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REVIEW ARTICLE

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# Literature review on renewable energy development and China's roadmap



**Abstract** The low carbon energy transition has attracted worldwide attention to mitigate climate change. Renewable energy (RE) is the key to this transition, with significant developments to date, especially in China. This study systematically reviews the literature on RE development to identify a general context from many studies. The goal is to clarify key questions related to RE development from the current academic community. We first identify the forces driving RE development. Thereafter, we analyze methods for modeling RE developments considering the systematic and multiple complexity characteristics of RE. The study concludes with insights into the target selection and RE development roadmap in China.

**Keywords** renewable energy, energy transition, technology innovation, technology diffusion, development preference, energy system modeling

## 1 Introduction

With the increasing severity of climate change and widespread concern among the international communities, many countries have adjusted their energy strategies to increase the proportion of renewable energy (RE). RE has significantly developed over the past decade owing to the different forces. In 2010–2019, global non-hydro RE investment has reached approximately \$2.6 trillion; investments in solar and wind energy reached approximately \$1.3 trillion and \$1 trillion, respectively. In 2018, the world's increased RE investment was approximately \$332.1 billion. This value was approximately 5.38 times the level in 2004 (Frankfurt School, 2019). In 2017, RE power accounted for approximately 70% of the world's newly installed power capacity, and RE accounted for approximately 10.4% of the world energy consumption. Of this total, RE electricity and hydropower accounted for 5.4% and 3.7%, respectively (REN21, 2018).

By 2017, 179 countries had proposed RE developmental goals, and 57 countries had suggested 100% RE electricity share targets (REN21, 2018). For example, the European Union (EU) has specified that its members should meet 20% of their energy demands with RE by 2020. The German government has reported plans to increase the share of RE in its energy system from 33% in 2018 to 40%–45% and 55%–60% by 2025 and 2035, respectively. In 2019, Germany's RE electricity generation reached its target ahead of schedule, accounting for more than 40% of the total electricity generation. In the UK, RE now provides 40% of its total electricity supply, while coal-fired power generation dropped to 2% of the total. According to the 13th Five-Year Plan for Renewable Energy Development, China's RE utilization should reach approximately 730 million tons of equivalent standard coal by 2020, and RE electricity should make up 27% of the total electricity generation.

In spite of such progress, RE developments in countries around the world remain in the exploratory stage, described as "crossing the river by feeling the stones". Strategy development, path selection, and policies have also been tentative. This tentativeness has created multiple complexities in selecting a country's direction and path with respect to RE development. An enhanced understanding of this process would help eliminate different interfering items, formulate effective and stable policies, and advance the sustainable development of RE.

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This study provides a review of the current RE literature. Moreover, this study discusses the driving forces for RE development, the widely used methodologies, China's targets and strategies, and China's RE developmental path. The contributions of this work to the study of RE development are as follows. First, this study presents a clear description of the current RE development situation and its driving forces in China. Second, this research promotes an enhanced understanding of the driving forces of RE development in a systematic way. Third, this study clarifies the topics and problems in RE development that need further studies on the basis of a comprehensive review on existed literatures and historical RE development in China.

## 2 RE development: What driving forces are at work?

RE has become an important part of the human energy supply system due to its reproducibility. The history of energy use is a history of continuously seeking alternative and enriching energy sources. Many scholars are optimistic about the future development of RE. Du (2014) believed that RE would be the pillar energy of the earth in the future. The scale of global RE development and utilization continues to expand. The cost to develop RE is rapidly decreasing. RE development has become a core approach for advancing energy transitions in many countries and is a key way to mitigate climate change. The important measures for China include advancing the revolutions in energy production and consumption and improving energy transitions.

RE development has its own general laws and characteristics. Accurately understanding these rules and characteristics will help us advance the transformation of the energy system and steadily mitigate climate change. Existing literature has mainly focused on identifying the forces driving RE development (Fig. 1).

### 2.1 Policy-driven effect of RE development

Policy is a significant driving force for RE development. Many studies have summarized the RE policies and development status of different countries. Scholars have applied empirical methods to analyze the influences of government policies on RE development. Boie (2016) categorized government policies into production incentives and investment incentives. He studied the driving effects of incentive policies on RE development. Maslin and Scott (2011) conducted multiple scenarios to predict future RE development on a global scale. They found that climate policies would place constraints on the scale of RE development, and the scale of RE would also be influenced by technical changes in RE and the ability of RE to integrate with conventional energy systems. Chu and Majumdar (2012) demonstrated that government policy is the key factor driving RE development. Zhou et al. (2015) found that government policy is important for RE development. However, the effects of these policies significantly vary in different stages of RE industrial development. York (2012) believed that developing and advancing RE technologies requires a long process. Governments of all countries need to issue targeted incentive policies for RE during this process. Carbon emission mitigation policies have also driven RE development in China to deal with the carbon dioxide emissions peak in the future (Yang et al., 2019).

A solid understanding of policy-driven RE development is needed to design policies in the future. Clarification on the contribution of the current policies to RE development is more important than evaluation of the policy performance. Ding et al. (2020b) gained insight into the mechanisms of how research and development (R&D) policies contribute to photovoltaic (PV) development worldwide, and discussed the problems caused by these R&D policies. Based on this study, various R&D efforts should focus on PV technology improvement, PV electricity penetration, and system integration technology. The reduction of policy supports might also have significant effects on RE development. An increasing number of studies are trying to mitigate this type of influences with an optimization of policy supports. Zhang et al. (2020b) studied the optimization of feed-in tariff policies with the reduction of subsidies to wind turbine considering the cancel of subsidies to RE developments. Zhou et al. (2020) emphasized the needs for demand-type policies and green certification transactions in China. Local

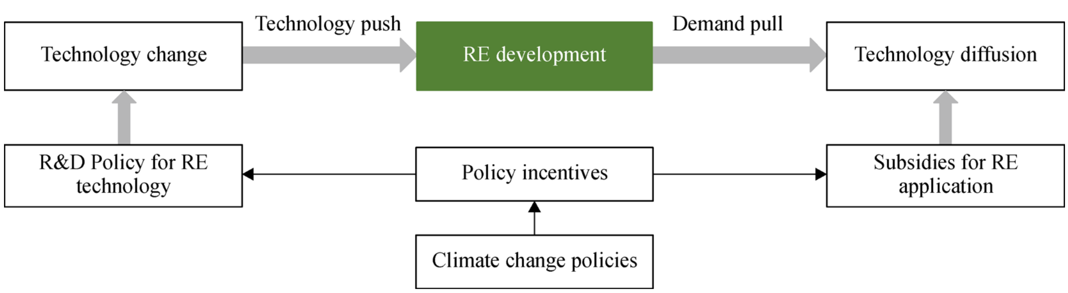


**Fig. 1** Driving forces of RE development.

government preferences are diversified in the RE development process, thereby leading to diversified policy needs (Bergmann et al., 2008). Examples include needs for demand-oriented policies to meet clean energy requirements, investment-oriented policies to drive the development of related industries, and resource-oriented policies to promote the utilization of RE resources. A clear question has emerged: How should the central government formulate policies based on real situations in different areas?

### 2.2 Technological change of RE development

Technical change has been recognized as an important force driving energy transition. Technological innovation in the energy field could be a key problem of national competitiveness. Constructing advanced energy systems that focus on clean energy supply is a major trend in shaping the world's energy transition. New energy systems should also transform energy consumption patterns (Shi and Wang, 2015).

The cost of technology is the key to large-scale application and market success for RE (Chu and Majumdar, 2012). Previous studies have concentrated on changes in the cost of RE technology and its influences (Baker et al., 2015; Levi and Pollitt, 2015). Benson and Magee (2014) analyzed the rate of improvements in PV, wind turbine, and other low carbon energy technologies. The research by Gonçalves da Silva (2010) showed that RE development is significantly constrained by its intrinsic energy cost and deployment path. Exogenous environmental costs exist for all energy, including RE. Hence, RE development must be comprehensively assessed to avoid significant harm to the environment (York, 2012). Pillai (2015) developed insights into the factors that drive declines in the cost of RE technology on the basis of the technological cost, sales, and corporate capital investments. Knowledge spillover through technological transfer is also an important factor for the RE cost decline. Scholars have studied the influences of institutional and corporate research on RE technological development and transfer in developing countries (de Coninck and Puig, 2015; Ockwell et al., 2015).

### 2.3 Technological diffusion effects of RE development

Technological diffusion is the information dissemination of new technologies or products caused by social learning (Bass, 1969; Mahajan et al., 1990). Consumption of a new technology in the market can strengthen public awareness of its value. This situation expands the technology's potential demand (Geroski, 2000; Usha Rao and Kishore, 2010; Alizamir et al., 2016). In reality, the application of RE technologies could be in different forms. RE technologies are utilized in various areas, such as different RE power generation stations (Dobrotkova et al., 2018; Malhotra et al., 2012). These technologies are also applied in buildings and agriculture. Such utilization of RE technologies is classified as distributed RE application. Recently, the Chinese government even uses solar PV to reduce rural poverty (Zhang et al., 2020a). In the field of RE technological development, Bollinger and Gillingham (2012) studied the influences of peer effects on PV diffusion. Social acceptance also plays an important role in diffusing RE technology (Viklund, 2004). People's acceptance of RE technologies is affected by the technology's characteristics (e.g., benefits and reliability) and business environment and psychological, social, and institutional factors (Islam, 2014; Kardooni et al., 2016). Kardooni et al. (2016) and Boie (2016) indicated that the essential factors for diffusing RE technology include social recognition and acceptance of RE technologies, tolerance of technological innovation, and fair attitudes toward different technologies.

In terms of the differences in technological development status, resources, and social environment, diffusions of RE technology vary in different areas. Jacobsson and Lauber (2006) found in the research on wind turbine and PV diffusion in Germany that RE diffusion rates differ among different regions. The energy transition is now an important force driving RE development. In the demand side, the energy transition and RE developmental call for a redesign of the current electricity market. RE technologies are significantly reshaping the electricity production and demand (Yu, 2019).

## 3 Methodologies and models applied in RE developmental studies

RE development has attracted increased scholarly attention. The literature shows that scholars' concentration has shifted from discussions on general macropolicy to endogenous issues on RE development. Research methodologies and models have advanced during this shift. The combination of qualitative and quantitative analyses and the integration of deterministic modeling and uncertainty simulations are now widely applied. These methodologies have been used to study the changes in RE technology, diffusion, and stakeholder decision-making processes (Table 1).

### 3.1 Methodologies and models for RE technological change

Understanding the RE technology change process is essential in constructing energy–environment–economic models. Kriegler et al. (2014) and Luderer et al. (2014) emphasized the effect of low carbon energy technologies on mitigating climate change by combining the results of Stanford Energy Modeling Forum Study 27 (EMF27) scenarios.

Modeling RE technological change processes has also

**Table 1** Methodologies and models applied in RE development studies

| Main issues | Methodologies and models | References |
|---|---|---|
| Technological change | Exogenous models (Hicks-neutral productivity gain and autonomous energy-efficiency improvement parameter) | Jorgenson and Wilcoxen, 1993; Nordhaus, 1994; Böhringer, 1998; Pizer, 1999 |
| | Endogenous models (learning curve and Cobb–Douglas function) | Kouvaritakis et al., 2000; Jakeman et al., 2004; Gillingham et al., 2008; Noailly and Smeets, 2015; Ding et al., 2020b |
| | Social survey | Peter et al., 2002; Reddy and Painuly, 2004; Axsen et al., 2015; Murakami et al., 2015 |
| Technological diffusion | Bass diffusion model | Purohit and Kandpal, 2005; Usha Rao and Kishore, 2009; Radomes Jr and Arango, 2015 |
| | Logistic model | Collantes, 2007 |
| | Epidemic diffusion model | Lund, 2006 |
| | Rogers model | Peter et al., 2002 |
| Subjective decision and behavior | Social survey and empirical analysis | Masini and Menichetti, 2012; Bauner and Crago, 2015; Langbroek et al., 2016 |
| | Agent-based modeling | Zhou et al., 2011; Snape et al., 2015; Bhagwat et al., 2016; Anatolitis and Welisch, 2017 |
| | Optimization | Zhu and Fan, 2011; Boomsma et al., 2012; Zhang et al., 2016; Li et al., 2019; Ding et al., 2020a |

Source: Grubb et al. (2002), Löschel (2002), Gillingham et al. (2008), and Usha Rao and Kishore (2010).

shifted from an exogenous process to an endogenous one (Nordhaus, 1994; MacCracken et al., 1999; Gillingham et al., 2008). Exogenous technological change theory holds that technology costs only change with time. Researchers have introduced exogenous technological change models into climate change modeling in different ways. One simple way is to define a Hicks-neutral productivity gain governing the entire economy development progress (Gillingham et al., 2008). Researchers have introduced an autonomous energy-efficiency improvement (AEEI) parameter to make this definition consistent with the fact that technological change is generally directed toward energy savings. AEEI denotes that energy efficiency increases with exogenous time throughout the economic system. AEEI is simple, easy to understand, and reduces the risks of nonlinearity and multi-equations (Nordhaus, 1994; MacCracken et al., 1999). Another type of exogenous technology modeling involves applying support technologies. Climate change models assume that support technological costs gradually decrease over time at a fixed rate. When constructing the models, multiple trends may be applied to determine the overall level and direction of technology changes.

Endogenous technological change is a common way that scholars model an RE technological change. When modeling endogenous RE technology change, researchers introduce a feedback mechanism to describe the effect of factors, such as policy, on the direction and rate of RE technological change. This feedback mechanism affects the RE technological change through various factors, such as energy price, increased R&D investment, and cumulative production experience (Gillingham et al., 2008). Endogenous technological change indicates that the cost changes of a technology are influenced by time, current prices, and historical prices and activities. This situation highlights the thinking behind endogenous technological change theory and modeling. Some scholars have analyzed the possible influences of historical prices on the current production on the basis of the endogenous technological change of RE (Newell et al., 1999; Jaffe et al., 2005). Gillingham et al. (2008) compared exogenous and endogenous RE technological change modeling. They constructed an endogenous RE technological change model and applied it to policy analysis. The endogenous RE technological change models use an unobservable variable, such as knowledge storage, to dominate the level and direction of technological change. This knowledge storage comes from various factors, such as historical prices, R&D investments, and experiential learning in production.

The learning curve, or experiential learning, is a widely used endogenous technological change model for RE. However, this methodology lacks the support of a mature theory. Accordingly, this model is mainly used as an exemplar method and tool, rather than as a tool that provides sufficient theoretical analysis. Fisher-Vanden et al. (2004; 2006) selected R&D investments as a source for knowledge to analyze the learning-by-researching effects on future energy consumption and carbon emissions. Popp (2001) and Noailly and Smeets (2015) used the number of patents as the variable to represent knowledge accumulation in R&D activities related to RE. Sue Wing (2008) used the energy saving experience induced by direct price as an independent variable in assessing the learning curve. A key goal of these methodologies and models is to identify the main forces driving RE development and the influences underlying these forces.

Learning curve models have significant challenges. In the literature, examples of experiential learning in the process of RE technological change include experience accumulated by direct prices, experience in R&D activities, and experience in production process. Many external factors affect the results of RE technological change. The first is the knowledge spillover between different countries. The process of internationalization and international exchanges become frequent, especially when addressing global climate change. Accordingly, knowledge spillover and technological transfer are important influences in RE technological change. de Coninck and Puig (2015) analyzed the effect of international technological transfer on technological innovation in developing countries by providing a system-level model of technological innovation. Ockwell et al. (2015) emphasized the complexities of international cooperation on RE technological innovation. They also constructed a system-level model to identify the influences of international technological transfer on low carbon technology development. Fluctuation of pricing with respect to materials is another factor impacting RE technology change, and it significantly affects the changes in technological costs (Weiss et al., 2010). Cost decomposition would significantly contribute to future technological change modeling using the learning curve method (Matteson and Williams, 2015; Zhou et al., 2019).

### 3.2 Methodologies and models for RE technological diffusion

The RE technology diffusion process can be divided into different periods. Stakeholder status, benefits, and acceptance of RE differ in different periods. In the literature, scholars have used social surveys and system modeling to analyze issues in RE technological diffusion.

Social surveys are frequently used methods for studying people's acceptance of RE technologies. Behavior, preferences, and attitudes play important roles with the progress of RE technology diffusion. Many studies have focused in this area, often on people's acceptance to RE technology and differences in their behaviors. Axsen et al. (2015) constructed a social survey among 1754 car buyers to assess their attitudes toward electrical vehicles. Thereafter, they analyzed the responses from residents in different sectors to assess attitudes toward plug-in and electric vehicles. Murakami et al. (2015) developed an online preference survey to assess consumer attitudes to different energy technologies. Consumer willingness-to-pay (WTP) is another factor that significantly influences RE technology diffusion. Sundt and Rehdanz (2015) conducted a meta-analysis on consumer WTP for green electricity. Axsen et al. (2015) compared consumer WTP for low carbon energy and nuclear energy in the US and Japan. They also provided insights into the differences between consumer perceptions and behaviors in different countries. Empirical analysis is also used to verify peer effects in the diffusion of RE technology (Bollinger and Gillingham, 2012).

System modeling is widely used to simulate the RE technological diffusion process. Existing studies have generally applied the bass diffusion model to analyze RE technological diffusion. Scholars have classified investors into different groups according to their knowledge, attitudes, and responses. These groups are known as innovators, early adopters, early and late majority, and laggards, respectively (Usha Rao and Kishore, 2010). Many studies have applied these methods to model different RE technological diffusion profiles. Ding et al. (2020a) divided RE technological diffusion into three periods to construct an RE diffusion model according to the status change of investors. Alizamir et al. (2016) and Ding et al. (2020a) integrated the technological diffusion and learning curve to analyze the optimization of policy supports for RE.

### 3.3 Methodologies for subjective decision and behavior in RE development

The complexity of different stakeholders in RE development calls for methodologies that analyze subjective decision and behaviors. RE development includes all aspects of technology R&D, equipment manufacturing, equipment application, energy production, energy service, and energy consumption. Government, electricity generators, grid operators, research institutes, and consumers are all stakeholders in RE development. These stakeholders experience cooperation, competition, and even conflicts. This notion highlights the complexity of analyzing people's decision making and behavior in RE development. Empirical analysis, agent-based modeling, and optimization models are all used to analyze stakeholder behaviors and preferences.

Empirical analysis and social surveys are used to identify factors influencing consumer behaviors and preferences. Analysis of the decision-making behaviors of investors and consumers from a market perspective is a current scholarly focus. Masini and Menichetti (2012) constructed an empirical model to analyze the problems in RE development by using European investors as a sample to consider investors' preferences with respect to risks and policies. Studies have also empirically analyzed consumer awareness and behaviors with respect to green and low carbon energy (Axsen et al., 2015; Murakami et al., 2015; Sundt and Rehdanz, 2015). Langbroek et al. (2016) investigated the effect of several policy incentives on consumer decision making by using a transtheoretical model of change and a state-choice experiment. Bauner and Crago (2015) combined the social survey and empirical model to analyze the effects of policy incentives on PV adoption.

Agent-based modeling is a bottom–up modeling approach, which helps analyze different agents' behaviors and their influences. This approach is used in energy system management (Zhou et al., 2011) and policy design (Bhagwat et al., 2016). Snape et al. (2015) constructed an agent-based model to analyze consumer responses to low carbon energy in the UK. The model results showed that non-economic barriers are the main reasons for low RE technology acceptance. Agent-based modeling can also be used to analyze RE auctions. Modeling the behavior of individual rational agents could support auction policy design (Anatolitis and Welisch, 2017). This approach also efficiently performs in forecasting the future markets of RE technology and electric vehicles (Eppstein et al., 2011; Shafiei et al., 2012). Agent-based modeling has made significant advances in operations management and in the optimal control of distributed energy systems (Li and Wen, 2014; Ringler et al., 2016).

Optimization models currently play significant roles in RE policy design and investment management. In response to uncertainties in RE development, scholars have introduced real options into dynamic optimization to search for an optimal investment in RE (Fernandes et al., 2011; Zhu and Fan, 2011; Boomsma et al., 2012; Zhang et al., 2016). Real option also performs well in evaluating policy efficiency (Zhang et al., 2014). Stochastic optimization and nonlinear optimization models have provided significant insights to inform policy designs for RE and carbon removal technologies (Li et al., 2019; Yao et al., 2020). A dynamic optimization model could help introduce supply and demand side interactions in RE system modeling (Ding et al., 2020a).

## 4 RE development target and path in China

China has made significant progress in RE development. Advancing energy transitions and increasing the proportion share of RE in total energy are now important national strategies for China. The price of a multisilicon PV module in China decreased to approximately \$0.52 by 2015, which is less than one tenth the price in 2007. In comparison with other countries, this value is less than half the price reported in Japan, which was approximately \$1.25 in 2015. By 2018, general multisilicon PV prices in China reduced to \$0.12–\$0.13/W[1)]. The system prices for different PV applications came in at 5.0–6.0 yuan/W (Lv et al., 2018). Figure 2 shows PV and wind turbine installations in China. The use of RE technologies in China has been somewhat limited compared with the significant increases in the cumulative installation capacities. In 2019, the electricity curtailments of wind turbines and PV power were $1.69 \times 10^{10}$ and $4.6 \times 10^{9}$ kWh, respectively. The average operational hours of wind turbines and PV in China were 2082 and 1169 h, respectively. Both these levels are lower than hydropower hours (3726 h).

Designing RE developmental goals in China is associated with many uncertainties. The goals associated with government plans have changed several times. For example, China's earliest PV development goal was set in 2007; the goal was to achieve 1.8 GW by 2020 and was proposed in the "medium- and long-term planning for renewable energy development". The PV goal was adjusted to 105 GW in 2016, as documented in the 13th Five-Year Plan for Renewable Energy Development (Fig. 3). The real achievements in RE development have generally significantly surpassed or fallen short of the goals. Table 2 presents some RE developmental goals and

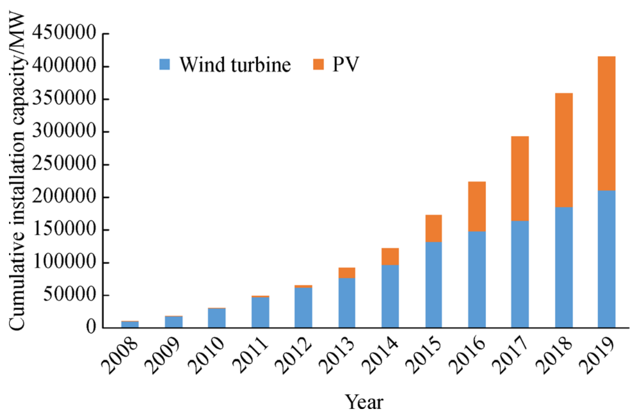


**Fig. 2** Cumulative installation capacities of wind turbines and PV in China (Source: China Electricity Council).

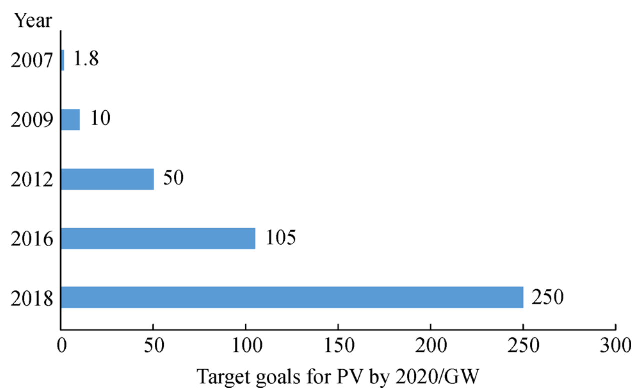


**Fig. 3** Adjustments in the development goal for PV by 2020 (Source: National RE plans and related news).

1) Available at: pv-magazine.com/2019/06/27/cell-and-module-prices-falling-in-china/

**Table 2** Examples of China's RE developmental goals and real achievements

| Goals and real achievements | Wind turbine (MW) | PV (MW) | Biomass power (MW) |
|---|---|---|---|
| 10th Five-Year Plan | | | |
| Goal | 1200 | 53 | |
| Real achievement | 1260 | 70 | |
| 11th Five-Year Plan | | | |
| Goal | 10000 | 300 | 5500 |
| Real achievement | 31000 | 800 | 5500 |
| 12th Five-Year Plan | | | |
| Goal | 100000 | 21000 | 13000 |
| Real achievement | 129000 | 43180 | 10300 |
| 13th Five-Year Plan | | | |
| Goal (by 2020) | 210000 | 105000 | 15000 |
| Real achievement (by 2019) | 210000 | 204000 | 22540 |

corresponding real achievements in China. For example, the goals associated with biomass power development were not achieved by 2015. The goals of PV RE development, especially of PV development, in different periods were significantly lower than the real achievements, indicating that RE development planning may be conservative. These results highlight the need for additional contributions to develop an improved mechanism for designing RE developmental goals and the future path.

Designing RE developmental goals requires integrating resources, environmental constraints, and economic development. Chen et al. (2008) proposed a comprehensive planning method for RE on the basis of the MESSAGE model coupled with the model for analysis of energy demand (MAED). They formulated RE developmental plans and supporting policies compatible with local resource conditions, economic development, and environmental goals by simulating the benefits and costs of incentive policies. The imbalance between RE developments in different regions also has great influences on China's RE development (Wang et al., 2020). Lin and Li (2015) analyzed China's 2050 goals for RE development on the basis of scenario analysis, case study, and quantitative methods. They discussed the feasible paths, possible effects, and road map for China's energy consumption and production revolution. The results revealed that environmental goals could cause changes in energy structure affecting China's RE developmental plans. Optimal energy costs and stable economic growth are also important in designing an RE development target (Shi et al., 2015).

With regard to the development path of RE, many scholars have concerned with the study of coordinated energy transformation and economic development. RE is key to global energy transition. The large-scale use of RE has gradually become an important force in reshaping the energy system affecting geopolitics and advancing the green economy (Zhao, 2017). Zeng et al. (2020) provided an optimization model for RE development with various RE resources. Foreign energy transformation provides significant experience for informing China's selection of RE development path. China should select the optimal path on the basis of the availability of natural resources compared with energy transitions in the US and Germany (Jin, 2016). Since the 1970s, Japan has continuously explored and practiced a model suitable for its own development. The model is mainly based on its own energy policies, policy orientation, and regulatory systems. The remarkable achievement in Japan RE development highlights important points for China (Li et al., 2017). Ma et al. (2018) researched China's energy transition and economic development on the basis of a cross-country comparison and a computable general equilibrium model. On this basis, they divided China's energy transition path into three periods. Bai et al. (2015) constructed an RE power planning and production simulation model considering the randomness and intermittence of RE electricity generation. They analyzed China's possible RE development scenarios in 2050 and described implications for path selection and policy design.

## 5 Conclusions

A series of studies have been conducted on RE development, with many important results and achievements. The existing research has found several important trends as follows.

First, a key question for future studies relates to identifying the forces driving RE development and their resulting effects. Different factors affect RE development, including policy, economic, and technology. Most studies have focused on the influences of a single factor. The appropriate policy is a key factor driving RE development. The technological push and diffusion also play important roles. Technological innovation and diffusion are related to market power. Hence, a mechanism that integrates those different driving forces is necessary for a stable RE development. This topic is important in RE development that deserves exploration.

Second, future studies on RE development should consider the contextual factors. The political, economic, and environmental situations in different countries form the context of RE development. Past studies have comprehensively compared and discussed the national energy system transition in different countries. These studies have been at the macrolevel, with few completing in-depth discussions about the contextual factors. A general structure and developmental path for RE are challenging to construct, especially embedding contextual factors, such as resource status, economic development, and institutional differences.

Third, subjective preferences and behaviors are important topics for future RE developmental studies. Studies have started to focus on the conflict and synergy between different agents in RE development. Most studies have concentrated on the choices and decisions of agents at the microlevel. Few studies have discussed the diversity and complexity of the different agents in RE development. The relationships and interactions between different agents must also be analyzed.

Fourth, the contributions of RE development preferences and their effects should also be assessed. Few studies have addressed this area. However, government, enterprise, and individual feelings often determine the direction and path of RE development. Even the preference of a country's government can create a major adjustment to the energy strategy. Future studies on RE development would significantly contribute to understanding the special contextual factor of development preference.

Fifth, further research is needed with respect to RE development goals and paths. Studies in this area are becoming increasingly diverse. Formulation of RE development goals is closely related to the countries' energy supply and demand, external resource availability, environmental constraints, industrial developmental prospects, and development preferences. The path selection of RE development should comprehensively consider the established goals, technical supports, and economic situations.

The low carbon energy transition concentrated on RE development has attracted worldwide attentions. RE developments' goal design and path selection are complex and have not been extensively studied in the literature. This study contributes to an enhanced understanding with respect to the driving forces of RE development. A systematic literature review highlights the needs for future studies in RE development.

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