A Framework for Sustainable Energy Strategy: An Approach to Integrate Carbon-Energy-Capital Flows among Key Stakeholders and Optimize Economic Resources

Kun Kong, Minyu Wu, and Nan Kong

***Abstract*—Facing the serious global warming, the carbon neutrality target is developed by most countries to mitigate climate change while realize high-quality development. An initiative of carbon neutrality involves multiple stakeholder groups and its implementation requires comprehensive coordination in different industries; thus, the objective of this paper is to develop an integrated framework that aims to realize carbon neutrality while optimizing economic resources. The framework was formulated on the basis of literature review, and defined six basic components together with the carbon, energy, and capital flows.**

***Index Terms*—Sustainable energy strategy, carbon neutrality, stakeholders.**

I. Introduction

Under the impact of rapid climate change in recent years, sustainable energy has been the prime concern in many economies; it motivated the deployment of sustainable energy in the national-level transition for green economy [1]. On the basis of the Paris Agreement, its long-term goal is to control growth of global average temperature within 2°C and strive to limit it within 1.5°C comparing to the pre-industrial levels. More and more evidence and studies have shown that there is no time to delay the combat of climate change, while the whole world has responsibility to do energy conservation and emission reduction for facing these challenges [2]. Most countries had set their plans of carbon peak and neutrality to promote sustainable energy in essential energy transition.

Global decarbonization is the essential way for slowing climate change [3], however, the cost of reducing emissions is quite high without the improvement of energy technologies [4]. The sustainable energy transition cannot be achieved in a society unless the government intervenes restrictions on carbon emissions through command and control or economic tools [3], [5]. The advance of latest energy policy reflects the cumulatively trend of shares of renewable energy in whole energy production process, not only because of strategic motivation, but also for the socio-economic and environmental incentives [6]. A broad concept of the world energy system actually is an interdependent and interactional overall system that is constituted by the economy, society, environment, and energy. The governance of energy system transition from fossil fuels to sustainable energy is crucial to different stakeholder groups. Considering each sector that influenced by energy system, and making outcomes could satisfy diverse stakeholder groups, the implication of sustainable energy by government policies and instructions is pivotal and complex, hence, the policies, technical solutions, and regional conditions should be consistent to promote the development of sustainable energy [7]. The transition extent highly relies on the effectiveness and influences of government interventions in energy market [8]. In view of the interactions between different stakeholder groups that impact the process of sustainable energy investment and implementation, and energy saving strategies, the two items are recognized as the most appropriate options to limit the goal of global warming [9].

How to design an effective policy to guide the energy transition and get over system inertia is a main problem [10]. The carbon emission involves different stakeholder groups in economic system, each person and enterprise have matters related carbon emissions, hence, the transition under carbon neutrality target not only need to focus each unit, but also require attention to the infrastructures, financial resources, and regulations [2], [7], [11]. The utilization of sustainable energy exacts opportune policies and technological innovation, while dynamic intervention from local participants is also important. The meaningfully seasonable information of sustainable energy is important for carbon neutrality target and sustainable energy promotion [9], [12].

With higher shares of sustainable energy in energy structure, considering the features of sustainable energy, instability and highly influenced by natural conditions, there are so many researchers who have paid attention to do prediction of energy supply and demand. Normal energy supply process relies on the demand from customers, while grid stability depends on the co-ordination of supply and demand, so that the right amount of energy in exact time is critical to balance smooth operation of power grid and better economic benefits [13]. The multifaceted policies of sustainable energy also caused uncertainties for carbon neutrality target realization [7]. Some reformers never considered the continuity of the plan, thus some areas deserted wind or solar energy because of the cost and volatility. Facing these problems, an integrated framework can be used to support greater management of carbon, energy, and capital fields in different stages in sustainable energy integration, and this would help to formulate sensible sustainable energy strategy.

Manuscript received December 15, 2021; revised March 7, 2022.

Kun Kong and Minyu Wu are with the Division of Business and Management, BNU-HKBU United International College, Zhuhai, China (e-mail: kunkong@uic.edu.cn, minyuwu@uic.edu.cn).

Nan Kong is with the Energy Electricity Research Center, Jinan University, Zhuhai, China (e-mail: nankong@jnu.edu.cn).

doi:10.18178/joebm.2022.10.3.689

Under the serious circumstances of climate, the promise about carbon neutrality from China's president Jinping Xi actively impacted the progress of limiting global warming at the 75th United Nations General Assembly in 2020, which is China will adopt stronger policies and measures to realize carbon dioxide emissions peak before 2030 and accomplish carbon neutrality before 2060. This promise indicated China's long-term vision of curbing the climate warming and controlling the global heating rate degree together with the whole world [2], and it will be the milestone to promote fully green development and transition in energy system and market, economic system, and technology innovation system [11]. The realization of carbon neutrality not only requires the accelerated transformation in energy structure, but also needs the revolution of economic system, it is a far-reaching reforms of supply side and demand side [11], [14], [15]. In order to achieve this goal, the dominant energy of China energy system needs to transform from fossil fuels to sustainable energy [10]. The realization of carbon neutrality target is a huge challenge with an enormous opportunity for whole economic system under the background of continuous economic growth with increasing energy demand, while decrease carbon emission to net zero.

This research aims to provide a framework among multiple stakeholder groups for the set of sustainable energy strategy which is unified, appropriate, and could optimize capital resources, thus to handle massive data from carbon, energy, and capital flows. Through the framework, it can provide orientation in local energy transition and sustainable energy strategy to accomplish carbon neutrality with cost-effective portfolio and realize high quality development. Meanwhile, considering the complex situations with multiple stakeholders, China will be used as research example in this research.

II. Literature Review

A. Sustainable Energy Strategy

Sustainability is shaping the way of world changes [16]. One of the most considerable challenges that all human beings need to confront is the increasingly global warming which caused by unlimited emissions of greenhouse gas like carbon dioxide, it will bring a catastrophic consequence to the world, hence, achieving carbon neutrality by the middle of this century is the most fundamental measure to slow the climate change [11]. To achieve carbon neutrality under the business as usual, the energy industry must contribute much greater proportion of carbon reduction [2]. Large-scale application of sustainable energy is primary element to gain sustainable development, therefore, most countries' governments revalue energy systems to design energy strategy and plans under their sustainable intentions [17].

Sustainable energy strategy signifies valid preparation of energy that can fulfill necessity while do not harm the capacity of future generations for their requirements [18]. Economic, environmental, and social sustainability were developed as the three principles of sustainable resources management [19]. Once renewable energy is promoted over environmental carrying capacity, the installation may cause negative effects to environment [20]. Hence, considering the energy transition to sustainable energy will influence different stakeholders, the three principles should be implemented throughout the set of sustainable energy strategy.

The preferable evaluation of energy policy outcomes is on the basis of detailed data [21]. Hence, the comprehensive data must be provided to support the sustainable energy strategy and related projects, these could facilitate transparency and reproducibility of energy models, also ensure the needed capital to achieve set carbon reduction goal [7], [22].

B. Carbon Neutrality Target

The realization of carbon neutrality in the middle of this century is the most essential way to response the seriously change of global climate [11]. The carbon neutrality is also called the net zero carbon dioxide emissions, signifies the amount of global anthropogenic carbon dioxide emissions are equal to the amount of carbon dioxide offset in a certain period [23]. There are a series of countries and economic entities have develop their schedule and action plan of achieving carbon emissions peak and carbon neutrality, like China, Japan, Singapore, European Union, British, New Zealand, etc. It will initiate government to set more positive goals on climate change, and benefit national sustainability and fundamental interests of people [2], [11]. The carbon neutrality target could drive the green transition in the energy system, economy system, societal system, and technology innovation system. The process of achieving carbon neutrality has extreme indefinity, accumulated advancement, path confidence, and interdependence with other countries' development, rather than a simple declaration, or incongruous activities [10].

The goal of carbon policy strategy is to decrease greenhouse gas emissions and mitigate global warming by promoting sustainable energy or energy efficiency measures; therefore, the carbon policy is pivotal tool for realizing energy transition with decarbonization [7]. Considering the different situation and available capital of the specific area to enable carbon neutrality, carbon policies could be set in varying degrees; the schedule, scale, location, energy effectiveness, environment, economy, and their interactions are the main factors to achieve target through the cost-effective method.

C. Transition to Sustainable Energy

The energy transition to sustainable energy plays one of the most significant roles of decarbonization, which is for the global warming [24]; therefore, the realization of carbon neutrality means totally energy revolution, technology revolution, and economy transformation [11]. The continuously enhancement of greenhouse gas emissions is driven by using fossil fuels as the primary energy based on the facts and evidences from reliable historical data [25]. Fossil fuels are unfriendly to environment and non-sustainable, the policy makers are trying to deal with energy demands without environment pollution, so that switching to sustainable energy is a viable option while mitigating global warming [24], [25]. The objective of sustainable energy is a comprehensive replacement of fossil energy, and the transition has been defined that it needs a controlled process for the gradual replacement of main fossil fuel by sustainable energy while maintaining the adequate

average energy service level [20].

The vision of throwing off import dependence of fossil fuel is the main force to make a country transforms its energy structure to renewable energy [24]. Some serious events in history provided the great opportunities for government to restructure their own energy structures, like the COVID-19 from 2020, it promoted countries to pay more attention to self-sufficiency in politics and economy, which benefits the development of sustainable energy and energy conservation to a considerable extent [14]. Nevertheless, although some energy transitions in the past years, the fully transition from fossil fuels to sustainable energy has never done before, and there is no reproducible experience in energy transition [20]. Accordingly, energy transition needs to take into account the performance, efficiency, finance, environment, etc., while the progress of energy system turns towards pivotal policy-making to fulfill strict and conflicting goals [26].

Energy transition to sustainable energy is multifaceted so that the analysis framework for sustainable energy has growing importance [7]. Sustainable energy involves two key units, which are energy efficiency (EE), and renewable energy sources, i.e., hydro energy, wind energy, solar energy, biomass, geothermal energy, tidal, and wave energy [18]. The large-scale applications of sustainable energy have to face so many questions in different aspects, some frameworks were developed in different levels and scales to analyze the transition. Abdin and Zio presented the frequency and magnitude of energy shortages must be considered for renewable energy applications through operational flexibility assessment for renewable energy expansion [27]. A detailed model was used to analyze tariffs and subsidies while limitations in the supply chain of sustainable energy was developed by [28]. Renewable energy technologies for dispersive low-carbon energy systems was analyzed by [29]. Financial and policy instruments are critical to achieve renewable energy targets were indicated through assessment of renewable energy strategy feasibility in relation to set targets [30]. A framework was created to facilitate policy-making process in renewable energy investment, through analytic network process (ANP) for the multi-criteria decision-making (MCDM) analysis based on technology, economy, environment, and society. The transition to sustainable energy involves multiple fields, the investment of sustainable energy and technology innovation are the key factors under the carbon neutrality target.

D. Government Intervention

Most governmental interventions pursue efficiency increase of industrial processes and motivate renovation [32]. As a governmental and comprehensive target with schedule, the proposed target of carbon neutrality leads to a series of government interventions to achieve it, which includes policies, regulations, goals, and laws, for instance, the set of sustainable energy policy, or subsidy and beneficial taxes of specific industries. Normally, the vision of using sustainable energy to decrease dependence in fossil fuel import needs national policies with support and financial subsidies, which are designed to reduce the uncertainties of new technologies' development [24]. Energy consumption and formulation of energy strategy should be established on the reduction of energy with high efficiency use, while should have recognition that growing consumption will beyond sustainable development with no doubt [18].

In China, a series of policies in the fields of energy and climate have come out in rapid succession after the proposed target of carbon neutrality, in many cases building on past policies and in other areas covering new ground [10]. From the central government to provincial governments, they set the policies in how to achieve the carbon neutrality target based on their own situations, most of them are in two categories: one is the governance of fossil fuels' usage and carbon dioxide emissions, and the other is sustainable energy promotion to reach green cycle and low-carbon development. In China's 14th Five-Year Plan sets target framework for energy policy between 2021 and 2025; it proposed five most important targets related to energy and listed in Table I:

TABLE I: FIVE MOST IMPORTANT TARGETS RELATED TO ENERGY IN CHINA'S 14TH FIVE-YEAR PLAN

No.	Target	Comparison
1	Reduce carbon intensity per unit of GDP by 18% from 2020 levels.	The 13th five-year plan target was 18%.
2	Reduce energy intensity per unit of GDP by 13.5 % from 2020 levels.	The 13th five-year plan target was 15%.
3	Increase the share of non-fossil sources in total energy consumption to 20%.	The 13th five-year plan target was 15%.
4	Continued promotion of what the document terms “clean and efficient use of coal”.	/
5	Discontinuation of a five-year GDP growth target.	The 14th five-year plan does not set a GDP growth target for the whole five-year period and targets will instead be determined on an annual basis.

E. Energy Market Transition and Reform, and Carbon Emissions Trading Scheme (ETS)

With the advance of energy market turn to renewable energy, the supply and demand of energy will experience material changes [9]. Energy transaction as an important part of this transformation has catch main attention. It asks exoteric market conditions to promote decentralized and centralized renewable energy trading through actional pricing principle, while such criteria only can be accomplished by tailored management tools for energy market regulation [7]. For the energy providers, one of the most notable changes is the radical improvement in the cost structure of renewable energy. In an increasing number of cases, renewable energy not only offers most cost-competitive options of energy supply, but also ticks the vital socioeconomic policy boxes of supply security and environmental responsibility [33]. Nevertheless, challenges remain for market reforms and renewable integration [10]. Under the transition of renewable energy and the growth of renewable share are highly connected with electrification of transportation and heating, energy consumption from the power grid may raise conspicuously [34], [35]. Market reform of electricity sector is essential for enabling clean energy transition and reducing carbon emissions [10].

The carbon emissions trading scheme (ETS) is an important policy tool towards carbon neutrality; hence, ensuring ETS is involved in the framework with distinct policy targets enhances the certainty [36]. While many

countries and regions continue to promote their carbon market construction process, new plans of carbon market have also been proposed by more governments. ETS interacts with miscellaneous economic spheres and specific mechanisms of different sections in a sophisticated policy environment [37]. Through enhancing integration of ETS and other policy tools, the efficacy of many policies could improve and realize more cost-effective and influential outcomes; however, the lack of coordination may result in duplicated or counterproductive outcomes [37]. In addition, the predominant price can be provided as the signal to encourage arrangement of low-carbon technologies and technological innovation through the allocation design of ETS while using market forces [38].

F. Economization of Resources

The true cost of climate change, social inequality, and inadequate governance, as well as the risks represented by these factors, are not truly reflected in prices [39]. Traditionally, prices reflect the costs and benefits of individual participants in the market. Nevertheless, the climate change cause harm to the entire society, and no company is willing to afford the costs. In this sight, government is expected to do the economization of resources for the external, and regulates scarcity [39]. In the absence of carbon pricing policies, it is much difficult to form long-term effective emission reduction constraints through solely relying on the synergistic emission reduction effects of energy and environmental policies. Hence, carbon pricing is a core issue in the top-level design of climate governance [40]. The mass-based design can make ETS to release consistent signals of carbon price to facilitate emissions reductions with the most cost-effective way [41].

III. Research Framework

Considering the sustainable energy strategy and energy transition of a specific area to accomplish the carbon neutrality and carbon emission peak as early as possible while optimizing economic resources, the three main aspects of sustainability: social, economic, and environmental aspects should be followed. The operation of economy and people's livelihood need energy consumption, then energy consumption produces greenhouse gas, which affects the global climate and environment; moreover, it influences the constraints on human behavior, so that to put forward new requirements on the way of economy development. Specifically, this means on the premise of satisfying energy demands of the economy and people's livelihood, while ensuring economic security and stable development to promote the transformation of energy structure from high-carbon fossil energy to carbon-neutral, low-carbon, and non-carbon energy for high quality development. Regarding the social aspect, different stakeholders have their own economic benefits, while the situations in different regions and fields should also be considered for achieving sustainability. For the economic and environmental aspects, the green low-carbon development is inevitable choice. The environmental sustainability (carbon neutrality) drives the economic and social sustainability, while the economic sustainability drives the green investment and financial systems (ETS and energy market) to achieve carbon neutrality with optimization of economic resources for stakeholders. Sustainable development drives the way of world changes, it will shape the economy while influence large quantities of industries and enterprises.

Through the analysis in literature review, the key components like energy structure, energy supply and consumption, policy support (like subsidy of sustainable energy), economic goals, detailed data analysis, and others are taken into account for the framework. Accordingly, the framework proposes six components for decision-making of sustainable energy strategy to optimize economic resources, which are a. carbon neutrality target; b. energy policy and regulations; c. energy market and transaction; d. carbon emissions trading scheme (ETS); e. green investment and technology innovation; and f. stakeholder approach.

Integrating the massive data from the six components, it can be integrated into three kinds of flows, which are carbon, energy, and capital flows. Due to the features of data and the complexity of framework, machine learning may suit for this multiple and massive data processing. Thus, the simulation results can be used to set sustainable energy strategy among key stakeholders to optimize economic resources while purpose a route of energy transition from fossil to renewable for specific area.

A. Carbon Neutrality Target

The aims of carbon policy strategy are encouraging sustainable energy or developing measures of energy efficiency to decrease the emissions of greenhouse gas and slow down the influences of global warming; hence, the carbon policies are the main factor of energy transition with decarbonisation [7]. After the talk of China’s President Xi Jinping on Climate Ambition Summit 2020, there is a series of policies, guidance and reports were released from the high-level departments of government and provincial government to support the carbon emission peak before 2030 and carbon neutrality before 2060 or much earlier. The declaration of China's carbon neutrality target indicated the orientation for the realization of zero carbon China, it provides important and valuable contents for the construction of ecological civilization and sustainable high-quality development, while becomes the strong driving force for energy revolution [2]. The different-level's government can set suitable policies to promote local industries to reach the carbon emissions peak and neutrality; however, one of the most important points is to find the cost-effective way among the location, time, scale, performance, and their inter-linkages [7].

In view of the existing situation of China, it needs to face the serious stress of carbon neutrality target while maintain the economy development. Therefore, the policies related to the carbon reduction and the subsidies or investment should be evaluated by detailed database from previous actual data or simulation to ensure the consequences. The strict data not only promotes outcomes evaluation of energy strategy, but also furthers transparency and repeatability of energy models [21], [22].

On account of the “China's 3060 carbon target”, the gradually clear policy support from macro to industry is the long-term motive force of development for wind and solar

power industries, for instance, the green power certificate and the consumption guarantee mechanism of renewable energy power, they will play a more and more importantly active role to help the continuous expansion of the upstream industry scale in the consumption side of energy [42]. These policies encourage enterprises to use or increase renewable energy in their production and attempt more corporate social responsibilities.

For the carbon neutrality target field of this framework, the following key elements are defined: a. the specific target to realize the carbon peak and neutrality for specific industries, including the time, scale, transition, etc.; b. the subsidy of renewable energy feed-in tariff; c. the funds for promoting specific industries (like energy storage industry); d. the cost of carbon neutrality; e. the development of energy efficiency.

B. Energy Policy and Regulations

As the energy market accelerates its transformation to sustainable energy, energy structure of supply and demand will have an important shift [9]. Due to the characteristics of renewable energy like instability and volatility, how to consumption them reasonably to avoid abandon of wind and solar power is necessary. The government issued the policy and regulations to solve these problems, not only the energy storage industry and the carbon capture, utilization and storage (CCUS), but also the financial system. While China is adding wind and solar at record rates, and prices are approaching grid parity, renewable energy in China continues to lack a stable, long-term regulatory system [10].

To make sustainable energy has more attractive for investors, the local regulatory system and supporting schemes have to be well considered and stable. For investors, the policies will remain and they will get funded in the long term are the main conditions of investment [43]. The deployment of sustainable energy is highly capital-intensive, investment in this field will not produce ideal feedback if there is no financial support scheme, because of sustainable energy is incapable to compete with a well-established fossil energy industry with heavily subsidized [1]. Asset owners will help China achieve its ambitious goal of carbon neutrality by 2060 and the international investors would like to support the target actively [44]. Thus, the government should issue a series policy and regulations in creating fair environment, mandatory climate report, and gradually implement financial market opening. These measures could bring the positive impact for economy and society.

For China, a more active goal on climate change is conductive to national sustainable development and fundamental interests of the people, while the green economy will act a positive part in promoting GDP; moreover, the national energy security will have better protection [2]. As the policy orientated industry, nearly all the state-owned corporations of energy industry in China have issued the realization plan of carbon peak and neutrality plan, it also interconnects with energy market. The China's Energy Development in the New Era was published by the State Council Information Office of the P. R. China [45], this report indicated five key concepts of energy policy, which are insisting on putting people as the center, insisting on the clean and low-carbon orientation, insisting on the core position of innovation, insisting on the development by reform, and insisting on the construction of community of common destiny for all mankind. Meanwhile, the Guiding Opinions on Energy Work in 2021 of National Energy Administration [46] indicated that main expected goals in 2021 including the energy structure, guarantee of energy supply, the energy quality and efficiency, the technology innovation, and the energy system reform.

For the energy policy and regulations field of this framework, following key elements are defined: a. the specific target, i.e., the percentage change of renewable and nonrenewable energy in structure; b. the subsidy of sustainable energy; c. the guidance of green investment; d. the related law of energy and carbon; e. the energy efficiency and technology innovation.

C. Energy Market

China's economy is continuously increasing while the demand of electricity is also growing. In 2020, some provinces occurred the lack of electricity then caused curtailment due to the rapid growth of industrial production or extreme weather. As progressively sustainable energy has connected to the grid, the stabilization and enough supply of electricity is much important. Meanwhile, some areas appeared the abandon of wind and solar power, so that the market-oriented development under the policy guidance may solve these.

The emphasis of energy market reform is building an unified, open, and orderly competitive system, while organizing the trading platforms of coal, electricity, oil, and natural gas based on the characteristics of different energy to promote the interaction between supply and demand [45]. Meanwhile, China's power sector is currently undergoing extensive reforms to extend potential of market-based mechanisms to determine power sector operations and improve system efficiency [38]. China has made slow but steady progress in the reform of power market, while transition of electricity transactions continuing to mid or long term bilateral contracts. More technologies are now eligible to participate in ancillary services markets. And in the much-watched field of spot power markets, all pilot provinces have now undergone trial trading periods. More spot market pilot provinces have been announced, and it looks likely that the spot market experiments will be accelerated [10].

China's power market reform has the potential to significantly raise system efficiency, reduce system costs and foster power sector decarbonization [38]. Despite there are recent progress in China's power market reform, its dispatch mechanism still differs from the least-cost approach used in most mature power markets. The timing of its market reform rollout may complicate the application of allocation methodologies and benchmark-setting [37]. Effective policy co-ordination, design flexibility and timely adjustments are thus vital to improve system efficiency and facilitate China's clean energy transition.

For the energy market field of this framework, these key elements are defined: a. the price of different energy in market; b. sustainable energy subsidy; c. the on-grid cost of sustainable energy; d. different kinds of electricity price; e. peak-valley price; f. energy supply and consumption.

D. Carbon Emissions Trading Scheme (ETS)

In the past few years, emissions trading systems experienced the elasticity test from real world, and demonstrated it is responsible and powerful instruments that will act as fundamental part in reaching net zero targets although the well-designed scheme of carbon markets is more complicated than some climate policies. The functioning well and resilient market certifies ETSs can realize mitigation with cost-effective way, at the same time, keeping economic competitiveness and promoting low-carbon investment [36].

According to public files of government, the national carbon market of China officially started operation from June 2021, and only the power generation industry is listed, but the coverage will gradually expand to eight high-level emission industries in the future. The national carbon market and its transaction between corporations will make enterprises to think more, not only the carbon emission, but also the technology innovation, the use of renewable energy, and price of carbon in market, etc. ETS can be a significant market-based instrument to help the country to realize climate target and energy transition [38].

The national ETS of China operated in 2021 in electricity industry, then it will extend to cover other related energy-intensive industries. It is the largest ETS of the world even in the primary stage, while covered coal and gas power plants account for more than 40% of CO_2 emissions from fossil fuel combustion in China. One of the most important parts of ETS is monitoring emissions. As for some power plants that do not take stock of emissions, the higher default factor of emissions will use to urge them to boost monitoring capacity for better data quality [37].

For the ETS field of this framework, these key elements are defined: a. the price of carbon; b. the allocation of carbon; c. the related policies and regulations; d. the electricity market reform; e. the influences of economy system.

E. Green Investment and Technology Innovation

The carbon neutrality target will bring huge green and low-carbon investment demand [11], and deliver a strong signal to the market, which will encourage more long-term value investors to pay attention to the zero-carbon development, and establish confidence in investing the zero-carbon assets, projects, and technologies [2]. The green finance is developing rapidly and the financial industry needs to accelerate the green transformation [44]. In China, the green financial system has made great progress in the past few years, however, it still faces many shortcomings under the carbon neutrality target [47].

In the process of advancing carbon neutrality target, green technology investment will contribute more than 2% of China's GDP by 2050 [2]. Most of these green investment needs to rely on the social assets, hence, the green financial system of green investment from social assets plays a key role in the realization of carbon neutrality [11]. The engagement of private capital is core for bridging financing gap of sustainable energy development, nevertheless, investors will further fund only the investment has financial attractiveness [43]. Meanwhile, the financial institutions should also participate the carbon neutrality target actively, not only for themselves, but also for other industries [48]. There is a series of green financial products in China including the green credit, green funds, green bonds, etc., however, the financial system is not complete. For example, most investors prefer short term benefits rather than medium or long term benefits, but the investment in energy industry no matter in technology or large-scale application of sustainable energy needs continuous and stable research input. The government has issued some guidance to promote the green investment and financial system, hence, the green financial system will be completed to better support the green investment than before, and plays a greater role for carbon neutrality target. Moreover, the green investment should not only focus on the green project themselves, but also pay attention to the transition of corporations or industries from high-carbon to low-carbon. As for the national carbon market, with its development and improvement, the financial institutions should participate it actively to strengthen the financial attribute of carbon market, and the price could truly reflect the value of carbon assets [48].

Under the target of carbon emissions peak and neutrality, the foundation of energy transition is technology innovation, thus to solve the cons of sustainable energy, nevertheless, making sustainable energy largely accesses to grid blindly to replace traditional is not worth anymore. The technology innovation of energy is much important for the mass application of sustainable energy, while development of most sustainable energy technologies has high threats while long-term returnable benefits [43]. One of the hot industries is the energy storage industries. With the increasing percentage of sustainable energy, the energy storage is the main way to balance the peak-valley demand and unstable supply. The distributed energy storage under the trend of internet of energy will be applied on a large scale gradually, and the high proportion of renewable energy will create the large scale demand of energy storage [2]. Moreover, the other technology innovation of energy is developing, for example, hydrogen energy, carbon capture, utilization and storage (CCUS), etc., these innovations will demonstrate their value and prospect through life cycle assessment, and the internal rate of return.

For the green investment and technology innovation field of this framework, these key elements are defined: a. the investment behaviors of financial institutions; b. the sources of medium and long term funds; c. the innovations of financial products; d. the government policy of green investment; e. the predicted research cost; f. the prospect and future demand of technology innovation; g. the risk; h. investment return of the innovation through internal rate of return.

F. Stakeholder Approach

People are conscious of sustainable development should be the new objective in strategic level because of rapid regression of environment and high consumption of natural resources, so that participation of different stakeholder groups offers chances to develop an issue in a wider range by attracting additional opinions for the move of formulating sustainable energy strategy [49]. Stakeholder participation could be the basis for developing common goals among actors [50].

Considering the broad audience of energy and energy

strategy, the balance of social, economic, and environmental sustainability is essential. Therefore, these key elements are defined in this field: a. economic benefits; b. environment influences; c. regions; d. development situation; e. time frame of energy transition and carbon neutrality; f. consumers; g. energy security.

The framework for sustainable energy strategy is based on the six components above, and involves three key flows of carbon, energy, and capital. The elements come from considerable sides that summarized from the part of literature review. Moreover, it affords an integrated understanding of energy transition and carbon neutrality, and the interaction effect between pivotal stakeholder groups and driving sectors for developing appropriate sustainable energy strategy to realize optimization of economic resources. Therefore, exploitation of the framework focuses decision-making area, while considering diverse stakeholder groups in energy transition and sustainable energy application under carbon neutrality target. The construct of integrated framework of sustainable energy strategy is illustrated in Fig. 1.

In this framework, each component has three flows with others, so that after the data input from the six components, it can be classify as the three flows according to the key variables of each field. Carbon flow reflects the quantities of carbon emissions, energy flow reflects the kind and volume energy usage, and capital flow reflect the use of investment. Due to the large quantities of data with many years in carbon, energy, and capital flows, machine learning may be used as an instrument to do the data processing and then simulate further situation. The simulation results are the output to provide key information for sustainable energy strategy to optimize economic resources.

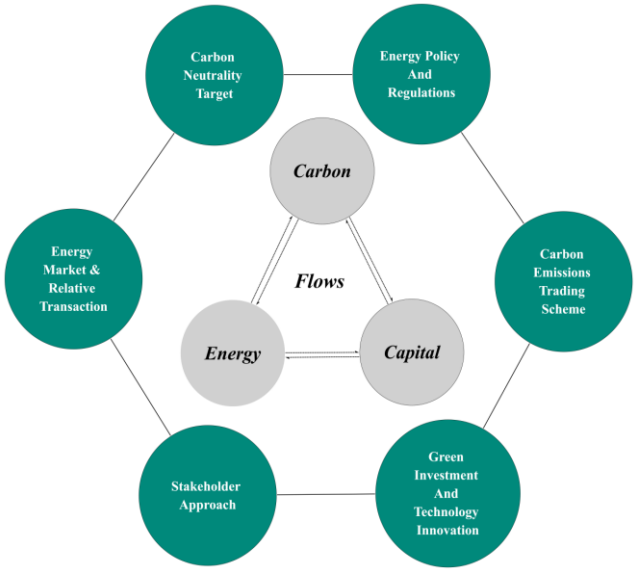


Fig 1. An Integrated Framework of Sustainable Energy Strategy.

IV. Discussion

The purpose of this project is to design appropriate sustainable energy strategy to optimize economic resources through the above mentioned comprehensive framework. A simulation model with machine learning could be developed based on the research framework. Through the combination of simulation and machine learning, the model aims to explore the optimal paths of energy transition and appropriate economic resources allocation among different stakeholders. The results would be useful for different decision-makers at different levels.

The data in the research can be gathered by methods of compiling. Miscellaneous independent sources can be used, such as statistical department, national and international official reports, private studies, and scientific papers. The data can be analyzed in statistical method, then do evaluation and cross-compared. For the energy policy and regulations, they can collect from government publications, and will be assessed through qualitative method.

For the framework in this study, the features of "process-centric" in simulation and "data-centric" in machine learning are both essential; thus, the coupled approach that combines simulation and machine learning can better generate the results for different decision-makers. Machine learning, is appropriate to analyze the continuously increasing and massive data from carbon, energy, and capital flows because by way of automatic parameter tuning, it could utilize previous data and results to better analyze and fit for the model. Moreover, the some current models may be considered as a foundation for the development of the simulation model. For example, the China energy modeling system, developed by CASS (Chinese Academy of Social Sciences), incorporates various technological paths and distinctive development scenarios into the overall energy system to conduct scenario analysis. Machine learning can be used as a main instrument for the framework to analyze six components while predicting the energy supply and consumption with promotion of sustainable energy. This is important to increase certainty of carbon neutrality realization within the given time frame while considering optimization of economic resources.

V. Conclusion

On the basis of historical data, the inappropriate sustainable energy strategy caused the waste not only in the economic resources, but also in the energy, e.g., the abandon of wind and solar PV in some regions [11]. Hence, the reasonable sustainable energy strategy is much important and useful for sustainable energy promotion and development with the optimization of economic resources, which is the outcomes of this research framework. In the context of carbon neutrality target, the framework in this study affords a distinct description of carbon, energy, and capital flows that is appropriate for developing sustainable energy strategy. The key factors in this framework aim to promote the optimal allocation of economic resources, which is essential for the prediction and structuration of energy transition and energy market reformation.

The six components of this framework will be analyzed to evaluate ideal carbon-incentive levels, so that to accomplish carbon neutrality and optimize financial investment for specific industry. To reach the results, the carbon, energy, and capital flows are defined by the framework as the regional level and field level. This approach optimizes and coordinates the sustainable energy and energy conservation in a sharing vision among stakeholder groups, thus to facilitate greater transparency and strategic consistency.

The framework showed how the integrated approach can be applied for sustainable energy to prioritize initiatives among multiple stakeholder groups. Regarding the data of carbon, energy, and capital flows input, e.g., volume carbon emissions and its limitation, investment, carbon neutrality target, while thinking over different stakeholders, the output data like carbon emissions will show how to optimize paths for sustainable energy and economic resources. The output data can be used to do the references for decision-making by calculation, e.g., the different transition paths, the realization process of carbon neutrality, economic resources allocation. It realizes the optimal allocation of capital. Moreover, the expand-ability analysis of the framework offers an actional calculation for government subsidies of sustainable energy usage while considering the signals of energy market. Through this, policies related to carbon neutrality can be deeper understanding to contribute in the public and private sectors.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors conducted the research; Kun Kong and Minyu Wu wrote the paper; Nan Kong analyzed the policies; all authors had approved the final version.

References

[1] E. Kiragu. (2015). Transition into a green economy: Are there limits to government intervention? SECO / WTI Academic Cooperation Project. [Online]. Available: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2712182

[2] B. P. Chen, Y. Lu, G. Y. Liu, T. Palme, M. T. Kong, R. Jacobsen, and L. Faeste. (2020). China climate path report. Boston Consulting Group. [Online]. Available: https://www.bcg.com/zh-cn/china-climate-path

[3] G. C. Unruh, "Understanding carbon lock-in," *Energy Policy*, vol. 28, no. 12, pp. 817-830, 2000.

[4] S. Barrett, "The coming global climate-technology revolution," *The Journal of Economic Perspectives*, vol. 23, no. 2, pp. 53-75, 2009.

[5] C. Fischer and R. G. Newell, "Environmental and technology policies for climate mitigation," *Journal of Environmental Economics & Management*, vol. 55, no. 2, pp.142-162, 2008.

[6] V. Skoulou, N. Mariolis, G. Zanakis, and A. Zabaniotou, "Sustainable management of energy crops for integrated biofuels and green energy production in Greece," *Renewable & Sustainable Energy Reviews*, vol. 15, no. 4, pp. 1928-1936, 2011.

[7] A. S. Vieira, R. A. Stewart, R. Lamberts, and C. Beal, "Renewable energy and energy conservation area policy (REECAP) framework: A novel methodology for bottom-up and top-down principles integration," *Energy Strategy Reviews*, vol. 32, p. 100544, 2020.

[8] R. Clemencon, "The two sides of the Paris Climate Agreement: Dismal failure or historic Breakthrough?" *The Journal of Environment & Development*, vol. 25, pp. 3-24, 2016.

[9] D. Gielen, F. Boshell, D. Saygin, M. D. Bazilian, N. Wagner, and R. Gorini, "The role of renewable energy in the global energy transformation," *Energy Strategy Reviews*, vol. 24, pp. 38-50, 2019.

[10] A. Hove, W. Y. Qian, K. M. Zhao, P. Geres, and Y. Z. Liu. (2021). China energy transition status report 2021. Sino-German Energy Transition Project. [Online]. Available: https://www.energypartnership.cn/fileadmin/user_upload/china/media_elements/publications/2021/EnTrans_Project_Brochure_EN.pdf

[11] H. Liang, W. Y. Zhao, L. Yang, and J. Ma, "Towards 2060 carbon neutrality - focusing on opportunities and challenges on the road to decarbonization," Beijing Institute of Green Finance and Sustainable Development & Hillhouse Industry and Innovation Research Institute, 2021.

[12] J. Young and M. Brans, "Analysis of factors affecting a shift in a local energy system towards 100% renewable energy community," *Journal of Cleaner Production*, vol. 169, pp. 117-124, 2017.

[13] K. S. Perera, Z. Aung, and W. L. Woon, "Machine learning techniques for supporting renewable energy generation and integration: A survey," in *Proc. International Workshop on Data Analytics for Renewable Energy Integration*, 2014, Springer International Publishing.

[14] J. J. Tu and Z. Yang, "The impact of the COVID-19 epidemic on China's energy economy," in *Proc. Agora Energy Transition Forum*, 2021.

[15] Energy Foundation. (2020). Synthesis report 2020 on China's carbon neutrality: China's new growth pathway: From the 14th five year plan to carbon neutrality. Energy Foundation, Beijing, China. [Online]. Available: https://www.efchina.org/Reports-en/report-lceg-20201210-en

[16] H. M. Zuehlke, C. Boehler, and M. Ermer. (2021). Sustainarama – How sustainability will change the world in 2050. Roland Berger Institute. [Online]. Available: https://www.rolandberger.com/en/Insights/Publications/Sustainarama-How-sustainability-will-change-the-world-in-2050.html

[17] I. Vera and L. Langlois, "Energy indicators for sustainable development," *Energy*, vol. 32, no. 6, pp. 875-882, 2007.

[18] M. Obrecht and M. Denac, "A sustainable energy policy for Slovenia: Considering the potential of renewables and investment costs," *Journal of Renewable & Sustainable Energy*, vol. 5, no. 3, pp. 2-39, 2013.

[19] H. E. Daly, "Beyond growth: The economics of sustainable development," *Population and Development Review*, 1996.

[20] S. Sgouris and C. Denes, "A framework for defining sustainable energy transitions: Principles, dynamics, and implications," *Sustainability*, vol. 6, no. 5, pp. 2601-2622, 2014.

[21] J. Urpelainen, J. Yang, J. H. Sais, and U. States, "Global patterns of power sector reform, 1982-2013," *Energy Strategy Reviews*, vol. 23, pp. 152-162, 2019.

[22] F. Gotzens, H. Heinrichs, J. Horsch, and F. Hofmann, "Performing energy modelling exercises in a transparent way — The issue of data quality in power plant databases," *Energy Strategy Reviews*, vol. 23, pp. 1-12, 2018.

[23] IPCC (The Intergovernmental Panel on Climate Change), *In: Global Warming of 1.5ºC. An IPCC Special Report on the Impacts of Global Warming of 1.5ºC above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*, 2018.

[24] I. Fischhendler, L. Herman, and L. David, "Light at the end of the panel: The Gaza Strip and the interplay between geopolitical conflict and renewable energy transition," *New Political Economy*, vol. 1, pp. 1-18, 2021.

[25] A. Oppong, J. Ma, and B. Ameyaw, "National energy transition strategies to harness local renewable energies based on criterion weights," International Association for Energy Economics (IAEE), 2019.

[26] P. Palensky and D. Dietrich, "Demand side management: Demand response, intelligent energy systems, and smart loads," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 3, pp. 381-388, 2011.

[27] I. F. Abdin and E. Zio, "An integrated framework for operational flexibility assessment in multi-period power system planning with renewable energy production," *Applied Energy*, vol. 222, pp. 898-914, 2018.

[28] L. Bird, J. Cochran, and X. Wang, *Wind and Solar Energy Curtailment: Experience and Practices in the United States*, 2014.

[29] N. Danilina and I. Reznikova, "Renewable energy technologies on the path towards decentralized low-carbon energy systems," in *Proc. E3S Web of Conferences*, vol. 250, no. 4, p. 03001. 2021.

[30] U. Zafar, T. U. Rashid, A. A. Kohsa, M. S. Khalil, and M. Rashid, "An overview of implemented renewable energy policy of Pakistan," *Renewable and Sustainable Energy Reviews*, vol. 82, pp. 654-665, 2018.

[31] B. Ozorhon, A. Batmaz, and S. Caglayan, "Generating a framework to facilitate decision making in renewable energy investments," *Renewable and Sustainable Energy Reviews*, vol. 95, pp. 217-226, 2018.

[32] E. Luiten, H. V. Lente, and K. Blok, "Slow technologies and government intervention: Energy efficiency in industrial process technologies," *Technovation*, vol. 26, pp. 1029-1044, 2006.

[33] P. Hughes. (2018). The transformation of energy markets and the role of innovation in reshaping national energy mixes. 2018 Summit Working Paper of Pacific Energy Summit. [Online]. Avaiable: https://www.nbr.org/publication/the-transformation-of-energy-markets-and-the-role-of-innovation-in-reshaping-national-energy-mixes/

[34] J. Weiss, R. Hledik, M. Hagerty, and W. Gorman. (2017). Electrification emerging opportunities for utility growth. The Brattle

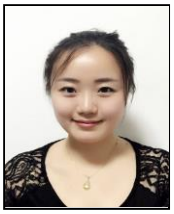
Group Inc. [Online]. Avaiable: http://files.brattle.com/files/7298_electrification_emerging_opportunities_for_utility_growth.pdf
[35] J. Weiss, R. Hledik, R. Lueken, T. Lee, and W. Gorman, "The electrification accelerator: Understanding the implications of autonomous vehicles for electric utilities," *The Electricity Journal*, vol. 30, no. 10, pp. 50-57, 2017.
[36] ICAP (International Carbon Action Partnership), "Emissions trading worldwide: Status report 2021," Berlin: International Carbon Action Partnership, 2021.
[37] IEA (International Energy Agency). (2020). China's emissions trading scheme: Designing efficient allowance allocation. [Online]. Available: https://webstore.iea.org/china-emissions-trading-scheme
[38] C. Cassisa, X. S. Chen, I. Handschuc, D. Zhang, and H. Y. Zhang. (2021). The role of China's ETS in power sector decarbonisation. International Energy Agency (IEA) & Tsinghua University. [Online]. Available: https://www.iea.org/reports/the-role-of-chinas-ets-in-power-sector-decarbonisation
[39] R. M. Henderson. (2021). Interview by Roland Berger Institute. [Online]. Available: https://www.rolandberger.com/en/Insights/Publications/Sustainarama-How-sustainability-will-change-the-world-in-2050.html
[40] J. J. Zhang, D. H. Liu, S. J. Liu, F. Y. Wang, P. Y. Wang, Z. X. Wang, and H. Q. R. Xia. (2019). Economic analysis of China's carbon pricing design: Policy recommendation report. [Online]. Available: https://www.efchina.org/Reports-zh/report-lceg-20190804-zh
[41] L. Goulder, X. L. Long, J. Y. Lu, and R. D. Morgenstern. (2020). China's unconventional nationwide CO_2 emissions trading system: The wide-ranging impacts of an implicit output subsidy. [Online]. Available: https://www.rff.org/documents/2331/RFF_WP_20-02.pdf.
[42] W. Q. Zhang, X. Y. Wu, and J. W. Zhang. (2021). Development trend of renewable energy under the "3060" carbon peak & neutrality goal - internal drive and interdisciplinary solution. Green Peace. [Online]. Available: http://www.greenpeace.org.cn/re-development-trend-report-20210517
[43] Jager *et al*. (2011). Financing renewable energy in the European energy market. European Commission, DG Energy.
[44] O. Bäte and L. Subran, "Asset owners can turbocharge China's journey to carbon neutrality," *Allianz,* 2021.
[45] The State Council Information Office of the P. R. China. (2020). China's energy development in the new era. [Online]. Available: http://www.scio.gov.cn/zfbps/32832/Document/1695117/1695117.htm
[46] The National Energy Administration of China (2021). The guiding opinions on energy work in 2021. [Online]. Available: http://www.nea.gov.cn/2021-04/22/c_139898478.htm
[47] J. Ma. (2021). Improve the green financial system with the goal of carbon neutrality. [Online]. Available: http://greenfinance.org.cn/displaynews.php?cid=77&id=3088
[48] M. C. Sun, Y. Xia, C. Liu, and J. M. Li. (2021). The path and method to realize carbon neutrality of China financial institutes. Haitong International Corporation. [Online]. Available: https://www.163.com/dy/article/G75LRRLG0519IGF7.html
[49] C. Bayley and S. French, "Designing a participatory process for stakeholder involvement in a societal decision," *Group Decision & Negotiation*, vol. 17, no. 3, pp. 195-210, 2008.
[50] S. Gustafsson, J. Ivner, and J. Palm, "Management and stakeholder participation in local strategic energy planning — Examples from Sweden," *Journal of Cleaner Production*, vol. 98, pp. 205-212, 2015.

Kun Kong has been admitted to the degree of master of science in green technology (energy) (merit) by the Hong Kong Baptist University in 2020, China, and the degree of bachelor of business administration (honours) (finance) by the Hong Kong Baptist University in 2019, China. The major field of his study is sustainable development.

He is the assistant instructor in the Division of Business and Management of BNU-HKBU United International College. His research interests include the carbon emissions and climate change, renewable energy strategies, business sustainability, and corporate social responsibility.

Minyu Wu has got the Ph.D. in management by the Massey University, New Zealand; and the master of management by the Massey University, New Zealand. The major field of his study is sustainability.

He is the assistant professor and the program director of Finance in the Division of Business and Management of BNU-HKBU United International College. His research interests include the corporate sustainability, corporate social responsibility, strategic management, and corporate governance.



Nan Kong has achieved master of science in finance from the International School of Management, Germany (2017-2019); and master of art in journalism in Peking University, China (2012-2014). The major field of her study is public management.

She is currently working at Jinan University as a college teacher. She also has four years' working experience in government, consulting company and media industry in Germany and China.