Prospects for Global Energy Transition and Digital Integration

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***Abstract*—This study delves into the realms of energy transition and digitalization, drawing upon the foundations of sustainable development, energy economics, low-carbon economy, and energy substitution theories. Adopting an international political economy perspective, it meticulously analyzes the prevailing trajectories of energy transition and digital integration. By juxtaposing the energy transition strategies employed by prominent global economies, such as the United States, China, Japan, and Middle Eastern nations, invaluable insights are garnered for the benefit of China's own endeavors. Ultimately, a set of comprehensive recommendations is proffered to guide national and corporate pursuits in the realms of energy transition and digitalization: 1) Articulate a definitive pathway toward renewable energy in the forthcoming era; 2) Meticulously select transitional energy sources, aligning them with prevailing contextual realities; 3) Foster an environment conducive to technological innovation and digital transformation; 4) Astutely seize the opportunities presented by big data to propel business and commercial model innovation.**

***Index Terms*—Energy transition, digitalization, low-carbon economy**

I. Introduction

Energy serves as a vital cornerstone in sustaining human activities and livelihoods, permeating every aspect of our existence in a complex and interconnected manner. A historical exploration of global energy development reveals two significant transitions in energy utilization that have profoundly shaped the trajectory of humanity. The first transition occurred during the 1880s when humanity moved away from primitive and rudimentary firewood towards the more reliable and stable energy source of coal. This marked the onset of the coal era, where coal surpassed firewood as the primary energy source (Xiong, 2010). Simultaneously, this era witnessed the emergence of the groundbreaking steam engine. Subsequently, the second transformative phase unfolded in the 1960s, heralding the ascendancy of oil and gas as the dominant energy sources, ultimately transitioning from the coal era to the oil era (Ding, 2017). The advent of the internal combustion engine played a pivotal role during this period, formally ushering humanity into the "oil and gas era". Esteemed scholars argue that the third energy transition is poised to supplant fossil fuels with these emerging energy alternatives (Zou Cai *et al.*, 2016).

Humanity's persistent energy demands have consistently driven innovations and revolutions in energy technology, thereby influencing production, lifestyles, and socioeconomics. Presently, digitalization has emerged as a crucial avenue for mitigating global carbon emissions. Research conducted by the World Economic Forum indicates that digital technology contributes to approximately a 15% reduction in global CO_2 emissions. Nations worldwide are implementing climate change mitigation strategies, exemplified by initiatives like the European Green Deal and Japan's Green Development Strategy, which emphasize the promotion of green and low-carbon transformations through digitalization. With the growing application and integration of digital technology across various energy industry domains including research and development, production and manufacturing, operation and maintenance, energy consumption monitoring, risk warning, and consumer services, the energy sector is undergoing profound transformation and substantial reconstruction transformation in the structure of energy consumption. The prevailing consensus among scholars is that the world is still entrenched in the oil era and is actively undergoing the complex process of the third energy transition.

Academic research on energy transition focuses primarily on four aspects: the connotation and laws of energy transition, factors influencing energy transition, and the effects of energy transition. Some scholars suggest that there are four fundamental laws of energy transition, with technological progress being the key driving force, especially in terms of advanced energy storage technologies. Factors influencing energy transition include environmental and policy factors, economic feasibility, and technology. Technology is consistently integrated throughout the energy transition and is closely related to energy security. Economic feasibility determines the outcome of the transition, while the environment and policy play a powerful guiding role. The spatial and regional imbalances in the global energy landscape act as internal driving forces. The global political landscape also has a significant impact on global energy, as geopolitical competition and power struggles between major nations intensify. Energy transition has numerous positive impacts, including driving industrial development, improving economic efficiency, and promoting sustainable development. The first two energy transitions have profoundly affected global industrialization, urbanization, and even geopolitical patterns, bringing about fundamental changes in energy production and consumption (Inglesi-lotz , 2016).

II. Research on the Integration of Energy and Digitization

Research focusing on the integration of energy and digitization highlights the crucial role of digital technologies in achieving peak carbon emissions and carbon neutrality. According to the World Economic Forum, leveraging digital technologies could lead to a 15% reduction in global carbon dioxide emissions. The interdependence between the digital economy and energy industry transformation is increasingly evident. Digitalization serves as a vital pathway for enterprise

Manuscript received August 9, 2023; revised September 13, 2023; accepted October 11, 2023.

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doi: 10.18178/joebm.2023.11.4.766

transformation and plays a significant role in carbon reduction within the energy sector. Countries worldwide have emphasized the utilization of digital technologies to facilitate national green and low-carbon transformations, exemplified by initiatives like the European Green Deal, Japan's Green Growth Strategy, and the US $2 trillion Infrastructure Plan (Wang, 2022).

Within the academic community in China, preliminary research on the integration of energy and digitization has commenced alongside the deepening integration of industrialization, informatization, energy revolution, and digital revolution. Digitalization holds the potential to promote clean energy production, optimize energy utilization, and nurture emerging market entities. Despite being in the early stages, the overall intelligent and digital transformation of industries, including oil and gas, is underway. However, challenges remain, such as the need for better coordination between digitalization and carbon reduction efforts, the scarcity of digital talents and infrastructure, energy security concerns, and digital isolation. Looking ahead, energy companies must reshape the energy value chain through digital transformation. This requires accelerating digitalization by nurturing digital talents, enhancing new energy infrastructure, and fostering innovation-driven development to ensure the sustainable growth of the energy industry. Strategic planning, path design, and the promotion of intelligent production and enhanced efficiency in the production process are crucial for enterprise-level digital transformation. From an industry-wide perspective, the future digital transformation of the energy sector should focus on digital asset lifecycle management, collaborative ecosystems, and new business spaces to drive digital development within the industry (Li and Lv, 2021).

III. Comparative Analysis of Energy Transitions in Major Countries

The global pursuit of energy transition is an ongoing endeavor, marked by significant variations in the transformation trajectories among nations due to disparities in resource endowments, economic development, institutional frameworks, and technological advancements. This chapter endeavors to shed light on the experiential accomplishments and prevailing challenges associated with the energy transitions in the United States, Germany, Japan, Middle Eastern nations, and China.

A. The United States

In the context of the United States' energy transition, as the foremost global economic powerhouse, the nation has witnessed an almost four-hundred-fold expansion in energy consumption over a span of three centuries. The impetus for change emerged from the oil crisis, prompting a fundamental shift in the United States' energy policy towards achieving "energy independence." In pursuit of this objective, the United States has redirected its focus towards novel energy sources, pioneering research and development endeavors in cutting-edge energy technologies, market regulation, and expanded energy supply. Notably, since 2009, the United States Department of Energy has actively sponsored an extensive array of research projects encompassing solar energy, clean power generation technologies, sustainable fuels, energy storage capabilities, carbon capture methodologies, and building energy efficiency, thereby rendering outstanding contributions to the global advancement of energy technology. Over the course of the two decades spanning from 2000 to 2020, the proportion of fossil fuels in the United States' primary energy consumption decreased from 85% to 79% (Zou *et al.*, 2021). Rooted in the bedrock of energy independence, the United States' energy transition endeavors consistently gravitate towards enhancing the cleanliness of its energy system. Consequently, the country defines renewable energy, nuclear power, natural gas, and coal-fired power plants equipped with carbon capture technology as integral components of its clean energy portfolio, while emphasizing a pragmatic approach that does not rigidly demand a 100% renewable energy quota. Leveraging its abundant fossil fuel reserves, the United States strategically considers natural gas and nuclear power as transitional energy sources, poised to facilitate a seamless transition towards an optimized energy landscape.

B. Germany

Turning our attention to Germany's energy transition, the nation, bereft of inherent resource advantages, grapples with a pronounced reliance on foreign oil and natural gas, exceeding the 90% mark. In the 1990s, Germany embarked on a trajectory aiming to assuage its energy security concerns by fostering the development of renewable energy sources. At the onset of the 21st century, Germany emphatically declared sustainable development as the foremost priority permeating its energy policy, characterized by a steadfast commitment to "energy security, economic efficiency, and environmental sustainability." The crux of Germany's energy transition resides in the steadfast promotion of renewable energy, complemented by concurrent efforts to enhance energy efficiency. Remarkably, Germany succeeded in surpassing its 2020 target by achieving a 36% increase in the proportion of renewable energy generation between 2000 and 2019. The nation's research initiatives are primarily oriented towards optimizing the utilization efficiency of decentralized energy systems, bolstering the stability and flexibility of renewable energy integration, and expanding collaborative frameworks within the energy sector. The triumphant trajectory of Germany's energy transition is attributed to three pivotal factors: firstly, the strategic development of efficient wind power and biomass energy utilization; secondly, the implementation of intelligent and automated management systems, coupled with the utilization of innovative materials and widespread efficiency enhancements across diverse sectors; and thirdly, the astute pursuit of intelligent and integrated energy system transformation.

C. Japan

In the context of Japan's energy transition, as a developed nation with the lowest energy self-sufficiency rate, Japan strategically harnesses its technological prowess to counterbalance its resource limitations. In the domain of energy supply, Japan ardently pursues a diversified portfolio of energy sources by exploring offshore oil and gas reserves, as well as embarking on commercial endeavors related to methane hydrates. In recent years, Japan's energy policies have been steadfastly focused on overcoming the repercussions stemming from the 2011 Great East Japan Earthquake and the subsequent nuclear incident. Pertaining to technological provisions, Japan is actively propelling the adoption of coal gasification combined cycle power systems, fuel cell power systems, and carbon capture and storage mechanisms. Addressing energy demand, Japan places great emphasis on the upscaling of hydrogen energy utilization, while making significant strides in the development of the hydrogen energy industry value chain. Japan is resolutely committed to constructing a future “hydrogen society” and envisions attaining carbon-free hydrogen sources by the year 2050 (Gao, 2019). Currently, Japan commands global leadership in terms of hydrogen energy and fuel cell technology patents, having entered the nascent phase of commercializing fuel cell vehicles and residential fuel cell systems.

D. Middle Eastern Countries

Since the global shift to the oil and gas era, the international energy landscape has heavily relied on these finite resources, with a significant dependency on the Middle East for energy supply. Regrettably, Middle Eastern nations have become excessively reliant on these resources, overlooking the imperative of establishing modern industrial foundations and robust national economic systems. While the inherent resource advantage of oil and gas has bolstered the influence and affluence of Middle Eastern countries, the ongoing energy transition highlights an inevitable decline in their global influence and wealth, as nations worldwide enhance their energy self-sufficiency and engage in extensive resource extraction. Consequently, countries such as Saudi Arabia, the United Arab Emirates, and Yemen have gradually recognized the urgency of this matter. They have come to realize that their abundant solar and wind energy resources present a remarkably cost-effective pathway for embracing renewable energy. Notably, the United Arab Emirates has achieved groundbreaking success with photovoltaic projects boasting costs as low as 1.7 cents per kilowatt-hour. Furthermore, the Middle East region faces significant pressure on its water resources, rendering a transition to renewable energy sources a viable means to alleviate some of the water consumption burdens associated with the electricity sector (Irena, 2022).

E. China

As the world’s second-largest economy and the most populous country, China faces numerous challenges in terms of population, resources, environment, and development. While coal still dominates the energy mix, China has been expanding its wind and solar power industries with strong government support. The country has also undertaken supply-side structural reforms, adjusted its energy structure, and diversified electricity applications, including cooling, electric vehicles, and digitalization.

The trends in China’s energy transition are likely to include bypassing the oil era and transitioning directly from the coal era to the renewable energy era, as well as improving energy efficiency across industries. However, China is currently facing obstacles in energy storage technologies and the development of intelligent grids, which are common challenges worldwide.

IV. Insights and Recommendations

A. Clearly Define the Path Towards Renewable Energy in the Future

It is necessary to further clarify that China’s energy transition ultimately leads to the renewable energy era. This can be achieved by developing a practical and feasible roadmap and timetable, gradually establishing a matching energy system. Based on the maturity of renewable energy technologies, installed capacity, and generation costs, it is important to timely adjust renewable energy support policies. This should be done in conjunction with systems such as full guaranteed purchase and green certificate trading, while establishing clear, fair, and transparent subsidy reduction and phase-out mechanisms. It is crucial to publicly disclose the timetable for subsidy reduction and phase-out, providing market participants with clear expectations. This will encourage renewable energy enterprises to proactively improve their technological and managerial capabilities, effectively reducing costs (Lin, 2018).

B. Select Transitional Energy Sources Based on Realistic Conditions

Given China’s natural geographic conditions, which are rich in coal, limited in natural gas, and deficient in oil, the country is still in the coal era. Taking into account resource endowments, environmental capacity, and energy security, China should position coal and natural gas as the main transitional energy sources. It is crucial to continuously promote the clean and efficient utilization of coal through technological advancements and policy interventions, such as the development of intelligent coal mines. Additionally, measures should be taken to enhance the share of natural gas in the primary energy consumption structure by actively promoting the establishment of a national pipeline company, reforming the existing single-authorized operation system, and increasing technological innovation and policy support for unconventional natural gas.

C. Increase Support for Technological Innovation and Digitalization

Energy transition on a global scale relies heavily on technological advancements and digital innovations. The post-digital era has witnessed the rapid rise of cutting-edge information technologies such as big data, AI intelligence, and the Internet of Things, reshaping the global competitive landscape and becoming a significant force influencing the energy sector. China should expedite the construction of data centers to enhance the intelligence level of its natural gas industry. Different energy sub-industries, including coal, oil, gas, and electricity, should explore and promote the application of digital technologies based on their specific requirements and development conditions. Strengthening international cooperation is essential to overcome bottlenecks in renewable energy and energy storage. Energy security is also of utmost importance, necessitating the core technical breakthroughs in energy data security.

D. Seize the Opportunities of Big Data for Business and Commercial Model Innovation

Enterprises should utilize data to build integrated, intelligent, and integrated management platforms, enabling exploration, sharing, and circulation of internal data. Considering the technological development trends in the energy sector, enterprises should steadily promote technological innovation based on their actual conditions. Energy permeates various aspects of life and strongly influences other industries and fields. By focusing on energy as a core, energy-related enterprises have immense potential for cross-domain innovation in commercial models. Future energy business models will increasingly rely on data and digital technologies, continuously developing towards low-carbon, clean, efficient utilization, and distributed energy. Enterprises will also provide relevant products and services based on customer demand, thereby promoting innovation in business operations and commercial models.

Conflict of Interest

The author declares no conflict of interest.

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