastructure is expected, assuming the hydrogen concentration is limited to up to 10% in the short term, the increase in the volumetric flowrate would be responsible for an increase in pressure drops, i.e., the energy consumption to convey gas [144].

    b. *Difficulties in calculating energy bills*. In the case of hydrogen injection into the natural gas grid, variation in the conveyed fuel properties may occur. Therefore, the measurement and control of natural gas and the hydrogen mixture composition become crucial when performing metering services and when calculating energy bills considering the time-variable injection into the grid [145]. In fact, the calorific value and other properties of the conveyed mixture have to be quantified to measure the delivered amount of energy. In accordance with the state of the art, Process Gas Chromatographs (PGCs) could be used within this scope [146]. These devices use helium as a carrier gas that, unfortunately, has a thermal conductivity similar to hydrogen. Therefore, since the detection method of such instruments is based on the difference in the thermal conductivity, a certification or a revamping is needed to correctly perform energy measurements. However, two situations can occur:

        i. *Hydrogen injection into the transmission network.* In this case, since the energy of the delivered mixture is measured before entering the distribution networks, the revamping and certification of PGCs can be limited to those instruments installed in REMI stations ("Regolazione e Misura" in Italian), i.e., the plant boundary limit between the natural gas transmission and distribution networks. In fact, since no injection occurs, there is no variation in mixture properties along the distribution network.

        ii. *Hydrogen injection into the distribution network*. With respect to the previous case, mixture properties can change along the network. Therefore, two end users supplied by the same network could receive fuel with different properties, i.e., energy content. Even if no significant difference in volumetric flowrate measurements and no structural damages were experienced up to a hydrogen concentration of 15% in diaphragm meters [147], the change in gas composition could be responsible for an energy metrological error greater than the maximum allowed. Therefore, a solution able to measure mixture properties should be proposed for the end users. Since PGCs are too expensive and complex, sensors should be considered to enable a continuous monitoring. However, even if several sensors are available in the market for hydrogen detection, no economic solution appears to be viable in the state of the art to measure the concentration of hydrogen in a mixture stream. In addition to the lack of a technological solution, it should also be noted that a massive roll-out strategy was started in Italy in 2013 to substitute more than 22 million natural gas meters with new smart meters that are not certified to operate in the case of hydrogen injection. Since the technical actions required for the massive roll-out of hydrogen-certified meters are similar to those performed for the gas smart meter roll-out, resource evaluation could be preliminarily performed with the data reported [148]. Assuming an average cost of EUR 70–80/device, more than EUR 1.5 billion should be allocated for the complete revamping of the Italian metering system. In addition, more than 1,800,000 man-days would be necessary to complete the revamping. Therefore, due to the great economic and human resources allocated for the purpose as analyzed in [148], the revamping of Italian smart meters and moving towards hydrogen blending would not appear to be sustainable in the short to medium term.

2. **T2.2**. As for the previous section, safety also represents a very crucial topic in the transport sector. In fact, even if it was concluded by experts that overall hydrogen is no more hazardous than conventional fuels, the performance of a detailed risk assessment for hydrogen transport is suggested in accordance with the methodologies reported in [149–151]. However, specific considerations apply for hydrogen injection into the Italian natural gas grid and for transport by trucks or railways:

    a. Safety is decisive in natural gas network operation [152]. For this purpose, a careful analysis is required for the transport of hydrogen through existing natural gas pipelines. In fact, possible interactions between hydrogen and network component materials have to be carefully considered. Many different materials are used in the Italian natural gas network [153,154]. A preliminary distinction has to be made between natural gas transport and distribution pipelines [155]. The first ones, that operate at pressures from 12 bar up to 120 bar, are made of steel, while polyethylene, iron and copper are also allowed in Italian distribution pipelines in accordance with system operative pressure. As reported in [156], in 2018, 76.5% of the Italian gas distribution network was made of steel, 21% of polyethylene, 2.73% of iron and the remaining part of other materials. Therefore, the main risk for the Italian steel and iron gas network in the case of hydrogen blending is due to possible embrittlement that results in crack propagation as reported in the literature. Maximum hydrogen concentration limits between [10%–20%] by volume [157] or slightly higher [15%–20%] by volume [51] are usually defined. Some authors recognized a slight increase in risk up to 50% even if a reduction of the maximum limits was suggested at high operative pressures [101]. No failure mechanisms, however, were identified for polyethylene pipes for 100% concentration of hydrogen, as demonstrated in the H21 project [158]. In addition to mechanical pipeline material degradation, other questions are still unsolved including, but not limited to, (i) the effect of existing defects on the maximum blending concentration, (ii) the vulnerability of high hardness welds that are present in already buried networks, (iii) the possible degradation of non-metallic parts such as the sealing parts of valves, (iv) the toxicological effect of hydrogen on health, (v) the need to recalibrate, adapt or substitute gas detectors as a function of the blending concentration, (vi) the impact of hydrogen concentration on the odorization mixture, (vii) the impact of hydrogen and natural gas admixtures on existing classified areas [159] and (viii) the effect on new ultrasonic and thermal mass smart meters or other components already in operation in the network.
    b. Concerning transport by trucks or railways, hydrogen has to be considered as a dangerous and flammable substance since it could have harmful effects for humans, the environment

and property along the pathway between the production plant and the final users. In the past, accidents involving hydrogen have occurred. Several accidents and lessons learned through the world are reported in [160]. On the 31st December 1969, for example, a hydrogen delivery truck accident occurred on a highway, causing property damage but, fortunately, no injuries or fatalities [161]. A more serious accident occurred in 2003 when tie-downs on a hydrogen transport trailer securing hydrogen cylinder packages failed [162]. Additionally, in this case, the deflagration and explosion damaged some vehicles and broke the windows of the nearest buildings. Therefore, risk and consequence analysis has to be performed in accordance with the literature before planning a road or a railway [163]. For this purpose, the interaction between the hydrogen vector, i.e., the truck or the railway, the transportation network and the impact area has to be recognized [164]. Preventive or protective measures can be necessary to minimize the risk to an acceptable level such as, for example, the obligation to transit through less-populated areas, the reduction of the hazardous substance quantity, the installation of hydrogen leak detectors, speed limits and so on. Therefore, to improve safety transport performances, logistic and economic performances are critically reduced.

3. **T2.3**. The same considerations reported in point T1.3 apply for hydrogen injection into the Italian natural gas grid. Even if some experimental activities started to be performed by the main Italian TSO, Snam S.p.A. [165], large-scale tests or projects have not been performed yet, and so limited competencies can be recognized in Italian natural gas TSOs and DSOs.

Some evaluations should also be noticed for final utilization.

1. **T3.1**. A possible impact on end users' equipment efficiency can be foreseen in the case of partial or complete substitution of natural gas with hydrogen as fuel. It is possible that low hydrogen concentration burners, furnaces, boilers, internal combustion engines and other equipment will be not negatively influenced. For example, [166] found that domestic, commercial and industrial appliances are likely to be suitable for up to a 10% concentration of hydrogen. The authors of [167] revealed that the limits on hydrogen concentration depend on the composition of the natural gas to which the hydrogen is added, distinguishing between fuel-rich premixed appliances and lean premixed appliances, and on the national Wobbe thresholds. The authors of [168] reported that hydrogen up to 30% by volume can be used to improve the lean-burn capability and flame burning velocity of natural gas engines. A different conclusion is expected in the case of a high hydrogen percentage concentration (or complete substitution) since negative effects may arise, as studied by the NaturalHy project [169] that identified different hydrogen limits for fuel-rich premixed appliances (up to 18–27%) and for fuel-lean premixed appliances (up to 52–56%) to avoid light back problems. These issues are particularly relevant in Italy due to the high diffusion of natural gas as the primary fuel for both industry and residential sectors. Additionally, the impact on existing methane vehicles should be evaluated.
2. **T3.2**. Concerning safety, particular attention should be paid to residential and civil sectors, for which specific measures have to be taken. As reported in a previous section, in fact, hydrogen flammability limits are greater than methane ones, increasing the risk of accident in the case of leakage. However, no fully recognized solution for risk minimization is yet available. In fact, some of the industrial approaches to minimize safety risks are not applicable in a domestic framework. For example, the area classification approach cannot be applied. However, even if a simplified methodology could be designed, no directive exists for the certification of devices to be installed in a space where an explosive atmosphere could occur. Hydrogen detector sensors, air ventilation openings near to the roof and; furthermore, the correct behavior of the end users are the only available solutions to minimize the probability of accidents. Since the greatest number of natural gas accidents in Italy can be directly or indirectly linked to consumers' incorrect behavior [170], the available solutions for hydrogen risk minimization are not sufficient.

3.1.3. Normative Barriers

A lacking Italian regulatory framework is the most specific and challenging barrier against P2H development:

1 **N1.1**. A specific definition for hydrogen production and storage by P2H as an economic activity is missing in the Italian legislative framework. The list of ATECO codes, i.e., the alpha-numerical classification of Italian economic activities [171], defines the categories of risk and the economic rules that each activity has to observe. Since no specific definition is present, P2H should be included in those activities characterized by the code 20.11.00, i.e., manufacturing of industrial gases. In fact, it is not possible at the moment to include P2H in those activities involving electricity transmission and distribution as defined by the code 35.1 since electricity storage is not included in the definition. Therefore, this activity is classified as a manufacturing one as the final product of P2H activity is hydrogen and not an electricity storage service. In addition, very complex procedures are needed to collect all the required permits and authorizations for the realization of a hydrogen production and storage plant. The Environmental Italian Law, i.e., the D.Lgs. n. 152 of the 3rd of April 2006 [172], includes the Environmental Impact Assessment (in Italian, VIA) and the Integrated Environmental Authorization (in Italian, AIA). Concerning authorizations related to safety, P2H plants fall within the Seveso Directive when the amount of hydrogen within the plant is greater than 5 tons [173]; when considering an LHV of 120,000 kJ/kg, more than 600 GJ or 167 MWh of stored hydrogen is required to overcome this value. Further steps have to be made with other local authorities, for example, in the Emilia-Romagna region, according to D.P.R. n° 151 of the 1st August 2011 [174], the authorization of the local fire department is required when more than 25 Nm^3/h of flammable gases are produced and/or in the case of a storage volume greater than 0.75 m^3. In addition, the National Institute for Insurance Against Industrial Injuries (INAIL) has to be involved in the process of the commissioning of the plant in accordance with the Ministerial Decree of 1st December 2004 [175]. In addition to the complex authoritative procedures, the uncertainty about time and about the final decision also has a very negative impact on P2H development in Italy.

Despite the size of the gas network infrastructure, several normative barriers currently hinder the potential of hydrogen injection:

2 **N2.1**. No dedicated regulatory framework is available for hydrogen blending into Italian natural gas networks from P2H plants. In fact, even if some rules exist for the introduction of renewable gases, pure hydrogen is not considered. Moreover, no legal framework exists for the connections of P2H plants to the natural gas network. The Authority Directive 64/2020/R/gas [176] foresees only biomethane injection. However, a maximum concentration for hydrogen in biomethane equal to 1.0% is defined in the most recent technical standard UNI TS 11537:2019 [177], i.e., double with respect to the limit defined in the previous version. In addition, it should be noted that, since hydrogen blending reduces the high heating value and the Wobbe index of the transported natural gas, the maximum hydrogen concentration should be calculated in accordance with the range defined in the Ministerial Decree of the 18 May 2018 [143] for the fluids to be transported in the natural gas networks, equal to [34.95; 45.28] MJ/Sm3 and [47.31; 52.33] MJ/Sm3.

Concerning final utilization, only one barrier was identified for hydrogen utilization in civil and residential applications, as well as in the mobility sector.

3 **N3.1**. No dedicated framework exists for hydrogen-fueled components in Italy. The mobility sector is the best example available. In fact, hydrogen vehicles can be considered as fueled electric vehicles since hydrogen is converted into electricity through fuel cells. Therefore, hydrogen vehicles should be defined in accordance with the Commission Regulation (EU) n.406/2010 of 26 April 2010 [178], which implements Regulation (EC) N.79/2009 concerning the approval of

hydrogen-fueled vehicles [179]. Despite the presence of a European Regulation, the Italian government has not completely adopted it and Directive 2007/46/EC [180] and 2014/45/EC [181] apply. In particular, the two directives define the administrative and technical rules when approving hydrogen vehicles but they have to be applied on a case-by-case basis [87].

3.1.4. Social Barriers

Public awareness and social acceptance can be considered as the most critical barriers for the success of the Italian P2H chain. With respect to previous barriers in which P2H chain steps were analyzed separately, in the case of social barriers, however, they are investigated together. As in other European countries, the public has no precise opinion about the "hydrogen economy". In fact, the role of hydrogen for the Italian energy market of the future is usually limited to intellectuals or energy sector stakeholders. Therefore, the lack of information results in several issues that are typical of the Italian context:

1. **S1.1**. The realization of a hydrogen production and storage plant could be opposed by the population of the area involved as has already occurred on several occasions for other renewable or renewable-related plants [182–184]. A NIMBY reaction could result from the realization of a P2H plant. In fact, the risk due to the presence of flammable gases, for example, could be sufficient to create local protest committees with the consequent project delay or interruption. Similar reactions could occur to oppose the realization of renewable power plants that, for energy transmission loss minimization, should be realized as close as possible to the P2H plant. This barrier is specifically critical in the Italian framework, since due to the lack of trust in politics and unsure public communication, citizens and, in general, public opinion showed in the last decade an increasing hostility against the development of energy plants, even if related to renewables sources.
2. **S2.1**. Additionally, hydrogen transport could be a very critical problem from a social point of view:

    a. *Hydrogen grid*. No problems are expected until new transport networks are realized. On the other hand, NIMBY reactions could be expected in the case of new pipelines as already observed in Italy for the Trans Adriatic Pipeline (TAP) project [185], whose activities were interrupted for many years and damage was caused by "TAP antagonists" [186].
    b. *Hydrogen transport by trucks, railways and ships*. Due to severe accidents that occurred during the transport of hazardous substances in Italy [187,188], hydrogen transport by trucks or by railways could be opposed by the population of the areas where the transport goes through. For example, no specific laws have to be followed in hydrogen transport, only small differences are present in terms of classification code or shipping procedures with respect to other gases, despite the greater risk in the case of accidents. For example, the Decree of the Ministry of Transport of 12 May 2017 currently applies to hydrogen conveyed by trucks [189] in accordance with the European regulation concerning the International Carriage of Dangerous Goods by Road, i.e., DIR/2016/2309/EC, commonly known as ADR 2017 [189]. In addition, specifically for trucks, the Italian framework is not favorable due to the already existing traffic congestion, especially on municipal and provincial roads. As a result, citizens are always in opposition to an increase in traffic, even if related to renewable energy or low-carbon initiatives. Since more than three trucks have to be moved for each MWh of hydrogen, assuming, for example, a nominal capacity of the electrolyzer of the P2H production site equal to 1 MW, and by considering a dedicated PV plant with a nominal operation equal to 1500 h/year (i.e., the typical value for the Italian framework), hydrogen production of 1500 MWh/year can be estimated. Therefore, assuming a 3400 m^3 capacity hydrogen delivery at 200 bar (up to 300 kg of hydrogen) [190], almost 150 trucks should be operated yearly, i.e., equivalent to almost one tank truck with a semitrailer (up to 65 feet)

every two days in accordance with the ADR rules [191]. A different result would be obtained in the case of liquefied hydrogen delivery [192], that would ensures a greater energy density than the pressurized case [88]. For example, assuming a tractor with a semi-trailer as for the previous example, up to 45 m^3, equivalent to 3200 kg of hydrogen or 105 MWh, can be delivered. Therefore, fewer than 15 trucks/year are estimated to be necessary. In the second case, however, other issues limit the applicability: (i) the increase in P2H plant CAPEX as a consequence of the realization of the hydrogen liquefaction plant [193], (ii) the high electrical energy consumption for the hydrogen liquefaction process up to 12 kWh/kg, i.e., 36% of the energy content [194] and (iii) the safety risks as a consequence of the need to store the liquefied hydrogen at the P2H plant, awaiting delivery to the final users. Therefore, it is reasonable to think that local people would be in opposition to a P2H installation due to the safety concerns related to hydrogen transport.

3. **S3.1**. Social acceptance is fundamental for the development of the "hydrogen economy" and may be critical in the following applications:

    a. *Residential and civil end users*. Methane is the primary energy source for household energy consumption in Italy. The public perception of natural gas is that it is a safe and reliable product to use for heating premises [195]. Therefore, it is reasonable to think that the same reaction will also be present in the case of hydrogen-fueled devices. On the other hand, if a revamping of the household equipment is required (i.e., boilers, hobs), it is not obvious that the end users will want to accept the related economic investment, if not supported by incentives or tax credits.
    b. *Mobility*. The use of methane-fueled or Liquefied Petroleum Gas (LPG)-fuelled vehicles is quite diffuse in Italy. Methane and LPG vehicles can usually be considered safer than gasoline or diesel vehicles [196], with the exception of a slow leak in an enclosed space. So, a low perceived risk about hydrogen mobility by Italian end users could be expected. On the other hand, the need for safety equipment in private or public garages to minimize the risk of the formation of an explosive mixture (like hydrogen detection devices and/or passive/active ventilation) may limit the interest in hydrogen vehicles for private use.

3.2. Possible Approaches for Overcoming the Barriers

As reported, several barriers specifically hinder P2H deployment in Italy. In this section, some possible approaches to overcome the barriers are proposed.

1. ***E.X***. As reported in a previous section, relatively high operative costs and the lack of an incentive strategy are specific to the Italian framework. The following actions should be implemented to address these barriers:

    a. *Operative costs.* The high purchase price of electricity in Italy has a negative impact on P2H project development. However, it should be noted that more than 40% of the total is related to taxes [114]. Therefore, a reduction of the fees is suggested to incentivize the P2H supply chain. For example, assuming an annual hydrogen production of 10^9 Nm^3/year in the first development phase, i.e., 1% of the natural gas annually conveyed in the Italian gas grid, almost 4.3 TWh/year would be consumed by a state-of-the-art water electrolysis process, i.e., almost 10% of the photovoltaic and wind power plant energy generation expected in 2025. Therefore, EUR 715 M/year (= 4.2×10^9 [kWh/year] × 16.61 [c€/kWh]) would be required for the purchase of electricity. Discounting all the taxes, a loss of state revenue of almost EUR 286 M/year would occur. However, tax discounts should apply only in the case of renewable energy consumption.
    b. *Supporting schemes.* How should the P2H supply chain be supported? Different solutions could be considered:

i. Hydrogen production and storage plants. The incentive should be defined as the sum of two components based on (i) plant size and (ii) measured hydrogen production when a surplus of renewable production occurs in the grid. In this way, it would be possible to correctly remunerate the energy storage capacity of the plant connected to the national grid. However, only renewable surplus power storage should be economically rewarded. For this purpose, a green hydrogen guarantee of origin scheme should receive funding, as proposed in the CertfHy project [197]. Two different schemes should be followed in accordance with the P2H plant's purpose. In the case of hydrogen production, incentive schemes should be able to make the technology investment competitive with SMR, while in the case of energy storage, electric batteries should be the reference. In particular, in accordance with estimated hydrogen production, i.e., 10^9 Nm^3/year, a total P2H installed capacity of 380 MW would be necessary for 8000 working hours per year, i.e., the amount common for hydrogen plants in industrial facilities, and 750 MW for 4000 working hours per year, in accordance with energy storage demand. Assuming the worst conditions, i.e., P2H vs. electric batteries for storage application, up to EUR 2.9 billion (= 750 [MW] × 1000 [kW/MW] × (4674 − 874) [€/kW]) could be required to sustain investment in P2H to make it competitive with state-of-the-art technology.

ii. Hydrogen transport. In the case of hydrogen injection into the natural gas network, performance-based remuneration already exists for gas operators [198]. However, gas operators are not allowed to exceed the maximum values recognized for gas tariffs by the authority. A possible solution could be increasing the recognized remuneration to cover investments made by gas operators to make the grid ready for hydrogen injection. Since no evidence is present in the literature about issues with a hydrogen concentration of up to 10% for gas network materials, investments would concentrate only on the substitution of meters and the installation of dedicated instruments for gas mixture analysis, such as gas chromatographs. For this purpose, assuming a safety coefficient of 50% to cover the revamping of other components, an investment of up to EUR 2.3 billion can be expected. However, end users would pay for such revamping of the gas grids in gas tariffs. To reduce the impact on end users, a credit tax of 50% would be suggested, resulting in a reduction of the state's income of up to EUR 1.2 billion. A different scenario would occur in the case of a 100% hydrogen economy for which an investment up to EUR 30 billion is estimated to be needed to make the Italian gas networks ready for conveying pure hydrogen.

iii. Hydrogen utilization. Existing reward schemes should simply be updated to also consider hydrogen-fueled devices/equipment in industrial, residential and transport sectors. For example, a tax expenditure could be foreseen for hydrogen or hydrogen/natural gas device purchasing. Similar approaches had success in Italy with photovoltaics or solar thermal installations. Assuming a tax credit of 50% to sustain the revamping of domestic appliances, EUR 500 million, i.e., less than 0.025% of the Italian Gross Domestic Product (GDP), should be allocated by the government for this purpose.

2. ***T.X***. Suggestions to overcome technical barriers in the Italian framework are given below:

a. *Relatively low efficiencies and energy density*. Research and development (R&D) is required to increase the technical competitiveness of P2H in comparison with state-of-the-art alternative technologies. In accordance with [199], the increase in R&D funding could reduce not only CAPEX, but also process efficiency. For this reason, a large public investment in the specific sector is required to improve the competitiveness of P2H technology. For example, new high energy density storage solutions such as, for example, chemical storage reaching densities of up to 120 kg/m^3, should be investigated [88]. An intensification of research activities could also make available for the market Solid Oxide Electrolysis (SOEL) or improve current commercial system efficiency (including auxiliaries) up to 80%, i.e., what is expected for SOEL systems [42]. Another crucial topic is the control strategy for P2H and the optimization of generation and storage to minimize hydrogen production costs: the application of innovative control strategies based on artificial intelligence and machine learning can increase the opportunity for P2H to be cost competitive with other technologies. In fact, a predictive control strategy allows decision-makers to plan power distribution prior to load and demand occurrence [200]. A P2H plants' output, i.e., methanation, injection into the grid, conversion into electricity or hydrogen production for industrial feedstock, would be selected based on real-time data aiming to maximize economic revenues.

b. *Safety*. Technical guidelines and standards have to be released by competent authorities, ministries and normative bodies as is already done for natural gas to maximize safety performances starting from hydrogen production up to final utilization. R&D activities related to the assessment of component performances in the presence of hydrogen should continue to be funded such as, for example, the THYGA project concerning the impact of hydrogen on residential gas appliances [201] or the HIGGS project about the injection of hydrogen into the gas transportation pipelines at different concentration levels [202].

c. *Lack of competencies and skills*. The "*hydrogen economy*" should be considered as a great opportunity for existing Italian companies. Italian engineering companies could enter into the worldwide P2H business starting with national experience, if supported. This would give a high return in terms of know-how and increasing occupancy in a strategic sector in accordance with an estimated 320,000–540,000 new jobs by 2040 [203,204].

3. ***N.X***. Suggestions to overcome normative barriers in the Italian framework are reported below:

   a. *Lack of regulatory framework for P2H*.

      i. *Hydrogen production and storage plants*. Since P2H aims to balance the electric networks in the case of congestion due to overgeneration and since the main economic revenues should be due to the balancing service and not to hydrogen selling, an update of existing ATECO codes is strongly recommended.

      ii. *Hydrogen transport through injection into the natural gas networks*. Since technical guidelines are available for this purpose in the literature, the Italian regulatory framework should simply be adapted to it. In this way, it would be possible for involved stakeholders to perform significant research activity and so increase know-how.

      iii. *Permits and authoritative procedures*. No dedicated procedures are available for P2H projects. Therefore, very complex and long approaches have to be followed to complete the activity. To support investors, a national simplified procedure should be implemented for P2H plants. Furthermore, as for other sectors, Best Available Technique (BAT) reference documents, i.e., BREF, should also be defined for P2H plants in order to help authorities make the final decisions.

4. ***S.X***. Regarding social barriers, no simple solution can be defined for the Italian framework. However, informative campaigns through social networks and traditional communication channels, as well as the involvement of citizens and associations through a participatory approach should be mandatory to improve public awareness and acceptance of P2H plants, as suggested for other renewable energy production systems [205].

Table 6 summarizes the existing barriers and identified targets and suggestions for the implementation of P2H in the Italian framework.

Table 6. Summary of existing barriers to Italian P2H implementation and possible targets/suggestions.

Code	Brief Description	Targets and Suggestions
	Production and storage	
E1.1	P2H CAPEX and OPEX are significantly higher than the competitive state-of-the-art technology. P2H is considered as an industrial activity, so no discount is applied for electricity consumption.	A reduction of CAPEX of at least 35% is suggested. Discounts should apply to renewable electricity consumption.
E1.2	Lack of incentives, tax breaks, subsidies or penalties to encourage Italian P2H market. Only electric batteries or domestic storage systems are incentivized.	Supporting schemes are required in order to incentive investments in P2H. For this purpose, contribution to the initial investment should be considered, similar to the Italian "Conto Termico" supporting scheme.
T1.1	Relatively low conversion rate from power to hydrogen and the low hydrogen density represent the technological obstacles to be addressed.	Research and development (R&D) is required to increase P2H market competitiveness and to add value to the Italian hydrogen value chain. The design of tailored innovative control strategies of P2H plants is crucial to further increase the whole hydrogen production efficiency.
T1.2	Hydrogen flammability limits increase the risk of accidents in the case of leakage from the plant. Complex design and safety limitations could be required to operate the plant.	Standardized design solutions should be identified and shared among the technical community in order to improve safety performance and to reduce the cost of P2H plant realization.
T1.3	New skills and competencies are required to design and to operate P2H plants.	Dedicated courses and collaboration between companies and universities/research centers should be stimulated to share know-how.
N1.1	No specific definition of hydrogen production and storage by P2H as an economic activity exists in the Italian legislative framework. In addition, very complex procedures are needed to collect all the required permits and authorizations for the realization of the plants.	Italian legislative framework should be updated to account for P2H. Dedicated procedures and authoritative approaches for P2H should be prepared to reduce the uncertainty about time and about the final decision.
S1.1	NIMBY reactions in the population could oppose the realization of P2H plants.	Informative campaigns through social networks and traditional communication channels, as well as the involvement of citizens and associations through a participatory approach should be mandatory to improve public awareness and acceptance of P2H plants.
	Transport and distribution	
E2.1	Various equipment installed in Italian natural gas grids is not suitable for hydrogen conveyance, requiring investment for revamping. Truck, railway and ship transport could be an alternative solution with respect to pipelines, but no assessment exists about the suitability of Italian infrastructure.	Supporting actions such as, for example, tax deductions, should be evaluated to sustain gas operators. An evaluation about the appropriateness of Italian infrastructure for hydrogen delivery (road, railways and ports) is required to identify the best strategy to adapt it to a hydrogen economy.
E2.2	Lack of incentives, tax breaks and subsidies is present.	Supporting schemes should be designed in order to sustain the investment required.
T2.1	An increase in flowrate would be needed to deliver the same amount of energy in the case of hydrogen blending. Difficulties in calculating energy bills would occur due to the variation of the conveyed fuel properties.	In the short term, the maximum hydrogen concentration in the existing gas networks should be limited to up to 10%. Dedicated infrastructure should be required for higher concentrations. Process Gas Chromatographs (PGCs) should be installed to evaluate the gas composition. However, hydrogen should be injected only into the gas transportation system.
T2.2	Safety is decisive in natural gas network operation. In particular, issues could occur in the case of hydrogen blending in pipelines in terms of material and installed device degradation, the need to recalibrate, adapt or substitute gas detectors as a function of the blending concentration and a possible impact of hydrogen concentration on odorization mixture.	Research and development (R&D) is needed to evaluate the possible negative impact of hydrogen in the long term. State-of-the-art information should be used to prioritize interventions and revamping.
T2.3	New skills and competencies are required to design and to operate P2H plants.	Dedicated courses and collaboration between companies and universities/research centers should be stimulated to share know-how.
N2.1	No dedicated regulatory framework is available for hydrogen blending into Italian natural gas networks from P2H plants. A maximum concentration for hydrogen in biomethane equal to 1.0% is defined in the most recent technical standard UNI TS 11537:2019.	Energy authorities should foresee hydrogen injection into the gas networks. Maximum hydrogen concentration should be defined in accordance with the R&D activities performed, as suggested in T2.2.
S2.1	Since a higher failure risk occurs in the case of hydrogen delivery, it is reasonable to think that local people would be in opposition to a P2H installation due to the safety concerns related to hydrogen transport.	Hydrogen transport and distribution operators should highlight to the local communities all the protective and mitigation strategies designed to minimize safety risks.

Table 6. *Cont.*

Code	Brief Description	Targets and Suggestions
	Utilization	
E2.1	Different economic impacts occur depending on the final end users. In particular, for residential customers, the complete substitution of methane with hydrogen seems to be unrealistic due to the efforts required for appliance revamping.	In a preliminary phase, hydrogen concentration should be limited to up to 10% for pipelines conveyed hydrogen, since no revamping of the existing devices seems to be required. No limits apply when hydrogen is used as feedstock for industrial purposes.
E2.2	Lack of incentives, tax breaks, subsidies is present.	Supporting schemes should be designed in order to sustain the investment required.
T2.1	Up to a concentration of 10%, burners, furnaces, boilers, internal combustion engines and other equipment will not be negatively influenced.	Research and development (R&D) is needed to design, test and validate devices able to operate at higher concentrations.
T2.2	Accident risk should be specifically evaluated for residential and civil applications for which specific measures have to be taken.	No fully recognized solutions for risk minimization are yet available. In fact, existing industrial approaches are not applicable in a domestic framework. Hydrogen detector sensors, air ventilation openings near to the roof; in addition, the correct behavior of the end users are the simplest and the most immediate solutions.
N2.1	No dedicated framework exists for hydrogen-fueled components in Italy.	The legal framework has to be updated as soon as possible in order to account for hydrogen-fueled components.
S2.1	If a revamping of equipment is required due to the change in the gas mixture, it is not obvious that the end users want to accept the related economic investment.	Supporting schemes, as suggested in E2.2, are fundamental to avoid end users' opposition to the hydrogen transition.

4. Conclusions

Despite the positive benefits, several barriers currently hinder P2H development in Italy and dedicated strategies have to be identified as soon as possible to move towards a mature "hydrogen market". First of all, since a high energy storage capacity is expected in the future in Italy, P2H could be part of the solution. However, Italian legal and regulatory frameworks do not clearly recognize P2H as a possible energy storage technology. Secondly, financial supporting schemes have to be identified specifically for P2H to remunerate their electric networks' balancing service. To date, in fact, only small residential energy storage systems and two pilot battery storage plants have been economically rewarded. Since small residential storage systems would be not able to balance the electric network in the case of a high renewable percentage, efforts have to be made to recognize the best financial supporting schemes for future energy storage systems. Thirdly, P2H could support the development of the "smart grid" concept in Italy. In fact, due to the high capillarity of the Italian natural gas network that accounts for almost 300.000 km of pipelines, no restrictions are theoretically present on connecting energy producers and end users. However, no rules are currently available for hydrogen blending into Italian gas networks. Even if technical limits are defined in the literature concerning pipeline safety, several other considerations are required to inject hydrogen into the networks. For example, no data are available about the performance of the existing devices installed for end users when a natural gas–hydrogen mixture is supplied to appliances including, but not limited to, the new smart meters. In this case, both safety and fiscal problems could occur. The modification of fuel characteristics should be carefully evaluated considering the impact on existing supply contracts and device certification. With regard to the existing legal framework, it would be very difficult to assess the responsibilities in the event of a failure or a malfunction.

Therefore, for the above reasons, a "national hydrogen program" should be started in accordance with the "European hydrogen strategy" that identifies cumulative investments in renewable hydrogen of up to EUR 180–470 billion before 2050 and water electrolysis capacities up to 6 GW by 2024 and up to 40 GW until 2030. From the preliminary assessment, the preliminary phase of the Italian hydrogen transition should be economically sustained with an economic effort of up to EUR 5 billion, taking into account investments required in gas infrastructure revamping, incentives, gas appliance substitution and certification and safety factors of 10%. On the other hand, the impact of the hydrogen economy on Italian GDP by 2050 is estimated to be EUR 22–37 billion thanks to the creation of 320,000–540,000 new jobs. However, to reach a 100% hydrogen economy, up to EUR 40 billion of investments are estimated to be needed to revamp the existing infrastructure. Therefore, since a great potential in P2H is identified, specific actions have to be planned and then put in action to address the recognized barriers involving all the possible interested actors such as P2H plant operators, the Italian energy authority, the Italian energy market, the electric and gas TSOs and DSOs, the Italian Manufacturers' Association, consumers' associations, authoritative competent bodies, universities and research centers. This would be the only way to ensure Italian P2H market uptake.

Author Contributions: M.P. conducted the conceptualization and revised the original draft; A.G. conducted the methodology and the preparation of the original draft; C.S. provided comments and gave important suggestions. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the ERANET funding program that co-financed the "*SuperP2G: Synergies Utilising renewable Power REgionally by means of Power To Gas*" project.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. United Nations Paris Agreement. Available online: https://unfccc.int/sites/default/files/english_paris_agreement.pdf (accessed on 23 January 2020).
2. Nachmany, M.; Mangan, E. Aligning National and International Climate Targets. 2020. Available online: https://www.lse.ac.uk/GranthamInstitute/wp-content/uploads/2018/10/Aligning-national-and-international-climate-targets.pdf (accessed on 27 December 2019).
3. The World Bank Electricity Production from Renewable Sources, Excluding Hydroelectric (kWh). Available online: https://data.worldbank.org/indicator/EG.ELC.RNWX.KH?view=chart (accessed on 18 April 2020).
4. Eurostat Eurotat Database. Available online: https://ec.europa.eu/eurostat/data/database (accessed on 18 April 2020).
5. Ministero Dello Sviluppo Economico Analisi e Statistiche Energetiche e Minerarie. Available online: https://dgsaie.mise.gov.it/ben.php (accessed on 18 April 2020).
6. Ministero dello Sviluppo Economico. *Piano Nazionale Integrato per l'Energia e il Clima*; Ministero dello Sviluppo Economico: Rome, Italy, 2019.
7. Capros, P.; Mantzos, L.; Papandreou, V.; Tasios, N. *European Energy and Transport*; European Commission: Brussels, Belgium, 2008.
8. Terna SpA. *Partecipazione Alla Regolazione di Frequenza e Frequenza-Potenza*; Terna SpA: Roma, Italy, 2008.
9. Pirovano, G.; Borgarello, M. *Frequenza di Rete e Sbilanci. Le Sfide Della Regolazione*; RSE: Milan, Italy, 2017.
10. Ahmad, T.; Zhang, H.; Yan, B. A review on renewable energy and electricity requirement forecasting models for smart grid and buildings. *Sustain. Cities Soc.* **2020**, *55*, 102052. [CrossRef]
11. AEEG. *Deliberazione 344/2012/R/EEL*; AEEG: Milan, Italy, 2012.
12. Terna SpA. *Codice di Trasmissione Dispacciamento, Sviluppo e Sicurezza Della Rete*; Terna SpA: Rome, Italy, 2015.
13. ISPRA. *Fattori di Emissione Atmosferica di Gas a Effetto Serra nel Settore Elettrico Nazionale e nei Principali Paesi Europei*; ISPRA: Roma, Italy, 2019.
14. Denholm, P.; O'connell, M.; Brinkman, G.; Jorgenson, J. *Overgeneration from Solar Energy in California: A Field Guide to the Duck Chart*; NREL: Golden, CO, USA, 2013.
15. Gonzalez-Salazar, M.A.; Kirsten, T.; Prchlik, L. Review of the operational flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1497–1513. [CrossRef]
16. Novakovic, B.; Nasiri, A. Introduction to electrical energy systems. In *Electric Renewable Energy Systems*; Academic Press: Cambridge, MA, USA, 2016; pp. 1–20.
17. Staffell, I.; Scamman, D.; Velazquez Abad, A.; Balcombe, P.; Dodds, P.E.; Ekins, P.; Shah, N.; Ward, K.R. The role of hydrogen and fuel cells in the global energy system. *Energy Environ. Sci.* **2019**, *12*, 463–491. [CrossRef]
18. Breeze, P. Large Scale Batteries. In *Power System Energy Storage Technologies*; Academic Press: Cambridge, MA, USA, 2018.
19. Chen, H.; Cong, T.N.; Yang, W.; Tan, C.; Li, Y.; Ding, Y. Progress in electrical energy storage system: A critical review. *Prog. Nat. Sci.* **2009**, *19*, 291–312. [CrossRef]

20. Directorate-General for Research Sustainable Energy Systems. *European SmartGrids Technology Platform*; Directorate-General for Research Sustainable Energy Systems: Brussels, Belgium, 2006.
21. Terna SpA. Progetti Pilota di Accumulo—Terna Spa. Available online: https://www.terna.it/it/sistema-elettrico/innovazione-sistema/progetti-pilota-accumulo (accessed on 18 April 2020).
22. ISTAT Risultati Economici Delle Imprese: Tutti i Settori Economici. Available online: http://dati.istat.it/Index.aspx?QueryId=23778 (accessed on 18 April 2020).
23. Tsiropoulos, I.; Tarvydas, D.; Lebedeva, N. *Li-ion Batteries for Mobility and Stationary Storage Applications Scenarios for Costs and Market Growth*; Publications Office of the European Union: Luxembourg, 2018.
24. Olivetti, E.A.; Ceder, G.; Gaustad, G.G.; Fu, X. Lithium-Ion Battery Supply Chain Considerations: Analysis of Potential Bottlenecks in Critical Metals. *Joule* **2017**, *1*, 229–243. [CrossRef]
25. Weil, M.; Ziemann, S. Recycling of traction batteries as a challenge and change for future lithium availability. In *Lithium-Ion Batteries: Advances and Applications*; Pistoia, G., Ed.; Elsevier: Amsterdam, The Netherlands; Oxford, UK, 2014; p. 528. ISBN 9780444595133.
26. Dias, A.P.; Alves Dias, P.; Blagoeva, D. *Cobalt: Demand-Supply Balances in the Transition to Electric Mobility*; Publications Office of the European Union: Luxembourg, 2018.
27. Azevedo, M.; Campagnol, N.; Hagenbruch, T.; Hoffman, K.; Lala, A.; Ramsbottom, O. *Lithium and Cobalt. A Tale of Two Commodities*; McKinsey & Company: Herisau, Switzerland, 2018.
28. Swiss Resource Capital AG. *Battery Metals Report 2019: Everything you Need to Know about the Battery Metals Lithium, Cobalt, Nickel and Vanadium!!* Swiss Resource Capital AG: Herisau, Switzerland, 2019.
29. Velázquez-Martínez, O.; Valio, J.; Santasalo-Aarnio, A.; Reuter, M.; Serna-Guerrero, R. A Critical Review of Lithium-Ion Battery Recycling Processes from a Circular Economy Perspective. *Batteries* **2019**, *5*, 68.
30. Dai, Q.; Kelly, J.C.; Gaines, L.; Wang, M. Life Cycle Analysis of Lithium-Ion Batteries for Automotive Applications. *Batteries* **2019**, *5*, 48. [CrossRef]
31. Ager-Wick Ellingsen, L. *LCA of Li-ion Batteries: Current State and Prospects*; NTNU: Norwegian University of Science and Technology: Trondheim, Norway, 2018.
32. TERNA SpA. Pubblicazioni Statistiche—Terna SpA. Available online: https://www.terna.it/it/sistema-elettrico/statistiche/pubblicazioni-statistiche (accessed on 30 June 2020).
33. European Commission. *Commission Staff Working Document on the Evaluation of the Directive 2006/66/EC on Batteries and Accumulators and Waste Batteries and Accumulators and Repealing Directive 91/157/EEC*; European Commission: Brussels, Belgium, 2019.
34. Golroudbary, S.R.; Calisaya-Azpilcueta, D.; Kraslawski, A. The life cycle of energy consumption and greenhouse gas emissions from critical minerals recycling: Case of lithium-ion batteries. In Proceedings of the Procedia CIRP, Naples, Italy, 17–19 July 2019; Elsevier: Amsterdam, The Netherlands, 2019; Volume 80, pp. 316–321.
35. Lund, H.; Salgi, G. The role of compressed air energy storage (CAES) in future sustainable energy systems. *Energy Convers. Manag.* **2009**, *50*, 1172–1179. [CrossRef]
36. Budt, M.; Wolf, D.; Span, R.; Yan, J. A review on compressed air energy storage: Basic principles, past milestones and recent developments. *Appl. Energy* **2016**, *170*, 250–268. [CrossRef]
37. Finkenrath, M.; Marquardt, R.; Moser, P.; Klafki, M.; Zunft, S. Status and Technical Challenges of Advanced Compressed Air Energy Storage (CAES) Technology. In Proceedings of the International Workshop on Environment and Alternative Energy, Organized by C3P and NASA Motivation for Large-Scale Energy Storage, Munich, Germany, 10–13 November 2009; pp. 1–8.
38. Alterach, J. *Idroelettrico*; RSE: Rome, Italy, 2015.
39. Rehman, S.; Al-Hadhrami, L.M.; Alam, M.M. Pumped hydro energy storage system: A technological review. *Renew. Sustain. Energy Rev.* **2015**, *44*, 586–598. [CrossRef]
40. Táczi, I. *Energy Regulators Regional Association Secretariat Pumped Storage Hydroelectric Power Plants: Issues and Applications Pumped Storage Hydroelectric Power Plants: Issues and Applications*; Energy Regulators Regional Association: Budapest, Hungary, 2016.
41. Götz, M.; Lefebvre, J.; Mörs, F.; McDaniel Koch, A.; Graf, F.; Bajohr, S.; Reimert, R.; Kolb, T. Renewable Power-to-Gas: A technological and economic review. *Renew. Energy* **2016**, *85*, 1371–1390. [CrossRef]
42. Buttler, A.; Spliethoff, H. Current status of water electrolysis for energy storage, grid balancing and sector coupling via power-to-gas and power-to-liquids: A review. *Renew. Sustain. Energy Rev.* **2018**, *82*, 2440–2454. [CrossRef]

43. Kotowicz, J.; Węcel, D.; Jurczyk, M. Analysis of component operation in power-to-gas-to-power installations. *Appl. Energy* **2018**, *216*, 45–59. [CrossRef]
44. IEA. *The Future of Hydrogen*; IEA: Paris, France, 2019.
45. H2IT. *Piano Nazionale di Sviluppo. Mobilità Idrogeno Italia*; H2IT Inc.: Milan, Italy, 2019.
46. Wulf, C.; Kaltschmitt, M. Hydrogen supply chains for mobility-Environmental and economic assessment. *Sustainability* **2018**, *10*, 1699. [CrossRef]
47. Karim, G.A. Hydrogen as a spark ignition engine fuel. *Int. J. Hydrogen Energy* **2003**, *28*, 569–577. [CrossRef]
48. Manoharan, Y.; Hosseini, S.E.; Butler, B.; Alzhahrani, H.; Senior, B.T.F.; Ashuri, T.; Krohn, J. Hydrogen fuel cell vehicles. Current status and future prospect. *Appl. Sci.* **2019**, *9*, 2296. [CrossRef]
49. Frontera, P.; Macario, A.; Ferraro, M.; Antonucci, P.L. Supported catalysts for CO2 methanation: A review. *Catalysts* **2017**, *7*, 59. [CrossRef]
50. Lecker, B.; Illi, L.; Lemmer, A.; Oechsner, H. Biological hydrogen methanation—A review. *Bioresour. Technol.* **2017**, *245*, 1220–1228. [CrossRef]
51. Quarton, C.J.; Samsatli, S. Power-to-gas for injection into the gas grid: What can we learn from real-life projects, economic assessments and systems modelling? *Renew. Sustain. Energy Rev.* **2018**, *98*, 302–316. [CrossRef]
52. European Commission. *A Hydrogen Strategy for a Climate-Neutral Europe*; European Commission: Brussels, Belgium, 2020.
53. Thema, M.; Bauer, F.; Sterner, M. Power-to-Gas: Electrolysis and methanation status review. *Renew. Sustain. Energy Rev.* **2019**, *112*, 775–787. [CrossRef]
54. FCHJU Beneficiaries and Budget. Available online: https://www.fch.europa.eu/page/beneficiaries-and-budget (accessed on 18 April 2020).
55. Hydrogen Europe Hydrogen Projects. Available online: https://hydrogeneurope.eu/projects (accessed on 18 April 2020).
56. European Commission CORDIS: Projects and Results. Available online: https://cordis.europa.eu/projects/en (accessed on 18 April 2020).
57. UNIfHY. Available online: https://hydrogeneurope.eu/project/unifhy (accessed on 18 April 2020).
58. SSH2S. Available online: https://hydrogeneurope.eu/project/ssh2s (accessed on 18 April 2020).
59. SOSLeM. Available online: https://www.soslem.eu/project/objectives/ (accessed on 18 April 2020).
60. SOL2HY2. Available online: https://hydrogeneurope.eu/project/sol2hy2 (accessed on 18 April 2020).
61. SOFCOM. Available online: https://hydrogeneurope.eu/project/sofcom (accessed on 18 April 2020).
62. ONSITE. Available online: https://www.fch.europa.eu/page/stationary-power-production-and-combined-heat-and-power#ONSITE (accessed on 18 April 2020).
63. Nellhi. Available online: http://www.nellhi.eu/home/1/2/iconed/articles (accessed on 18 April 2020).
64. MCFC-CONTEX. Available online: https://hydrogeneurope.eu/project/mcfc-contex (accessed on 18 April 2020).
65. LOLIPEM. Available online: https://www.fch.europa.eu/page/stationary-power-production-and-combined-heat-and-power#LOLIPEM (accessed on 18 April 2020).
66. HPEM2GAS. Available online: https://hpem2gas.eu/ (accessed on 18 April 2020).
67. HEALTH-CODE. Available online: https://pemfc.health-code.eu/ (accessed on 18 April 2020).
68. H2FC-LCA. Available online: https://www.hydrogeneurope.eu/project/h2fc-lca (accessed on 18 April 2020).
69. FluMaBack. Available online: https://hydrogeneurope.eu/project/flumaback (accessed on 18 April 2020).
70. FITUP. Available online: https://hydrogeneurope.eu/project/fitup (accessed on 18 April 2020).
71. FCpoweredRBS. Available online: http://fcpoweredrbs.eu/ (accessed on 18 April 2020).
72. EVERYWH2ERE. Available online: http://www.everywh2ere.eu/project-brief/ (accessed on 18 April 2020).
73. ENDURANCE. Available online: http://www.durablepower.eu/index.php/project (accessed on 18 April 2020).
74. ELECTROHYPEM. Available online: https://www.electrohypem.eu/ (accessed on 18 April 2020).
75. EDEN. Available online: http://www.h2eden.eu/approach (accessed on 18 April 2020).
76. DURAMET. Available online: https://www.duramet.eu/about.html (accessed on 13 April 2020).
77. DEMOSOFC. Available online: http://www.demosofc.eu/ (accessed on 13 April 2020).
78. D-CODE. Available online: https://www.fch.europa.eu/page/stationary-power-production-and-combined-heat-and-power#D-CODE (accessed on 13 April 2020).
79. ARTIPHYCTION. Available online: https://hydrogeneurope.eu/project/artiphyction (accessed on 13 April 2020).
80. CoMETHy. Available online: https://www.hydrogeneurope.eu/project/comethy (accessed on 13 April 2020).

81. CH2P. Available online: https://ch2p.eu/about/ (accessed on 13 April 2020).
82. BioROBURplus. Available online: https://www.bioroburplus.org/ (accessed on 13 April 2020).
83. BIOROBUR. Available online: https://www.hydrogeneurope.eu/project/biorobur (accessed on 13 April 2020).
84. BIONICO. Available online: http://www.bionicoproject.eu/sample-page (accessed on 13 April 2020).
85. REMOTE. Available online: https://www.remote-euproject.eu/remote-project/ (accessed on 13 April 2020).
86. Tlili, O.; Mansilla, C.; Linβen, J.; Reuß, M.; Grube, T.; Robinius, M.; André, J.; Perez, Y.; Le Duigou, A.; Stolten, D. Geospatial modelling of the hydrogen infrastructure in France in order to identify the most suited supply chains. *Int. J. Hydrogen Energy* **2020**, *45*, 3053–3072. [CrossRef]
87. Cigolotti, V.; Mcphail, S.J.; Tommasino, M.C. *HyLAW National Policy Paper—Italy*; HyLaw Project: Brussels, Belgium, 2018.
88. Andersson, J.; Grönkvist, S. Large-scale storage of hydrogen. *Int. J. Hydrogen Energy* **2019**, *44*, 11901–11919. [CrossRef]
89. Hydrogen Council. *Path to Hydrogen Competitiveness. A Cost Perspective*; Hydrogen Council: Brussels, Belgium, 2020.
90. IEA. The Future of Hydrogen. Available online: https://www.iea.org/reports/the-future-of-hydrogen (accessed on 5 September 2020).
91. Taibi, E.; Miranda, R.; Vanhoudt, W.; Winkel, T.; Lanoix, J.-C.; Barth, F. *Hydrogen from Renewable Power: Technology Outlook for the Energy Transition*; International Renewable Energy Agency: Abu Dhabi, UAE, 2018.
92. Cormos, A.-M.; Szima, S.; Fogarasi, S.; Cormos, C.-C. Economic Assessments of Hydrogen Production Processes Based on Natural Gas Reforming with Carbon Capture. *Chem. Eng. Trans.* **2018**, *70*, 1231–1236.
93. GME Gestore dei Mercati Energetici SpA. Available online: https://www.mercatoelettrico.org/it/ (accessed on 6 September 2020).
94. ARERA Prezzi Finali del Gas Naturale per i Consumatori Industriali—UE e Area Euro. Available online: https://www.arera.it/it/dati/gpcfr2.htm (accessed on 6 September 2020).
95. Kalamaras, C.M.; Efstathiou, A.M. Hydrogen Production Technologies: Current State and Future Developments. *Conf. Pap. Energy* **2013**, *2013*, 1–9. [CrossRef]
96. Zakeri, B.; Syri, S. Electrical energy storage systems: A comparative life cycle cost analysis. *Renew. Sustain. Energy Rev.* **2015**, *42*, 569–596. [CrossRef]
97. Dixon, R.K. Advancing towards a hydrogen energy economy: Status, opportunities and barriers. *Mitig. Adapt. Strateg. Glob. Chang.* **2007**, *12*, 305–321. [CrossRef]
98. Felderhoff, M.; Weidenthaler, C.; Von Helmolt, R.; Eberle, U. Hydrogen storage: The remaining scientific and technological challenges. *Phys. Chem. Chem. Phys.* **2007**, *9*, 2643–2653. [CrossRef] [PubMed]
99. IEA Limits on Hydrogen Blending in Natural Gas Networks. Available online: https://www.iea.org/data-and-statistics/charts/limits-on-hydrogen-blending-in-natural-gas-networks-2018 (accessed on 4 September 2020).
100. Floristean, A. *List of Legal Barriers*; HyLaw Project: Brussels, Belgium, 2019.
101. Melaina, M.; Antonia, O.; Penev, M. Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues. *Contract* **2013**, *303*, 275–3000.
102. IEA Batteries and Hydrogen Technology: Keys for a Clean Energy Future—Analysis. Available online: https://www.iea.org/articles/batteries-and-hydrogen-technology-keys-for-a-clean-energy-future (accessed on 4 September 2020).
103. Tsoutsos, T.D.; Zoulias, E.I.; Lymberopoulos, N.; Glöckner, R. Analysis of the Barriers for the Hydrogen Energy Technology in Stand.-alone Power Systems. *Wind Eng.* **2004**, *28*, 615–619. [CrossRef]
104. Sabihuddin, S.; Kiprakis, A.E.; Mueller, M. A numerical and graphical review of energy storage technologies. *Energies* **2015**, *8*, 172–216. [CrossRef]
105. Kirubakaran, A.; Jain, S.; Nema, R.K. A review on fuel cell technologies and power electronic interface. *Renew. Sustain. Energy Rev.* **2009**, *13*, 2430–2440. [CrossRef]
106. HyLaw Project Home | HyLAW Online Database. Available online: https://www.hylaw.eu/ (accessed on 18 April 2020).
107. Kreeft, G. Legislative and Regulatory Framework for Power-to-Gas. In *Germany, Italy and Switzerland*; STORE&GO Project: Karlsruhe, Germany, 2018.
108. European Commission. *Semestre Europeo 2020: Valutazione dei Progressi in Materia di Riforme Strutturali, Prevenzione e Correzione Degli Squilibri Macroeconomici e Risultati Degli Esami Approfonditi a Norma del Regolamento (UE) n. 1176/2011*; European Commission: Brussels, Belgium, 2020.

109. Deichmann, U.; Zhang, F. Dealing with Uncertainties in Energy Investments. Available online: https://blogs.worldbank.org/climatechange/dealing-uncertainties-energy-investments (accessed on 1 August 2020).
110. Ogden, J.M. *Prospects for Hydrogen in the Future Energy System*; Res. Rep.—UCD-ITS-RR-18-07; UC Davis Institute of Transportation Studies: Davis, CA, USA, 2018.
111. Kumar, P.; Britter, R.; Gupta, N. Hydrogen fuel: Opportunities and barriers. *J. Fuel Cell Sci. Technol.* **2009**, *6*, 0210091–0210097. [CrossRef]
112. Chardoneet, C.; De Vos, L.; Genoese, F.; Roig, G.; Bart, F.; De Lacroix, T.; Ha, T.; Van Genebet, B. *Study on Early Business Cases for H2 in Energy Storage and More Broadly Power to H2 Applications*; FCH-JU: Brussels, Belgium, 2017.
113. European Commission. *Statistical Annex: European Economic Forecast—Autumn 2019*; European Commission: Brussels, Belgium, 2019.
114. European Commission Electricity Price Statistics. Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics#Electricity_prices_for_non-household_consumers (accessed on 1 August 2020).
115. AEEGSI. *Testo Integrato Delle Disposizione dell'Autorità per L'energia Elettrica e il Gas Per L'erogazione dei Servizi di Trasmissione e Deistribuzione Dell'energia elettrica. Periodo di Regolazione 2012–2015*; AEEGSI: Milan, Italy, 2015.
116. ARERA. *Deliberazione 169/2019/R/EEL*; ARERA: Milan, Italy, 2019.
117. GSE. Sistemi di Accumulo. Available online: https://www.gse.it/servizi-per-te/fotovoltaico/sistemi-di-accumulo (accessed on 30 June 2020).
118. Checchi, C.; Reguzzoni, M. *L'economia dell'idrogeno: Un possibile alleato a sostegno della decarbonizzazione*; Newsletter del GME: Rome, Italy, 2019; pp. 26–31. Available online: https://www.mercatoelettrico.org/Newsletter/20190415Newsletter.pdf (accessed on 6 April 2020).
119. MISE. *D.M. 4 Luglio 2019*; MISE: Rome, Italy, 2019.
120. Bianchini, A.; Guzzini, A.; Pellegrini, M.; Saccani, C. Natural gas distribution system: Overview of leak detection Systems. In Proceedings of the XXI Summer School 'Francesco Turco'—Industrial Systems Engineering, Naples, Italy, 13–15 September 2016; pp. 123–127.
121. Wang, A.; van der Leun, K.; Peters, D.; Buseman, M. *European Hydrogen Backbone*; Gasunie: Utrecht, The Netherlands, 2020.
122. European Commission. EU Transport Scoreboard. Available online: https://ec.europa.eu/transport/facts-fundings/scoreboard_en (accessed on 30 July 2020).
123. ARERA Composizione Percentuale del Prezzo del Gas Naturale per Un Consumatore Domestico Tipo. Available online: https://www.arera.it/it/dati/gs3.htm (accessed on 30 June 2020).
124. Italian Government. *D.L. 23 Maggio 2000, n. 164*; Italian Government: Rome, Italy, 2000.
125. ARERA. *Relazione Annuale*; ARERA: Milan, Italy, 2019.
126. MISE. *Bilancio Energetico Nazionale*; MISE: Rome, Italy, 2017.
127. Heines, M.R.; Polman, E.A.; de Laat, J.C. Reduction of CO2 emissions by adding hydrogen to natural gas. In Proceedings of the Greenhouse Gas Control Technologies Conference, Vancouver, BC, Canada, 5–9 September 2004.
128. Forni, F. In Italia 2,3 milioni di auto a GPL, 1 a metano, 131 mila ibride/elettriche. QN Motori. 2017. Available online: http://motori.quotidiano.net/autoemotonews/in-italia-23-milioni-di-auto-a-gpl.htm (accessed on 20 April 2020).
129. H2 South Tyrol H2 Südtirol: Home. Available online: https://www.h2-suedtirol.com/it/ (accessed on 1 August 2020).
130. Viesi, D.; Crema, L.; Testi, M. The Italian hydrogen mobility scenario implementing the European directive on alternative fuels infrastructure (DAFI 2014/94/EU). *Int. J. Hydrogen Energy* **2017**, *42*, 27354–27373. [CrossRef]
131. MobilitàH2.it Map of Hydrogen Refuelling Stations in Italy. Available online: https://www.mobilitah2.it/stations (accessed on 1 August 2020).
132. GSE About Us. Available online: https://www.gse.it/en (accessed on 1 August 2020).
133. Hydrogen Europe Fuel Cell Vehicles: EU Must Act to Build Up Much-Needed Hydrogen Infrastructure. Available online: https://hydrogeneurope.eu/news/fuel-cell-vehicles-eu-must-act-build-much-needed-hydrogen-infrastructure (accessed on 1 August 2020).
134. Hydrogen Europe. *Green Hydrogen Investment and Support Report*; Hydrogen Europe: Brussels, Belgium, 2020.
135. Italian Government. *Decreto Rilancio*; Italian Government: Rome, Italy, 2020.

136. Italian Government. *D.lgs. 9 aprile 2008, n. 81. Testo Unico Sulla Salute e Sicurezza sul Lavoro*; Italian Government: Rome, Italy, 2016; pp. 147–150.
137. European Commission. *Direttiva 94/9/CE*; European Commission: Brussels, Belgium, 1994.
138. European Commission. *Directive 2014/34/UE*; European Commission: Brussels, Belgium, 2014.
139. Cavendish Energy LLC. *Emerging Occupations and Skills in the Hydrogen/Fuel Cell Economy and Associated Education and Training Requirements*; Cavendish Energy LLC: Chicago, IL, USA, 2016.
140. Madden, B.; Chan, E.; Alvin, S. *Techno-Economic Modelling of Electrolyser Systems*; FCH JU: Brussels, Belgium, 2014.
141. Bianchini, A.; Guzzini, A.; Pellegrini, M.; Saccani, C. Natural Gas Distribution Networks: How Failures' Databases Can Improve Existing Safety Performances. In Proceedings of the 24th Summer School Francesco 2019, Bergamo, Italy, 11–13 September 2019.
142. Bianchini, A.; Guzzini, A.; Pellegrini, M.; Saccani, C. Earthquake and earth movement monitoring: The possibility to use Natural Gas distribution infrastructure. In Proceedings of the XXII Summer School 'Francesco Turco'—Industrial Systems Engineering, Palermo, Italy, 13–15 September 2017; pp. 143–149.
143. Ministro dello Sviluppo Economico. *Decreto Ministeriale 18 Maggio 2018*; Ministero dello Sviluppo Economico: Rome, Italy, 2018.
144. Abeysekera, M.; Wu, J.; Jenkins, N.; Rees, M. Steady state analysis of gas networks with distributed injection of alternative gas. *Appl. Energy* **2016**, *164*, 991–1002. [CrossRef]
145. Hydrogen Europe. *Hydrogen Europe Vision on the Role of Hydrogen and Gas Infrastructure on the Road Toward a Climate Neutral Economy—A Contribution to the Transition of the Gas Market*; Hydrogen Europe: Brussels, Belgium, 2019.
146. Altfeld, K.; Pinchbeck, D. Admissible hydrogen concentrations in natural gas systems. *Gas Energy* **2013**, *2103*, 1–2.
147. Jaworski, J.; Blacharski, T. Study of the effect of addition of hydrogen to natural gas on diaphragm gas meters. *Energies* **2020**, *13*, 3006. [CrossRef]
148. Bianchini, A.; Guzzini, A.; Pellegrini, M.; Saccani, C. Gas smart metering in Italy: State of the art and analysis of potentials and technical issues. In Proceedings of the Summer School Francesco Turco 2018, Palermo, Italy, 12–14 September 2018; pp. 49–55.
149. IEA Hydrogen Implementing Agreement—Task 37. Available online: http://ieahydrogen.org/Activities/Task-37-Hydrogen-Safety-Task.aspx (accessed on 3 August 2020).
150. IEA Hydrogen Implementing Agreement—Task 31. Available online: http://ieahydrogen.org/Activities/Task-31.aspx (accessed on 3 August 2020).
151. DNV Research & Innovation. *Main Report-Survey of Hydrogen Risk Assessment Methods*; IEA: Paris, France, 2008.
152. Bianchini, A.; Guzzini, A.; Pellegrini, M.; Saccani, C. Natural gas distribution system: A statistical analysis of accidents data. *Int. J. Press. Vessel. Pip.* **2018**, *168*, 24–38. [CrossRef]
153. Ministero dello Sviluppo Economico Decreto 17 Aprile 2008. Available online: https://www.gazzettaufficiale.it/atto/serie_generale/caricaDettaglioAtto/originario?atto.dataPubblicazioneGazzetta=2008-05-08&atto.codiceRedazionale=08A02872&elenco30giorni=false (accessed on 18 April 2020).
154. Ministero dello Sviluppo Economico Decreto 16 Aprile 2008. Available online: https://www.gazzettaufficiale.it/eli/id/2008/05/08/08A02871/sg (accessed on 18 April 2020).
155. Bianchini, A.; Donini, F.; Guzzini, A.; Pellegrini, M.; Saccani, C. Natural gas pipelines distribution: Analysis of risk, design and maintenance to improve the safety performance. In Proceedings of the XX Summer School 'Francesco Turco'—Industrial Systems Engineering, Naples, Italy, 16–18 September 2015; pp. 243–248.
156. ARERA. *Documento per la Consultazione 338/2019/R/GAS*; ARERA: Milan, Italy, 2019.
157. Marcogaz. *Impact of Hydrogen in Natural gas on End-Use Applications*; Marcogaz: Brussels, Belgium, 2017.
158. H21 Project. Available online: https://www.h21.green/about/ (accessed on 18 April 2020).
159. Dehaeseleer, J.; General, S. The effects of injecting hydrogen (renewable gases). In Proceedings of the EASEE-Gas GMOM, Budapest, Hungary, 28 March 2018.
160. Hydrogen Tools Lessons Learned. Available online: https://h2tools.org/lessons (accessed on 3 August 2020).
161. Hydrogen Tools Hydrogen Delivery Truck Roll over Accident. Available online: https://h2tools.org/lessons/hydrogen-delivery-truck-roll-over-accident (accessed on 3 August 2020).

162. Hydrogen Tools Hydrogen Cylinder Transport Accident Results in Explosion. Available online: https://h2tools.org/lessons/hydrogen-cylinder-transport-accident-results-explosion (accessed on 3 August 2020).
163. BS EN 31000:2010. *Risk Management. Risk Assessment Techniques*; ISO: Geneva, Switzerland, 2010; pp. 79–81.
164. Conca, A.; Ridella, C.; Sapori, E. A Risk Assessment for Road Transportation of Dangerous Goods: A Routing Solution. In Proceedings of the Transportation Research Procedia, Volos, Greece, 26–27 May 2016; Elsevier: Amsterdam, The Netherlands, 2016; Volume 14, pp. 2890–2899.
165. SNAM Snam e l'idrogeno. Available online: https://www.snam.it/it/hydrogen_challenge/snam_idrogeno/ (accessed on 30 June 2020).
166. GPA Engineering. *Hydrogen Impacts on Downstream Installations and Appliances*; GPA Engineering: Adelaide, Australia, 2019.
167. De Vries, H.; Mokhov, A.V.; Levinsky, H.B. The impact of natural gas/hydrogen mixtures on the performance of end-use equipment: Interchangeability analysis for domestic appliances. *Appl. Energy* **2017**, *208*, 1007–1019. [CrossRef]
168. Albayrak, B. Use of Hydrogen-Methane Blends in Internal Combustion Engines. In *Hydrogen Energy—Challenges and Perspectives*; InTech: London, UK, 2012.
169. Vries, D.; Florisson, O.; Tiekstra, G.C. Safe Operation of Natural Gas Appliances Fueled with Hydrogen/Natural Gas Mixtures (Progress Obtained in the NaturalHy-Project). In Proceedings of the International Conference on Hydrogen Safety, San Sebastian, Spain, 11–13 September 2007.
170. Comitato Italiano Gas Incidenti da gas combustibili 2017. Available online: http://www.forumcig.it/incidenti-da-gas-combustibili-2017/?doing_wp_cron=1596464089.5708539485931396484375 (accessed on 3 August 2020).
171. ISTAT. *Classificazione Delle Attività Economiche Ateco 2007*; Istituto Nazionale di Statistica (ISTAT): Roma, Italy, 2009.
172. Italian Government. *D.lgs 3 aprile 2006, n. 152*; Italian Government: Rome, Italy, 2006.
173. European Hydrogen and Fuel Cell Associations. New EU Seveso II Directive Keeps Onsite H2 Storage at 5 Tons. Available online: https://www.h2euro.org/latest-news/eha-in-action-home/ec-proposal-for-new-seveso-ii-directive-keeps-onsite-h2-storage-treshold-at-5-tons/ (accessed on 18 April 2020).
174. Italian Government. *D.P.R. 1 agosto 2011, n. 151*; Italian Government: Rome, Italy, 2011.
175. Ministero delle Attività Produttive. *Decreto 1 Dicembre 2004, n. 329*; Ministero delle Attività Produttive: Roma, Italy, 2004.
176. ARERA. *Allegato A. Deliberazione 64/2020/R/gas*; ARERA: Milan, Italy, 2020.
177. UNI TS 11537:2019. *Immissione di Biometano Nelle Reti di Trasporto e Distribuzione di Gas Naturale 2019*; UNI TS: Trieste, Italy, 2019.
178. European Commission. *Commission Regulation no 406/2016*; European Commission: Brussels, Belgium, 2010.
179. European Commission. *Regulation (EC) no 79/2009*; European Commission: Brussels, Belgium, 2009.
180. European Commission. *Directive 2007/46/EC*; European Commission: Brussels, Belgium, 2007.
181. European Commission. *Directive 2014/45/EU*; European Commission: Brussels, Belgium, 2014.
182. Pellizzone, A.; Allansdottir, A.; De Franco, R.; Muttoni, G.; Manzella, A. Geothermal energy and the public: A case study on deliberative citizens' engagement in central Italy. *Energy Policy* **2017**, *101*, 561–570. [CrossRef]
183. Caporale, D.; De Lucia, C. Social acceptance of on-shore wind energy in Apulia Region (Southern Italy). *Renew. Sustain. Energy Rev.* **2015**, *52*, 1378–1390. [CrossRef]
184. Caporale, D.; Sangiorgio, V.; Amodio, A.; De Lucia, C. Multi-criteria and focus group analysis for social acceptance of wind energy. *Energy Policy* **2020**, *140*, 111387. [CrossRef]
185. Mocavini, G. The Trans-Adriatic Pipeline and the Nimby Syndrome. Available online: http://www.lab-ip.net/the-trans-adriatic-pipeline-and-the-nimby-syndrome/ (accessed on 30 June 2020).
186. Spagnolo, C. Gasdotto Tap, Molotov Contro L'azienda che ha Spostato Gli Ulivi: Danni alla Recinzione. La Repubblica, Roma, Italy. 2017. Available online: https://bari.repubblica.it/cronaca/2017/05/18/news/gasdotto_tap_molotov_contro_l_azienda_che_ha_spostato_gli_ulivi_incendiata_la_recinzione-165725387/ (accessed on 30 March 2020).
187. The Guardian Train Carrying Liquid Gas Explodes in Italy Killing 12 | Italy. Available online: https://www.theguardian.com/world/2009/jun/30/train-crash-viareggio-lucca (accessed on 3 August 2020).
188. BBC Bologna Crash: Tanker Truck Fireball Kills Two and Injures Dozens. Available online: https://www.bbc.com/news/world-europe-45087884 (accessed on 3 August 2020).

189. Ministero delle Infrastrutture e dei Trasporti. *Decreto Ministeriale 12 Maggio 2017*; Ministero delle Infrastrutture e dei Trasporti: Roma, Italy, 2017.
190. AIR LIQUIDE. Il Futuro che Verrà: Air Liquide, le Applicazioni Dell'idrogeno. 2004. Available online: https://www.assolombarda.it/fs/20041215125725_119.pdf (accessed on 2 April 2020).
191. MIT. *ADR: Parte 4. Disposizioni Relative Alla Utiliazione Degli Imballaggi e Delle Cisterne*; MIT: Rome, Italy, 2013.
192. Dagdougui, H.; Sacile, R.; Bersani, C.; Ouammi, A. Hydrogen Storage and Distribution: Implementation Scenarios. In *Hydrogen Infrastructure for Energy Applications*; Elsevier: Amsterdam, The Netherlands, 2018; pp. 37–52.
193. Connelly, E.; Penev, M.; Elgowainy, A.; Hunter, C. *Current Status of Hydrogen Liquefaction Costs*; Department of Energy of the United States of America: Washington, DC, USA, 2019.
194. European Commission EUROPA—Increasing Hydrogen Liquefaction in Europe. Available online: https://setis.ec.europa.eu/publications/setis-magazine/fuel-cells-and-hydrogen/increasing-hydrogen-liquefaction-europe (accessed on 4 August 2020).
195. Church, B.; Winckles, G. Assessing the safety of gas installations in buildings. *J. Build. Apprais.* **2005**, *2*, 86–94. [CrossRef]
196. Brecher, A.; Epstein Alexander, K.; Breck, A. *Review and Analysis of Potential Safety Impacts of and Regulatory Barriers to Fuel Efficiency Technologies and Alternative Fuels in Medium- and Heavy-duty Vehicles*; US National Highway Traffic Safety Administration: Washington, DC, USA, 2015; Volume 193.
197. CertifHy. Available online: https://www.certifhy.eu/ (accessed on 18 April 2020).
198. ARERA. *Directive/2019/R/GAS*; ARERA: Milan, Italy, 2019.
199. Schmidt, O.; Gambhir, A.; Staffell, I.; Hawkes, A.; Nelson, J.; Few, S. Future cost and performance of water electrolysis: An expert elicitation study. *Int. J. Hydrogen Energy* **2017**, *42*, 30470–30492. [CrossRef]
200. Chong, L.W.; Wong, Y.W.; Rajkumar, R.K.; Rajkumar, R.K.; Isa, D. Hybrid energy storage systems and control strategies for stand-alone renewable energy power systems. *Renew. Sustain. Energy Rev.* **2016**, *66*, 174–189. [CrossRef]
201. THYGA Testing Hydrogen Admixture for Gas Applications. Available online: https://thyga-project.eu/ (accessed on 7 September 2020).
202. HIGGS Hydrogen In Gas GridS: A Systematic Validation Approach at Various Admixture Levels into High-Pressure Grids. Available online: https://cordis.europa.eu/project/id/875091/it (accessed on 7 September 2020).
203. SNAM H2 Italy 2050, una Filiera Nazionale Dell'idrogeno Per la Crescita e la Decarbonizzazione Dell'italia: Lo Studio Realizzato da The European House—Ambrosetti in Collaborazione con Snam. Available online: https://www.snam.it/it/media/news_eventi/2020/H2_Italy_2050_Ambrosetti_Snam.html (accessed on 6 September 2020).
204. Redazione Energia, L'italia Guiderà la Rivoluzione Energetica: «Impatto sul Pil Fino a 40 Miliardi nel 2050». 2020. Available online: https://www.corriere.it/economia/lavoro/20_settembre_05/idrogeno-l-italia-guidera-rivoluzione-energetica-impatto-pil-fino-40-miliardi-2050-371ade7e-ef70-11ea-94cc-1f80cc642b17.shtml (accessed on 6 September 2020).
205. Seetharaman; Moorthy, K.; Patwa, N.; Saravanan; Gupta, Y. Breaking barriers in deployment of renewable energy. *Heliyon* **2019**, *5*, e01166. [CrossRef]