

Exploring the research landscape of Hydrogen Valleys: A bibliometric analysis

Marzena Frankowska *, Katarzyna Cheba **

* *Institute of Management, University of Szczecin,
Cukrowa 8, 71-004 Szczecin, Poland
marzena.frankowska@usz.edu.pl*

** *Faculty of Economics, West Pomeranian University of Technology in Szczecin,
Żołnierska 47, 71-210 Szczecin, Poland
katarzyna.cheba@zut.edu.pl*



Article history:

Received: July 29, 2023
1st Revision: October 29,
2023
Accepted: November 11,
2023

DOI:

[10.14254/jsdtl.2023.8-2.27](https://doi.org/10.14254/jsdtl.2023.8-2.27)

Abstract: The Hydrogen Valleys concept is growing in importance in the political landscape. Numerous national strategies dedicated to hydrogen, published internationally in recent years, recognize its advantages. The article aimed to check the scale of researchers' and scientists' interest in this topic, especially in relation to the importance and significance attached to this concept by policymakers. The study used the bibliographic method. In the first stage of the study, papers that contained the term 'hydrogen valleys' in the title, abstract or keywords were selected from the publications available in the Web of Science (WoS) database. A quantitative analysis of the collected publications was carried out in the second phase. The third stage focused on an in-depth content analysis of the publications. Bibliographic research was conducted using VOSviewer software. The WoS database identified only 284 publications dealing with hydrogen valleys. There is a systematic increase in the number of cited papers. However, the research result shows that the most frequently cited publications are studies presenting different types of technological solutions and concepts. The study indicates the existence of a significant research gap in the field of research on the creation and development of Hydrogen Valleys. Despite the growing interest in creating and operating hydrogen valleys, it can be assumed that this is still an under-explored area in the literature, especially in economic and social research. Authors' interest in publishing in this area is expected to increase with the development of hydrogen technologies in the coming years.

Keywords: Hydrogen Valleys, green hydrogen, Green Deal, bibliometric analysis, co-occurrence, cluster

1. Introduction

Clean hydrogen is universally considered a critical energy vector in the global efforts to limit greenhouse gas emissions. Over the last few years, it has become a central talking point around the global energy transition away from fossil fuels in industrial processes, mobility, and energy sectors. What is essential, it enables decarbonization in sectors whose emissions are challenging to reduce. It has vast potential for industrial development and job creation. It is an essential lever to meet the transformation goals. Thus, numerous national strategies dedicated to hydrogen, published internationally in recent years, recognize its advantages. The European Green Deal (European Commission, 2019) and Hydrogen Strategy (European Commission, 2020), among others, map out this transformation and place clean hydrogen as one of the priority areas where innovative and market-ready technologies are needed to accelerate the phasing out of fossil fuels and ensure economic and social welfare for EU citizens. One of the essential tools for implementing the hydrogen economy at the regional level is Hydrogen Valleys. Over the past several years, the Fuel Cells and Hydrogen Joint Undertaking (FCH JU) has been setting up, in collaboration with the European Commission, so-called Hydrogen Valleys. The concept aims to enable the emergence of locally integrated hydrogen ecosystems for climate change mitigation and regional economic development (Weichenhain et al., 2022). In March 2023, the European Commission decided to sign the Joint Declaration on Hydrogen Valleys, "Moving the hydrogen economy from niche to scale". The declaration emphasized that *Hydrogen Valleys are one of the best answers to challenging tasks as they bring together clean hydrogen production, storage, distribution and end-use into fully functioning and sustainable local or regional value chains. In doing so, they create ecosystems where research and innovation can be tested in real time and find immediate use leading to further advances in the hydrogen sector. Hydrogen Valleys are a strong instrument to showcase how the EU hydrogen economy works at the local level for citizens* (European Commission, 2023). It was also committed to joining efforts to accelerate research, development, demonstration, and deployment of Hydrogen Valleys and related infrastructure. In addition, the European Commission declared its engagement in presenting a roadmap that strives to establish Hydrogen Valleys in all Member States and to double the number of Hydrogen Valleys across Europe by 2025 (Clean Hydrogen JOINT UNDERTAKING, 2024).

The Hydrogen Valleys concept is growing in importance in the political landscape. Therefore, the scale of researchers' and scientists' interest in this topic must be checked.

Therefore, the article aims to answer the following research questions:

- To what extent is the topic of hydrogen valleys covered in research?
- What are the thematic connections of hydrogen valley research with other research areas?
- Within which scientific disciplines is research on hydrogen valleys mainly undertaken (including economic, technical, spatial, legal, managerial, and social)?

The research was carried out in a three-stage process using bibliographic analysis in the Web of Science database. The article is organized as follows: after the introduction in the first part, the second part presents the concept of hydrogen valleys and their archetypes. Then, section 3 describes the research procedure, and section 4 presents the research results. The work ends with a discussion and conclusions, including an indication of the direction of future research.

2. The concept of Hydrogen Valleys and their archetypes

Increased interest in hydrogen and, as a result, the emergence of the hydrogen market economically stimulates hydrogen production in the regions and the deployment of associated technologies, creating new jobs and showcasing the regions as environmental pioneers. Since the economic activity is concentrated in space, processes may be accompanied by an agglomeration effect. Some scholars maintain that the tendency of firms and individuals to cluster in space is one of the most prominent features of contemporary economic geography (Krugman, 1991). Such 'agglomeration economies' explain why activities cluster spatially and why concentrations of firms and individuals tend to persist over time (Löf & Andersson, 2009). In this context, the concept of "Hydrogen Valleys" appeared. The concept was introduced by the European Union and developed by the Fuel Cells and Hydrogen Joint Undertaking, whose successor is The Clean Hydrogen Partnership. This concept aims to

enable the emergence of ecosystems with locally integrated hydrogen fuels in favour of reducing climate change and developing regional economy.

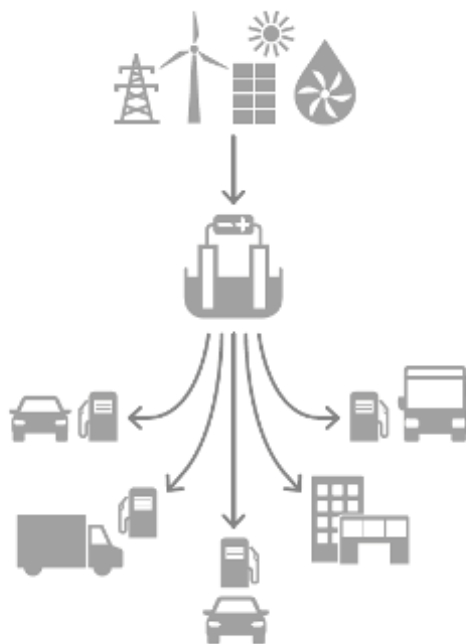
Hydrogen Valleys are regional ecosystems that cover multiple stages in the hydrogen value chain along their geographic scope. These stages range from hydrogen production (often even dedicated production from renewables) to the subsequent storage of hydrogen and distribution to off-takers via various transport and storage methods. They are essential steps towards enabling the development of a new hydrogen economy (Weichenhain et al., 2021). Furthermore, the Hydrogen Valleys have begun to form the first regional "hydrogen economies".

In recent years, the Hydrogen Valleys have acquired an international dimension with the emergence of new projects worldwide. The landscape of Hydrogen Valleys is developing under the increased impetus of the private sector and is structured around so-called project archetypes. The Hydrogen Valleys will noticeably develop throughout the 2020s due to the increase in the overall number of projects and because the announced projects themselves are gaining in importance and complexity (for example, hydrogen production volume and investment forecasts).

Hydrogen Valleys revolve around established value chain archetypes, where different goals promise short-term business justifications. The observed three classic configurations are the following:

- local, small-scale and mobility-focused projects,
- local, medium-sized and industry-focused projects,
- large-scale projects geared towards international export.

Figure 1: Smaller-scale local mobility-centered Hydrogen Valleys (Archetype 1)



Source: Weichenhain, U., Kaufmann, M., Hölscher, M., & Scheiner, M. (2022). Going Global: An update On Hydrogen Valleys and Their Role in the New Hydrogen Economy.

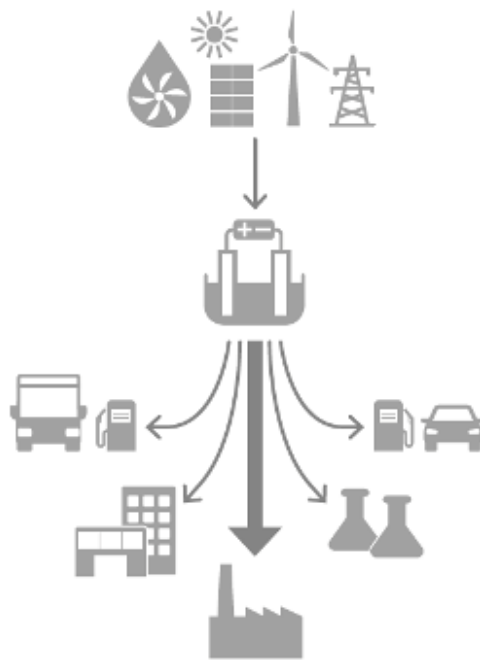
The smaller scale Hydrogen Valley is assumed to have typically 1–10+ MW of local electrolyzer capacity. These projects typically focus on the decarbonization efforts of regional mobility fleets (hydrogen fuel cell trucks, buses, trains, etc.). The Valley matches the combined demand with the built-out of jointly used hydrogen refuelling stations and centralized clean hydrogen production. Such mobility Valleys are often the first stage of the hydrogen ecosystem and have the longest legacy of all archetypes (especially in Europe). They have historically enjoyed substantial public support but are now moving to more and more commercial business models. According to Mission Innovation Hydrogen Valley Platform (2022), project examples include the Zero Emission Valley Auvergne-Rhône-Alpes (FR), the Hydrogen Valley South Tyrol (IT), and the Hydros spider project (CH).

The medium-scale Hydrogen Valley is assumed to have typically 10-300+ MW of local electrolyzer capacity. These Valleys are based on a local or regional hydrogen production source (usually clean hydrogen) directly at the site of one or more large industrial consumers serving as “anchor load”, such as refineries or fertilizer production plants (i.e., conversion from grey to clean hydrogen). Mobility off-takers complete this ecosystem, adding the hydrogen assets (fleets, hydrogen refuelling stations, storage and distribution). All are benefitting from lower hydrogen supply costs. The key to success for such projects is a seamless integration of hydrogen production in the established production processes on the anchor off-taker(s).

According to Mission Innovation Hydrogen Valley Platform (2022), this type of Hydrogen Valley continues to grow (numbers of partners and production sizes), with the first projects with capacities of up to 20 MW already operational in the EU and the US. Project examples include Hydrogen Holland 1 (NL), Basque Hydrogen Corridor (ES), and HyNet North-West England (UK).

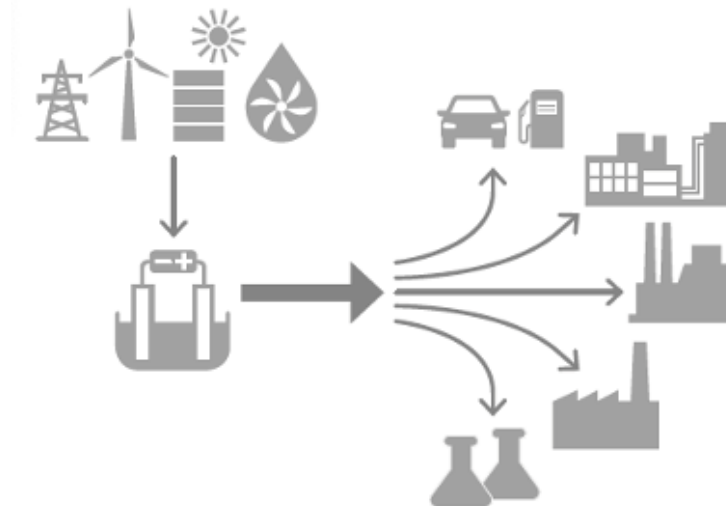
The large-scale Hydrogen Valley is assumed to typically have 250-1,000+ MW of local electrolyzer capacity. This type of Valley is characterized by focusing on low-cost production of clean hydrogen for local off-take, but ultimately mainly regional and international export to connect supply and demand centres on a global scale. The projects are typically co-located with dedicated additional renewable capacities (e.g., pure PV, PV combined with onshore wind, or pure offshore wind). Such “megaprojects” are led mainly by energy majors or sovereign developers. According to Mission Innovation Hydrogen Valley Platform (2022), the first project is to approach final investment decisions, especially in the Middle East and Australia. Key projects include Project NEOM (KSA), Aqua Ventus (DE), H2 Magallanes (CL), and Pilbara Hydrogen Hub (AU).

Figure 2. Medium-scale Hydrogen Valleys focusing on industrial decarbonization (Archetype 2)



Source: Weichenhain, U., Kaufmann, M., Hölscher, M., & Scheiner, M. (2022). Going Global: An update On Hydrogen Valleys and Their Role in the New Hydrogen Economy.

Figure 3: Large-scale and ultimately export-oriented Hydrogen Valleys (Archetype 3)



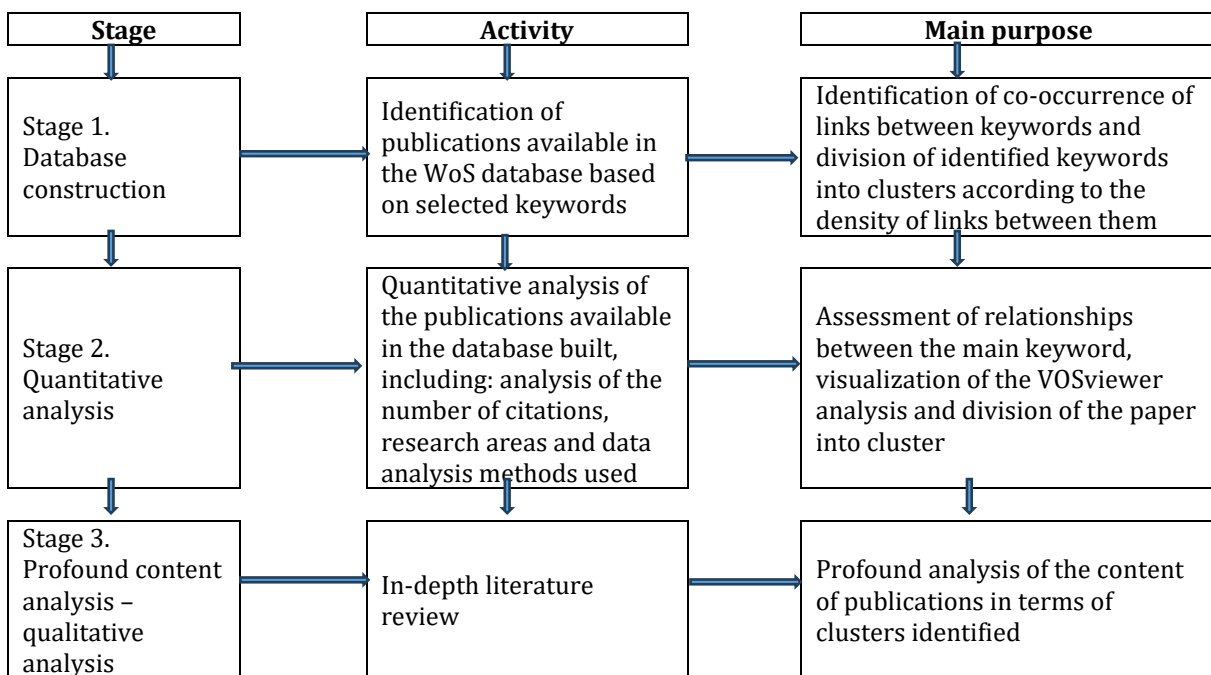
Source: Weichenhain, U., Kaufmann, M., Hölscher, M., & Scheiner, M. (2022). Going Global: An update On Hydrogen Valleys and Their Role in the New Hydrogen Economy.

Hydrogen Valleys have become a global concept, with new integrated projects emerging worldwide. While still predominantly present in the traditional hydrogen "lead markets" (Europe, Asia, North America), more projects are developing on all continents. The industry is increasingly involved in hydrogen valley projects. Does scientific interest follow them? To what extent are Hydrogen Valleys the subject of scientific research?

3. Research procedure

The research procedure applied in the paper covers three stages. Figure 4 presents the flowchart of this procedure.

Figure 4: Systematic literature review flowchart



Source: own elaboration

In the first stage of the study, papers that contained the term 'hydrogen valleys' in the title, abstract or keywords were selected from the publications available in the Web of Science database. As one of the study's aims was to identify and analyze in-depth publications that do not focus only on technological aspects, the WoS database was also searched by adding terms related to sustainability and social aspects related to the creation of hydrogen valleys to the original term. The search resulted in two databases of publications. The first included papers dealing with issues related to the creation and development of hydrogen valleys. The second database included only those publications in which the term was discussed in the context of social and environmental development.

In the study's second phase, a quantitative analysis of the collected publications was carried out. Among other things, the density of the links between the keywords, their division into clusters and the number of citations of the identified publications were considered.

The third stage focused on an in-depth content analysis of the publications. Papers that addressed issues related to the social and environmental determinants of the Hydrogen Valley's development and technological aspects were considered. Bibliographic research was conducted using VOSviewer software, version 1.6.20 (van Eck & Waltman 2010).

4. Systematic literature review - in-depth quantitative and qualitative analysis of publication content

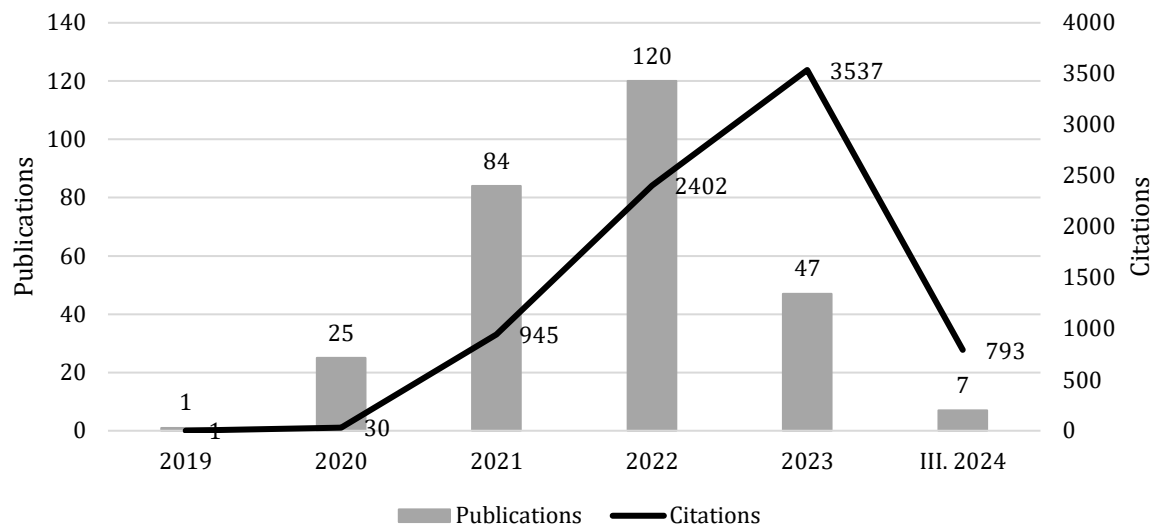
The search results, including the relevant keywords, are the starting point for a more in-depth analysis of the quantitative and qualitative publications in the WoS database (Table 1). The searches shown in the table refer to the two categories, all fields and topics. The search for publications started with the term 'hydrogen valley*', where the character '*' replaces the various possible inflectional endings, and the quotation marks indicate that both words appearing side by side in the text. In the next step, the term 'soci*' was added to the original search term in order to identify works that refer to social aspects related to the operation of hydrogen valleys.

Table 1: Number of papers identified in the WoS according to the selected keywords

The combination of topics	Number of papers (all fields/ topic)
„hydrogen valley*“	284/ 12
„hydrogen valley*“ AND „soci*“	14/ 2
„hydrogen valley*“ AND sustainab*	23/4

Source: own elaboration based on WoS database

As the WoS database identified only 284 publications dealing with hydrogen valleys in some form or other, these papers were used as a first step to perform quantitative analyses, taking into account, among other things, the year of publication, the number of citations, the affiliation of the authors or the thematic scope of the research carried out. Figure 5 shows the evolution of the number of publications and citations of these papers.

Figure 5: Total publications and citations by year

Source: own elaboration based on WoS database

The information presented in the graph confirms a relatively high interest in research in hydrogen valleys, particularly an increasing interest in work in this area between 2020 and 2022. There is also a systematic increase in the number of cited papers. The highest number of citations - 3537 - was observed in 2023. The first article in this field did not appear in the WoS database until 2019, coinciding with the establishment the first hydrogen valley in the European Union - the European Hydrogen Valleys Partnership. It is also worth noting the rather significant drop in the number of papers in 2023, when only 47 publications in this field were published. Despite the growing interest in creating and operating hydrogen valleys, it can be assumed that this is still an under-explored area in the literature. The interest of authors in publishing in this area is expected to increase with the development of hydrogen technologies in the coming years. Table 2 provides information on the most cited publications in this area.

Table 2: The most cited publications

Publications (year)	Author	Journal	Total citations
Pt single atoms supported on N-doped mesoporous hollow carbon spheres with enhanced electrocatalytic H ₂ -evolution activity (2021)	Kuang, P., Wang, Y., Zhu, B., Xia, F., Tung, C. W., Wu, J., ... & Yu, J.	<i>Advanced Materials</i> , 33(18), 2008599	313
Transition-metal phosphides: activity origin, energy-related electrocatalysis applications, and synthetic strategies (2020)	Pu, Z., Liu, T., Amiin, I. S., Cheng, R., Wang, P., Zhang, C., ... & Mu, S.	<i>Advanced Functional Materials</i> , 30(45), 2004009	308
Ru-doped 3D flower-like bimetallic phosphide with a climbing effect on overall water splitting (2020)	Chen, D., Lu, R., Pu, Z., Zhu, J., Li, H. W., Liu, F., ... & Mu, S.	<i>Applied Catalysis B: Environmental</i> , 279, 119396	249
Comprehensive understandings into complete reconstruction of precatalysts: synthesis, applications, and characterizations (2021)	Liu, X., Meng, J., Zhu, J., Huang, M., Wen, B., Guo, R., & Mai, L.	<i>Advanced Materials</i> , 33(32), 2007344	222
Regulative electronic states around ruthenium/ruthenium disulphide heterointerfaces for efficient water splitting in acidic media (2021)	Zhu, J., Guo, Y., Liu, F., Xu, H., Gong, L., Shi, W., ... & Mu, S.	<i>Angewandte Chemie</i> , 133(22), 12436-12442	185
Reconstruction-determined alkaline water electrolysis at industrial temperatures (2020)	Liu, X., Guo, R., Ni, K., Xia, F., Niu, C., Wen, B., ... & Mai, L.	<i>Advanced Materials</i> , 32(40), 2001136	179

Ultralow Ru loading transition metal phosphides as high-efficient bifunctional electrocatalyst for a solar-to-hydrogen generation system (2020)	Chen, D., Pu, Z., Lu, R., Ji, P., Wang, P., Zhu, J., ... & Mu, S.	<i>Advanced Energy Materials</i> , 10(28), 2000814	164
Cobalt single atom site isolated Pt nanoparticles for efficient ORR and HER in acid media (2021)	Liang, L., Jin, H., Zhou, H., Liu, B., Hu, C., Chen, D., ... & Mu, S.	<i>Nano Energy</i> , 88, 106221	160
Synthesis of reduced graphene oxide supported nickel-cobalt-layered double hydroxide nanosheets for supercapacitors (2021)	Zhang, L., Cai, P., Wei, Z., Liu, T., Yu, J., Al-Ghamdi, A. A., & Wageh, S.	<i>Journal of Colloid and Interface Science</i> , 588, 637-645	156
Complete reconstruction of hydrate pre-catalysts for ultrastable water electrolysis in industrial-concentration alkali media (2020)	Liu, X., Meng, J., Ni, K., Guo, R., Xia, F., Xie, J., ... & Zhao, D.	<i>Cell Reports Physical Science</i> , 1(11)	140

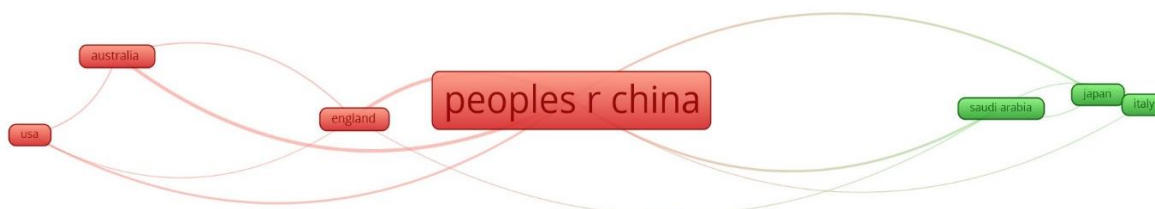
Source: own elaboration based on WoS database

The information presented in the table shows that the most frequently cited publications are studies presenting different types of technological solutions and concepts. These are mainly works that fall into areas such as:

- materials science multidisciplinary (129 publications),
- chemistry physical (1050),
- nanoscience technology (62),
- chemistry multidisciplinary (60),
- energy fuels (59),
- physics applied (55).

In the database constructed, the most significant number of papers were published by authors from China (267 publications) (Figure 6). This is followed by Australia and England, which each have 13 papers. There are far fewer papers by authors from the European Union. In total, only 23 such papers were identified.

Figure 6: Clusters network – countries



Source: own elaboration in VOSviewer software

In the next step, to identify the tendencies of the literature, especially to answer how research on this topic is divided into research areas (clusters), an analysis of co-occurrence of keywords was carried out based on articles with at least 7 co-citations. This phase of the study led to the division of the publications analyzed into 4 clusters (Figure 7).

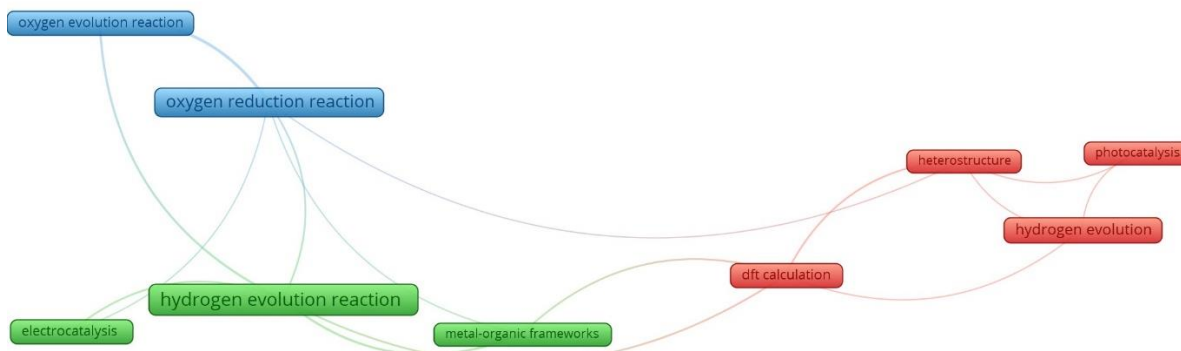
Figure 7: Clusters network – all identified keywords



Source: own elaboration in VOSviewer software

In each of these clusters, the identified keywords with the highest co-occurrence describe technological aspects related to the creation and development of hydrogen valleys. This is even more evident when looking at the co-occurrence of keywords identified directly by the authors of these papers (Figure 8).

Figure 8: Clusters network – authors keywords



Source: own elaboration in VOSviewer software

In this case, the keywords identified were grouped into 3 clusters. Cluster 1 included papers that identified combinations between words such as DFT calculation – density functional theory calculation, heterostructure, hydrogen evolution and photocatalysis. Cluster 2 covers the following keywords: electrocatalysis, hydrogen evolution reaction and metal-organic frameworks. Cluster three identified links between the following terms: oxygen evolution reaction and oxygen reduction reaction.

According to the information presented in Table 1, works referring to social or sustainability aspects are few. Their citation rate is also relatively low (Table 3).

Table 3: The most cited publications with references to social or sustainability aspects

Publications (year)	Author	Journal	Total citations
Prospect of hydrogen energy in Asia-Pacific: A perspective review on techno-socio-economy nexus (2021)	Aditiya, H. B., & Aziz, M.	<i>International Journal of Hydrogen Energy</i> , 46(71), 35027-35056	67
Local government policies and public transport decarbonization through the production and adoption of fuel cell electric vehicles (FCEVs) in China (2023)	Yeung, G., & Liu, Y.	<i>Journal of Cleaner Production</i> , 422, 138552	1
Development of a Hydrogen Valley for Exploitation of Green Hydrogen in Central Italy (2022)	Ficco, G., Arpino, F., Dell'Isola, M., Grimaldi, M., & Lisi, S.	<i>Energies</i> , 15(21), 8072	1
Performance simulation of hydrogen-electric transit bus running in a mountain environment (2023)	Ciancetta, F., Di Pasquale, M., D'Ovidio, G., Fabri, G., Ometto, A., Ranieri, S., & Villante, C.	<i>European Transport</i> , 90	0

Source: own elaboration based on WoS database

Among the most frequently mentioned keywords in these papers, in addition to green hydrogen or hydrogen valley, links to the term hydrogen evolution reaction are evident in public reaction to the creation and development of hydrogen valleys. Aditiya and Aziz (2021) point out in their work that "countries with active hydrogen policies and high R&D capacity could lead the strategy, while countries with high capacity in primary energy supply and economic advantage would benefit the group in providing energy and commercial resources respectively". They also point out that social acceptance is critical to the acceptance of energy system transformation. According to them, countries with a high social security index could potentially reduce the risk of public backlash against the new hydrogen energy systems in the future. The work of Yeung and Liu (2023) points out that a combination of infrastructure, supply and demand initiatives can facilitate the socio-technical transition to decarbonize public transport in favour of hydrogen-based transport. In most papers analyzed, social or sustainability aspects are mainly discussed in the context of technological developments. There is a lack of work directly addressing the social determinants of the creation and development of hydrogen troughs or their impact on achieving sustainable development goals.

5. Conclusion

Hydrogen is essential to replace natural gas, coal, and oil in hard-to-decarbonize industry, mobility, and energy sectors. Although Hydrogen Valleys are a young concept, they should become an essential cornerstone in producing, importing, transporting, and using clean hydrogen in Europe. So far, the Hydrogen Valleys and similar concepts, such as hydrogen hubs, ecosystems, etc., are perceived as local agglomerations of various hydrogen users, shared infrastructure, and joint supply sources. They aim to scale the industry and take the "New Hydrogen Economy" to the next level.

This approach is typical of the activities of the European Union's policymakers, which is visible in its strategic documents and programs financing industrial development and energy transformation. However, significant involvement at the political level is not accompanied by scientific research in this area.

The study indicates the existence of a significant research gap in the field of research on the creation and development of Hydrogen Valleys. At the current stage, issues such as the establishment and development of Hydrogen Valleys, management and coordination of Hydrogen Valleys, cooperation with stakeholders, and social aspects related to, among others, the issue of social acceptance of investments in hydrogen technologies are entirely omitted. There are also no regional studies on modelling the spatial development of Hydrogen Valleys using, for example, the achievements of agglomeration economics. Worryingly, research results prove a disconnect between the European

Union's strategic documents regarding achieving climate neutrality, decarbonization and increasing energy security and the scope of research conducted on Hydrogen Valleys.

The findings of this work may have important implications for the success of implementing the hydrogen economy in the future. Researchers from the social and economic sciences may be relatively unaware of the changes in the global economy, which may explain their current lack of interest. Therefore, even greater efforts are necessary to popularize processes aimed at decarbonization and achieving climate neutrality. The point is for scientists and society to understand the current transformation's direction better.

The paper's authors are also aware that the results presented from the Web of Science database search represent only a certain part of the research on the operation of hydrogen troughs. Knowledge of technological developments in this area could also be sought in patent application databases. A key element could also be identifying the knowledge of different social groups, e.g. local residents or entrepreneurs in the area.

Funding

The publication was partially funded by the Faculty of Economics, West Pomeranian University of Technology in Szczecin: "Green Lab. Research and Innovations".

Conflicts of interest

The authors declare no conflict of interest.

Citation information

Frankowska, M., & Cheba, K. (2023). Exploring the research landscape of Hydrogen Valleys: A bibliometric analysis. *Journal of Sustainable Development of Transport and Logistics*, 8(2), 348-359. doi:10.14254/jsdtl.2023.8-2.27

References

- Aditiya, H. B., & Aziz, M. (2021). Prospect of hydrogen energy in Asia-Pacific: A perspective review on techno-socio-economy nexus. *International Journal of Hydrogen Energy*, 46(71), 35027-35056. <https://doi.org/10.1016/j.ijhydene.2021.08.070>
- Chen, D., Lu, R., Pu, Z., Zhu, J., Li, H. W., Liu, F., ... & Mu, S. (2020). Ru-doped 3D flower-like bimetallic phosphide with a climbing effect on overall water splitting. *Applied Catalysis B: Environmental*, 279, 119396. <https://doi.org/10.1016/j.apcatb.2020.119396>
- Chen, D., Pu, Z., Lu, R., Ji, P., Wang, P., Zhu, J., ... & Mu, S. (2020). Ultralow Ru loading transition metal phosphides as high-efficient bifunctional electrocatalyst for a solar-to-hydrogen generation system. *Advanced Energy Materials*, 10(28), 2000814. <https://doi.org/10.1002/aenm.202000814>
- Ciancetta, F., Di Pasquale, M., D'Ovidio, G., Fabri, G., Ometto, A., Ranieri, S., & Villante, C. (2023). Performance simulation of hydrogen-electric transit bus running in a mountain environment. *European Transport*, 90, 9, 1-10. <https://doi.org/10.48295/ET.2023.90.9>
- Clean Hydrogen Joint Undertaking, Work Programme 2024. (2024). https://www.clean-hydrogen.europa.eu/system/files/2024-01/Clean%20Hydrogen%20JU%20AWP%202024%20-%20all%20chapters_Final_For_Publication.pdf
- European Green Deal. (2019). https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
- European Commission (2023), ANNEX. *Joint Declaration on Hydrogen Valleys - Moving the hydrogen economy from niche to scale* (1-4). https://research-and-innovation.ec.europa.eu/system/files/2023-03/C_2023_1131_F1_ANNEX_EN_V4_P1_2523210.PDF

- Ficco, G., Arpino, F., Dell'Isola, M., Grimaldi, M., & Lisi, S. (2022). Development of a Hydrogen Valley for Exploitation of Green Hydrogen in Central Italy. *Energies*, 15(21), 8072.
- Krugman, P. (1991). Increasing returns and economic geography. *Journal of Political Economy*, 99(3), 483-499. <https://doi.org/10.3390/en15218072>
- Kuang, P., Wang, Y., Zhu, B., Xia, F., Tung, C. W., Wu, J., ... & Yu, J. (2021). Pt single atoms supported on N-doped mesoporous hollow carbon spheres with enhanced electrocatalytic H₂-evolution activity. *Advanced Materials*, 33(18), 2008599. <https://doi.org/10.1002/adma.202008599>
- Liang, L., Jin, H., Zhou, H., Liu, B., Hu, C., Chen, D., ... & Mu, S. (2021). Cobalt single atom site isolated Pt nanoparticles for efficient ORR and HER in acid media. *Nano Energy*, 88, 106221. <https://doi.org/10.1016/j.nanoen.2021.106221>
- Liu, X., Guo, R., Ni, K., Xia, F., Niu, C., Wen, B., ... & Mai, L. (2020). Reconstruction-determined alkaline water electrolysis at industrial temperatures. *Advanced Materials*, 32(40), 2001136. <https://doi.org/10.1002/adma.202001136>
- Liu, X., Meng, J., Ni, K., Guo, R., Xia, F., Xie, J., ... & Zhao, D. (2020). Complete reconstruction of hydrate precatalysts for ultrastable water electrolysis in industrial-concentration alkali media. *Cell Reports Physical Science*, 1(11). <https://doi.org/10.1016/j.xcrp.2020.100241>
- Liu, X., Meng, J., Zhu, J., Huang, M., Wen, B., Guo, R., & Mai, L. (2021). Comprehensive understandings into complete reconstruction of precatalysts: synthesis, applications, and characterizations. *Advanced Materials*, 33(32), 2007344. <https://doi.org/10.1002/adma.202007344>
- Lööf, H., & Andersson, M. (2009). *Agglomeration and Productivity—evidence from firm-level data*. CECIS, The Royal Institute of Technology, Stockholm. <https://doi.org/10.1007/s00168-009-0352-1>
- Pu, Z., Liu, T., Amiin, I. S., Cheng, R., Wang, P., Zhang, C., ... & Mu, S. (2020). Transition-metal phosphides: activity origin, energy-related electrocatalysis applications, and synthetic strategies. *Advanced Functional Materials*, 30(45), 2004009. <https://doi.org/10.1002/adfm.202004009>
- Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, 84(2), 523-538. <https://doi.org/10.1007/s11192-009-0146-3>
- Weichenhain, U., Kaufmann, M., Benz, A., & Gomez, G. M. (2021). *Hydrogen valleys: insights into the emerging hydrogen economies around the world*. Publications Office of the European Union.
- Weichenhain, U., Kaufmann, M., Hölscher, M., & Scheiner, M. (2022). *Going Global: An update On Hydrogen Valleys and Their Role in the New Hydrogen Economy*. Publications Office of the European Union.
- Yeung, G., & Liu, Y. (2023). Local government policies and public transport decarbonization through the production and adoption of fuel cell electric vehicles (FCEVs) in China. *Journal of Cleaner Production*, 422, 138552. <https://doi.org/10.1016/j.jclepro.2023.138552>
- Zhu, J., Guo, Y., Liu, F., Xu, H., Gong, L., Shi, W., ... & Mu, S. (2021). Regulative electronic states around ruthenium/ruthenium disulphide heterointerfaces for efficient water splitting in acidic media. *Angewandte Chemie*, 133(22), 12436-12442. <https://doi.org/10.1002/ange.202101539>.

