Chapter **6**

Financing Solutions for the Economic Feasibility of Hydrogen Projects: Case Study in China

Farhad Taghizadeh-Hesary, Yanfei Li, Ehsan Rasoulinezhad, Aline Mortha, Yan Long, Yu Lan, Zhehao Zhang, Nan Li, Xunwen Zhao, and Yao Wang

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Chapter 6

Financing Solutions for the Economic Feasibility of Hydrogen Projects: Case Study in China

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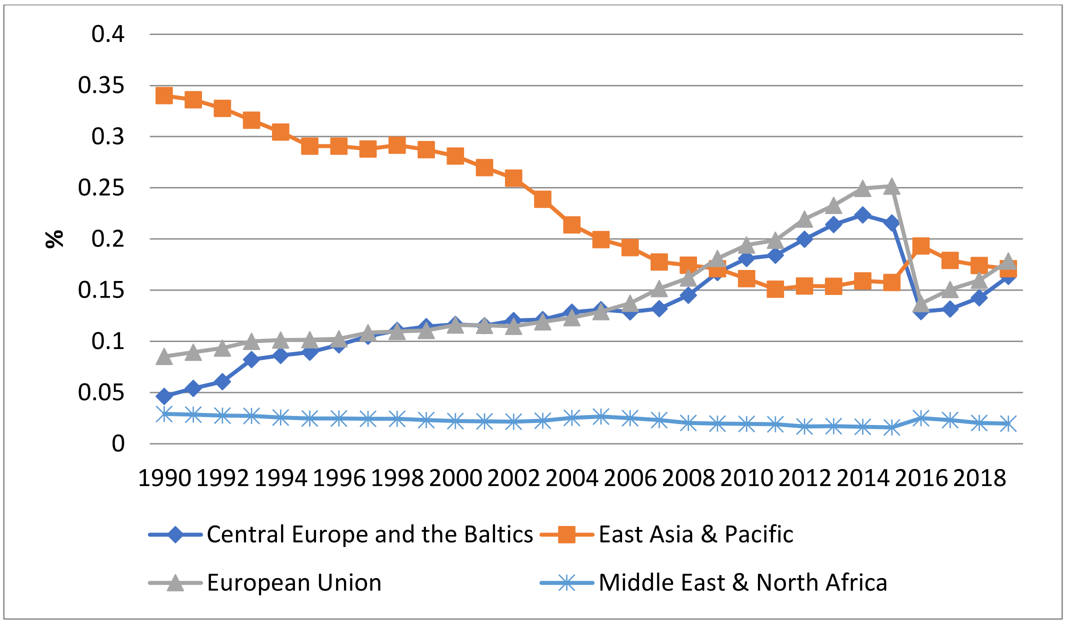
This chapter emphasises the economic and financial feasibility analysis of hydrogen energy projects in China to identify appropriate financing solutions for them. Cost–benefit and sensitivity analysis approaches were carried out for the three hydrogen projects in Guangdong province (two cases) and Jiang Xi province (one case). The profitability analysis revealed that the examined hydrogen projects in China at the real discount rate of 8% are profitable. Moreover, the sensitivity analysis results depicted different reactions of hydrogen projects to the financing cost variables. Besides, hydrogen projects are more sensitive to the discount and income tax rates, amongst other financing costs. The main reasons are the capital-intensive nature of green energy projects and the role of tax in the return on investment of green projects in the long term. Moreover, the results revealed that a lower financing risk could make the net present value (NPV) of a project more profitable, and the NPV becomes positive on a shorter horizon. The optimal weight of bank loans for the studied hydrogen projects in China was calculated at nearly 56%, meaning the weight of green bonds is approximately 44%. In other words, diversifying channels of financing instead of just relying on bank loans is recommended. As a major policy implication, we recommended various de-risking tools, such as the green credit guarantee corporation, to attract private investments in hydrogen projects.

Keywords: Hydrogen project, economic feasibility, sensitivity analysis, de-risking tools

1. Introduction

The oil price crisis beginning in the 1970s is the primary origin of the alarming fossil fuel participation in the global economy (e.g. see Ringel, 2006; Aquila et al., 2016; and Junior et al., 2019). Consequently, this alarming situation became central in the scholars' approach to study appropriate alternatives to fossil fuels that are environment-friendly. The consumption of renewable energy resources has increased over the last decades; however, their movements in different regions are not a stable, increasing slope. Figure 6.1 shows the ratio of renewable energy consumption to fossil fuel energy consumption in various world regions. It shows that this ratio's movement did not increase, particularly after the oil price drop in 2014.

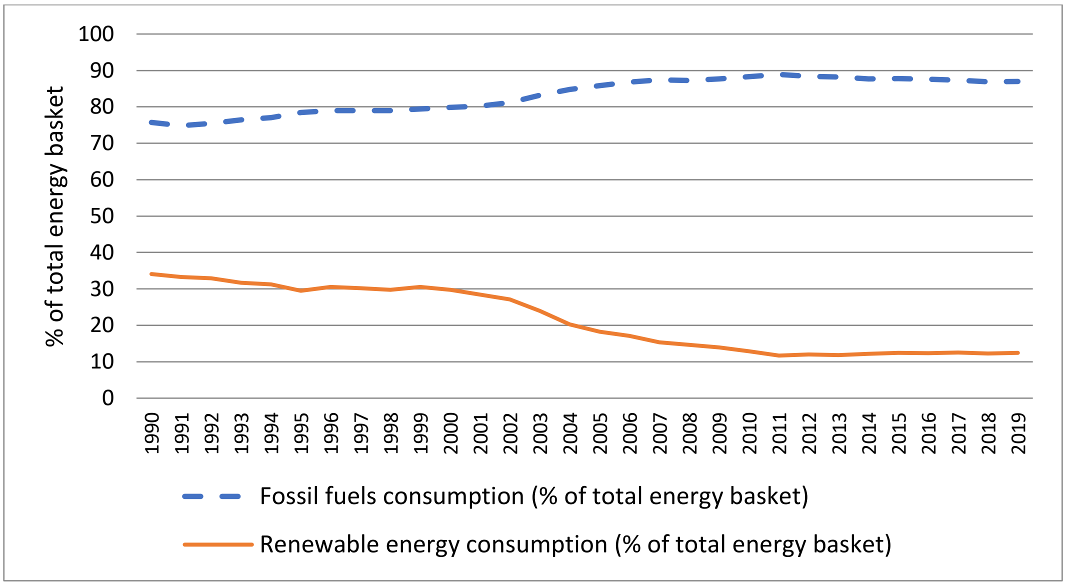
Figure 6.1: Ratio of Renewable Energy Consumption to Fossil Fuel Energy Consumption (%)



Source: Authors' compilation based on World Bank database and BP 2020 report.

The lack of increased movement to renewable energy resources is more highlighted for the major carbon emitters globally due to their contributions to the global threats of climate change and air pollution. China is the biggest carbon emitter globally (Zheng et al. 2019), spreading over 9,825 million tonnes of carbon dioxide (CO_2) in 2019. This is more than the total CO_2 emissions of North America (5,975 million tonnes); Europe (4,110 million tonnes); the Commonwealth of Independent States (2,085 million tonnes); and Africa (1,308 million tonnes) in 2019 (BP, 2020). Therefore, China is the first country that needs more efficient and diversified policies and attention to promote renewable energy resources in its total energy basket. Due to its impressive economic growth, its primary energy consumption has significantly jumped over the last decades. Based on the *Statistical Review of World Energy* (BP, 2020), China's primary energy consumption per capita increased from about 7.6 gigajoules per capita in 1965 to 32.9 gigajoules per capita in 2000. Since then, due to its remarkable domestic production growth, the consumption of energy as a primary production input had risen rapidly and reached approximately 98.8 gigajoules per capita in 2019. This high level of increased energy consumption has made China consume more common and economical fossil fuels than green energy resources. Figure 6.2 shows the rate of fossil fuels and renewable energy consumption in China from 1991 to 2019.

Figure 6.2: Renewable Energy and Fossil Fuels Energy Consumption in China (% of total energy basket)



Source: Authors' compilation based on World Bank database and BP 2020 report.

As represented in Figure 6.2, since 2000, the fossil fuels share in China's total energy basket has been increasing. Vice versa, the share of clean energy in the total energy consumption basket has gradually decreased. Murata et al. (2016) expressed that the country's clean development mechanism would be vital for our globe by reducing air pollution and controlling climate changes.

Recently, China has been ambitious in supporting green projects and developing green energy technologies to improve its energy security, lower its carbon emissions, and boost renewable energy contribution in its local economic sectors. The appropriate renewable energy potential in China can be a reliable factor in this way. Table 6.1 reports China's capacity in selected renewable energy resources.

Table 6.1: Renewable Energy Capacity in China, 2000–2019 (MW)

Renewable Energy Source	2000	2005	2010	2015	2019
Wind capacity	341	1,060	29,633	131,048	210,478
Solar capacity	34	141	1,022	43,549	205,493
Geothermal capacity	22	22	24	26	26

Source: Authors' compilation based on BP 2020 report.

Amongst different green energy sources, hydrogen is a secondary energy source that Chinese scientists and scholars have considered clean and environment-friendly to substitute for fossil fuels. Deyou (1994) declared that, in the mid-1990s, the government approved the hydrogen energy research programme to help boost the share of hydrogen in China's total energy basket. Since then, the government has approved and issued different plans and policies to support the hydrogen projects. Hong and Jin (2021) argued that various policies and plans, such as China's 5-year plans, make the target of green project investment clearer and more accessible. However, according to the arguments of several scholars, such as Yuan and Lin (2010), Pudukudy et al. (2014), and Ren et al. (2020), hydrogen project enhancement in China faces various challenges and obstacles.

Hydrogen projects generally need the participation of private investors who make decisions based on costs and benefits. Voica et al. (2015) expressed that fiscal constraints are the major challenge towards green investments for which increasing motivations for the participation of private investors is a suitable solution. In another study, Engelen et al. (2016) revealed that the main reason behind the low level of private investment in hydrogen projects is their limited return. Tian et al. (2020) mentioned that the financial feasibility environment investment plays a chief role in exploring whether a green project is profitable for private investors to consider in decision-making.

Few academic studies focused on the financial and economic feasibility of hydrogen projects. Examples are those conducted by Shah (2020) for Pakistan, Southall et al. (2016) for the United Kingdom, Derbal-Mokrane et al. (2011) for Algeria, and Wietschel and Hasenauer (2007) for the European Union. Moore (1983) also studied the feasibility of advanced technology for hydrogen production, particularly for the case of China (e.g. see Qiu et al. [2020]; Liu et al. [2020] for underground hydrogen storage; and Lv et al. [2008] for hydrogen production). The authors did not find any studies related to the economic and financial feasibility of ongoing hydrogen projects in China. Therefore, this chapter will fill in this literature gap using project data from the interviews and analysing data through the cost–benefit approach and sensitivity analysis.

Section 2 of this chapter reviews the literature to debate earlier studies and clarify the literature gap. Section 3 discusses the policies and initiatives for the hydrogen economy in China, and Section 4 discusses the research methodology. Section 5 presents the findings, followed by the last section, which concludes and explores major policy implications.

2. Literature Review

2.1. Economic feasibility of hydrogen projects

The economic feasibility of hydrogen production is being debated amongst scholars, as hydrogen is still expensive (IEA, 2019). First, its economic feasibility depends on the technology used for production and the price of primary resources used as inputs. IEA (2019) and Zhang et al. (2020a) highlighted that hydrogen produced from hydrocarbons remains the cheapest option for hydrogen production in industries. This is reflected by the fact that more than 96% of hydrogen supplied globally is produced from fossil fuels (IEA, 2019; Zhang et al., 2020b). Even in recent years, Keipi et al. (2018) highlighted that the thermal decomposition of methane, which represents nearly half of the global hydrogen production, remains more competitive than any other method, including water electrolysis powered by electricity from renewable sources.

Even if fossil fuels remain the favoured option due to low costs, increasing concerns over climate change have prompted several studies to examine the economic feasibility of low-carbon hydrogen production. Hence, some research focused on alternative, low-emissions hydrogen production strategies based on fossil fuels. Through a comprehensive review of the literature on the topic, Muradov (2017) compared different hydrogen production strategies, namely, coupling fossil fuel production with carbon capture and storage (CCS), decomposition of light hydrocarbons, and using renewable and nuclear electricity for powering hydrogen production from fossil fuels. Despite the technological maturity of the CCS, the author highlighted that it remains economically unfeasible without regulatory or economic incentives and due to long-term uncertainties of the CCS's storage capacity. Hydrogen produced from a light hydrocarbon can be a low-carbon option but is technologically not mature enough to represent a viable method (Muradov, 2017).

Similarly, Khojasteh Salkuyeh, Saville, and MacLean (2017) analysed emerging methods for producing hydrogens such as syngas chemical looping (SCL) and chemical looping reforming (CLR) and compared them with steam methane reforming and auto-methane reforming in terms of economic feasibility. The study concluded that, even though the CLR is the most economically profitable method, scaling up and commercialisation remain challenges that impede CLR deployment (Khojasteh Salkuyeh et al., 2017). Most industrial-scale hydrogen plants use the steam methane reforming (SMR) process to convert hydrocarbons to H_2, CO, and CO_2 (Welaya et al., 2012). However, the SMR technology has higher CO_2 emissions than other natural gas–reforming technologies (Wilhelm et al., 2001). Khojasteh Salkuyeh et al. (2017) showed that the SCL with carbon capture is more financially attractive than the autothermal reforming and SMR processes only when the carbon price is above \$47/tonne CO_2. Their financial analysis shows that the minimum hydrogen selling price of the CLR system is 50%–90% of the price for the other technologies. Finally, a carbon price of only \$5/tonne CO_2 is required to make the CLR option (with zero direct carbon emissions) more financially attractive than the SMR.

A second option for low-carbon hydrogen production is water electrolysis, using electricity produced from renewable energy and water. However, some studies tended to dismiss this option due to high costs (Nagashima, 2018). Muradov (2017) confirmed the relative lack of competitiveness of renewable energy as input for hydrogen production since water electrolysis would necessitate a spectacular increase of renewables' share in the energy mix to become a viable option. However, a recent article by Proost (2020) examined the economically viable minimum production scale needed for hydrogen produced from renewable energy sources (RES)) to compete with hydrogen produced from fossil fuels. Using recent data on hydrogen production costs and life-cycle analysis (including capital expenditure), the author finds that parity could be achieved at a small production scale. However, this would require further intensification of the water electrolysis process (Proost, 2020). Using a similar approach, Dinh et al. (2020) posited that offshore wind farms would become profitable soon. Generally speaking, if most research acknowledges that hydrogen production from RES is costly, many studies on wind and solar farms still advocate for the economic feasibility of hydrogen production from RES. For instance, Yan et al. (2017), Fereidooni et al. (2018), Li and Kimura (2018), Kimura and Li (2019), and Nadaleti et al. (2020) found that hydrogen production from renewable surplus is a viable option to solve curtailment issues. Finally, Hou et al. (2017) explored different configurations of offshore wind farms that demonstrated benefits and profitability of some cases provided demand was sufficient.

Nevertheless, even if hydrogen production from water electrolysis is deemed economically feasible, it relies heavily on freshwater as an input. Hence, it might be limited in regions of scarce water (Shi et al., 2020). In particular, the People's Republic of China (PRC) is especially at risk due to its high water scarcity index.

2.2. Hydrogen produced from renewable sources to supply fuel cell vehicles (FCVs)

This study aims to determine the economic feasibility of hydrogen projects. Thus, this subsection discusses recent studies that examined the feasibility of using hydrogen produced from RES to supply the FCVs. The transport sector is often amongst the main emitters of greenhouse gases (GHGs). Using renewable hydrogen to fuel vehicles has offered certain benefits, including a greater degree of energy security, a reduction in pollution level, and a drop in GHG emissions (Southall and Khare, 2016; Li and Taghizadeh-Hesary, 2020a and 2020b). Nevertheless, the development of renewable–produced hydrogen has been relatively slow.

The first obstacle to its development is the 'chicken and egg dilemma' (Southall and Khare, 2016; Campiñez-Romero et al., 2018). Campíñez-Romero et al. (2018) argued that the main reason behind the lack of FCVs is the lack of H2 refuelling network, contributing to low demand for FCVs. Similarly, Reddi et al. (2017) highlighted that the costs of refuelling stations dominate the hydrogen costs for FCVs. The high cost of equipment, relatively small infrastructure, lack of economies of scale, and low level of utilisation of existing stations explain this phenomenon. However, the study also showed that the levelized hydrogen costs can be drastically reduced from improved capacity utilisation and developed economies of scale (Reddi et al., 2017). Generally, to create hydrogen-refuelling stations, a fundable and economically viable infrastructure is necessary, which is not the case because of the low demand. Southall and Khare (2016) addressed the issue arguing that, despite commercial-scale hydrogen production, the distribution network depends on hydrogen vehicles' sales. They proposed the example of collaboration between the United Kingdom's industry and government to end the vicious circle.

The lack of infrastructure for hydrogen-refuelling stations is the high upfront investment needed to build them. Nagashima (2018) argued that the biggest hurdle for hydrogen vehicles is the lack of fuelling infrastructure. Despite heavy subsidies for FCV development in Japan, the tight regulations and technical constraints contribute to increased costs for infrastructure building: a hydrogen station costs two to three times more than in Europe. However, some authors argued that the lack of infrastructure and financial resources used to be an issue at the beginning of fossil fuel commercialisation (Singh et al., 2015). Therefore, such issue can be overcome with government authorities' support and state subsidies (Campiñez-Romero et al., 2018). Indeed, subsidies could be crucial for reducing hydrogen technologies' costs (Nistor et al., 2016) and would help increase the share of hydrogen produced from renewable energy sources (Southall and Khare, 2016). While wind technology can meet all demand for FCVs in the short run, once the FCV fleet is established, RES alone cannot produce enough hydrogen to satisfy demand (Southall and Khare, 2016). Through a case study of a Swiss district, Prasanna and Dorer (2017) shared similar views. While results proved that hydrogen produced for *photovoltaic thermal collectors* is technically viable if combined with short- and long-term storage, their model does not include hydrogen use for mobility. In particular, stored hydrogen is fully used to meet peak demand in winter. Hence, the authors argued that a greater storage capacity would be required for hydrogen to meet both power and transportation demand.

Most studies that assessed the economic feasibility of hydrogen use for FCVs concluded that subsidy schemes and economies of scale of installed electrical equipment and the electrolyser capacity and hydrogen storage equipment could bring down costs (Southall and Khare, 2016). In particular, Nistor et al. (2016) argued that the hydrogen unit cost could be below that of petrol if the expected return on investment period is over 10 years for the proton exchange membrane and electrolysers, and 5 years for alkaline electrolysers. While hydrogen technologies seem to be profitable in the long term, short-term hydrogen production infrastructure, coupled with renewable energy tariffs, is still financially viable under certain configurations (Southall and Kharem, 2016).6

2.3. Policies and initiatives helping renewable energy development in the PRC

In recent years, published literature on the development of renewable energy has grown tremendously. Since the study aims to look at the economic feasibility of hydrogen produced from renewable sources, it is crucial to understand what can help increase renewable energy production. Because of the size of the literature on the topic, we narrowed down this literature review to examine previous studies analysing the PRC's case. As mentioned in the introduction, the PRC has experienced spectacular growth in renewable energy, led by generation from wind and solar photovoltaic. Simultaneously, the country has a high curtailment rate for these two technologies, partly explained by regional disparity (Du and Takeuchi, 2020), which extensive hydrogen storage could solve.

First, the PRC introduced public schemes to encourage the growth of renewable energy. The country has extensive subsidies to support renewable energy development nationally and regionally since the Renewable Energy Law of 2005. These subsidies are of various forms, from research and development incentives for vehicles and solar power since 2009 to tax preference systems and direct subsidies (Shen and Luo, 2015). Evaluating the effect of these subsidies, Shen and Luo (2015) concluded that, while the multiplication of subsidies has undoubtedly contributed to the acceleration of renewable energy

[6] The authors used average wind speeds in the United Kingdom for their calculations. Varying wind speed might affect the results of the study.

development, it also created overcapacity issues, fierce competition, and lack of funds. In 2009, the country introduced a regionally differentiated feed-in-tariff. Du and Takeuchi (2020) evaluated the policy's success in fostering solar and wind power growth. They concluded that the policy had mixed effects for solar power in 2011 and 2013 but had a positive and significant impact on wind for regions with a lower endowment, especially after the tariff gap widened between regions (Du and Takeuchi, 2020). This was not the first study to show that the feed-in-tariff results are highly dependent on tariff and subsidy rates (Böhringer et al., 2013). After controlling tariff size, contract duration, digression rate, electricity price for each country, and production costs, Jenner, Groba, and Indvick (2013) found that feed-in-tariff had little effect on renewable generation. Finally, the PRC has been considering implementing an emission trading scheme (ETS) since 2017. Because the ETS charges more for fossil fuel, this policy could indirectly foster renewable growth through increased demand. Using a Computable General Equilibrium framework, Lin and Jia (2020) explored the ETS's impact on renewable development and different revenue-sharing scenarios. They concluded that the ETS could help renewable development if the revenue generated from the policy is used as a renewable energy subsidy.

A second option to increase the economic feasibility of renewable projects is the use of private green finance. Financial instruments to fight climate change have been steadily rising. In particular, the use of green bonds, a form of fixed-type security solely defined by its aim to finance 'green' projects, has been rising in the PRC. As of 2019, the country is the second issuer of these bonds, both in number and amount (CBI, 2020). Flaherty et al. (2017) proved that green bonds could finance climate change mitigation practices and improve intergenerational welfare in an empirical analysis of overlapping generation models. Similarly, Lee and Zhong (2015) presented a hybrid form of bonds to bridge the investment gap for renewable projects. The bond consists of a portfolio of renewable projects, which can manage risks associated with initial project development while providing enough capital funds to support projects. Finally, Taghizadeh-Hesary and Yoshino (2019) proposed another framework, mixing public and private entities, to reduce risks associated with renewable projects. The Green Credit Guarantee Scheme presented in the study aims to decrease risks and uncertainties of renewable projects through credit guarantee, in turn, financed by tax spillovers generated by the installation of renewable energy (Taghizadeh-Hesary and Yoshino, 2019). The PRC had implemented a credit guarantee for green projects in some selected pilot cities (Li et al., 2018).

3. Policies and initiatives for hydrogen energy in the PRC

Since John Bockris introduced the concept of hydrogen economy in the early 1970s, many scholars and policymakers in different countries have considered using this energy resource instead of fossil fuels. However, hydrogen has not considerably contributed to the total energy basket in the world. As a major energy consumer and the biggest air polluter globally, China has tried to boost hydrogen production to reach a higher level of green energy than fossil fuels. It produced over 12.4 million tonnes of hydrogen in 2007 for ammonia, methanol, and oil refining processes (Deng et al., 2010). The hydrogen produced in China has increased dramatically and generates over 20 million tonnes annually in recent years. Compared with other pioneers in the green economy, in January 2020, the number of hydrogen-refining stations were about 61, 81, and 116 in China, Germany, and Japan, respectively (Yue and Wang, 2020).

China is motivated to use appropriate production technologies to increase its hydrogen production capacity (Gao et al., 2020). Because the currently produced hydrogen in China is from coal via 1,000 gasifiers (about 5% of China's total coal consumption [De Blasio and Pflugmann, 2020]), the country needs to ensure green hydrogen.

Notably, China has invited pioneer foreign companies to produce green hydrogen. For example, Siemens Energy Company, with Beijing Green Hydrogen Technology Development Co. Ltd., will provide the first-megawatt green hydrogen production project in the Yanquing District of Beijing (Larson, 2020).

Without government support, cooperation with foreign companies and hydrogen energy production's capacity could not expand. In the 1990s, China's major approach to renewable energy development was ensuring agricultural fuels (Liu, 2019). Since the early 2000s, the regulations related to green energy resources had been gradually improved to help electricity production (Huang and Huang, 2017). Due to China's severe air pollution, the government passed the Renewable Energy Law (REL) in 2005, reflecting the country's acceptance of renewable energy development. However, due to a few barriers, such as the rapid growth of fossil fuel capacity, lack of connection between renewable generation capacity with the electricity grid, and low efficiency of renewable electricity plants in China, REL could not lead China to an optimal level of the green economy (Wang et al., 2010). In 2016, the 13th Five-Year National Development Plan of China included enhancing on-board hydrogen storage systems and constructing hydrogen refuelling stations (Gosens et al., 2017). In the same year, the government issued a road map on the hydrogen fuel industry, which estimated that total hydrogen fuelling stations would be 100 and 1,000 units in 2020 and 2030, respectively (Yuanyuan, 2020).

In February 2018, a government-supported alliance, the China Hydrogen Alliance, was launched to improve the hydrogen sector. In March 2019, to upgrade the green regulations, China added policies to construct renewable hydrogen facilities for new energy vehicles, motivating the car industry to produce vehicles fuelled by renewable hydrogen (De Blasio and Pflugmann, 2020). In 2020, for the first time, hydrogen was listed as an energy source in the PRC's Energy Law as an essential solution to decarbonising transportation in the country. Bruno Forget, Air Liquide's head of hydrogen in China, mentioned that the government's energy strategy for 2020 provides different policies to support China's hydrogen energy sector (S&P Global Platts, 2020). This government support is also motivated by the 2022 Winter Olympics, making China develop green energy consumption, especially for transportation purposes. Zhang et al. (2020a) proved that a fuel cell transit bus with renewable hydrogen is economically feasible for China, highlighting this motivation.

Through existing government support for the hydrogen economy, the investment flow in this sector increased considerably from approximately US$11 billion in the first 6 months of 2018 to about US$14 billion in the same period of 2019, emphasising China's efforts to increase the contribution of hydrogen in its total energy consumption.

4. Theoretical Approach and Sample Data Description

There are various methods for evaluating and calculating the economic and financial feasibility of investment projects. However, in energy-related projects, many scholars, such as Ertürk (2012), Li et al. (2013), Holdermann et al. (2014), and Arnold and Yildiz (2015), suggested that the net present value (NPV) method is the key indicator of economic and financial feasibility. Its features make it possible to consider the risks and calculate the value created by investing in an energy project. So, when the NPV of an energy project is more than zero, it means that the project creates value. Thus, the energy project is economically justifiable. Through a comparative analysis, Taylor (1988) found out that the NPV leads to a better result than other criteria, such as NPV/K. Yang et al. (2012) declared that the NPV's acceptance happens when its measure is greater than zero; otherwise, the project should be rejected. The NPV criterion can be expressed by Eq. 1 as follows:

$$NPV = -I + \sum_{j=1}^{n} \frac{CF_j}{(1+k)^{j'}} \qquad (1)$$

CF_j denotes the cash flow in period j, while k represents the minimum attractiveness rate (the minimum return that the investor wants to obtain in the energy project investment). I stands for investment. In the NPV equation, cash flow (CF) shows money value in the energy project, whereas a discount rate is employed to explore the value at present. Therefore, the flow volume is determined by the project developer's view, including both client and investor.

Furthermore, we determined the internal rate of return (IRR) to check the profitability of the hydrogen project investment. The related equation is as follows:

$$0 = \sum_{t-1}^{n} (C_t - C_0)(1 + IRR)^{-t} \qquad (2)$$

In Eq. 2, $C_t - C_0$ depicts net cash flow at t_{th} year.

To explore results in more detail, we employed a sensitivity analysis method to prioritise the major parameters that significantly impact the target cost. In this study, we used the gradient sensitivity analysis through the Expert Choice 11 software to prioritise the financing cost impacts on the NPV of the examined hydrogen projects in China.

This research was undertaken in three hydrogen projects located in China's southern provinces Guangdong and Jianxi. The first one has a hydrogen production purpose and located in the Jiangxi province of China. Its electrolyser capacity is about 30 MW and produces 12 tonnes of hydrogen (gas) per day. Moreover, 12 liquid hydrogen refuelling stations have a specification of 1,000 kg/d.

The second sample is a liquefaction plant of liquefied hydrogen located in Taihe county in Jiangxi province. It includes transporting liquid hydrogen via tube trailers from Jiangxi to Foshan city in Guangdong province for 500 kilometres.

The third project is a hydrogen refuelling station in Foshan city of Guangdong province, tasked to fill buses with hydrogen fuel. It costs over US$16 million,[7] including various expenditures such as equipment (US$714,000); land and construction cost (US$57,400); capital (US$5,886,000); total debt amount (US$2,522,800); a loan interest rate of 5%; and revenue volume of US$1,126,200.

We gathered all the required data to calculate the hydrogen projects' economic and financial feasibility by interviewing the experts working on those projects. The average cost of equipment for the three hydrogen projects in China is nearly US$65,000, while the estimated operation and maintenance cost is US$2 million. The estimated land and construction cost is US$50,000, and financing cost of US$10 million.

Table 6.2 reports the financing costs indicators.

Table 6.2: Financing Costs of Hydrogen Projects (%)

Parameter of Costs	Value
Discount rate	8%
Equity/Debt ratio	30%/70%
Loan interest	5%
Operation period (project life)	20 years
Repayment period	10 years
Income tax rate	20%

Source: Authors' compilation from interviews with the project managers.

The discount rate of green energy projects, such as hydrogen one, is almost between 6%–10%; in our sample, the average is 8%. Moreover, loan interest and income tax rates are 5% and 20%, respectively. The repayment period is 10 years, and the operation period 20 years. The loan interest of these three projects averages 5%. In contrast, the equity/debt ratio is 30%/70%, meaning that about 70% of the initial capital investment in China's hydrogen projects is from bank loans.

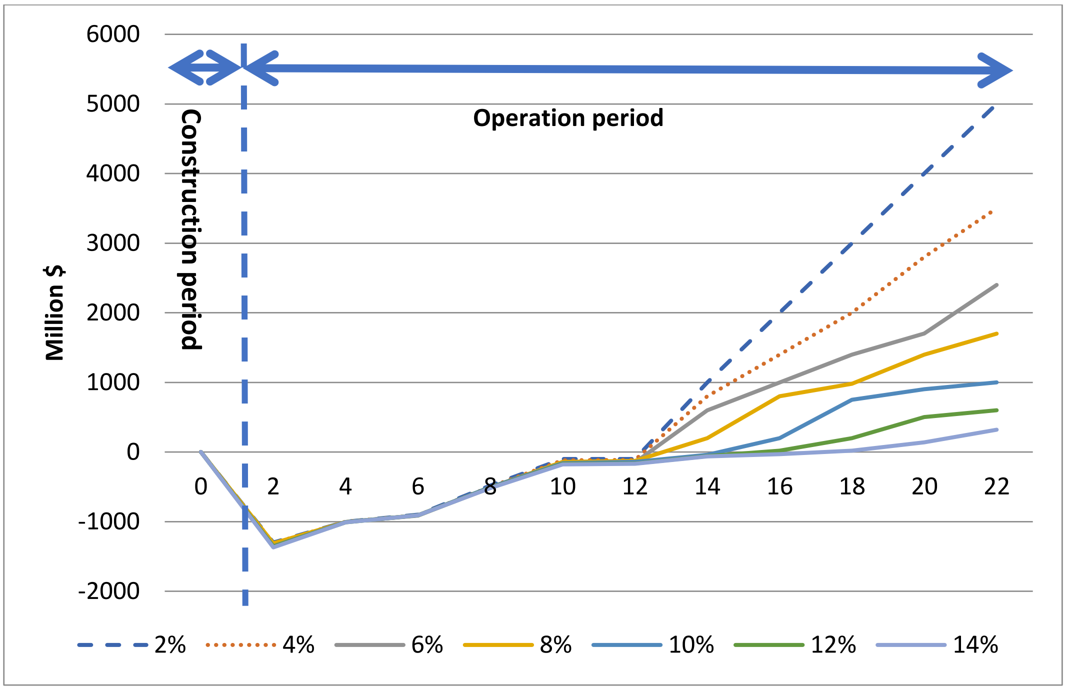
[7] US$1.00 = CNY6.48.

5. Empirical Results

5.1. Analysis of profitability

To analyse the hydrogen project's economic feasibility, we used NPV and IRR to explore profitability. Figure 6.3 shows the NPV findings of China's hydrogen projects with different discount rates. The NPV curves in different discount rates (2%–14%) have two breakpoints: (i) at 2% at the end of the construction period of large-scale liquefaction project (the construction period for CCHP (combined cooling heating and power systems) wind project is 2 months and for the bus project, it depends on buying buses and running the project; and (ii) at 12% (at the middle of the project life) when the equipment needs major repair or replacing. Vogel (2014) and Okoro et al. (2019) named it as a depreciation line that happens over 10 years over the operation period.

Figure 6.3: NPV of Hydrogen Project in China with Different Discount Rates



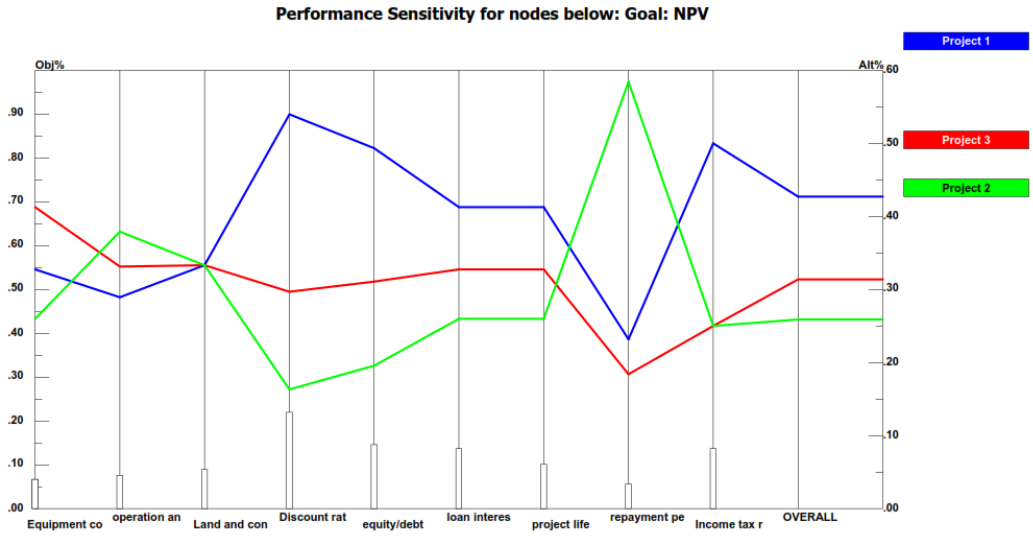
Source: Authors' calculation.

The average IRR for the three hydrogen projects is calculated at 15.38%, which is more than the real discount rate (8%) of a hydrogen project in China. A project is economically feasible if its IRR exceeds the real discount rate (Liu et al., 2020). Thus, we can conclude that China's hydrogen projects are economically feasible based on the profitability analysis.

5.2. Sensitivity analysis

We carried out a sensitivity analysis to explore the effects on the NPV of hydrogen projects due to different costs. To this end, we conducted a gradient sensitivity analysis via the Expert Choice software.

Figure 6.4: The Sensitivity of Costs of Hydrogen Projects



Source: Authors' calculation from Expert Choice 11.

Figure 6.4 illustrates the sensitivity analysis results and reveals that the NPV of hydrogen projects in China is more sensitive to financing costs, such as discount rate, income tax rate, and loan interests. The main reason for the high sensitivity of these projects to the discount rate is due to the capital-intensive nature of green energy projects, as expressed by earlier studies (Walker, 1996; Shakya et al., 2005). Regarding the income tax rate, following Assidi et al. (2016), tax policy is a significant factor in increasing/decreasing investment returns and attracting/not attracting investments. Moreover, the sensitivity of each project to the cost variables is not similar. For instance, as shown in Figure 4, Project 1 is more sensitive to financing costs than the second and third hydrogen projects in China. Project 1, which is in Jiangxi province, produces hydrogen, its electrolyser's capacity is about 30 MW, and produces 12 tonnes of hydrogen (gas) per day.

6. Financing Risk of Hydrogen Projects

The empirical findings, represented in Section 5, emphasise the role of financing solutions to lower the project's financial risk. If we use scenario analysis to find the expected NPV of a hydrogen project based on different financing schemes, we can define the share of bank loans and green bonds (Table 6.3).

Table 6.3: Input–Output Table for the NPVs Based on Different Funding Scenarios, %

NPV	Share of Bank Loans	Share of Green Bonds
NPV0	100	0
NPV1	90	10
NPV2	80	20
NPV3	70	30
NPV4	50	50

Source: Authors' compilation.

If the equation for calculation of NPV is considered as Eq. (4):

$$NPV = \sum_{t=1}^{n} \frac{(C_1 - C_0)}{(1+i)^t} \qquad (4)$$

The financing risk (σ^2) can be included in Eq. (4) as follows:

$$E(NPV) = \sum_{t=1}^{n} \frac{(C_1 - C_0)}{(1+i)^t + \sigma^2} \qquad (5)$$

Calculating the E(NPV), considering the financing risks at different interest rates, represents a new version of Figure 6.3. We gathered data from the Green Bond Bloomberg terminal database, which includes data of 339 green bonds issuers in China with different Moody's risk ratios. Examples of these issuers are the Sihui Rural Commercial Bank, Bank of Guizhou, Industrial Bank Co Ltd, Fudian Bank, China Everbright Water, China Three Gorges Corporation, Huishang Bank, and Kaifeng Development Investment. We addressed different long-term ratings in nine groups (Table 6.4).

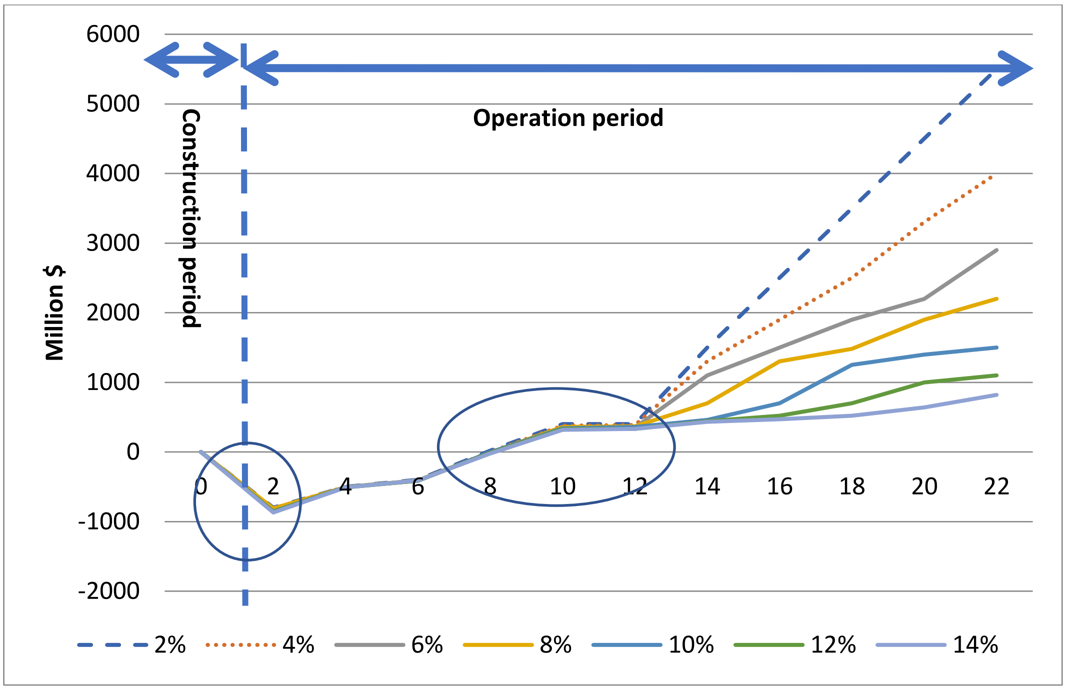
Table 6.4: Classification of Different Long-Run Investment Rating by Moody's

Rank	Rating	Description
1	Aaa	The highest quality and lowest credit risk
2	Aa1, Aa2, Aa3	High quality and very low credit risk
3	A1, A2, A3	Upper-medium quality and low credit risk
4	Baa1, Baa2, Baa3	Medium quality and moderate credit risk
5	Ba1, Ba2, Ba3	Significant credit risk
6	B1, B2, B3	Speculative and high credit risk
7	Caa1, Caa2, Caa3	Poor quality and very high credit risk
8	Ca	Highly speculative
9	C	The lowest quality and low ability to recover interest or principal

Source: Authors' compilation from Moody's (www.moodys.com).

Amongst 339 green bond issuers in China, the highest risk is for the Panda Green Energy Group, with a rating of Caa2. There are 28 issuers with a rating of A1 (the lowest risk amongst other issues in China). We classified nine various ratings into three ones as upper-middle quality (As with number 1), middle quality (Bs with number 2), and poor quality (Cs with number 3). We calculated the average ratio of the 339 Chinese issuers with 0.8 (meaning, the average green issuers in China have upper-middle quality and ability to recover principal and interest) and then used Equation (5). Figure 6.5 shows the E(NPV) at different discount rates.

Figure 6.5: E(NPV) of Hydrogen Projects in China with Different Discount Rates



Source: Authors' calculation.

Compared with Figure 6.3, a lower financing risk can make the NPV of the project more profitable, and the NPV became positive earlier. Green bond issuers in China should have a good risk ratio to reduce the financing risks of green projects.

Investors always try to optimise the financing portfolio. For a hydrogen project, the utility of the investors (U) can be written as Eq. (6):

$$U = r - \beta\sigma^2 \qquad (6)$$

Where r denotes IRR of the project depending on different financing schemes, whereas σ^2 shows the project's financing risk depending on different financing schemes. Defining r_L and r_B as IRR in case of 100% bank loan financing and 100% financing by green bonds, respectively, we can write Equations 7–9 as:

$$r = \alpha r_L + (1-\alpha).r_B \quad (7)$$

$$\sigma^2 = \alpha^2.\sigma_L^2 + (1-\alpha)^2.\sigma_B^2 + 2\alpha.(1-\alpha).\sigma_{L.B} \quad (8)$$

$$U = \alpha r_L + (1-\alpha).r_B - \beta\{\alpha^2.\sigma_L^2 + (1-\alpha)^2.\sigma_B^2 + 2\alpha.(1-\alpha).\sigma_{L.B}\} \quad (9)$$

Solving the agent's utility maximisation problem, we applied the first-order condition to α (share of financing from bank loans). Then, we derived the optimal weight as Eq. (10):

$$\frac{\delta U}{\delta \alpha} = r_L - r_B - 2\beta.\alpha.\sigma_L^2 - 2\beta.(1-\alpha).\sigma_B^2 + \beta(2-4\alpha).\sigma_{L.B} = 0 \quad (10)$$

Consequently, the optimal weight of bank loans can be calculated as Eq. (11):

$$\alpha^* = \frac{\frac{1}{\beta}(r_L - r_B) + 2\sigma_{L.B} - 2\sigma_B^2}{2\sigma_L^2 - 2\sigma_B^2 + 4\sigma_{L.B}} \quad (11)$$

The optimal weight of bank loans for the studied hydrogen projects in China, based on the data gathered from the projects and financing risks of 0.8 (as mentioned before), is nearly 56%. This means the weight of green bonds is approximately 44% (1–0.56). In other words, the share of green projects financing by bank loan should be more than green bonds. However, instead of relying on bank loans, the financing channels' diversification can reduce the financing risk and increase the expected NPC. The role of green bond financing is so important in these projects (as also argued by Zhang et al., 2020b). In line with Cao et al. (2021), China tries to improve green investments based on the Green Bond Issuance Guideline, which loosened barriers to green energy investments. Based on the optimal weight of bank loans, an appropriate mix of bank loans and green bonds is highly recommended to lower the financing risk of China's hydrogen projects. Not only can reducing risks associated with hydrogen projects spark further interest from investors, but it can also help reduce costs in the long term. Furthermore, establishing a green credit guarantee corporation (GCGC) as a new de-risking tool can be used to reduce the risk of green bonds in hydrogen projects. Taghizadeh-Hesary and Yoshino (2020) proved that a GCGC could lower the investment risk in green projects through credit enhancement and create a balance in private borrowers' and financial institutions' creditworthiness.

7. Concluding Remarks

Given the need for countries worldwide to develop green projects to reduce environmental pollution and combat the threat of climate change, exploring the worthiness of green projects needs to be answered. Amongst the countries, China has focused on developing and implementing renewable energy projects, primarily hydrogen, due to the country's high consumption of fossil fuels and being the largest carbon dioxide emitter. This paper studied the profitability and sensitivity analysis of the three ongoing hydrogen projects in Jiang Xi and two projects in Guangdong, China. The major concluding remarks based on the empirical findings are as follows:

1) Using data on capital expenditure and operating costs of hydrogen projects in areas with high hydrogen demand, decreasing the financing risks of hydrogen projects is needed.
2) The examined hydrogen projects in China, at a real discount rate of 8%, are profitable.
3) The sensitivity analysis revealed different reactions of hydrogen projects to financing cost variables. Therefore, each project needs different and adopted policies to lower financing risks and increase return on investment.
4) Various de-risking tools to absorb investment in hydrogen projects can be used. One of the latest is establishing the GCGC, which can lead to credit enhancement in green projects.
5) Hydrogen projects are more sensitive to discount and income tax rates amongst other financing costs. The main reasons are the capital-intensive nature of green energy projects and the role of taxes in the return on investment of green projects in the long term.
6) A lower financing risk can make the NPV of a project more profitable, and the NPV becomes positive on a shorter horizon. That most green bond issuers in China have a good risk ratio reduces the financing risks of these kinds of projects.
7) The optimal weight of bank loans for hydrogen projects in China was calculated at nearly 56%, meaning the weight of green bonds is approximately 44% (1–0.56). In other words, the share of green projects financing by bank loan should be more than green bonds. However, the role of green bond financing is so important in these projects.

As for recommendations for future studies, we can highlight the role of the study on challenges in developing clean technology, the infrastructure of hydrogen vehicles, and cooperation in green projects amongst emerging markets. Applying advanced techniques, such as the Artificial Neural Networks for a larger sample, is highly recommended to determine the impacts of various costs of hydrogen projects.

References

Aquila, G., L.C.S. Rocha, P.R. Junior, E.O. Pamplona, A.R. Queiroz, and A.P. Paiva (2016), 'Wind Power Generation: An Impact Analysis of Incentive Strategies for Cleaner Energy Provision in Brazil', *Journal of Clean Production*, 137, pp.1100–08.

Arnold, U. and Ö. Yildiz (2015), 'Economic Risk Analysis of Decentralized Renewable Energy Infrastructures and a Monte Carlo Simulation Approach, *Renewable Energy*, 77, pp.227–39.

Assidi, S., Kh. Aliani, and M. Omri (2016), 'Tax Optimization and the Firms' Value: Evidence from the Tunisian Context', *Borsa Istanbul Review*, 16(3), pp.177–84.

Böhringer, C., A. Keller, E. van Der Werf (2013), 'Are Green Hopes Too Rosy? Employment and Welfare Impacts of Renewable Energy Promotion', *Energy Economics*, 36, pp.277–85, http://search.proquest.com/docview/1429917551/.

BP (2020), 'Statistical Review of World Energy', https://nangs.org/analytics/bp-statistical-review-of-world-energy (accessed 1 February 2020)

Campíñez-Romero, S., A. Colmenar-Santos, C. Pérez-Molina, and F. Mur-Pérez (2018), 'A Hydrogen Refuelling Station's Infrastructure Deployment for Cities Supported on Fuel Cell Taxi Roll-out,' *Energy*, 148, pp.1018–31, https://doi.org/10.1016/j.energy.2018.02.009.

Cao, X., Ch. Jin, and W. Ma (2021), 'Motivation of Chinese Commercial Banks to Issue Green Bonds: Financing Costs or Regulatory Arbitrage?', *China Economic Review*, 66, https://doi.org/10.1016/j.chieco.2020.101582.

Climate Bonds Initiative (CBI) (2020), 'Green Bonds: The State of the Market 2019', https://www.climatebonds.net/resources/reports/green-bonds-global-state-market-2019 (accessed 2 February 2021).

De Blasio, N. and F. Pflugmann (2020), 'Is China's Hydrogen Economy Coming? A Game-Changing Opportunity', Cambridge, MA: Belfer Center Report, https://www.belfercenter.org/sites/default/files/files/publication/Is%20China%27s%20Hydrogen%20Economy%20Coming%207.28.20.pdf (accessed 4 January 2021).

Deng, X., H. Wang, H. Huang, and M. Ouyang (2010), 'Hydrogen Flow Chart in China', *International Journal of Hydrogen Energy*, 35(13), pp.6475–81, https://doi.org/10.1016/j.ijhydene.2010.03.051.

Derbal-Mokrane, H., A. Benzaoui, A. M'Raoui, and M. Belhamel (2011), 'Feasibility Study for Hydrogen Production Using Hybrid Solar Power in Algeria', *International Journal of Hydrogen Energy,* 36(6), pp.4198–207, https://doi.org/10.1016/j.ijhydene.2010.06.078.

Deyou, B. (1994), 'Recent R&D Program of Hydrogen Energy in China', *International Journal of Hydrogen Energy,* 19(9), pp.777–9.

Dinh, V., P. Leahy, E. Mckeogh, J. Murphy, and V. Cummins (2020), 'Development of a Viability Assessment Model for Hydrogen Production from Dedicated Offshore Wind Farms', *International Journal of Hydrogen Energy,* https://doi.org/10.1016/j.ijhydene.2020.04.232.

Du, Y. and K. Takeuchi (2020), 'Does a Small Difference Make a Difference? Impact of Feed-In Tariff on Renewable Power Generation in China', *Energy Economics,* 87, https://doi.org/10.1016/j.eneco.2020.104710.

Ertürk, M. (2012), 'The Evaluation of Feed-In Tariff Regulation of Turkey for Onshore Wind Energy based on the Economic Analysis,' *Energy Policy*, 45, pp.359–67.

Engelen, P., C. Kool, and Y. Li (2016), 'A Barrier Options Approach to Modeling Project Failure: The Case of Hydrogen Fuel Infrastructure', *Resource and Energy Economics*, 43, pp.33–56, https://doi.org/10.1016/j.reseneeco.2015.10.001.

Fereidooni, M., A. Mostafaeipour, V. Kalantar, and H. Goudarzi (2018), 'A Comprehensive Evaluation of Hydrogen Production from Photovoltaic Power Station', *Renewable and Sustainable Energy Reviews,* 82(P1), pp.415–23, https://doi.org/10.1016/j.rser.2017.09.060.

Flaherty, M., A. Gevorkyan, S. Radpour, and W. Semmler (2017), 'Financing Climate Policies through Climate Bonds – A Three Stage Model and Empirics', *Research in International Business and Finance,* 42, pp.468–79, https://doi.org/10.1016/j.ribaf.2016.06.001.

Gao, G., Y. Tian, X. Gong, Zh. Pan, K. Yang, and B. Zong (2020), 'Advances in the Production Technology of Hydrogen Peroxide', *Chinese Journal of Catalysis*, 41(7), pp.1039–47.

Gosens, J., T. Kaberger, and Y. Wang (2017), 'China's Next Renewable Energy Revolution: Goals and Mechanisms in the 13th Five Year Plan for Energy', *Energy Science and Engineering*, 5(3), https://doi.org/10.1002/ese3.161.

Holdermann, C., J. Kissel, and J. Beigel (2014), 'Distributed Photovoltaic Generation in Brazil: An Economic Viability Analysis of Small-Scale Photovoltaic Systems in the Residential and Commercial Sectors', *Energy Policy*, 67, pp.612–17.

Hong, Ch., and X. Jin (2021), ' Green Change in the Core Build-Up Areas of China: Information from MODIS Data', *Ecological Indicators*, 122, https://doi.org/10.1016/j.ecolind.2020.107270.

Hou, P., W. Hu, C. Chen, and Z. Chen (2017), ' Overall Optimization for Offshore Wind Farm Electrical System', *Wind Energy*, 20(60), pp.1017–32.

Huang, H. and H. Huang (2017), 'China's Policies and Plans for Clean Energy Production', *Energy Sources, Part B: Economics, Planning and Policy*, 12(12), 1046–53, https://doi.org/10.1080/15567249.2017.1349214.

International Energy Agency (IEA) (2019), *The Future of Hydrogen*. Paris: IEA. https://www.iea.org/reports/the-future-of-hydrogen (accessed 1 January 2021).

Jenner, S., F. Groba, and J. Indvik (2013), 'Assessing the Strength and Effectiveness of Renewable Electricity Feed-In Tariffs in European Union Countries', *Energy Policy,* 52(C), pp.385–401, https://doi.org/10.1016/j.enpol.2012.09.046.

Junior, P., E. FIschetti, V. Araujo, R. Peruchi, G. Aquila, L. Rocha, and L. Lacerda (2019), 'Wind Power Economic Feasibility under Uncertainty and the Application of ANN in Sensitivity Analysis', *Energies*,12, doi: 10.3390/en12122281.

Keipi, T., H. Tolvanen, and J. Konttinen (2018), ‘Economic Analysis of Hydrogen Production by Methane Thermal Decomposition: Comparison to Competing Technologies’, *Energy Conversion and Management,* 159, pp.264–73, https://doi.org/10.1016/j.enconman.2017.12.063.

Khojasteh Salkuyeh, S., B. Saville, and H. MacLean (2017), ‘Techno-economic Analysis and Life Cycle Assessment of Hydrogen Production from Natural Gas Using Current and Emerging Technologies’, *International Journal of Hydrogen Energy,* 42(30), pp.18894–909, https://doi.org/10.1016/j.ijhydene.2017.05.219.

Larson, A. (2020), ‘China Will Get Green Hydrogen from Siemens-Sourced System Powermag’, https://www.powermag.com/china-will-get-green-hydrogen-from-siemens-sourced-system/ (accessed 4 January 2021).

Lee, C.W. and J. Zhong (2015), ‘Financing and Risk Management of Renewable Energy Projects with a Hybrid Bond’, *Renewable Energy,* 75 (C), pp.779–87, https://doi.org/10.1016/j.renene.2014.10.052.

Li, C.-B., G.-S. Lu, and S. Wu (2013), ‘The Investment Risk Analysis of Wind Power Project in China’, *Renewable Energy*, 50, pp.481–87.

Li, H., J. Wang, X. Yang, Y. Wang, and T. Wu (2018), ‘A Holistic Overview of the Progress of China’s Low-Carbon City Pilots’, *Sustainable Cities and Society,* 42, 289–300, https://doi.org/10.1016/j.scs.2018.07.019.

Li, Y. and Sh. Kimura (2018), ‘Economic Competitiveness and Environmental Implications of Hydrogen Energy and Fuel Cell Electric Vehicles in ASEAN Countries: The Current and Future Scenarios’, *Energy Policy*, 148 (Part B), January 2021, p.111980.

Li, Y. and F. Taghizadeh-Hesary (2020a), ‘Energy Storage for Renewable Energy Integration in ASEAN and East Asian Countries: Prospects of Hydrogen as an Energy Carrier vs. Other Alternatives’, *ERIA Research Project Report* 2020 No. 09, September 2020, Jakarta: ERIA.

Li, Y. and F. Taghizadeh-Hesary (2020b), ‘Electricity Prices and the Economic Feasibility of Using Hydrogen Energy for Road Transport in the People’s Republic of China’, *ADBI Working Paper Series* No. 1185*,* Tokyo: Asian Development Bank Institute.

Lin, B. and Z. Jia (2020), ‘Is Emission Trading Scheme an Opportunity for Renewable Energy in China? A Perspective of ETS Revenue Redistributions’, *Applied Energy,* 263, https://doi.org/10.1016/j.apenergy.2020.114605.

Liu, B., Sh. Liu, Sh. Guo, and Sh. Zhang (2020), ‘Economic Study of a Large-Scale Renewable Hydrogen Application Utilizing Surplus Renewable Energy and Natural Gas Pipeline Transportation in China’, *International Journal of Hydrogen Energy*, 45(13), pp.1385–98, https://doi.org/10.1016/j.ijhydene.2019.11.056.

Liu, J. (2019), ‘China’s Renewable Energy Law and Policy: A Critical Review’, *Renewable and Sustainable Energy Reviews*, 99, pp.212–19.

Lv. P., Ch. Wu, L. Ma, and Z. Yuan (2008), ‘A Study on the Economic Efficiency of Hydrogen Production from Biomass Residues in China’, *Renewable Energy,* 33(8), pp.1874–79, https://doi.org/10.1016/j.renene.2007.11.002.

Moore, R. (1983), ‘Economic Feasibility of Advanced Technology for Hydrogen Production from Fossil Fuels’, *International Journal of Hydrogen Energy,* 8(11–12), pp.905–11, https://doi.org/10.1016/0360-3199(83)90114-3.

Muradov, N. (2017), 'Low to Near-Zero CO_2 Production of Hydrogen from Fossil Fuels: Status and Perspectives', *International Journal of Hydrogen Energy,* 42(20), pp.14058–88. https://doi.org/10.1016/j.ijhydene.2017.04.101.

Murata, A., J. Liang, R. Eto, K. Tokimatsu, K. Okajima, and Y. Uchiyama (2016), 'Environmental Co-benefits of the Promotion of Renewable Power Generation in China and India through Clean Development Mechanisms', *Renewable Energy*, 87 (Part 1), pp.120–9, https://doi.org/10.1016/j.renene.2015.09.046.

Nadaleti, W., G. Borges Dos Santos, and V. Lourenço (2020), 'The Potential and Economic Viability of Hydrogen Production from the Use of Hydroelectric and Wind Farms Surplus Energy in Brazil: A National and Pioneering Analysis', *International Journal of Hydrogen Energy,* 45(3), pp.1373–84, https://doi.org/10.1016/j.ijhydene.2019.08.199.

Nagashima, M. (2018), 'Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications', *Études de l'Ifri*, Ifri, October 2018.

Nistor, S., D. Saraansh, F. Zhong, and M. Sooriyabandara (2016), 'Technical and Economic Analysis of Hydrogen Refuelling', *Applied Energy,* 167, pp.211–20, http://dx.doi.org/10.1016/j.apenergy.2015.10.094.

Okoro, O., Z. Sun, and J. Birth (2019), '10 - Thermal Depolymerization of Biogas Digestate as a Viable Digestate Processing and Resource Recovery Strategy', in *Advances in Eco-Fuels for a Sustainable Environment*, *Woodhead Publishing Series in Energy,* https://doi.org/10.1016/B978-0-08-102728-8.00010-3.

Prasanna, A. and V. Dorer (2017), 'Feasibility of Renewable Hydrogen-Based Energy Supply for a District', *Energy Procedia,* 122, pp.373–78, https://dx.doi.org/10.1016/j.egypro.2017.07.420.

Proost, J. (2020), 'Critical Assessment of the Production Scale Required for Fossil Parity of Green Electrolytic Hydrogen', *International Journal of Hydrogen Energy,* 45(35), pp.17067–75, https://doi.org/10.1016/j.ijhydene.2020.04.259.

Pudukudy, M., Z. Yaakob, M. Mohammad, B. Narayanan, and K. Sopian (2014), 'Renewable Hydrogen Economy in Asia – Opportunities and Challenges: An Overview', *Renewable and Sustainable Energy Reviews*, 30, pp.743–57.

Qiu, Y., S. Zhou, J. Wang, J. Chou, Y. Fang, G. Pan, and W. Gu (2020), 'Feasibility Analysis of Utilising Underground Hydrogen Storage Facilities in Integrated Energy System: Case Studies in China', *Applied Energy,* p.269, https://doi.org/10.1016/j.apenergy.2020.115140.

Reddi, E., A. Elgowainy, N. Rustagi, and E. Gupta (2017), 'Impact of Hydrogen Refuelling Configurations and Market Parameters on the Refuelling Cost of Hydrogen', *International Journal of Hydrogen Energy,* 42(34), pp.21855–65, https://doi.org/10.1016/j.ijhydene.2017.05.122.

Ren, X., L. Dong, D. Xu, and B. Hu (2020), 'Challenges towards Hydrogen Economy in China', *International Journal of Hydrogen Energy,* 45(59), pp.34326–45, https://doi.org/10.1016/j.ijhydene.2020.01.163.

Ringel, M. (2006), 'Fostering the Use of Renewable Energies in the European Union: The Race between Feed-in Tariffs and Green Certificates', *Renewable Energy*, 31, pp.1–17.

S&P Global Platts (2020), 'New Policies Will Support Use of Hydrogen as Energy Fuel in China', https://www.spglobal.com/platts/en/market-insights/latest-news/electric-power/072720-interview-new-policies-will-support-use-of-hydrogen-as-energy-fuel-in-china-air-liquides-h2-director (accessed 4 January 2021).

Shah, S. (2020), 'Feasibility Study of Renewable Energy Sources for Developing the Hydrogen Economy in Pakistan', *International Journal of Hydrogen Energy,* 45(32), pp.15841–5.

Shakya, B.D., L. Aye, and P. Musgrave (2005), 'Technical Feasibility and Financial Analysis of Hybrid Wind–Photovoltaic System with Hydrogen Storage for Cooma', *International Journal of Hydrogen Energy,* 30, pp.9–20.

Shen, J. and C. Luo (2015), 'Overall Review of Renewable Energy Subsidy Policies in China – Contradictions of Intentions and Effects', *Renewable & Sustainable Energy Reviews,* 41, pp.1478–88, https://doi.org/10.1016/j.rser.2014.09.007.

Shi, X., X. Liao, and Y. Li (2020), 'Quantification of Fresh Water Consumption and Scarcity Footprints of Hydrogen from Water Electrolysis: A Methodology Framework', *Renewable Energy,* 154, pp.786–96, https://doi.org/10.1016/j.renene.2020.03.026.

Singh, S., S. Jain, V. PS, A. Tiwari, M. Nouni, J.K. Pandey, and S. Goel (2015), 'Hydrogen: A Sustainable Fuel for Future of the Transport Sector', *Renewable and Sustainable Energy Reviews,* 51, pp.623–33, http://dx.doi.org/10.1016/j.rser.2015.06.040.

Southall, G. and A. Khare (2016), 'The Feasibility of Distributed Hydrogen Production from Renewable Energy Sources and the Financial Contribution from UK Motorists on Environmental Grounds', *Sustainable Cities and Society,* 26, pp.134–49, http://dx.doi.org/10.1016/j.scs.2016.05.009.

Taghizadeh-Hesary, F. and N. Yoshino (2020), 'Sustainable Solutions for Green Financing and Investment in Renewable Energy Projects', *Energies,* 13(4), p.788, https://doi.org/10.3390/en13040788.

Taghizadeh-Hesary, F. and N. Yoshino (2019), 'The Way to Induce Private Participation in Green Finance and Investment', *Finance Research Letters,* 31, pp.98–103, http://doi.org/10.1016/j.frl.2019.04.016.

Taylor, P. (1988), 'Superiority of NPV over NPV/K, and Other Criteria in the Financial Appraisal of Projects: The Case of Energy Conservation', *Management*, 6(4), pp.223–25, https://doi.org/10.1016/0263-7863(88)90006-3.

Tian, J., R. Xue, X. Yang, Ch. Wang, X. Ji, and Y. Shan (2020), 'Corporate Innovation and Environmental Investment: The Moderating Role of Institutional Environment', *Advances in Climate Change Research*, 11(2), pp.85–91.

Vogel, H.G. (2014), *Process Development: From the Initial Idea to the Chemical Production Plant.* Weinheim: Wiley.

Voica, M., M. Panait, and I. Radulescu (2015), 'Green Investments – Between Necessity, Fiscal Constraints, and Profit', *Procedia Economics and Finance*, 22, pp.72–79, https://doi.org/10.1016/S2212-5671(15)00228-2.

Wang, F., H. Yin, and Sh. Li (2010), 'China's Renewable Energy Policy: Commitments and Challenges', *Energy Policy*, 38(4), pp.1872–78, https://doi.org/10.1016/j.enpol.2009.11.065.

Walker, S. (1996), 'Appendix: Cost and Resource Estimation', in G. Boyle (ed.), *Renewable Energy: Power for a Sustainable Future*, 1st ed. Oxford: Oxford University Press.

Welaya, Y.M.A., M.M. El Gohary, and N.R. Ammar (2012), 'Steam and Partial Oxidation Reforming Options for Hydrogen Production from Fossil Fuels for PEM Fuel Cells', *Alexandria Engineering Journal*, 51, pp.69–75.

Wietschel, M. and U. Hasenauer (2007), 'Feasibility of Hydrogen Corridors between the EU and its Neighbouring Countries', *Renewable Energy,* 32(13), pp.2129–46, https://doi.org/10.1016/j.renene.2006.11.012.

Wilhelm, D.J., D.R. Simbeck, A.D. Karp, and R.L. Dickenson (2001), 'Syngas Production for Gas-to-Liquids Applications: Technologies', *Fuel Processing Technology*, 71, pp.139–48.

Yan, X., C. Gu, F. Li, and Q. Ai (2017), 'Cost–Benefit Comparison of Different Techniques for Addressing Wind Curtailment', *Energy Procedia,* 142, pp.1759–64. https://doi.org/10.1016/j.egypro.2017.12.560.

Yang, J., W. Chen, B. Chen, and Y. Jia (2012), 'Economic Feasibility Analysis of a Renewable Energy Project in the Rural China', *Procedia Environmental Sciences,* 13, pp.2280–83, doi: 10.1016/j.proenv.2012.01.217.

Yuanyuan, L. (2020), 'Investment in Chinese Hydrogen Sector in 1H 2019 Climbs 17%, Surpassing US $14B', *Renewable Energy World*, https://www.renewableenergyworld.com/2019/10/22/investment-in-chinese-hydrogen-sector-in-1h-2019-climbs-17-surpassing-us-14b/#gref (accessed 6 January 2021).

Yuan, K. and W. Lin (2010), 'Hydrogen in China: Policy, Program, and Progress', *International Journal of Hydrogen Energy*, 35(7), pp.3110–13, https://doi.org/10.1016/j.ijhydene.2009.08.042.

Yue, M. and Ch. Wang (2020), 'Hydrogen: China's Progress and Opportunities for a Green Belt and Road Initiative', Beijing: Green Belt and Road Initiative Center, https://green-bri.org/hydrogen-chinas-progress-and-opportunities-for-a-green-belt-and-road-initiative (accessed 2 January 2021).

Zhang, G., J. Zhang, and T. Xie (2020a), 'A Solution to Renewable Hydrogen Economy for Fuel Cell Buses – A Case Study for Zhangjiakou in North China', *International Journal of Hydrogen Energy,* 45(29), pp.14603–13, https://doi.org/10.1016/j.ijhydene.2020.03.206.

Zhang, M., Y. Lian, H. Zhao, and Ch. Xia-Bauer (2020b), 'Unlocking Green Financing for Building Energy Retrofit: A Survey in the Western China,' *Energy Strategy Reviews*, 30, https://doi.org/10.1016/j.esr.2020.100520.

Zheng, J., Zh. Mi, D. Coffman, S. Milcheva, Y. Shan, D. Guan, and Sh. Wang (2019), 'Regional Development and Carbon Emissions in China', *Energy Economics,* 81, pp.25–36, https://doi.org/10.1016/j.eneco.2019.03.003.