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ARTICLE

Developing China's Hydrogen Economy: National Regulation Through Local Experimentation

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Abstract

Hydrogen is playing an increasingly important role in China's energy and climate policy, with significant implications for the development of a global hydrogen industry. However, China's approach to the regulation of hydrogen, and, in particular, the role of local authorities in promoting hydrogen refuelling stations and fuel cell vehicles, has so far received limited scholarly attention. This article aims to contribute to the literature on hydrogen regulation and to the transnational environmental law scholarship on decentralization by examining how China promotes hydrogen at the national and local levels. The case of China shows how, in jurisdictions with a sufficient degree of decentralization, local initiatives can play a key role in driving the development of hydrogen. By testing different approaches to hydrogen regulation, local experimentation helps to manage the uncertainties associated with this new energy source. At the same time, China's experience confirms the 'environmental federalism' theory on the importance of regulatory harmonization to reduce transaction costs and local protectionism. As the Chinese government develops its national regulatory approach on hydrogen, it has the opportunity to take into account both local and international experience and engage with other major economies in an effort to promote an internationally harmonized regulatory landscape.

Keywords: Hydrogen; Decentralization; Environmental federalism; Chinese energy law; Fuel cell vehicles; Hydrogen refuelling stations

1. Introduction

Hydrogen is becoming an increasingly important element in the global energy transition, including in China.[1] Developing China's hydrogen economy requires ambitious regulatory reforms,[2] but hydrogen policy and regulation in China largely

[1] National Development and Reform Commission (NDRC), 'The Mid-and-Long-Term Hydrogen Industrial Development Plan 2021–2035' (《氢能产业发展中长期规划（2021–2035 年）》), 2022, available (in Chinese) at: https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202203/P020220323314396580505.pdf. Note: The English translations of the policies and regulations in this article are not official versions.

[2] See, e.g., NDRC & National Energy Administration (NEA), 'Notice on the Implementation Plan of Promoting the High-Quality Development of New Energy' (《关于促进新时代新能源高质量发展实施

remains under-researched, in contrast to the attention given to the topic in the European Union (EU), the United States (US), and Australia.[3] This is an important gap in the literature, given the impact that China, as a major energy consumer and emitter of greenhouse gases, is expected to have on how the hydrogen sector develops globally.[4] Thus, understanding China's regulatory developments in the field of hydrogen is relevant to the debate on the role of hydrogen for global decarbonization efforts.

The legal literature on hydrogen has helped to identify common barriers to the development of hydrogen,[5] proposed regulatory best practices to overcome these barriers,[6] and examined regulatory pathways to the establishment of a hydrogen market.[7] In the context of this debate, what is China's regulatory approach to the development of hydrogen technologies? Drawing on the findings of the existing legal literature on hydrogen, this article critically examines China's hydrogen regulation. Specifically, it focuses on hydrogen refuelling stations and fuel cell vehicles, which have been prioritized by China's local and national authorities to date.

Besides its relevance to the global hydrogen industry and the study of regulatory approaches to hydrogen, China's case is of broader theoretical significance for the transnational environmental law scholarship on regulatory decentralization. The Chinese government has adopted the National Hydrogen Development Plan,[8] but most concrete actions to develop a hydrogen economy have been taken by local governments. As explained in the literature on the decentralization of environmental regulation and 'environmental federalism', in many jurisdictions experimentation at the subnational level has played an important role in developing innovative new regulatory approaches, allowing policy learning to take place ahead of national

方案的通知》), 2022, available (in Chinese) at: https://www.gov.cn/zhengce/content/2022-05/30/content_5693013.htm; NDRC, ibid.

3 See, e.g., E. Cammeraat, A. Dechezleprêtre & G. Lalanne, *Innovation and Industrial Policies for Green Hydrogen* (Organisation for Economic Co-operation and Development (OECD), 2022); A. Scheibe & R. Poudineh, *Regulating the Future European Hydrogen Supply Industry* (Oxford Institute for Energy Studies (OIES), 2023); R. Poudineh & M. Palovic, *Polygrid 2050* (OIES, 2022); A. Barnes, *The EU Hydrogen and Gas Decarbonisation Package* (OIES, 2023); K. Talus & M. Martin, 'A Guide to Hydrogen Legislation in the USA' (2022) 15(6) *Journal of World Energy Law & Business*, pp. 449–61; J. Prest, J. Woodyatt & J.P.J. Pettit, 'Comparing the Hydrogen Strategies of the EU, Germany, and Australia' (2021) 19(2) *Oil, Gas & Energy Law*, pp. 1–65; K. Brent, 'Regulating Australia's Green Hydrogen Industry' (2022) 36(6) *Australian Environment Review*, pp. 130–5.

4 See, e.g., N.D. Blasio & F. Pflugmann, 'China: The Renewable Hydrogen Superpower', *Belfer Center for Science and International Affairs*, May 2021; B.E. Lebrouhi et al., 'Global Hydrogen Development' (2022) 47(11) *International Journal of Hydrogen Energy*, pp. 7016–48; X.H. Gong, R. Quitzow & A. Boute, *China's Emerging Hydrogen Economy* (Research Institute for Sustainability (RIFS), 2023).

5 G. Mete & L. Reins, 'Governing New Technologies in the Energy Transition' (2020) 14(3) *Carbon & Climate Law Review*, pp. 210–31; S. Lavrijssen & B. Vitéz, 'Make Hydrogen Whilst the Sun Shines' (2020) 14(4) *Carbon & Climate Law Review*, pp. 266–80; M. Baumgart & S. Lavrijssen, 'Exploring Regulatory Strategies for Accelerating the Development of Sustainable Hydrogen Markets in the European Union', *Journal of Energy & Natural Resources Law*, 29 Sept. 2023, pp. 1–30.

6 See, e.g., International Energy Agency (IEA), 'Global Hydrogen Review 2021', Oct. 2021.

7 See, e.g., S.L. Penttinen, 'Regulatory and Policy Instruments to Promote Decarbonization in the Energy Sector', in L. Reins & J. Verschuuren (eds), *Research Handbook on Climate Change Mitigation Law* (Edward Elgar, 2022), pp. 338–62; A. Barnes & K. Yafimava, *EU Hydrogen Vision* (OIES, 2020); Scheibe & Poudineh, n. 3 above, pp. 18–29.

8 NDRC, n. 1 above.

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harmonization.[9] Previous analyses of the decentralization of environmental (and, in particular, climate) governance and federalism have provided insights into a number of major economies, including those of the EU,[10] US,[11] Canada,[12] Australia,[13] and Russia.[14] The role of local hydrogen initiatives in China represents an important yet under-researched case in the study of decentralization in environmental regulation.

Against this background, we examine both China's national policy and the acts adopted by the provincial and municipal authorities that have led to the development of hydrogen. Our analysis of the relevant legal texts is complemented by interviews, which shed additional light on the application of the relevant legal framework, and thus bridge the gap between legal theory and practice. The interviews were conducted in 2022 and early 2023 with five practising lawyers with relevant advisory experience in the energy sector (coded HL1 to 5), and with five energy policy analysts researching China's hydrogen economy (coded HP1 to 5) (see Appendix 1 for background information). These experts commented on national and local hydrogen policy and regulation, and expressed their views on the regulatory support required to develop hydrogen projects in China (see interview questionnaire in Appendix 2).

Our analysis of China's hydrogen regulation shows how, with limited regulatory action at the central level, local governments have played a critical role in developing China's hydrogen industry. Although total production of green hydrogen in China remains limited, important progress has been made, through local regulation, with the development of hydrogen refuelling stations and fuel cell vehicles. China's experience

[9] See, e.g., J. Reich, 'Federalism and Mitigating Climate Change: The Merits of Flexibility, Experimentalism, and Dissonance' (2021) 10(2) *Transnational Environmental Law*, pp. 263–91 (emphasizing the importance of 'ample room for regulatory experimentalism at the lower layers of federalism': ibid., p. 263); B. Sovacool, 'The Best of Both Worlds' (2008) 27(2) *Stanford Environmental Law Journal*, pp. 397–476, at 430; B. Turnheim, P. Kivimaa & F. Berkhout (eds), *Innovating Climate Governance* (Cambridge University Press, 2018); K. Kern, 'Cities as Leaders in EU Multilevel Climate Governance' (2019) 28(1) *Environmental Politics*, pp. 125–45; A. Fenna, S. Jodoin & J. Setzer, 'Climate Governance and Federalism: An Introduction', in A. Fenna, S. Jodoin & J. Setzer (eds), *Climate Governance and Federalism* (Cambridge University Press, 2023), pp. 1–13.

[10] See, e.g., M. Jänicke & R. Quitzow, 'Multi-Level Reinforcement in European Climate and Energy Governance' (2017) 27(2) *Environmental Policy and Governance*, pp. 122–36; M. Alberton, 'Climate Governance and Federalism in the European Union', in Fenna, Jodoin & Setzer, n. 9 above, pp. 128–49.

[11] See, e.g., Sovacool, n. 9 above; K. Engel, 'Why Not a Regional Approach to State Renewable Power Mandates?' (2012) 3 *San Diego Journal of Climate & Energy Law*, pp. 79–105; J. Rossi, 'The Shaky Political Economy Foundation of a National Renewable Electricity Requirement' (2011) 20 *University of Illinois Law Review*, pp. 361–80; J. Saurer & J. Monast, 'Renewable Energy Federalism in Germany and the United States' (2021) 10(2) *Transnational Environmental Law*, pp. 293–320; B. Rabe & H. Smith, 'Climate Governance and Federalism in the United States', in Fenna, Jodoin & Setzer, n. 9 above, pp. 306–27.

[12] See, e.g., S.V. Valentine, 'Canada's Constitutional Separation of (Wind) Power' (2010) 38(4) *Energy Policy*, pp. 1918–30; K. Harrison, 'Climate Governance and Federalism in Canada', in Fenna, Jodoin & Setzer, n. 9 above, pp. 64–85.

[13] See, e.g., S. Jones, 'The Future of Renewable Energy in Australia' (2009) 68(1) *The Australian Journal of Public Administration*, pp. 1–20; A. Kallies, 'The Australian Energy Transition as a Federalism Challenge: (Un)cooperative Energy Federalism?' (2021) 10(2) *Transnational Environmental Law*, pp. 211–35.

[14] A. Boute, 'Renewable Energy Federalism in Russia' (2013) 25(2) *Journal of Environmental Law*, pp. 261–91.

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is relevant for the broader debates on hydrogen regulation and environmental decentralization, as it illustrates how local action can be instrumental in addressing national regulatory barriers to hydrogen and providing support for this new industry. At the same time, the case of China shows that local initiatives can result in a certain degree of market fragmentation and protectionism. Building on the theory on clean energy federalism and decentralization, we argue that this fragmentation and protectionism require central coordination to avoid harming the further development of China's hydrogen industry. In this process, local regulatory experimentation and international best practices provide valuable inputs for future national hydrogen regulation.

This article is structured as follows. Section 2 introduces the theory on hydrogen regulation and the transnational environmental law scholarship on decentralization/federalism to which this article contributes. Section 3 briefly presents China's hydrogen strategy, and the varying ambitions of the central and local governments. Sections 4 and 5 focus on local initiatives, by firstly looking at the removal of regulatory barriers to the development of hydrogen projects, followed by an analysis of support mechanisms. With this local regulatory experimentation in mind, Sections 6 and 7 critically reflect on the need for a harmonized framework for hydrogen in China, before summarizing the key contribution of our study to the theory on hydrogen regulation and environmental decentralization.

2. Theory on Hydrogen Regulation and Decentralization

In parallel with the increasing attention on hydrogen,[15] there is growing interest in the regulatory reforms that are needed to enable the development of this new source of energy. The scholarship on such regulatory reforms provides an important basis for understanding the national regulatory barriers to hydrogen in China, including the regulation of hydrogen as a hazardous chemical and the absence of harmonized rules governing the hydrogen infrastructure and the subsidization of hydrogen projects. Reciprocally, understanding China's approach to hydrogen, and, in particular, its focus on fuel cell vehicles and refuelling stations, is highly relevant for the broader debate on hydrogen regulation, given China's role as the largest hydrogen producer in the world and its significant influence on the international energy market.[16]

Besides the technical aspects of hydrogen regulation, the transnational environmental law theory on decentralization and federalism provides a framework for understanding the role of local authorities in China's hydrogen regulation.

[15] See, e.g., IEA, 'Hydrogen', last update 10 July 2023, available at: https://www.iea.org/energy-system/low-emission-fuels/hydrogen; International Renewable Energy Agency (IRENA), 'Hydrogen', *IRENA*, last update 1 Apr. 2024, available at: https://www.irena.org/Energy-Transition/Technology/Hydrogen; R. Bridle & E. Beedell, 'Should Governments Subsidize Hydrogen?', *International Institute for Sustainable Development*, 19 Jan. 2021, available at: https://www.iisd.org/articles/insight/should-governments-subsidize-hydrogen.

[16] See, e.g., Gong, Quitzow & Boute, n. 4 above; IEA, n. 6 above.

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In China, the importance of local experimentation has been highlighted not only in the governance of its economic rise and technological development[17] but also in its climate and energy policy.[18] Local experimentation has helped to address certain national regulatory barriers to hydrogen but has created new obstacles of market fragmentation and protectionism that, according to environmental decentralization theory, require central coordination.[19]

2.1. The Role of Regulation in Enabling Hydrogen Development

In the debate on the regulation of hydrogen, scholars, legal practitioners, and industry experts firstly focus on its legal nature and, in particular, its characterization as an energy carrier or a dangerous chemical.[20] Hydrogen has long been used in the chemical industry.[21] Because hydrogen is highly flammable, its production, transportation, and use have been subject to the stringent regulations applicable to dangerous chemicals.[22] Complying with these strict regulatory requirements increases the transaction costs for companies in the sector and can delay the realization of hydrogen projects.[23] By contrast, categorizing hydrogen as an energy carrier and subjecting it to energy regulation allows broadening its use beyond the chemical industry.[24] Its flammability is manageable by improving the protocols for the safe handling of hydrogen in energy applications, drafting safety standards for hydrogen use, and developing safety practices.[25] The consensus, therefore, is that, to facilitate the deployment of hydrogen, it is necessary to regulate it as an energy carrier and to formulate new safety standards where existing standards do not adequately reflect the characteristics of this new technology development.[26]

In the context of the energy transition, it is essential to distinguish between the various forms of hydrogen in use and their very different carbon

[17] S. Heilmann, 'Policy Experimentation in China's Economic Rise' (2008) 43 *Studies in Comparative International Development*, pp. 1–26.

[18] See, e.g., K. Lo, H. Li & K. Chen, 'Climate Experimentation and the Limits of Top-Down Control' (2020) 63(1) *Journal of Environmental Planning and Management*, pp. 1–18; B. Wang, A. Boute & X. Tan, 'Price Stabilization Mechanisms in China's Pilot Emissions Trading Schemes' (2020) 20(1) *Climate Policy*, pp. 46–59.

[19] See, e.g., Sovacool, n. 9 above, pp. 421–6.

[20] D. Majumder-Russell, *Hydrogen Projects* (Global Law and Business, 2021), p. 64.

[21] IEA, 'The Future of Hydrogen: Seizing Today's Opportunities', June 2019, p. 32.

[22] IEA, n. 6 above, p. 38.

[23] M. Meidan, *China's Emerging Hydrogen Strategy and the 2060 Net Zero Commitment* (OIES, 2021), p. 58.

[24] IEA, n. 6 above, p. 32.

[25] See, e.g., Vinson & Elkins LLP, 'Federal Hydrogen Regulation in the United States', 10 Dec. 2020, available at: https://www.jdsupra.com/legalnews/federal-hydrogen-regulation-in-the-54947; Hydrogen Safety Panel, 'Safety Planning for Hydrogen and Fuel Cell Projects', Nov. 2017, available at: https://h2tools.org/sites/default/files/Safety_Planning_for_Hydrogen_and_Fuel_Cell_Projects-November2017_0.pdf.

[26] OECD, 'Hydrogen Safety Measures and Their Significance', *OECDiLibrary*, 2023, available at: https://www.oecd-ilibrary.org/sites/b72f97b6-en/index.html?itemId=/content/component/b72f97b6-en. See also Y. Oharenko & R. Bridle, *Making Green Hydrogen a Global Trade Commodity for Enhanced Climate Ambition* (International Institute for Sustainable Development, 2021); IEA, n. 6 above, p. 38.

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footprints.[27] Hydrogen is most commonly categorized as grey, blue, green or renewable, and pink.[28] Green/renewable hydrogen is produced through water electrolysis powered by renewable electricity, while pink hydrogen is produced from nuclear power.[29] Both blue and grey hydrogen are produced from fossil fuels, but in the case of the former carbon emissions are captured and stored underground.[30] To recognize the contribution of hydrogen to decarbonization, the different types of hydrogen and their respective carbon footprints must be subject to certification and tracing.[31]

Introducing climate-friendly hydrogen broadens the use of renewable energy power and thus cannot be isolated from renewable energy development.[32] States have an important role in supporting the creation of hydrogen markets by securing the offtake of hydrogen at a sufficiently attractive price,[33] as has been the case with the development of electricity production from renewable energy sources. A case in point is the introduction of feed-in tariffs, which catalyzed the deployment of solar and wind energy and enabled production to be scaled up and costs to be reduced.[34] The creation of demand for hydrogen via policy and regulation will also be needed to stimulate hydrogen production at scale.[35] As hydrogen does not yet account for a large share of global energy consumption, support mechanisms (such as investment aid, taxation benefits, auctions, and contracts for difference) are essential to create an enabling environment for investment.[36]

To facilitate the development of the infrastructure on which the hydrogen economy depends,[37] it is necessary to clarify the administrative procedures governing the

[27] K. Chege, 'Legal/Policy Tools and Strategies for Hydrogen in the Low-Carbon Transition', in G. Bellantuono et al. (eds), *Handbook of Energy Law in the Low-Carbon Transition* (De Gruyter, 2023), pp. 217–40.

[28] H2 Bulletin, 'Hydrogen Colours Codes', available at: https://www.h2bulletin.com/knowledge/hydrogen-colours-codes.

[29] Ibid.

[30] Ibid.

[31] European Clean Hydrogen Alliance, 'Reports of the Alliance Roundtables on Barriers and Mitigation Measures', Oct. 2021, p. 15; R. Fleming, 'Clean or Renewable Hydrogen and Power-to-Gas in EU Energy Law' (2021) 39(1) *Journal of Energy and Natural Resources Law*, pp. 43–63, at 48; Barnes, n. 3 above, p. 18. See also IEA, 'Towards Hydrogen Definitions based on Their Emissions Intensity', Apr. 2023, p. 45.

[32] D. Gielen, E. Taibi & R. Miranda, *Hydrogen: A Renewable Energy Perspective* (IRENA, 2019).

[33] See, e.g., S.Z. Zhiznin et al., 'Economics of Hydrogen Energy of Green Transition in the World and Russia – Part I' (2023) 48(2) *International Journal of Hydrogen Energy*, pp. 21544–67; Scheibe & Poudineh, n. 3 above.

[34] D.N. Peng & R. Poudineh, 'Electricity Market Design under Increasing Renewable Energy Penetration' (2019) 61 *Utilities Policy*, pp. 1–13, at 2.

[35] See, e.g., Barnes, n. 3 above, p. 5; I. Staffell et al., 'The Role of Hydrogen and Fuel Cells in the Global Energy System' (2019) 12(2) *Energy & Environmental Science*, pp. 463–91, at 475.

[36] Majumder-Russell, n. 20 above; IEA, n. 6 above, p. 16; A. Patonia & R. Poudineh, *Cost-Competitive Green Hydrogen: How to Lower the Cost of Electrolysers?* (OIES, 2022); Y.F. Li, X.P. Shi & H. Phoumin, 'A Strategic Roadmap for Large-Scale Green Hydrogen Demonstration and Commercialisation in China' (2022) 47(58) *International Journal of Hydrogen Energy*, pp. 24592–609, at 24606.

[37] PWC, 'Four Building Blocks to Establish a Low Carbon Hydrogen Economy', 2023, available at: https://www.strategyand.pwc.com/de/en/industries/energy-utilities/laying-the-foundations-of-a-low-carbon-hydrogen-market-in-europe.html.

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construction and operation of this infrastructure.[38] As hydrogen transportation networks will inherit the natural monopoly character of the current gas transmission networks, states also need to determine whether to require the separation (or unbundling) of infrastructure and storage activities from production and supply, and how to organize access to the networks.[39] Because repurposing existing gas pipelines can be cheaper than building new pipelines, regulators must also consider how to regulate the blending of hydrogen with natural gas and how to repurpose these gas pipelines.[40] Key issues are whether hydrogen falls within the definition of gas under gas regulations, and how safety codes can be developed for the injection of hydrogen into gas pipelines.[41] Regulations should also focus on the deployment of hydrogen refuelling stations, required to supply fuel cell vehicles.[42]

A key challenge in the development of the regulatory framework governing hydrogen, and the generating of investment in the field, is the uncertainty that characterizes this new industry, requiring flexibility and experimentation.[43]

2.2. Decentralization and Experimentation in Environmental Regulation

The development of hydrogen faces many uncertainties. Firstly, it remains uncertain whether green hydrogen and its derivatives will play a leading role in a future energy system, because of unresolved technical and resource-related questions.[44] Secondly, the infrastructural development is at an early stage, and it is not yet clear which mode of hydrogen transport will prevail.[45] Thirdly, it is difficult to predict both the end-use sectors where hydrogen will play a major role, and its more general role in stabilizing an energy system dominated by renewable resources.[46] In this context, local experimentation has a role to play in the development of regulatory responses to the uncertainties characterizing the hydrogen industry.

[38] Majumder-Russell, n. 20 above; Poudineh & Palovic, n. 3 above, p. 3.

[39] See, e.g., Barnes, n. 3 above, p. 8; U. Scholz et al., 'The New EU Gas Package', *Freshfields Bruckhaus Deringer*, 13 Apr. 2022, available at: https://sustainability.freshfields.com/post/102hmmq/the-new-eu-gas-package-setting-the-scene-for-hydrogen-grids-and-other-hydrogen; EU Agency for the Cooperation of Energy Regulators (ACER) and Council of European Energy Regulators (CEER), 'When and How to Regulate Hydrogen Networks?', 9 Feb. 2021, available at: https://www.acer.europa.eu/Official_documents/Position_Papers/Position%20papers/ACER_CEER_WhitePaper_on_the_regulation_of_hydrogen_networks_2020-02-09_FINAL.pdf.

[40] IEA, n. 6 above, p. 38; Scheibe & Poudineh, n. 3 above, p. 14.

[41] R. Fleming & J.P. Fershee, 'The "Hydrogen Economy" in the United States and the European Union', in D. Zillman et al. (eds), *Innovation in Energy Law and Technology* (Oxford University Press, 2018), pp. 137–53, at 149; R. Gerboni, 'Introduction to Hydrogen Transportation', in R. Gupta, A. Basile & T.N. Veziroğlu (eds), *Compendium of Hydrogen Energy, Volume 2* (Woodhead, 2015), pp. 283–99.

[42] CMS, 'CMS Expert Guide to Hydrogen Energy Law and Regulation', 2021, available at: https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen. See also Fleming & Fershee, n. 41 above, p. 142.

[43] Scheibe & Poudineh, n. 3 above, p. 7; see also IEA, n. 6 above, p. 181.

[44] See, e.g., A. Odenweller, 'Probabilistic Feasibility Space of Scaling Up Green Hydrogen Supply' (2022) 7 *Nature Energy*, pp. 854–65.

[45] D. Ellis, 'Three Key Uncertainties to Resolve to Drive Hydrogen Scale', *H2 View*, 26 Aug. 2022, available at: https://www.h2-view.com/story/three-key-uncertainties-to-resolve-to-drive-hydrogen-scale.

[46] P.C. Dos Reis, 'Hydrogen Demand: Several Uses but Significant Uncertainty', European University Institute, 18 Jan. 2021, available at: https://fsr.eui.eu/hydrogen-demand-several-uses-but-significant-uncertainty.

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Experimentation in environmental governance by subnational (or decentralized) authorities has played an important role in the development of new mechanisms of energy and climate regulation.[47] Within the EU, for instance, national policy and regulation sometimes function as de facto experiments before being adopted generally by the EU.[48] In a similar vein, the literature on 'clean energy federalism' highlights the role that subnational authorities may play in stimulating policy innovation.[49] Regions have served as 'laboratories' to test various clean energy policy instruments, and have helped to overcome the climate policy inaction of the central government.[50]

Compared with national regulators, decentralized authorities can be better positioned and equipped to elaborate appropriate policies to tackle specific environmental and energy problems that vary in scope and intensity from place to place.[51] Innovative regulatory options at the local level, if successful, could then be incorporated into national laws.[52] Decentralized policy innovation may be motivated by a range of reasons other than their environmental benefit.[53] Regions may create their own support mechanisms independently from national initiatives to boost local innovation, promote local economic development, create employment, and potentially take advantage of the export opportunities for new technologies.[54] Although these decentralized initiatives can help to overcome national inaction, they can also result in inefficiencies because of a lack of coordination,[55] and potentially lead to legal challenges (for example, under trade, competition, or constitutional law).[56]

Scholars have highlighted the benefits that harmonized clean energy rules provide for industry, and the economies of scale associated with this central coordination.[57] Convergence towards uniform support schemes reduces transaction costs for investors. The familiarity of companies and financiers with the 'rules of the game' facilitates their understanding of the regulatory framework and could thus help with investment decisions. A centralized approach also offers the benefits of 'learning effects' derived from cumulative volume of production (economies of scope).[58]

[47] Kern, n. 9 above.
[48] Jänicke & Quitzow, n. 10 above, p. 124.
[49] F. Mormann, 'Clean Energy Federalism' (2015) 67(5) *Florida Law Review*, pp. 1621–81; J. Rossi & T. Hutton, 'Federal Preemption and Clean Energy Floors' (2013) 91(4) *North Carolina Law Review*, pp. 1283–356.
[50] Sovacool, n. 9 above, pp. 430–1; Fenna, Jodoin & Setzer, n. 9 above, pp. 4–5; A. Fenna, 'Reflections on Climate Governance and Federalism', in Fenna, Jodoin & Setzer, n. 9 above, pp. 328–36; Boute, n. 14 above.
[51] Sovacool, n. 9 above, p. 431.
[52] Heilmann, n. 17 above, p. 3.
[53] See, e.g., Boute, n. 14 above; Engel, n. 11 above; Sovacool, n. 9 above; Rossi, n. 11 above.
[54] Rossi, n. 11 above, p. 371.
[55] Fenna, Jodoin & Setzer, n. 9 above, pp. 5–6.
[56] D.A. Farber, 'Environmental Federalism in a Global Economy' (1997) 83(7) *Virginia Law Review*, pp. 1283–319; M.G. Faure & J.S. Johnston, 'The Law and Economics of Environmental Federalism: Europe and the United States Compared' (2009) 27(3) *Virginia Environmental Law Journal*, pp. 205–74; A.C. Lin, 'Uncooperative Environmental Federalism: State Suits Against the Federal Government in an Age of Political Polarization' (2020) 88(4) *George Washington Law Review*, pp. 890–948.
[57] Sovacool, n. 9 above, p. 421; Fenna, Jodoin & Setzer, n. 9 above, p. 6.
[58] B. Sovacool & C. Cooper, 'Big *Is* Beautiful' (2007) 20(4) *The Electricity Journal*, pp. 48–61, at 57.

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The literature on clean energy federalism and regulatory experimentation thus highlights the trade-offs between regulating the hydrogen economy at the national level of government, which may reduce transaction costs and promote economies of scale and scope, and the benefits of local regulatory innovation and learning, driven by economic benefits and flexibility. These trade-offs are discussed in the following section in the context of an emerging hydrogen economy in China, characterized by an significant degree of regulatory experimentation and innovation at the provincial and local levels.

3. China's Hydrogen Policy

With a volume of 35 million tons at the end of 2022, China's hydrogen production accounts for approximately one third of the global output.[59] However, most of China's hydrogen is still produced from coal,[60] with renewable hydrogen production amounting only to 56,000 tons in 2022.[61] Hydrogen is utilized primarily in the refinery and chemical industries.[62] To meet this demand, China has developed a hydrogen transportation infrastructure, which includes eight pure hydrogen pipelines and five gas pipelines with hydrogen blending.[63] Hydrogen development has been concentrated mainly in five regions, building on existing chemical capacity (namely, the Beijing-Tianjin-Hebei Region, Yangtze River Delta, Pearl River Delta, the emerging 'Hydrogen Corridor' in Henan province, and the Ningdong Energy and Chemical Industry Base).[64] In parallel, China is manufacturing hydrogen fuel cells, and has started to deploy fuel cell vehicles.[65] In 2022, China had more than 12,682 licensed fuel cell

[59] Gong, Quitzow & Boute, n. 4 above; IEA, n. 6 above. China's hydrogen production was expected to reach 45.75 million tons in 2023: China Commercial Industry Research Institute, 'Analysis and Forecast of the Current Status and Development Trends of China's Hydrogen Energy Industry Market in 2023' (《2023年中国氢能源行业市场现状及发展趋势预测分析》), 30 Dec. 2023, available (in Chinese) at: https://www.sohu.com/a/748354146_121763369.

[60] D. Xu et al., 'Potential Analysis of Carbon Dioxide Capture, Utilization and Storage Equipped Low Carbon Hydrogen Production' (《通过耦合碳捕集、利用与封存实现低碳制氢的潜力分析》) (2021) 10 *Thermal Power Generation*, pp. 53–61, at 59; X. Meng et al., 'Review of China's Hydrogen Industry Policy and Scientific and Technological Development Hotspots in 2019' (《2019 年中国氢能政策、产业与科技发展热点回眸》) (2020) 38(3) *Science & Technology Review*, pp. 172–83.

[61] Q.M. Sun, 'Hydrogen Energy' (《氢能》), *Nanjing Securities*, 13 July 2023, available (in Chinese) at: https://pdf.dfcfw.com/pdf/H301_AP202307141592272311_1.pdf.

[62] Guosen Securities, 'Securities Report: Hydrogen Industry' (《证券研究报告：氢能》), 2021, available (in Chinese) at: https://dfscdn.dfcfw.com/download/A2_cms_f_20211217113703787692&direct=1&abc2685.pdf.

[63] BJX Hydrogen, 'The Location of China's Hydrogen Pipelines' (《我国管道输氢分布地图》), 7 May 2023, available (in Chinese) at: https://m.bjx.com.cn/mnews/20220527/1228855.shtml.

[64] Z. Sui, 'Enlightenment of China's LNG Industry Chain Development on Hydrogen Energy Industry Development under Carbon Neutrality Target' (《碳中和目标下我国 LNG 产业链发展对氢能 产业发展的启示》) (2021) 46(4) *Natural Gas Chemical Industry*, pp. 5–20, at 11.

[65] T. Wang, 'Advances of Fuel Cell Industrialization and Enlightenments with the Inspiration to China' (《燃料电池产业最新进展及对我国的启示》) (2013) 30(5) *Science & Technological Progress and Policy*, pp. 74–77, at 75; W. Yi et al., 'Enhance the Hydrogen Application in China's Energy System to Accelerate the Energy Transition' (《氢能促进我国能源系统清洁低碳转型的应用及进展》) (2018) 46(2) *Environmental Protection*, pp. 20–34, at 32; China Hydrogen Alliance, 'White Paper on China Hydrogen Energy and Fuel Cell Industry' (《中国氢能源及燃料电池白皮书》), 2019, available (in Chinese) at: http://www.china-nengyuan.com/news/china-nengyuan_news_141562.pdf.

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vehicles,[66] the third largest stock of such vehicles worldwide (after Korea and the US), and the fastest-growing market, with a 60% increase in 2022.[67] China also had more than 300 hydrogen refuelling stations in operation, the largest refuelling capacity globally.[68]

In March 2022, the Chinese government adopted its National Hydrogen Development Plan, emphasizing the role of hydrogen in decarbonizing energy consumption and achieving carbon neutrality in hard-to-abate sectors.[69] The Plan prioritizes fuel cell vehicles (focusing on heavy-duty commercial vehicles), with a target of around 50,000 units by 2025.[70] To supply these vehicles, the government promotes the development of hydrogen refuelling stations, by converting existing petrol and gas stations and by constructing refuelling stations with on-site hydrogen production. China aims to produce 100,000 to 200,000 tons of green hydrogen per year by 2025.[71] The 14th Five-Year Plan of Renewable Energy Development, also adopted in 2022, aims to develop demonstration projects for on-grid renewable hydrogen production, referring to hydrogen production from power grids with a large penetration of renewable energy power that is recognized by China's Green Electricity Certificate system,[72] and off-grid renewable hydrogen production.[73] Besides green hydrogen, China aims to produce pink hydrogen from nuclear power.[74]

China's national hydrogen targets are complemented by more ambitious local initiatives.[75] Local hydrogen development plans emphasize boosting the productivity of fuel cells and fuel cell vehicles to develop local value chains in this sector.[76] The production targets for fuel cell vehicles at the local level (see Table 1) exceed the central

[66] China Hydrogen Alliance, 'Report on the Industrial Development of Hydrogen and Fuel Cell in 2022' (《中国氢能源及燃料电池产业发展报告2022》), 2023.

[67] See also IEA, 'Global EV Outlook 2023: Catching up with Climate Ambitions', Apr. 2023, pp. 35–6.

[68] Ibid., p. 38.

[69] NDRC, n. 1 above.

[70] Ibid.

[71] Ibid.

[72] NDRC, MOF & NEA, 'Notice on Effectively Completing the Full Coverage of Renewable Energy Green Electricity Certificates to Promote Renewable Electricity Consumption' (《做好可再生能源绿色电力证书全覆盖工作促进可再生能源电力消费的通知》), 2023, available (in Chinese) at: https://www.ndrc.gov.cn/xxgk/zcfb/tz/202308/t20230803_1359092.html.

[73] NDRC et al., 'The 14th Five-Year Plan of Renewable Energy Development' (《"十四五"可再生能源发展规划》), 2022, available (in Chinese) at: https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202206/P020220602315308557623.pdf. For on-grid and off-grid renewable hydrogen production see, e.g., O. Borm & S.B. Harrison, 'Reliable Off-Grid Power Supply Utilizing Green Hydrogen' (2021) 5(3) *Clean Energy*, pp. 441–6; T. Nguyen et al., 'Grid-Connected Hydrogen Production via Large-Scale Water Electrolysis' (2019) 200 *Energy Conversion and Management*, article 112108.

[74] NDRC, n. 1 above.

[75] Gong, Quitzow & Boute, n. 4 above; Y.H. Lou & A.S. Corbeau, *China's Hydrogen Strategy* (Columbia University Center on Global Energy Policy, 2023), pp. 2–10.

[76] See, e.g., Changshu Municipal People's Government, 'Industrial Development Plans of Hydrogen Fuel Cells 2021–2030' (《常熟市氢燃料电池产业发展规划 2021–2030》), 2021, available (in Chinese) at: http://www.changshu.gov.cn/zgcs/c108192/202107/fc19c75d013444dbb04007942f8dcbf6/files/323bbfd1243e483d8ed5ab8f57a8ca8f.pdf; Office of Jiaxing Municipal People's Government, 'Guidance on Hydrogen Development in Jiaxing' (《嘉兴市人民政府办公室关于加快推动氢能产业发展的实施意见》), 2021, available (in Chinese) at: https://www.jiaxing.gov.cn/art/2021/6/15/art_1229426374_2302539.html; Ningxia Provincial People's Government, 'Guiding Opinions on Accelerating and Fostering the Development of the Hydrogen Industry' (《宁夏回族自治区人民政府办公厅关于加快培育氢能产业发展的指导意见》), 2020, available (in Chinese) at: https://www.nx.gov.cn/zwgk/gfxwj/202005/t20200506_2055453.html.

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Table 1. Local Targets for Hydrogen Fuel Cell Vehicles

Industrial Clusters	Selected Cities/Provinces	2025 Target	Licensed Vehicles in 2022
Yangtze River Delta	Zhejiang province	5,000	320
	Shanghai	10,000+	1,908
Beijing-Tianjin-Hebei Region	Hebei province	10,000	480
	Beijing	10,000+	1,528
Hydrogen Corridor in Henan province	Henan province	5,000+	318
Pearl River Delta	Guangdong province	10,000+	3,300
Others	Shandong province	10,000+	848
Total		60,000+ (compared with national target of 50,000)	8,702

Source: Authors' own research, based on local hydrogen development plans[77] and media reports[78]

[77] Provincial Government of Zhejiang, 'Implementation Plan of Developing New Energy Vehicles' (《浙江省加快新能源汽车产业发展行动方案》), 2023, available (in Chinese) at: https://fzggw.zj.gov.cn/art/2023/1/29/art_1229123351_2455742.html; Shanghai Municipal Government, 'Mid-and-Long Term Hydrogen Development Plan of Shanghai 2022–2035' (《上海市氢能产业发展中长期规划 2022–2035》), 2022, available (in Chinese) at: https://www.shanghai.gov.cn/cmsres/89/890a5d14a42a497993546b558f525cb0/331d8ca143e43fd6548afed86b594190.pdf; Hebei Development and Reform Commission, 'Implementation Opinions on Promoting Hydrogen Industry Development in Hebei' (《河北省推进氢能产业发展实施意见》), 2019, available (in Chinese) at: http://info.hebei.gov.cn/hbszfxxgk/329975/329988/330035/6852718/6881830/index.html; Beijing Municipal Bureau of Economy and Information Technology, 'The Development Plan of Beijing's Hydrogen Fuel Cell Vehicles Industry 2020–2025' (《北京市氢燃料汽车产业发展规划2020–2025》), 2020, available (in Chinese) at: https://jxj.beijing.gov.cn/jxdt/tzgg/202010/P020201030351907215253.pdf; Henan Provincial People's Government, 'The Mid-and-Long-Term Plan on Hydrogen Industrial Development 2022–2035 in Henan' (《河南省氢能产业发展中长期规划2022—2035》), 2022, available (in Chinese) at: https://fgw.henan.gov.cn/2022/09-08/2603392.html; Provincial Government of Guangdong, 'Notice on Accelerating the Hydrogen Industrial Development in Guangdong' (《广东省加快氢能产业创新发展的意见》), 2023, available (in Chinese) at: https://www.cpnn.com.cn/news/dfny/202311/t20231107_1648599.html; Provincial Government of Shandong, 'Mid-and-Long Term Hydrogen Development Plan of Shandong 2020–2030' (《山东省氢能中长期发展 计划 2020–2030》), 2020, available (in Chinese) at: http://nyj.shandong.gov.cn/module/download/downfile.jsp?classid=0&filename=7819fa6f53a04ff5ba64a6f2fbe05b37.pdf.

[78] For the existing volumes, Hydrogen Fuel Cell Exhibition (HFCE), 'Interpreting Notice on Accelerating the Hydrogen Industrial Development in Guangdong' (《解读广东省加快氢能产业创新发展的意见》), *HFCE News*, 7 Nov. 2023, available (in Chinese) at: http://www.hfceexpo.cn/news/6385.html; China Auto, '22 Hydrogen Refuelling Stations and 848 Hydrogen Fuel Cell Vehicles' (《已建成加氢站22座，推广燃料电池车辆848辆》), 7 Jan. 2022, available (in Chinese) at: https://www.chinaautoms.com/a/new/2022/0107/20659.html; X.T. Wen, 'Zhejiang's New Energy Vehicle Industry Is Getting Better' (《浙江新能源汽车产业家底丰厚》), *Zhejiang Daily*, 23 Nov. 2023, available (in Chinese) at: https://zjrb.zjol.com.cn/html/2023-11/23/content_3701015.htm?div=-1; BJX Hydrogen, 'What Are the Progresses of the Five Pilot City Clusters for Fuel Cell Vehicles' (《五大示范城市群进展如何》), 1 June 2022, available (in Chinese) at: https://m.bjx.com.cn/mnews/20220601/1229935.shtml; 21 Economics, 'Beijing Issued Its Development Plan of Hydrogen Refuelling Stations' (《北京发布加氢站发展规划》), 24 Nov. 2022, available (in Chinese) at: https://www.21jingji.com/article/20221124/herald/4c8cd89a05260f38db4ea46021c58a45.html; Wisdom Think Tank, 'Which City Is the Hydrogen City in China' (《谁是中国氢能源之都?》), *36kr News*, 9 Oct. 2022, available (in Chinese) at: https://36kr.com/p/1950206183491974.

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Table 2. Local Targets for Hydrogen Refuelling Stations

Industrial Clusters	Select Provinces/Cities	2025 Target	Existing Stations in 2022
Yangtze River Delta	Jiaxing	20	7
	Shanghai	70	13
Beijing-Tianjin-Hebei Region	Beijing	74	11
	Hebei province	50	24
Pearl River Delta	Foshan	30	21
	Guangzhou	50+	7
	Shenzhen	10	3
Hydrogen Corridor in Henan province	Henan province	100+	6
Ningxia province	Ningdong Energy and Chemical Base	10+	1
Total		414+ (no national target)	93

Source: Authors' own research, based on local hydrogen development plans[79] and media reports[80]

government's target. Building hydrogen refuelling stations is another priority at the local level (see Table 2),[81] while the central government did not disclose its targeted volume of hydrogen refuelling stations.

In the formulation of its hydrogen strategy, China has taken into account the experience of other countries, such as Japan,[82] which has been committed to hydrogen

[79] Office of Jiaxing Municipal People's Government, n. 76 above; Beijing Municipal Bureau of Economy and Information Technology, n. 77 above; Hebei Development and Reform Commission, n. 77 above; Foshan Development and Reform Commission, 'The Development Plan of Hydrogen Industrial Development in Foshan Nanhai District 2020–2035' (《佛山市南海区氢能产业发展规划 2020–2035》), 2020, available (in Chinese) at: https://pdf.dfcfw.com/pdf/H3_AP202003061375959946_1.pdf; Shanghai Municipal Government, n. 77 above; Provincial Government of Henan, 'Notice on the Implementation Plan on Accelerating the Development of New Energy Vehicles Industry' (《河南省加快新能源汽车产业发展实施方案的通知》), 2021, available (in Chinese) at: https://www.jiyuan.gov.cn/gov_special/2021/wrwqxd/zcwj_wrwq/t754591.html; Ningxia Development and Reform Commission, 'The Plan of the Development of the Hydrogen Industry in Ningxia' (《宁夏回族自治区氢能产业发展规划》), 2022, available (in Chinese) at: https://www.nx.gov.cn/zwgk/gfxwj/202005/t20200506_2055453.html.

[80] For existing volumes, Gao Gong Industry Insights (GGII), 'The Report on the Analysis of China's Hydrogen Refuelling Stations' (《2022 年中国加氢站行业分析报告》), 2022, available (in Chinese) at: https://www.gg-ii.com/art-2736.html; D.C. Lin, 'Shenzhen Needs Hydrogen Refuelling Stations' (《深圳除了充电桩也需"加氢站"》), *China Energy News*, 10 Feb. 2023, available (in Chinese) at: https://www.china5e.com/news/news-1147436-1.html; Henan Provincial People's Government, n. 77 above; Shiyin Data, 'Sinopec Built the Largest Number of Hydrogen Refuelling Stations' (《中石化建站数量第一》), 27 Apr. 2022, available (in Chinese) at: https://m.evpartner.com/news/detail-61138.html.

[81] See, e.g., Foshan Development and Reform Commission, 'Industrial Development Plan of New Energy Vehicles in Nanhai District, Foshan 2015–2025' (《佛山市南海区新能源汽车产业规划 2015–2025》), 2015, available (in Chinese) at: https://www.nanhai.gov.cn/fsnhq/zwgk/zdgk/fzgh/content/post_1328103.html.

[82] See, e.g., China Power, 'Re-examination of Japan's Hydrogen Strategy: Implications for China's Hydrogen Development' (《日本反思氢能战略给我国什么启示》), 24 Feb. 2023, available (in Chinese)

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production from fossil fuels and the development of fuel cell vehicles (passenger vehicles).[83] However, inadequate attention to renewable hydrogen production is a liability for Japan's energy transition,[84] and electric vehicles and hybrid vehicles have proven to be more competitive in the passenger vehicles market, compared with fuel cell vehicles.[85] Building on this experience, China's National Hydrogen Development Plan focuses on the promotion of heavy-duty commercial vehicles and renewable hydrogen production. To achieve its targets, China must remove the existing regulatory barriers to hydrogen, building on the relevant international regulatory experience.[86]

4. Removing Regulatory Barriers to Hydrogen in China

In contrast to other jurisdictions that have started to develop a specific legal basis to facilitate the deployment of hydrogen,[87] the Chinese government has not yet adopted a national framework on hydrogen, which thus remains subject to China's rules on dangerous chemicals and infrastructure. In this context, regulatory experimentation by local governments has focused on relaxing the existing requirements governing hazardous chemicals imposed on the production, transportation, storage, and use of hydrogen to accelerate the development of this industry, while seeking to ensure the safe operation of hydrogen projects. This experience is relevant to the broader debates on hydrogen regulation and environmental decentralization, as it illustrates the relevance of local experimentation, for example, on the legal status of hydrogen and the permitting of refuelling stations, to overcome national regulatory paralysis.

4.1. Hydrogen under China's Hazardous Chemical Regulation

Under Chinese law, hydrogen is still categorized as a hazardous chemical, and is therefore registered under the 2015 Catalogue of Hazardous Chemicals.[88] The production, transportation, storage, and use of hydrogen, along with the construction of associated infrastructure, is subject to China's relatively strict Regulation on the

at: http://mm.chinapower.com.cn/zx/jzqb/20230224/189763.html; International Science & Technology Innovation Center, 'Implications of Japan's Hydrogen Strategy for China's Hydrogen Industrial Development' (《日本的氢能发展战略及对我国氢能产业的启示》), 23 June 2023, available (in Chinese) at: https://www.astidev.com/index.php?c=show&id=97; S.W. Zhang, 'Similarities and Differences in Hydrogen Development in Germany and China' (《中德氢能战略有何异同》), *China Steel News*, 11 Dec. 2023, available (in Chinese) at: http://www.csteelnews.com/xwzx/hydt/202312/t20231211_82490.html.

[83] Basic Hydrogen Strategy of Japan (2017), available at: https://climate-laws.org/documents/basic-hydrogen-strategy-2017_7bd7?id=2017-basic-hydrogen-strategy_68dc.

[84] International Science & Technology Innovation Center, n. 82 above.

[85] China Power, n. 82 above.

[86] Zhang, n. 82 above.

[87] Y. Zabanova, *The EU in the Global Hydrogen Race* (RIFS, 2023), p. 8; L. Eicke, *US Hydrogen Policy* (RIFS, 2023); T.S. Hunter, J. Pettit & M. Taylor, 'Implications of "Net-Zero Emissions by 2050" for the Hydrocarbon Industry' (2023) 16(3) *Journal of World Energy Law and Business*, pp. 280–301.

[88] Catalogue of Hazardous Chemicals (2015 version) (《危险化学品目录 2015版》), available (in Chinese) at: https://www.mem.gov.cn/gk/gwgg/xgxywj/wxhxp_228/201509/t20150902_232638.shtml.

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Safety Management of Hazardous Chemicals (2002).[89] In particular, hydrogen production requires a safety production licence for hazardous chemicals and a production licence for industrial products.[90] Hydrogen storage requires an operation licence for hazardous chemicals,[91] and the transportation of hydrogen by road is subject to monitoring by the public security authorities.[92] The use of hydrogen also requires safety permits.[93]

As explained in the hydrogen regulation literature (Section 2.1), the status of hydrogen as a hazardous chemical poses a major obstacle to the development of the industry. In China, it limits the development of hydrogen projects to chemical industrial parks.[94] As confirmed by our interviewees (HL1 to 5), the regulation of hydrogen as a hazardous chemical (as opposed to an energy carrier) is a barrier to the development of infrastructure projects in the sector. The complex administrative procedures associated with the safety requirements for hazardous chemicals can increase the transaction costs for hydrogen companies and delay the realization of hydrogen projects.[95] China's experience thereby confirms existing transnational analyses of hydrogen regulation, emphasizing how the legal status of hydrogen has an impact on its development in national energy systems.[96]

To promote the development of local hydrogen value chains, a number of provincial and municipal governments have relaxed the requirement to build hydrogen projects in chemical industrial parks. In Shandong province, for instance, projects that combine renewable hydrogen production and hydrogen refuelling can be built outside chemical industrial parks 'under safe conditions'.[97] Similarly, in Guangdong province and the district of Lingang in Shanghai, companies can build hydrogen refuelling stations with on-site hydrogen production in logistics parks, open-air parking lots, and port terminals, provided that their safety can be demonstrated.[98] The Xinjiang

[89] Regulation on the Safety Management of Hazardous Chemicals (《危险化学品安全管理条例》) (2002, amended in 2011), available (in Chinese) at: https://www.gov.cn/zwgk/2011-03/11/content_1822783.htm; Meidan, n. 23 above, p. 58.

[90] Regulation on the Safety Management of Hazardous Chemicals, n. 89 above, Arts 6(1) and (3).

[91] Ibid., Arts 6(1), 33.

[92] Ibid., Arts 6(1) and (3).

[93] Ibid., Art. 6(1).

[94] Ministry of Emergency Management, 'Are Projects for Hydrogen Pipelines Located in Industrial Parks Construction Projects for Dangerous Chemicals?' (《化工园区内氢气公共输送管道是否为危险化学品建设项目?》), 24 Jan. 2022, available (in Chinese) at: https://www.mem.gov.cn/hd/gzly/lyhf/202201/t20220119_406939.shtml; China Association of Automobile Manufacturers, 'To Break the Perception of Hydrogen by Law as a Dangerous Chemical' (《传统危化品管理的"氢"规戒律待破》), 22 July 2019, available (in Chinese) at: http://www.caam.org.cn/chn/8/cate_82/con_5224986.html.

[95] Meidan, n. 23 above, p. 58.

[96] Fleming, n. 31 above, p. 47; Brent, n. 3 above.

[97] Provincial Government of Shandong, 'Notice on the Second List of Support Policies for Making Steady Progress and Achieving High-Quality Development in 2022' (《2022年山东省人民政府印发关于促进实体经济高质量发展的实施意见政策清单（第二批）的通知》), 2022, available (in Chinese) at: http://www.shandong.gov.cn/art/2022/4/1/art_107851_118299.html.

[98] Guangdong Reform and Development Commission et al., 'Interim Measures of Managing the Construction of Hydrogen Refuelling Stations' (《广东省燃料电池汽车加氢站建设管理暂行办法》), 2023, available (in Chinese) at: https://gdee.gd.gov.cn/attachment/0/524/524349/4207158.pdf; Management Committee of Free Trade Zone – Lingang Special Area, 'Several Rules on the

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Autonomous Region has promoted demonstration projects for renewable hydrogen production and hydrogen refuelling stations with on-site hydrogen production outside chemical industrial parks by granting favourable treatment to project operators in administrative procedures.[99] The Wuhan government has defined hydrogen production as the production of an energy carrier 'under safe conditions'.[100] There have been two large renewable hydrogen projects in Xinjiang, including the world's largest solar-hydrogen project.[101] In July 2023, the Hebei provincial government exempted renewable hydrogen production from the licensing requirement for hazardous chemicals.[102]

Under Chinese law, provincial and municipal regulations cannot conflict with Chinese constitutional law or national laws and administrative regulations.[103] Local initiatives that allow hydrogen activities to be carried on outside chemical industrial parks conflict with the Regulation on the Safety Management of Hazardous Chemicals. In practice, safety concerns have also limited the development of hydrogen production and refuelling projects outside chemical industrial parks.[104] However, according to our interviewees (HL1 and 4), the central government tolerates these local initiatives, as it seeks to explore solutions and experiment with alternative approaches to facilitate the development of China's hydrogen value chain. Indeed, the central government is considering recognizing hydrogen as an energy carrier,[105] and allowing hydrogen production outside industrial parks.[106] Local governments and analysts agree that recognition under Chinese law of hydrogen as an energy carrier

Construction and Operation of Hydrogen Refuelling Stations' (《临港新片区燃料电池汽车加氢站建设运营若干规定》), 2021, available (in Chinese) at: https://evhui.com/124472.html.

[99] Xinjiang Reform and Development Commission, 'Three-Year Action Plan on Hydrogen Industrial Development' (《新疆氢能产业发展三年行动方案》), 2023, available (in Chinese) at: http://xjdrc.xinjiang.gov.cn/xjfgw/c108389/202309/865a18400dd74b77ab1a804747e1a695.shtml.

[100] Municipal Government of Wuhan, 'Opinions on Supporting Hydrogen Industrial Development' (《武汉市人民政府关于支持氢能产业发展的意见》), 2022, available (in Chinese) at: https://www.wuhan.gov.cn/zwgk/xxgk/zfwj/gfxwj/202203/t20220331_1948213.shtml.

[101] 'Sinopec's First Green Hydrogen Plant Starts Production in Xinjiang', *Reuters*, 30 June 2023, available at: https://www.reuters.com/business/energy/sinopecs-first-green-hydrogen-plant-xinjiang-starts-production-xinhua-2023-06-30.

[102] Provincial Government of Hebei, 'Safety Management Measures of the Hydrogen Industry in Hebei Province (Trial Implementation)' (《河北省氢能产业安全管理办法试行》), 2023, Art. 9, available (in Chinese) at: http://www.xiongan.gov.cn/2023-07/28/c_1212249679.htm.

[103] Legislation Law of PRC (《立法法》), 2000, revised 2015, Art. 63, available (in Chinese) at: https://www.gov.cn/xinwen/2023-03/14/content_5746569.htm.

[104] San Teng Hydrogen Production, 'The First Year of Hydrogen Production Outside Chemical Industrial Parks?' (《非化工园区制氢元年到来?》), *Sohu News*, 1 June 2022, available (in Chinese) at: https://www.sohu.com/a/553166641_120104159.

[105] See Energy Law of PRC (Draft) (《能源法草案》) (2020), Art. 115, available (in Chinese) at: https://npcobserver.com/wp-content/uploads/2020/04/energy-law-2020-draft.pdf (recognizing hydrogen as an energy carrier). See also A. Wang, *China's Hydrogen Development* (OIES, 2023), p. 5. The 2020 Draft Energy Law is an ongoing initiative to codify the regulation of China's energy sectors.

[106] PRC Law on the Safety Management of Hazardous Chemicals (Draft for Public Opinions) (《中华人民共和国危险化学品安全法征求意见稿》), 2020, Art. 21, available (in Chinese) at: https://www.mem.gov.cn/gk/tzgg/tz/202010/t20201002_368140.shtml.

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is necessary to diversify hydrogen applications, remove regulatory barriers, and formulate new standards.[107]

According to the theory on hydrogen regulation (see Section 2.1), these legislative reforms, if adopted, would be an important step in developing China's hydrogen economy. For the International Energy Agency, classifying hydrogen as an energy carrier is necessary for it to be a 'freely tradable energy asset', with its transportation subject to less stringent requirements than for hazardous substances (its previous classification).[108] By officially recognizing hydrogen as an energy carrier, China would follow international regulatory practice in the field. For instance, Germany amended its Energy Industry Act in July 2021 to recognize hydrogen transported through pure hydrogen pipelines as an energy carrier.[109] In the Netherlands, hydrogen is considered an alternative energy carrier for the purposes of hydrogen transportation.[110] In the United Kingdom (UK), hydrogen falls within the definition of gas and is regulated as part of gas networks.[111]

4.2. Regulation of Refuelling Stations

Despite the central government's objective of developing hydrogen refuelling stations, hydrogen blending, and hydrogen pipelines,[112] it has not yet issued specific regulations on the development of these facilities. The energy lawyers interviewed for this article (HL2, 3 and 4) explain this regulatory gap by emphasizing that the hydrogen pipelines already in place are still at the demonstration stage. By contrast, provincial and municipal authorities have taken the initiative to regulate their hydrogen infrastructure and, in particular, hydrogen refuelling stations.[113]

[107] J. Tu & L. Wang, 'Prospects of Renewable Hydrogen in China and Its Role in Industrial Decarbonization' (《可再生氢在中国的前景及在工业脱碳中的作用》), German Federal Ministry for Economic Affairs and Climate Action & Agora, 2023, available (in Chinese) at: https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2023/202304_Prospects_of_Renewable_Hydrogen_web_CN.pdf; Hubei Provincial Development and Reform Commission, 'The State and Prospects of China's Hydrogen Industrial Development' (《氢能源行业发展现状及前景》), 29 Dec. 2022, available (in Chinese) at: https://fgw.hubei.gov.cn/fbjd/xxgkml/jgzn/wgdw/nyj/nykjzbc/gzdt/202212/t20221229_4469185.shtm; China Energy, 'Regulatory Relaxation for Promoting Hydrogen Refuelling Stations Still Requires Breakthroughs' (《给加氢站松绑尚需诸多突破》), 14 Nov. 2022, available (in Chinese) at: http://paper.people.com.cn/zgnyb/html/2022-11/14/content_25949608.htm.

[108] IEA, n. 6 above, p. 38.

[109] Electricity and Gas Supply Act (Gesetz über die Elektrizitäts- und Gasversorgung (Energiewirtschaftsgesetz) (7 July 2005, amended in 2021 and 2023), s. 3, No. 14, available (in German) at: https://www.gesetze-im-internet.de/enwg_2005/BJNR197010005.html; CMS, 'Hydrogen Law, Regulations & Strategy in Germany' (last update Nov. 2021), available at: https://cms.law/en/int/expert-guides/cms-expert-guide-to-hydrogen/germany.

[110] Dutch Authority for Consumers and Markets, 'Guidelines Regarding Network Companies and Alternative Energy Carriers', 2021, available (in Dutch) at: https://www.acm.nl/nl/publicaties/leidraad-netwerkbedrijven-en-alternatieve-energiedragers; Fieldfisher, 'Shaping Europe's Hydrogen Economy: Netherlands', 2023, available at: https://hydrogen.fieldfisher.com/0008.html.

[111] Gas Act 1986, s. 48(1), available at: https://www.legislation.gov.uk/ukpga/1986/44/data.pdf; Fieldfisher, 'Shaping Europe's Hydrogen Economy: UK', 2023, available at: https://hydrogen.fieldfisher.com/0010.html.

[112] NDRC, n. 1 above.

[113] Zhonglun Law Firm, 'The Development and Regulatory Governance of Hydrogen Refuelling Stations' (《加氢站的发展及法律监管》), 8 Jan. 2021, available (in Chinese) at: www.zhonglun.com/Content/2021/01-08/1602146438.html.

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Depending on the location, the construction of hydrogen refuelling stations requires either administrative approval (such as Shanghai, Hebei province, Dalian, Fuzhou, and Foshan)[114] or merely registration with the local development and reform administration (such as Wuhan and Tianjin).[115] Licensing requirements typically include a land planning permit, approval by the fire bureau and the meteorology bureau, and construction approval from the administrative approval bureau.[116] To operate hydrogen refuelling stations, companies must also apply for gas-filling quality certification and an operating permit for dangerous chemicals.[117] Of these procedures, obtaining land-use permits to build hydrogen refuelling stations with on-site production is particularly challenging,[118] as it requires permitting for industrial use where local governments have not yet addressed the barrier posed by the regulation of hydrogen as a dangerous chemical.[119] In these areas, operators of refuelling stations face the difficult task of sourcing and transporting the hydrogen necessary for providing commercial refuelling services.[120]

These investments also face obstacles under the central-level Administrative Measures on Government Concession Rights for Infrastructure and Public Utilities (2015),[121] which do not explicitly cover hydrogen refuelling stations. Despite this

[114] Hebei Development and Reform Commission, n. 77 above; Fuzhou Municipal People's Government, 'Interim Regulations on Constructing, Operating and Managing Hydrogen Refuelling Stations in Fuzhou' (《福州市加氢站建设运营暂行规定》), 2020, Art. 8, available (in Chinese) at: http://www.fuzhou.gov.cn/zwgk/gb/202012/t20201228_3914634.htm.

[115] Hannan District Government, 'Interim Provisions for the Approval and Management of Hydrogen Refuelling Stations in Wuhan Economic and Technological Development Zone (Hannan District)' (《武汉经济技术开发区（汉南区）加氢站审批及管理暂行办法》), 2018, Arts 2–4, available (in Chinese) at: https://www.whkfq.gov.cn/xxgk/zc/qtzdgk/gwhqzf/202001/t20200119_898549.html; Office of Tianjin Municipal People's Government, 'Action Plan of Tianjin Hydrogen Development (2020–2022)' (《天津市氢能产业发展行动方案 2020—2022》), 2020, available (in Chinese) at: https://www.tj.gov.cn/zwgk/szfwj/tjsrmzfbgt/202005/t202005192370654.html.

[116] See, e.g., Hannan District Government, n. 115 above, Arts 2–4.

[117] Office of Municipal Government of Shanghai, 'Management Measures of the Construction and Operation of Hydrogen Refuelling Stations that Serve Fuel-Cell Vehicles in Shanghai' (《上海市燃料电池汽车加氢站建设运营管理办法》), 2022, Art. 9, available (in Chinese) at: http://heic.org.cn/newshow.asp?id=318; Nanjing Emergency Management Bureau et al., 'Interim Measures for Managing the Construction and Operation of Hydrogen Refuelling Stations' (《南京市加氢站建设运营管理暂行规定》), 2022, Art. 8, available (in Chinese) at: https://safety.nanjing.gov.cn/njsaqscjdglj/202207/t20220704_3633947.html.

[118] International Economic Cooperation Research Group of PRC, *Research on China's Hydrogen Industrial Policy* (Social Science Academic Press, 2021), p. 236.

[119] Ministry of Housing and Urban Design Administration, 'Code for Classification of Urban Land Use and Planning Standards of Development Land' (《城市用地分类与规划建设用地标准》), 2012, available (in Chinese) at: https://www.planning.org.cn/law/uploads/2013/1383993139.pdf. See also M.Y. Hu et al., 'Current Situation, Analysis of Obstacles and Suggestions for Countermeasures for the Development of Hydrogen Refuelling Stations in the Yangtze River Delta' (2023) 10(3) *Journal of Southern Energy Construction*, pp. 1–10.

[120] On the challenge of land use see Guangdong Provincial Government, 'Hydrogen Refuelling Stations with On-Site Production Outside Chemical Industrial Parks' (《非化工园区可建制氢加氢一体站》), 27 Oct. 2022, available (in Chinese) at: http://www.gd.gov.cn/zwgk/zdlyxxgkzl/scaq/content/post_4036290.html.

[121] NDRC, 'Administrative Measures on Government Concession Rights for Infrastructure and Public Utilities' (《基础设施和公用事业特许经营管理办法》), 2015, available (in Chinese) at: https://www.ndrc.gov.cn/xxgk/zcfb/fzggwl/201504/W020190905494983771573.pdf.

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regulatory gap, some local governments (such as Chengdu and Zhejiang) have developed hydrogen refuelling stations based on concession agreements.[122] As with the development of hydrogen projects outside chemical industrial parks, local authorities are experimenting with the use of concession agreements for hydrogen refuelling stations, pending reform of China's national regulation on concessions.

Local regulatory intervention has helped to address national regulatory barriers to the development of hydrogen refuelling stations with on-site production.[123] By 2022, around 24 hydrogen refuelling stations were operating with on-site hydrogen production in China.[124] At the same time, analysts point out the heavy administrative burden that project developers face in the absence of regulatory harmonization.[125]

As explained in the literature on environmental federalism and decentralization (Section 2.2), navigating the different environmental requirements that apply in each province and municipality creates challenges, and thus transaction costs, for companies. Esty, for instance, argues that 'fragmented markets are unattractive to potential investors'.[126] Reciprocally, as explained by Sovacool, 'uniformity helps manufacturers and industry by providing a consistent and predictable statutory environment'.[127] Harmonizing environmental regulation, therefore, benefits the industry by reducing transaction costs. On this basis, regulatory intervention by

[122] Chengdu Economic and Information Bureau et al., 'Management Measures of the Construction and Operation of Hydrogen Refuelling Stations (Trial Implementation)' (《成都市加氢站建设运营管理办法(试行)》), 2021, available (in Chinese) at: https://cdjx.chengdu.gov.cn/cdsjxw/c132827/2021-03/22/baeaeff1e89c4e009db33431b4741d60/files/fa83b056f4d8405794bf5734d42ec858.pdf; Zhejiang Housing and Urban-Rural Development, 'Implementation Opinions on Improving the Construction and Operation of Hydrogen Refuelling Stations (Draft)' (《关于加强汽车加氢站建设运营的实施意见(征求意见稿)》), 2023, available (in Chinese) at: https://jst.zj.gov.cn/art/2023/3/7/art_1229159359_58932016.html. See also China South Rail (CSR), 'China's Hydrogen Trams Built and Operated by CSR' (《中车四方签下我国氢能源有轨电车第一单》), available (in Chinese) at: https://www.crrcgc.cc/qsy/g12764/s6497/t281872.aspx.

[123] China Energy, n. 107 above.

[124] 'Prospects and Difficulties for Developing China's Hydrogen Refuelling Stations with On-Site Production' (《制氢加氢一体站前景与桎梏》), *Sohu News*, 11 May 2022, available (in Chinese) at: https://www.sohu.com/a/674619117_120717004. It is reported that 'hydrogen refuelling stations with on-site hydrogen production have been in trial operation respectively in Dalian, Datong, Changchun and Foshan': Community of Better Enterprise Advancement (CBEA), 'Hydrogen Refuelling Stations in 2019' (《2019 年建成的加氢站》), Dec. 2019, available (in Chinese) at: http://www.cbea.com/qtyy/201912/034840.html; BJX Hydrogen, 'Can We Promote the Large-Scale Use of Hydrogen Refuelling Stations with On-Site Hydrogen Production?' (《深度观察制氢加氢一体站能否大规模推广?》), Nov. 2021, available (in Chinese) at: https://m.bjx.com.cn/mnews/20211109/1186775.shtml.

[125] Zhonglun Law Firm, n. 113 above. See also International Economic Cooperation Research Group of PRC, n. 118 above, p. 235.

[126] D. Esty, 'Revitalizing Environmental Federalism' (1996) 95 *Michigan Law Review*, pp. 570–653, at 619.

[127] Sovacool, n. 9 above, p. 421. See also K. Engel, 'State Environmental Standard-Setting: Is There a "Race" and Is It "To the Bottom"?' (1997) 48(2) *Hastings Law Journal*, pp. 271–398; D. Stokes, 'Renewable Energy Federalism' (2022) 106 *Minnesota Law Review*, pp. 1757–825, at 1763 ('establishing coordinated development guidelines allows for consistency and efficiency across the energy industry'); H. Doremus & M. Hanemann, 'Of Babies and Bathwater: Why the Clean Air Act's Cooperative Federalism Framework Is Useful for Addressing Global Warming' (2008) 50(3) *Arizona Law Review* pp. 799–834, at 826.

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China's central government would help to streamline the administrative procedures applicable to the construction and operation of refuelling stations, and scale up the infrastructure needed for the development of China's hydrogen economy. This approach would follow international practice, such as in the EU where Member States are required to ensure that a minimum number of publicly accessible hydrogen refuelling stations are deployed by the end of 2030, with operators subject to minimum requirements governing access to their refuelling infrastructure.[128]

5. Regulatory Support for Hydrogen in China

China's central government has established financial mechanisms to support the deployment of fuel cell vehicles and refuelling stations. However, these schemes have remained limited in time and scope, leaving local authorities in charge of supporting the development of China's hydrogen economy. China's decentralized hydrogen regulation helped the hydrogen economy to take off, but local support mechanisms resulted in a subsidy race across regions. China's experience with the subsidization of hydrogen is of broader relevance for the debate on hydrogen regulation and environmental decentralization, as it helps in understanding how local subsidies can replace national initiatives to support the hydrogen industry, but create inefficiencies as local governments compete with each other.

5.1. Subsidizing Fuel Cell Vehicles

Since 2015, China's central government has subsidized the purchase of fuel cell vehicles.[129] Automobile companies received subsidies; thus, consumers could buy fuel cell vehicles at discounted rates. For example, for a 49-ton hydrogen fuel cell bus costing around 1.4 million renminbi (RMB) in 2016, subsidies could amount up to 500,000 RMB.[130] These subsidies have been gradually reduced, and were eventually phased out at the end of 2022 to avoid over-investment in fuel cell vehicles (see Table 3).[131] However, local governments continued to support fuel cell vehicles and

[128] Regulation (EU) 2023/1804 on the Deployment of Alternative Fuels Infrastructure [2023] OJ L 234/1, Arts 6–7.

[129] Ministry of Finance (MOF) et al., 'Notice of the Fiscal Subsidy Policies for the Promotion and Application of New Energy Vehicles (2016–2020)' (《关于 2016–2020 年新能源汽车推广应用财政支持政策的通知》), 2015, available (in Chinese) at: https://www.gov.cn/xinwen/2015-04/29/content_2855040.htm.

[130] L. Zhang et al., 'Hydrogen Use in the Transportation Sector and the Cost Analyses of Fuel Cell Vehicles' (2022) 7(4) *Petrochemicals and Green Low-Carbon*, pp. 1–30. As the manufacturing costs of different vehicles vary, we took the cost of a 49-ton heavy hydrogen fuel cell bus as an example, according to the available cost analyses.

[131] MOF et al., 'Notice of Improving the Policies on Government Subsidies for Promotion and Application of New Energy Vehicles' (《关于完善新能源汽车推广应用财政补贴政策的通知》), 2020, available (in Chinese) at: https://www.gov.cn/zhengce/zhengceku/2020-04/23/content_5505502.htm. See also BJX Hydrogen, '"Replacement of Subsidy with Rewards" Demonstration Application of Fuel Cell Vehicles Landed' (《"以奖代补" 燃料电池汽车示范应用落地》), 8 Sept. 2021, available (in Chinese) at: https://news.bjx.com.cn/html/20210908/1175518.shtml.; BJX Hydrogen, 'Can "Replacement of Subsidy with Rewards" Solve All the Problems' (《"以奖代补"能解决一切问题吗》), 9 July 2021, available (in Chinese) at: https://m.bjx.com.cn/mnews/20210709/1163057.shtml.

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Table 3. Central-level Subsidies for the Purchase of Fuel Cell Vehicles between 2016 and 2022

Types of Fuel Cell Vehicle	Subsidies/Vehicle in 2016 (RMB)	Reduction in 2017 (Base Year: 2016)	Reduction in 2019 (Base Year: 2016)	Reduction in 2020	Reduction in 2021 (Base Year: 2019)	Reduction in 2022 (Base Year: 2021)
Passenger vehicles	200,000	20%	40%	10% (private use; base year: 2019)	20% (private use)	30% (private use)
Light vehicles	300,000					
Heavy/ medium-size bus or vans	500,000			40% (public use; base year: 2016)	10% (public use)	20% (public use)

Source: Authors' own research, based on Ministry of Finance[132]

[132] MOF et al., n. 131 above; MOF et al., n. 129 above; MOF et al., 'Notice of Further Improving the Policies on Government Subsidies for Promotion and Application of New Energy Vehicles' (《关于进一步完善新能源汽车推广应用财政补贴政策的通知》), 2020, available (in Chinese) at: https://www.gov.cn/zhengce/zhengceku/2020-12/31/content_5575906.htm; MOF et al., 'Notice on the Policies on Government Subsidies for Promotion and Application of New Energy Vehicles in 2022' (《关于2022 年新能源汽车推广应用财政补贴政策的通知》), 2021, available (in Chinese) at: https://www.gov.cn/zhengce/zhengceku/2021-12/31/content_5665857.htm.

Table 4. Local Subsidies for Hydrogen Refuelling Stations

Industrial Clusters	Cities/ Provinces	Subsidies for Operating HRS to Companies	One-off Subsidies for Building HRS to Companies*
Yangtze River Delta	Jiaxing	15 RMB/kg (annual decrease by 3 RMB/kg)	Up to 4 mln RMB
Beijing-Tian-Hebei Region	Tianjin	N/A	Up to 5 mln RMB
	Zhangjiakou	N/A	Up to 8 mln RMB
Pearl River Delta	Foshan	9 RMB/kg	Up to 8 mln RMB
	Guangzhou	15 RMB/kg	Up to 2.5 mln RMB
Others	Chengdu	20 RMB/kg	Up to 5 mln RMB

* The subsidies for building hydrogen refuelling stations (HRS) depend on the investment amount and the daily refuelling capacity of stations.
Source: Authors' own research, based on local hydrogen development plans[133]

the production of fuel cell equipment.[134] Local governments have also allocated resources to support the construction and the operation of refuelling stations (see Table 4). Local subsidies incentivize the purchase of fuel cell vehicles, stimulate the formation of domestic assembly lines for fuel cells, facilitate access to hydrogen by supporting the construction of hydrogen refuelling stations, and contribute to the formation of hydrogen-industry clusters based on fuel cells and fuel cell vehicles (such as the Beijing-Tianjin-Hebei Region).[135] As seen above (Section 3), China produced 12,682 units of fuel cell vehicles and needs to bring this number to 37,318

[133] Office of Tianjin Municipal People's Government, n. 115 above; Foshan Development and Reform Commission, 'Implementation Details of Support Measures of the Industrial Development of New Energy Vehicles' (《佛山市南海区促进新能源汽车产业发展扶持办法》), 2020, available (in Chinese) at: http://www.nanhai.gov.cn/attachment/0/289/289044/5397491.pdf; Zhangjiakou Government, 'Implementation Plan of Phase I Project of Securing Hydrogen Supply to Zhangjiakou' (《张家口氢能保障供应体系一期工程建设实施方案》), 2020, scanned version is available (in Chinese) at: https://m.bjx.com.cn/mnews/20200310/1052255.shtml; Office of Jiaxing Municipal People's Government, n. 76 above; Guangzhou Development and Reform Commission, 'Implementation Details of the Measures of Promoting Hydrogen Industrial Development of Development Zones of Guangzhou' (《广州市黄埔区广州开发区促进氢能产业发展办法实施细则》), 2021, available (in Chinese) at: https://www.gzcpc.org/raw/info/id/3029; Office of Chengdu Municipal People's Government, 'Guidance on Promoting the High-Quality Development of the Hydrogen Industry in Chengdu' (《成都市人民政府办公厅关于促进氢能产业高质量发展的若干意见》), 2020, available (in Chinese) at: http://www.caam.org.cn/chn/chn/9/cate_104/con_5231114.html.

[134] See, e.g., Beijing Economic and Information Bureau, 'Notice on Applications for Pilot Projects for Fuel Cell Vehicles in Beijing 2021–2022' (《关于开展 2021–2022 年度北京市燃料电池汽车示范应用项目申报的通知》), 2022, available (in Chinese) at: https://www.beijing.gov.cn/fuwu/lqfw/gggs/202204/t20220408_2670154.html; Shanghai Development and Reform Commission, 'Several Policies on Supporting Fuel Cell Vehicles' (《上海关于支持本市燃料电池汽车产业发展若干政策》), 2023, available (in Chinese) at: https://www.sh-hitech.com/ryrd/4042.html; Shenzhen Development and Reform Commission, 'Hydrogen Industrial Development Plan 2021–2025' (《深圳市氢能产业发展规划2021–2025》), 2021, available (in Chinese) at: http://fgw.sz.gov.cn/zwgk/qt/tzgg/content/post_9459760.html; Office of Chengdu Municipal People's Government, n. 133 above.

[135] Huanqiu News, 'Subsidy Policies: Golden Time for Hydrogen Development' (《补贴政策出台 中国氢能迎来四年发展黄金期》), *People News*, 26 Apr. 2020, available (in Chinese) at: http://finance.people.com.cn/bank/n1/2020/0426/c1004-31688422.html; Chuancai Securities, 'Policies at the Local Level: Waiting

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units to meet the 2025 target. This development could be facilitated by the reduction in the cost of fuel cells (at 2,000 yuan/kw in 2022), which in turn reduces the cost of manufacturing fuel cell vehicles and contributes to their commercialization.[136]

However, analysts have warned that local support may not be sufficient to create enough demand for hydrogen in a cost-effective way, and may have only a limited influence on the pace of technological innovation.[137] As the local subsidy rates for fuel cell vehicles are aimed mainly at increasing the sales volume of such vehicles and the core equipment for fuel cells, rather than improving technology innovation or operational efficiency,[138] Chinese companies could develop a certain degree of dependence on foreign fuel cell technology.[139] Also, as current sales are stimulated largely by governmental subsidies, it is difficult to judge how far market forces can play a role in adjusting sales volumes.[140]

At the same time, analysts are concerned that local subsidies could lead to the expansion of the local manufacturing capacity of fuel cell equipment and vehicles without paying sufficient attention to the current demand for these vehicles.[141] For example, we were told by the board of directors of Sunwise, a company engaged in the hydrogen business, that one of their hydrogen refuelling stations built in Shanghai has not yet become commercially viable because there are not enough fuel cell vehicles in use.[142] Similarly, in Guangdong province, more than 3,000 fuel cell vehicles have received vehicle licences but, by July 2023, there were only 1,200 vehicles in use.[143] Sales of fuel cell vehicles do not necessarily equate to the effective utilization of these vehicles.[144] Although local subsidies played an important role in compensating for reduced national support, these support measures struggled to adequately address

for the Top-Design' (《框架初成 静待顶层设计》), 2020, available (in Chinese) at: http://pdf.dfcfw.com/pdf/H3_AP202003301377173310_1.PDF.

[136] China Automobile, 'The Analysis of Subsidy Policies of HRS' (《加氢站补贴政策分析》), 1 Mar. 2021, available (in Chinese) at: https://www.chinaautoms.com/a/new/2021/0301/17327.html.

[137] H. Wang, 'A Study on the Reform of Energy Supervision System from the Perspective of Organization Law' (2019) 21(1) *Journal of Southwest Petroleum University*, pp. 1–7, at 4.

[138] T. Zhu, 'The Features, Problems and Status of China's Hydrogen Industry', *China Development Observation*, 10 Nov. 2021, available (in Chinese) at: https://cdo.develpress.com/?p=12270.

[139] L. Xu & L.D. Zhao, 'New Energy Technology Innovation Effect of Key Industrial Policy' (2019) 41(1) *Resources Science*, pp. 13–21, at 18.

[140] China Clean Energy Development Mechanism Fund, 'The Possible Boost of the Hydrogen FCV Market' (《氢燃料电池汽车市场今年或将爆发》), 29 Jan. 2023, available (in Chinese) at: https://www.cdmfund.org/32365.html.

[141] Y. Yuan and M. Tan-Mullins, 'An Innovative Approach for Energy Transition in China?' (2023) 15(2) *Sustainability*, pp. 1265–89, at 1277; H. Wang & J.Y. Yin, 'Local Industrial Policies and Industry Innovation and Development' (2021) 47(5) *Journal of Finance and Economics*, pp. 64–78, at 66; Wang, n. 105 above, p. 10. See also 'Behind the Local Government's Bet on Hydrogen Energy' (《地方政府押注氢能背后：重复建设、地方保护、骗补等弯路还会再走一次吗》), *China News*, 1 Mar. 2021, available (in Chinese) at: https://www.chinanews.com.cn/gn/2021/03-01/9421280.shtml.

[142] China Association of Automobile Manufacturers, 'More Than 20 Cities for the Development of Hydrogen FCVs' (《20多个城市抢跑氢燃料电池汽车》), 2 Mar. 2021, available (in Chinese) at: http://www.caam.org.cn/search/con_5233251.html.

[143] Hydrogen Energy Industry Promotion Association, 'Low Operation Efficiency of HRS?' (《加氢站缘何"吃不饱"?》), 24 July 2023, available (in Chinese) at: https://cn-heipa.com/newsinfo/6200215.html.

[144] Ibid.

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one of the crucial factors in building an efficient hydrogen market: a satisfactory balance between supply and demand.

5.2. Pilot Hydrogen Schemes

The central government established a pilot city regime for hydrogen refuelling stations in 2014[145] and for fuel cell vehicles in 2020.[146] Establishing pilot regimes for testing energy technologies (fuel cell vehicles in this case) at the local level is a common strategy of the Chinese government.[147] In both regimes the central government allocates funds from the national budget to pilot cities or pilot city clusters proposed by the local authorities.[148] Pilot schemes for refuelling stations benefit from central government funds if they meet the technical standards and capacity requirements set by the government (for example, refuelling no less than 200 kg of hydrogen per day).[149] Similarly, the pilot city regime for fuel cell vehicles aims to commercialize and industrialize the key technologies relevant for fuel cells and fuel cell vehicles, and stimulate hydrogen supply (especially clean hydrogen supply).[150] The criteria for receiving subsidies include the adoption of a specific fuel cell technology, total vehicle mileage, the volume of total hydrogen supply (more than 5,000 tons per year), the emissions standard for hydrogen production (less than 15 kg CO_2 for every 1 kg of hydrogen) and the price of refuelling (no more than 35 yuan/kg hydrogen).[151] The Ministry of Finance, together with other ministries (including the National Development and Reform Commission), reviews on a yearly basis the compliance of the pilot cities and city clusters with these criteria and grants funding to local governments on this basis.[152]

The technical criteria set by the central government seek to promote further innovation in the manufacturing of fuel cells. The criterion of total vehicle mileage helps to avoid local governments incentivizing companies to manufacture new fuel cell vehicles without requiring these vehicles actually to be used. By creating demand for renewable or low-carbon hydrogen, the criteria for the emissions standard and the volume of hydrogen supply should incentivize decarbonization. Lower refuelling

[145] MOF et al., 'Notice of Awarding the Construction of Charging Facilities of New Energy Vehicles' (《关于新能源汽车充电设施建设奖励的通知》), 2014, available (in Chinese) at: http://www1.shanghaiinvest.com/cn/viewfile.php?id=8690.

[146] MOF et al., 'Notice of the Pilot Application of Fuel Cell Vehicles' (《关于开展燃料电池汽车示范应用的通知》), 2020, available (in Chinese) at: https://www.gov.cn/zhengce/zhengceku/2020-10/22/content_5553246.htm.

[147] H. Uhdea & G. Malima, 'Experimenting with Local Electricity Markets in China' (2020) 69 *Energy Research & Social Science*, pp. 1–8, at 1–3.

[148] MOF et al., n. 145 above; MOF et al., n. 146 above.

[149] MOF et al., n. 145 above.

[150] BJX Hydrogen (9 July 2021), n. 131 above.

[151] MOF et al., 'The Demonstration Objectives and Credits Evaluation System for Pilot City Clusters of Fuel Cell Vehicles' (《燃料电池汽车城市群示范目标和积'分评价体系》), 2020, available (in Chinese) at: http://www.heic.org.cn/upload/file/20210826/16299474328508986.pdf.

[152] MOF et al., n. 146 above.

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prices can help to incentivize the use of hydrogen fuel cell vehicles without the need for subsidizing the purchase of the vehicles. Thus, through its assessment criteria, the central government aims to contribute to the promotion of fuel cell vehicles and the deployment of hydrogen refuelling facilities.

5.3. The Risk of Local Protectionism

Another effect of local ambition has been the emergence of a certain degree of protectionism, as local authorities seek to maximize the benefits of the hydrogen transition for their economy. For example, the governments of Chengdu, Panzhihua, and Jiaxing grant funding to companies that set up new subsidiaries focusing on fuel cell vehicles in their cities, and help companies in completing the administrative procedures for investing in these places.[153] The government of Ningxia aims to attract companies that engage in the manufacture of key components for fuel cell vehicles to establish a business presence in Ningxia province.[154] Changshu seeks to become the manufacturing base of key equipment for hydrogen fuel cells, an objective it seeks to achieve by promoting the development of fuel cells and fuel cell vehicles.[155] According to our interviewees (HL1 to 5 and HP1, 4, 5), although these plans do not formally impose obligations on companies, many governments view the establishment of local manufacturing capacity as a precondition to benefit from support.

Furthermore, a number of local hydrogen development plans directly identify the main industrial beneficiaries.[156] Where the local government purchases fuel cell vehicles that are equipped with components manufactured by a certain company, and refers in its tenders to the technical standards corresponding to these components,[157] competitors' access to these markets will be jeopardized.

Localization measures can lead to inefficient investment practices, with distortive effects on the emerging national market, in particular where local authorities seek to attract investment in their local hydrogen-industry parks without giving full consideration to the hydrogen supply-demand balance within their administrative

[153] See, e.g., Office of Jiaxing Municipal People's Government, n. 76 above; Office of Chengdu Municipal People's Government, n. 133 above; Panzhihua Development and Reform Commission, 'Several Measures for Promoting Hydrogen Industrial Development (Draft for Opinions)' (《关于支持氢能产业高质量发展的若干政策措施征求意见稿》), 2022, available (in Chinese) at: http://fgw.panzhihua.gov.cn/zwgk/tzgg/4194488.shtml.

[154] Ningxia Provincial People's Government, n. 76 above.

[155] Changshu Municipal People's Government, n. 76 above.

[156] See, e.g., Henan Provincial People's Government, n. 77 above; Shaanxi Development and Reform Commission, '14th Five-Year Plan of Hydrogen Development' (《陕西省"十四五"氢能产业发展规划》) (2022), available (in Chinese) at: https://sndrc.shaanxi.gov.cn/web.files/uploadfile/J77VFn/ue/file/20220822/1661159538898066271.pdf; Zhangjiakou Municipal People's Government, 'Development Plan of Zhangjiakou's Hydrogen Energy (2019–2035)' (《氢能张家口建设规划 2019—2035》), 2019, available (in Chinese) at: http://www.zjknews.com/news/202201/24/354941.html.

[157] 'Are the Objectives of Developing Fuel Cell Vehicles in Different Provinces and Cities Too Ambitious?' (《各地氢燃料电池汽车规划目标是否定得过高》), *Sohu News*, 2 Sept. 2022, available (in Chinese) at: https://www.sohu.com/a/581895644_121119176.; *China News*, n. 141 above.

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Table 5. Fuel Cell Vehicles and Hydrogen Refuelling Stations in Shanghai

	Units of Licensed Fuel Cell Vehicles	Units of Hydrogen Refuelling Stations in Operation
By September 2020	1,455	10
By the end of 2021	1,512	10
By the end of 2022	1,908	13
By the end of September 2023	2,374	21

Source: Authors' own research, based on Shanghai government,[158] media reports,[159] and research institutes[160]

area.[161] In Shanghai, for example, there were already more than 200 companies active in the various segments of the hydrogen value chain in 2020,[162] a disproportionate number of industrial players, compared with the still limited, albeit growing, volume of licensed fuel cell vehicles in the city (see Table 5). In China more generally, the 300 hydrogen refuelling stations in operation in 2022 could support more than 30,000 hydrogen vehicles,[163] compared with the 12,682 licensed units.

In pursuit of career development,[164] local officials can seek to actively promote the localization of hydrogen manufacturing capacity to take credit for the associated local economic benefits, even if this undermines the development of a more cost-efficient national hydrogen market.[165] Launching similar projects for fuel cell vehicles in different cities can result in inefficiencies[166] if companies need to cater for the interests of different local governments.[167] Moreover, it often happens that the market share of a

[158] See, e.g., Shanghai Municipal Government, n. 77 above.

[159] 'Industrial Development of Hydrogen and Fuel Cells in 2020' (《2020 氢能与燃料电池产业最新动态》), *The Paper*, 8 Dec. 2020, available (in Chinese) at: https://www.thepaper.cn/newsDetail_forward_10312344; see also BJX Hydrogen, n. 78 above; 'Accelerating the Promotion of FCVs in Shanghai' (《上海氢燃料电池汽车推广再提速》), *People's News*, 31 July 2023, available (in Chinese) at: http://paper.people.com.cn/zgnyb/html/2023-07/31/content_26009815.htm.

[160] GGII, n. 80 above; Hydrogen and the Future, 'The Analysis of the Applications of Hydrogen FCVs between 2016–2022' (《氢燃料电池商用车应用情况分析》), 29 Mar. 2023, available (in Chinese) at: https://www.h2weilai.com/cms/index/shows/catid/55/id/8041.html.

[161] *China News*, n. 141 above; *Sohu News*, n. 157 above.

[162] *The Paper*, n. 159 above.

[163] Hydrogen Energy Industry Promotion Association, n. 143 above.

[164] Boosting the local economy is a common way of achieving career promotion; see National Development Research Institute of Peking University, 'Report on Institutional Reform for China's Energy Sector', 2014, p. 25; H. Zhang, 'Exploring Energy Resilience in China's Energy Law in the Carbon Neutrality Era' (2020) 30(1) *Asia Pacific Law Review*, pp. 167–87, at 185.

[165] To achieve rapid economic growth, local governments have sought quick results in industrial development and enhanced manufacturing capacity, e.g., increases in the volume of hydrogen refuelling stations; see, e.g., Wang, n. 105 above. See more generally M.M. Pearson, 'Local Government and Firm Innovation in China's Clean Energy Sector', in L. Brandt & T.G. Rawski (eds), *Policy, Regulation and Innovation in China's Electricity and Telecom Industries* (Cambridge University Press, 2019), pp. 96–133, at 105.

[166] China Energy, 'Fuel Cell Vehicle Market' (《燃料电池汽车市场》), 11 Oct. 2021, available (in Chinese) at: http://paper.people.com.cn/zgnyb/html/2021-10/11/content_25883275.htm; China Automobile, 'When Will Local Protectionism for New Energy Vehicles Stop?' (《新能源汽车地方保护何时休》), 26 Jan. 2018, available (in Chinese) at: http://auto.china.com.cn/news/20180125/686283.shtml.

[167] J.Z. Li, 'Charging Chinese Future' (2020) 45(20) *International Journal of Hydrogen Energy*, pp. 11409–23, at 11420.

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specific city or province is captured by companies with large local investments rather than those with the most advanced hydrogen technology.[168] Therefore, administrative intervention to protect local value chains of fuel cell vehicles adopted by local governments may not enable continued technological innovation (for example, hydrogen use in transportation), which is crucial for creating a hydrogen market.[169] Indeed, this has also been emphasized in the National Hydrogen Development Plan, which identifies signs of low-quality hydrogen development and competition at the local level.[170]

6. National Hydrogen Regulation through Local Experimentation

China's experience with the development of hydrogen illustrates the role of local initiatives in addressing national regulatory barriers and gaps regarding the development of new clean energy technologies. As explained in the literature on environmental decentralization/federalism, regions can act as 'laboratories' for the experimentation of new regulatory approaches[171] and pioneers in the development of new policy initiatives.[172] To promote local investment in hydrogen, provincial and municipal authorities in China have actively supported the purchase of fuel cell vehicles and the deployment of hydrogen refuelling stations through subsidy schemes. Although absolute numbers remain limited, these local regulatory interventions have started to establish the basis of China's hydrogen economy, compensating for limited central government regulation.

At the same time, China's hydrogen experience confirms the risk of fragmentation associated with local clean energy initiatives, as conceptualized in the literature on environmental federalism and decentralization.[173] China's case also shows how local ambition can result in a certain degree of protectionism through the preferential treatment of locally manufactured fuel cell equipment and vehicles. The literature on clean energy and trade law discusses how localization incentives for clean energy technologies have increased the cost, and reduced the speed, of their deployment.[174] Similarly, fragmentation and localization could increase the cost of China's hydrogen transition.[175]

[168] *China News*, n. 141 above; China Energy, n. 166 above.

[169] S. Ren, Y. Hao & H. Wu, 'Government Corruption, Market Segmentation and Renewable Energy Technology Innovation' (2021) 300 *Journal of Environmental Management*, pp. 1–11, at 2.

[170] NDRC, n. 1 above.

[171] Sovacool, n. 9 above, p. 430; Fenna, Jodoin & Setzer, n. 9 above, p. 5.

[172] R. Quitzow, 'The Concept of "Lead Markets" Revisited' (2014) 10 *Environmental Innovation and Societal Transitions*, pp. 4–19.

[173] See, e.g., Esty, n. 126 above, p. 619.

[174] See, e.g., D. Nelson & L. Puccio, 'Nihil Novi Sub Sole' (2021) 20(4) *World Trade Review*, pp. 491–508, at 496; H. Bahar, J. Egeland & R. Steenblik, *Domestic Incentive Measures for Renewable Energy with Possible Trade Implications* (OECD, 2013).

[175] Academics have warned that the fragmented administration of this new industry could hinder its development; see, e.g., M. Zhang & X.N. Yang, 'The Regulatory Perspectives to China's Emerging Hydrogen Economy' (2022) 14(15) *Sustainability*, pp. 1–20; Z.X. Duan & K. Shi, 'Review and Problem Analysis on the Development of Hydrogen Fueling Stations in China' (2021) *Proceedings of the American Society of Mechanical Engineers 2021*, pp. 1–6, at 4; X.Y. Meng et al., 'Status Quo of China Hydrogen Strategy in

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As emphasized in the literature on lead markets, pioneers may benefit from so-called first-mover advantages if their policy initiatives and related technologies are adopted by other regions at a later stage.[176] These economic benefits may also stimulate a subsidy or regulatory race with other competing regions.[177] Subsidy races can potentially drive policy innovation and learning, but are frequently also linked to the prioritization of local champions, and may therefore generate inefficiencies (that is, higher costs) and face the risk of legal challenges.

In China, the input that local regulatory experimentation provides to the central government explains why the latter has not yet intervened to rein in the local subsidy race and localization efforts. As explained by our interviewees (HL1 to 5, HP1 and 4), the government's policy is first to allow the development of a hydrogen ecosystem in China before building the national market, even if this comes at the cost of a certain degree of localization. The central government is waiting for value chains to become more mature before regulating the emerging industry. This approach would allow the government to better manage the uncertainties characterizing the hydrogen industry. More detailed and responsive central guidance might then take into account the complexities of hydrogen development and consider the various technicalities of implementing local hydrogen development plans.

To mitigate the transaction costs resulting from market fragmentation and local protectionism, the environmental decentralization literature emphasizes the role of regulatory harmonization.[178] On this basis, intervention by China's central authorities will eventually be needed to accelerate the development of its hydrogen economy. Steps towards such harmonization are already being taken. Indeed, one of the objectives of establishing a reward regime for pilot city clusters is to push forward cooperation among cities, to break administrative area restrictions and to level the playing field across regions.[179] Building on the hydrogen investment promotion and administration measures implemented at the local level, the National Development and Reform Commission has a role to play in implementing a unified market access system in the hydrogen sector and requiring local governments to remove their protectionist measures.[180]

However, as advocated by proponents of 'cooperative federalism', harmonization should not fully neutralize regulation at the local level, taking into account the benefits of local action for clean energy policy.[181] In China, a certain degree of harmonization of

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the Field of Transportation and International Comparisons' (2020) 46(57) *International Journal of Hydrogen Energy*, pp. 28887–99, at 28887.

[176] Quitzow, n. 172 above, p. 4.

[177] L.L. Davies, 'State Renewable Portfolio Standards' (2012) 3 *San Diego Journal of Climate & Energy Law*, pp. 3–80, at 46. See also B. Rabe, 'Race to the Top: The Expanding Role of U.S State Renewable Portfolio Standards' (2007) 7(3) *Sustainable Development Law and Policy*, pp. 10–7.

[178] Sovacool, n. 9 above, p. 421; Stokes, n. 127 above, p. 1763; Doremus & Hanemann, n. 127 above, p. 826.

[179] MOF et al., n. 146 above.

[180] The Communist Party of China and the State Council, 'Opinions on Accelerating the Construction of a Unified National Market' (《中共中央 国务院关于加快建设全国统一大市场的意见》) (2022), available (in Chinese) at: https://www.gov.cn/zhengce/2022-04/10/content_5684385.htm.

[181] On 'cooperative federalism' and clean-energy policy see, e.g., Mormann, n. 49 above; Rossi & Hutton, n. 49 above.

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the criteria governing the support of hydrogen projects would help in managing the expectations of investors in the sector, while preserving the benefits of local hydrogen initiatives. Based on the theory on hydrogen regulation (Section 2.1), regulatory reforms should prioritize the recognition of hydrogen as an energy carrier instead of a hazardous chemical, and should certify the different types of hydrogen to facilitate support for renewable-based generation.[182] Local initiatives to date have enabled hydrogen projects to develop outside the regulatory regime. This local experimentation provides valuable input to develop a harmonized national framework on hydrogen.

7. Conclusion

There are various challenges for the development of hydrogen as a vehicle for decarbonization. Each challenge requires regulatory intervention across different dimensions, ranging from carbon footprint measurement, safety requirements, and modes of transport to measures to stimulate production and use across different applications and end-use sectors. The role of governments (both central and local) in this context is to reduce uncertainty and risks across the hydrogen sector by defining the regulatory landscape, providing public funding to support infrastructure development, and creating demand for hydrogen and hydrogen-related technologies. However, it is precisely this uncertainty that poses a risk, not only for private entities and investors but also for governments. Against this background, regulatory experimentation can be used to manage the uncertainties of hydrogen development, as with previous developments in the broader field of climate and energy regulation.

China's experience shows that local authorities can play an important role in developing and regulating hydrogen through experimentation. China has started to develop a hydrogen industry, focusing mainly on hydrogen refuelling stations and fuel cell vehicles. The Chinese government did not set out a national regulatory framework on the basis of which this new industry should be developed. Rather, it has relied on local experimentation to gain experience with the development of projects in the various segments of the hydrogen value chains and 'test the waters' before addressing the regulatory barriers and inefficiencies that affect these local experiments. Although the deployment of hydrogen – and, in particular, green hydrogen – remains limited in absolute numbers, China's provincial and municipal authorities have played a determining role in starting to develop the sector by helping to overcome regulatory barriers to the realization of hydrogen projects and actively supporting these investments, in close cooperation with industrial actors. In sum, the Chinese experience shows how, in jurisdictions with a sufficient degree of decentralization, local initiatives can help the central government to test regulatory approaches to hydrogen.

At the same time, China's experience points to the limits of developing hydrogen through local initiatives, and the need for regulatory harmonization to accelerate further development of the industry. Because they are overly concerned with the pursuit of local economic benefits, local initiatives in China have resulted in a certain degree of

[182] Majumder-Russell, n. 20 above; IEA, n. 31 above.

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protectionism and inefficiency in the allocation of public finance. Although local hydrogen initiatives have helped China in developing its hydrogen industry, treating local companies more preferably will, in the long run, hinder the development of a hydrogen market in China. National regulation will thus eventually be necessary to address the obstacles that localization requirements and the local subsidy race pose to the development of hydrogen. Following the theory on environmental decentralization and federalism, harmonized hydrogen rules can be expected to reduce transaction costs for investors, and generate economies of scale and learning effects.

The development of a national regulatory approach will be crucial in determining how Chinese actors will engage with the emerging international hydrogen sector. Reducing the scope for local protectionism within China by the introduction of clearly defined national-level rules would also play an important role in ensuring a level playing field within the international market.[183] At the same time, the absence of a clearly defined national regulatory regime at the current stage offers an important opportunity for promoting harmonization, not only across Chinese provinces but also with other major economies. As the Chinese central government develops its national regulatory approach, it has the opportunity to take into account both local and international experience and engage with other major economies in an effort to promote an internationally harmonized regulatory landscape.

In this vein, future research should engage in comparative analysis of China's approach with other major economies, most importantly the US and the EU. For now, China's approach reveals parallels to the US approach, where the government is relying strongly on the concept of regional hydrogen hubs that have been selected in a competitive process.[184] At the same time, US federal policy does not seek to restrict any particular form of hydrogen production, but rather provides a broad set of incentives; similar to China, these incentives have raised protectionist concerns. The EU, in contrast, has chosen to develop a detailed regulatory framework, including quotas for renewable hydrogen within the industrial sector. This is intended to steer investment into renewable hydrogen production, based on narrowly defined requirements. This, in turn, has raised fears that this regulatory approach may not provide sufficient incentives for investment, slowing down the hydrogen ramp-up.[185] The EU's strong regulatory landscape also raises questions regarding future compatibility with approaches in other major economies, such as China and the US, which could hamper the formation of a global hydrogen market. Systematic comparative regulatory analysis could provide an important point of reference for identifying opportunities and barriers for regulatory alignment.

[183] See, e.g., H. Zhang et al., 'The Impact of Subsidies on Overcapacity' (2016) 94(C) *Energy*, pp. 821–7; S. Yu et al., 'Determinants of Overcapacity in China's Renewable Energy Industry' (2021) 97(C) *Energy Economics*, pp. 1–12; M.M. Fang, 'A Crisis or an Opportunity?' (2020) 54(1) *Journal of World Trade*, pp. 103–26.

[184] Eicke, n. 87 above, p. 10.

[185] Zabanova, n. 87 above, p. 8.

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Appendix 1

HL1: senior lawyer, advising on energy and infrastructure projects (law firm)
HL2: lawyer, specializing in energy law (law firm)
HL3: lawyer, specializing in energy law (law firm)
HL4: senior lawyer, with experience advising on hydrogen projects (law firm)
HL5: senior lawyer, specializing in energy law (law firm)

HP1: lead-researcher on China's clean energy transition (research institute)
HP2: policy and economic analyst, specializing in climate finance (research institute)
HP3: policy analyst, focusing on investments in China's renewable energy sector (research institute)
HP4: policy analyst, specializing in China's energy transition, with a focus on hydrogen (research institute)
HP5: senior policy analyst, specializing in hydrogen (research institute)

Appendix 2

Sample questionnaire for lawyers

- What are hydrogen companies most concerned about when making decisions on investing in a hydrogen project or when they lay out their hydrogen business?
- Why did the central government wait to formulate a hydrogen development strategy until hydrogen projects had already started to operate?
- What are the implications of listing hydrogen as energy in the Energy Law (Draft)?
- Do local hydrogen policies or regulatory measures allow the development of hydrogen projects outside chemical industrial parks, despite the requirements of the national law on dangerous chemicals?
- What support mechanisms did local and national authorities adopt to promote the development of hydrogen?
- Is 'local protectionism' affecting the development of fuel cell vehicles?
- How would you assess the existing regulation, and governance, governing the construction and operation of hydrogen refuelling stations?
- How do companies navigate the different regulatory requirements governing the implementation of hydrogen projects in different cities and provinces? Could you please give some examples?
- How would you assess the existing local hydrogen development plans? Did they succeed in promoting innovation?

Sample questionnaire for energy policy analysts

- Could you introduce the layout of China's hydrogen value chains?
- What are major technical and economic barriers to the development of hydrogen value chains?
- Can current hydrogen-related policies, together with policies generally in charge of promoting clean energy development, help to address these barriers?
- How can China develop hydrogen without a central regulatory framework at the current stage?

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- What companies are playing an important role in developing China's hydrogen development plans? What are their business strategies?
- Why do local governments focus on the development of fuel cell vehicles?
- What is the role of hydrogen in China's energy transition?
- How do companies adjust to the different regulatory requirements governing the implementation of hydrogen projects in different cities and provinces?
- How would you assess the existing local hydrogen development plans? Did they succeed in promoting innovation?

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