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Using system dynamics to evaluate the impact of subsidy policies on green hydrogen industry in China

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Highlights

- A system dynamics model of the green hydrogen industry development.
- The installation of the green hydrogen production in different subsidy scenarios.
- The carbon emission reduction and subsidy policy cost for the green hydrogen.
- The impact of single and combination subsidy policies on the green hydrogen industry.

Abstract

This paper establishes a system dynamics model for the development of green hydrogen (GH) industry in China supported by government subsidy policies. The changes in the installed capacity, return on investment and carbon emission reduction of GH and the corresponding government expenditure are simulated under different single and combination subsidy scenarios including subsidy form, intensity, duration and decline mode. The result shows that the subsidy policies for investment, production, hydrogen-production electricity price and income tax rate will promote the development of the GH industry to varying degrees. A flexible combination subsidy policy needs to be adopted to coordinate with the development, technology and subsidy expenditure of the GH industry. Specifically, in the initial stage, 35%~40% of the initial investment-based subsidy or 30%~40% of the production-based subsidy can be employed for 5 years to ensure the GH industry's rapid development, combined with income tax rate (15%~20%) and higher hydrogen-production electricity price (0.3–0.35 yuan/kWh), or with low hydrogen-production electricity price (0.25–0.3yuan/kWh) and 25% income tax rate. The government will then dynamically adjust the subsidy policy according to the scale, technological progress and cost, and reduce the subsidy intensity by 5%~10% every 1–2 years to make it gradually decline to the end.

Introduction

Hydrogen production is mainly divided into three color codes according to cleanliness: Gray, Blue and Green. Gray hydrogen is principally produced through the reforming of fossil fuels, which will generate a great number of industrial waste gases and cause severe environmental pollution. The process of blue hydrogen production is an improvement of gray hydrogen production, which incorporates carbon capture and storage technology, but it still has certain carbon emissions. However, green hydrogen (GH) is regarded as a form of clean energy with low-carbon-emissions production method which is mainly realized by electrolysis of water-using renewable energy. And GH basically does not generate any environmental pollution in the whole process of production. Transition from gray or blue hydrogen to green hydrogen is becoming the current idea for hydrogen production development (Dawood et al., 2020).

GH is identified as an energy source that may help decarbonize the energy system. This is because it is an alternative energy carrier to electricity or fossil fuels which has many potential applications, and can be converted to heat or electricity without carbon emissions (IEA, 2019a). At the same time, the production of GH possibly can achieve excellent renewable energy absorbency, reduced wind and solar energy abandonment, and improve renewable energy utilization. Thus, the production of GH is one of the effective measures to accelerate and achieve carbon emission reduction. The growth of the green hydrogen industry can not only ensure the stability and flexibility of energy supply, but also reduce carbon emissions (Colbertaldo et al., 2019). In addition, GH is easy to store and transport due to its high energy density which allows GH to be stored and used to generate electricity at any time as an energy buffer carrier to enhance the resilience and efficiency of the power system. Hence GH also indirectly solves the randomness of renewable energy power output (Sahin, 2017).

However, the GH production is still costly, which is mainly due to the high electrolysis cost and equipment investment caused by limited technology, high electricity price and so forth. In the meantime, as the safety of hydrogen storage and transportation needs to be guaranteed, the amount of hydrogen storage and transportation is low while costly, which makes it difficult for the GH industry to achieve economic benefits under the existing technical level, let alone large-scale commercial applications (Klumpp, 2016). Even in European and American countries where large GH production industries exist, the cost of GH production is relatively high (2.5USD/kg H2 in USA, 3-4USD/kg H2 in Europe and 2.5–3.5USD/kg H2 in Australia) (IEA, 2019a). Although there is technical feasibility for GH production, the economic feasibility is still low and needs to be improved. Therefore, in order to reduce the cost of GH production and promote the development of the GH industry, the governments of many countries such as China, the United Kingdom, and Japan have implemented some GH subsidy policies (GPDRC, 2020; IRENA International Renewable Energy Agency, 2019).

China currently has the world's largest hydrogen production capacity, but most of it is dominated by gray hydrogen (The proportion of coal gasification and natural gas reforming to produce hydrogen in hydrogen production is 80%) (Shan and Wang, 2020). The production cost of GH in China is about 3-5USD/kg H2 (Chi and Yu, 2018), which is nearly 1-0.5USD/kg H2 higher than that of European and American countries (IEA, 2019a). The Chinese government also attaches great importance to the development of green hydrogen. The green hydrogen production is especially appropriate for developing countries with plenty of renewable energy sources and positively linked to the sustainable development goals of economic growth. (Falcone et al., 2021). In recent years, the China Hydrogen Alliance and the National Energy Administration have issued top-level designs such as the green hydrogen industry infrastructure development white paper and blue paper (CHA China Hydrogen Alliance, 2020; IAC The Investment Association of China, 2021). A few local provincial and municipal governments have also launched some support policies for hydrogen energy-related technology research and development, infrastructure construction, hydrogen fuel cell industry, and energy storage. It is proposed to encourage the application of electrolysis of water for hydrogen production in areas rich in clean energy, promote the construction of clean energy distributed projects and facilitate local consumption of clean energy in multiple ways (NEA, 2020a, NEA, 2020b). The government should actively explore the conversion of surplus power from renewable energy into hydrogen energy so as to realize the efficient use of renewable energy (NDRC, 2018). Incentives and subsidies are provided for newly establishment of fuel cell vehicle hydrogen refueling stations (NMF, 2014). 30% investment subsidy is given to a hydrogen production station with a certain scale (FBIIT, 2020). The government will stimulate the industrialization of low-cost and large-scale hydrogen production based on renewable energy, invest funds to support the research and demonstration of wind/solar complementary large-scale hydrogen production technology, and gradually establish hydrogen production, storage, and transportation network (HDRC, 2020). However, the Chinese government has not yet introduced a specific national-level subsidy policy for the green hydrogen industry. The GH industry still has problems such as high hydrogen production and storage costs, low or uncertain investment returns, etc., which seriously affect the enthusiasm of relevant entities to invest in the GH industry. Government plays a significant role in avoiding the failure of hydrogen sustainable deployment and in helping hydrogen to achieve its potential. In the future, Chinese government will promote the progress of hydrogen technology and industrial development, and organize the planning of the hydrogen energy industry and key technical equipment research, and actively facilitate application demonstrations (NEA, 2020a, NEA, 2020b). That raises the question of how far governments should go to promote the development of low-carbon hydrogen in the near term (Meng et al., 2020). Therefore, what kind of green hydrogen subsidy policy should China implement? In order to promote the sustainable development of the GH industry, and avoid overcapacity caused by blind investment and excessive subsidy funding pressure at the same time. In the face of different GH technology levels and industry scale, etc., what kind of GH subsidy methods should the government adopt? At different development stages, how to design the subsidy intensity and standard? How to implement dynamic adjustment of subsidy policies and how to design a fallback mechanism for capital subsidies? These questions are all worth studying.

For the reminder, Section 2 discusses the feasibility of GH production and the problems existing in GH industry, summarizes the previous literature on the various subsidy policies for the development of GH in different countries around the world, and introduces the system dynamics methodology; Section 3 formulates the system dynamics model to study the economic benefits and carbon emission reduction effects of green hydrogen industry under different subsidy policy scenarios, provides the data for the analysis, and evaluates the validation of the system dynamics model; Section 4 designs the subsidy scenarios, provides the analysis and discussion for the stimulated results; and Section 5 presents the conclusion and policy implications.

Section snippets

Literature review

In recent years, some scholars have studied the feasibility of GH production from the perspective of technology and economy, compared the economic and environmental benefits of green hydrogen and gray hydrogen production. And they pointed out some key elements that now constrain current large-scale development of green hydrogen. A case in point, Gokcek and Kale (2018) have calculated the most optimal capacity of wind-PV hybrid power system. After analyzing the levelized cost, they found that a

System dynamics model

To study the economic benefits and carbon emission reduction effects of green hydrogen industry under different policy scenarios, this paper establishes a causal relationship model and a stock flow model to analyze the costs/benefits and development of green hydrogen industry in the future under different government subsidy policies from qualitative and quantitative perspectives, respectively. In this paper, both of the models are established under the Vensim PLE7.3.5 environment.

Results analysis and discussion

Considering learning rate, government subsidy, the green hydrogen price and electricity price, we use the data of 2021 as a baseline to simulate the dynamic evolution of green hydrogen installed capacity, the corresponding required government expenditure and carbon emission reduction benefits in China under different subsidy scenarios over the next 30 years.

Conclusion and policy implications

This paper develops a system dynamics model to simulate the variation trend of installed capacity, ROI, carbon emission reduction benefits and corresponding government subsidy expenditure of Chinese green hydrogen industry over the next 30 years under different subsidy policies. It is achieved by evaluating the impact of the combination policy of single and multiple subsidies on the development of the green hydrogen industry under different scenarios of learning rate and hydrogen pricing

CRediT authorship contribution statement

Li Chengzhe: Conceptualization, Methodology, Writing – original draft, preparation, Writing – review & editingEditing. **Libo Zhang:** Supervision, Conceptualization, Methodology, Project administrationProject management, Writing – review & editing. **Ou Zihan:** Data, Formal analysis, Writing – review & editingEditing. **Ma Jiayu:** Data, Formal analysis, Writing – review & editingEditing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Recommended articles

References (57)

M. Ball *et al.*
The hydrogen economy-Vision or reality?
Int. J. Hydrogen Energy (2015)

Q. Chai *et al.*

Technologies and policies for the transition to a sustainable energy system in China
Energy (2010)

J. Chi *et al.*
Water electrolysis based on renewable energy for hydrogen production
Chin. J. Catal. (2018)

P. Colbertaldo *et al.*
Impact of hydrogen energy storage on California electric power system: towards 100% renewable electricity
Int. J. Hydrogen Energy (2019)

F. Dawood *et al.*
Hydrogen production for energy: an overview
Int. J. Hydrogen Energy (2020)

K.G. Dos Santos *et al.*
Hydrogen production in the electrolysis of water in Brazil, a review
Renew. Sustain. Energy Rev. (2017)

P.M. Falcone *et al.*
Hydrogen economy and sustainable development goals: review and policy insights
Curr.Opin. Green Sustain. Chem (2021)

J.Y. Gao *et al.*
Effects of public funding on the commercial diffusion of on-site hydrogen production technology: a system dynamics perspective
Technol. Forecast. Soc. Change (2022)

M. Gokcek *et al.*
Techno-economical evaluation of a hydrogen refuelling station powered by Wind-PV hybrid power system: a case study for zmir-eme
Int. J. Hydrogen Energy (2018)

S.M. Jarvis *et al.*
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Renew. Sustain. Energy Rev. (2018)

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