Trends in Agricultural Energy System

Subjects: Agricultural Engineering
Contributor: Feifei Yang

Agricultural energy system is a typical integrated cooling, heating and power system.

Keywords: agricultural energy ; photovoltaic ; bioenergy ; micro energy grid

1. Introduction

Agricultural energy system is a typical integrated cooling, heating and power system. The air temperature, soil moisture, light intensity and other facility agricultural environment elements are maintained by integrated cooling, heating and power systems. Carbon dioxide from energy production can feed crops and this carbon cycle is called carbon rich agriculture. Compared with residential and building energy systems, the integration of cold, heat, electricity and gas in agriculture is more obvious. The agricultural energy system is an important scenario for the application of an integrated cooling, heating and power system (ICHPS). ICHPS can be used to adjust the thermal environment of facility agriculture and electricity systems can adjust the water and light environment of facility agriculture. Currently, agricultural production consumes 70% of the freshwater resources and 30% of the available energy on Earth [1][2]. Around the world, Israel, the United States and the Netherlands are in the leading positions in the field of agricultural energy, while China is in the development stages. Agricultural water-saving irrigation technology in Israel, biomass power generation in the United States and greenhouse horticulture technology in the Netherlands accelerate the development of agricultural energy systems. Some studies predict that by 2025, the agricultural energy consumption in China will reach 1616.1 million tons of standard coal, approximately twice the value recorded in 2016 [3]. The proportion of energy consumed by various agricultural activities also differs in different regions. Agricultural mechanical equipment is the main source of agricultural energy consumption in China, whereas fertilizer application accounts for the largest proportion of agricultural energy consumption in Iran [4], Pakistan [5] and India (approximately 50%) [6]. The energy consumed by product processing accounts for 51.14% of the total energy consumption in Brazil; agricultural mechanical equipment, fertilizer and diesel have the greatest contributions to the total energy consumption in Turkey [7]; and agricultural machinery and their maintenance consume larger amounts of energy in developed countries such as the United States and the United Kingdom [8]. With respect to developed countries, such as the United States and the Netherlands, agricultural machinery accounts for the largest proportion of energy consumption due to the high level of domestic mechanization. With respect to developing countries, such as Pakistan and India, fertilizer application and other sources of energy consumption account for the largest proportion. With respect to China, the energy consumed by agricultural machinery accounts for the highest proportion due to the vigorous introduction of advanced technologies from developed countries.

With prominent problems such as population growth, resource shortages and environmental change, sustainable development has become the focus of countries all over the world and agricultural sustainability has also attracted increasing attention [9]. By analyzing agricultural energy consumption, the existing schemes are able to evaluate agricultural sustainability [10], which will improve our understanding of the sustainability of agricultural development. Various agricultural activities, such as agricultural production, harvesting, processing, storage and sales, are accompanied by energy consumption, which substantially increases the consumption of energy in the form of fossil fuels [11][12] and carbon dioxide emissions [13]. Although an increase in agricultural energy consumption may improve agricultural production and exerts a positive effect on agriculture, the process of agricultural energy consumption also exerts a negative effect on social development and the natural environment [14]. In recent years, the problems caused by agricultural energy consumption have received increasing attention [15] and countries are also trying to reduce the negative effects of agricultural energy consumption by reducing greenhouse gases (GHG, which contains carbon dioxide, methane and nitrous oxide) emissions [16]. Most studies examining the effects of agricultural energy consumption analyze agricultural energy consumption from the perspectives of the environment and economy.

From the perspective of the environment, the rapid increase in energy consumption following development in all areas of life has led to an increase in GHG emissions, producing a series of environmental problems, such as the greenhouse effect, groundwater recession, biodiversity loss, soil pollution and water pollution [17]. The negative effect of energy consumption on the ecological environment is becoming increasingly serious [18]. Rodriguez et al. [19] investigated six environmental evaluation models and found that the ecological model was the most suitable approach for an agricultural environmental assessment, because it helped assess the environmental impact of agricultural energy consumption. Activities related to agricultural energy consumption, such as crop planting, livestock breeding and aquatic product fishing [20][21], all emit carbon dioxide and thus agricultural energy consumption is also positively correlated with carbon dioxide emissions. Using the logarithmic mean Divisia index (LMDI) to analyze the change in agricultural carbon dioxide emissions in China [22], provinces in eastern China were shown to have a developed economy and advanced agricultural technology, while the central and western provinces were behind in terms of agricultural technology. Therefore, the central and western provinces of China generally lag behind the eastern provinces in terms of agricultural energy consumption and carbon dioxide emissions [23]. Due to the excessive use of modern agricultural technology and fertilizer in China and the low fertilizer utilization rate, the environmental pollution in China is higher than in ordinary developing countries and much higher than in developed countries such as the United States.

From the perspective of the economy, an analysis of the energy costs of the four agricultural subsections in China revealed that planting and forestry have a positive impact on peasants' income, while animal husbandry and fishery have a negative impact on peasants' income [24]. By analyzing agricultural energy costs worldwide, irrigation water and fertilizer input account for a large proportion of the total agricultural energy costs in various countries [25]. Some scholars have recently established models to predict energy costs of agricultural machinery [26], but the cost predicting other agricultural activities must be improved. If a cost forecasting model can be established for each stage of agricultural activities to achieve an accurate cost prediction, it will help to adjust the proportion of agricultural energy input to the least energy input, obtain the greatest economic benefit and reduce agricultural energy costs. According to the current status of China, data from the National Bureau of Statistics showed that the proportions of agricultural energy consumption in 2015, 2016 and 2017 were approximately 1.915%, 1.96% and 1.99%, respectively [27]. The proportion of agricultural energy consumption continues to increase in China and the agricultural energy input is also increasing. With the increase in renewable energy production, many studies have proposed to reduce the investment of non-renewable energy in agriculture by incorporating mature renewable energy power generation technologies, such as solar and wind power generation [28][29][30][31]. Partial replacement of fossil fuels with renewable energy [32] will not only produce substantial economic benefits but also help reduce GHG [33] and carbon emissions [34]. Econometric techniques were used to analyze agricultural data from the top 12 EU countries [35] and Iran [36] and agricultural energy consumption generally had a negative impact on agricultural economic benefits. Compared with developed countries, a large part of China is still in a traditional agricultural stage and thus the agricultural economic benefits lag far behind the developed countries.

From the perspective of energy, the key problems in the development of modern agriculture in China are listed below: (1) The first problem is environment-energy-food collaborative security. The industry barrier between energy and agriculture is one of the bottleneck problems hindering the environment–energy–food collaborative security. (2) Another problem is the insufficient driving force for agricultural production. Insufficient investments in fixed assets and high energy costs are bottleneck problems hindering the development of large-scale agriculture. (3) Finally, intensification and large-scale agricultural production are problems. The low-level informatization and automation is one of the bottleneck problems hindering the development of agricultural clusters.

Currently, China is developing agricultural energy internet technology to solve these problems: (1) Key technologies for deep coupling optimization of heterogeneous energy and agricultural production, such as concentration photovoltaic and diffraction interferometry, agricultural textile power generation technology, etc., are being developed. These technologies will break barriers between the existing energy and agricultural systems, achieve the synergy of agriculture and energy, promote the development of clean energy and reduce environmental pollution. (2) The engineering mode of the integration of new energy and modern agriculture, such as agriculture–solar hybrid, fishery–solar hybrid, etc., has been proposed to break the barriers between the existing energy and agricultural industries, achieve the cross-border integration of "internet + energy + agriculture", promote the large-scale operation of agricultural production with a new industrial mode, stimulate agricultural production investments and promote the development of agricultural scale and economy. (3) The Internet of Things (IoT) and artificial intelligence technology (AIT) have been introduced to promote intelligent agricultural production, gradually achieve the integration of IoT in agriculture and power systems, stimulate the development of agricultural production in terms of scale, cluster and intelligence and promote the transformation and upgrading of agricultural clusters.

2. Wind Power for Agriculture

Foreign scholars actively conducted projects that combine crop production and wind power generation [36][37]. Due to the limitations of wind power in agriculture [25], some studies tried to combine it with other renewable energy sources to meet demand [38][39]. The research status of wind power for agriculture in China is introduced as follows. According to Feng et al. [34], improvements in the utilization rate of agricultural land increase the wind energy potential of China by approximately 36.8%. The most abundant wind power is located in Northwest China and the population is concentrated in the southeast, but abundant agricultural land is available in the east that could be used. The development of agricultural wind power in China is valuable and feasible. Through simulation, optimization, technical and economic analyses, the most economical and reliable configuration scheme of an off-grid hybrid power system in remote rural areas was as follows: 104 kW photovoltaic modules, three 10 kW wind turbines, a 50 kW biogas fuel diesel generator (BDG), a 331 kW battery and a 99 kW converter. The annual energy production was approximately 322 MWh, which made the village independent of the main power grid and supplied power to users at a reasonable cost of $0.201/kWh [35]. The combination of photovoltaic and wind power generation is suitable for agricultural development in off-grid areas of China. In summary, China does not currently maximally exploit wind power in agriculture, with a small installed capacity and low technical level, which has great potential for development. Some practices in the United States and other developed countries in the development of wind power, such as wind power agriculture, power netlist, etc., are at the leading level of the world and China should learn these techniques.

3. Solar Energy for Agriculture

The application of solar energy in agriculture is a research hotspot and one of the important ways to promote low-carbon agricultural production. At present, foreign scholars carried out a series of research on the problems and advantages of the application of solar greenhouse [40], solar air heater [41] and greenhouse coverage materials [42][43]. The research status of photovoltaic agriculture in China is initially introduced. Li et al. [44] mainly studied the social impact of a photovoltaic greenhouse. The survey showed that photovoltaic greenhouse would provide jobs and increase taxes. Most photovoltaic agriculture was designed to place photovoltaic panels on farmland or greenhouses. When simultaneously considering photovoltaic power generation and agricultural production, the more important factor was that they would be promoted without affecting the other process, rather than simply combining them. Many studies have investigated methods to improve power generation efficiency without affecting crop growth. Domestic scholars have used the principle of light for technological transformation. Wu et al. [45] designed a photovoltaic greenhouse system using biconvex Fresnel lens for photovoltaic power generation and storing the residual heat of solar energy in water. The photovoltaic cells of this system were not placed on the top of the greenhouse, no shading problem occurred and the Fresnel lens did not absorb the scattered light from the sun; thus, the scattered light was still able to be used for plant growth. In addition, some scholars considered not installing photovoltaic panels on farmland or greenhouses, but installed floating photovoltaic panels on the water, namely, floating photovoltaic panels. Zhou et al. [46] used floating photovoltaic power and hydropower generation in a complementary operation and considered the maximization of the ratio of water storage to storage capacity and water supply to water demand to improve the water-food-energy synergy. In some areas of China, the high sunlight intensity at noon produces an excessively high temperature in the greenhouse. From the perspective of reducing the temperature in the greenhouse while generating electricity, the solar shading by photovoltaic panels is an advantage that may be exploited in some areas with a high sunlight intensity. Feng et al. [47] developed a new type of solid composite parabolic concentrator as a transparent covering material for greenhouses that reduces the light transmittance at noon and the unobstructed light is used for photovoltaic power generation. Numerous agricultural photovoltaic power generation industries market their own products. China has applied photovoltaic power generation to many aspects of agricultural production. Xue et al. [48] described the use of photovoltaic power generation for wastewater purification and pumping agricultural water; a mode of “power generation and aquaculture” using the agricultural environments such as greenhouses and fishponds, was also shown to generate electricity, plant and breed at the same time. Liu et al. [49] matched photovoltaic power generation with movable sprinkler irrigation equipment (SMSIE), which saved both water and energy. Li et al. [50] used a solar water pumping system to simultaneously solve the energy crisis and water crisis and increased the crop yield in developing countries far away from the grid. Studies have also examined the combination of photovoltaic power generation and solar heat collection for bee breeding in China. He et al. [51] proposed a new type of solar beehive system. The system used the solar collector to heat beehives and solar photovoltaic power generation to drive a fan to cool beehives, ensuring that the beehives would maintain a better thermal environment and thus improve the yield and quality of honey. Photovoltaic power generation not only directly provides electric energy but also electrolyzes water to produce hydrogen with the generated electricity. Anifantis et al. [52] proposed a system that used the generated electricity to electrolyze water and produce hydrogen during the day and then converted hydrogen into electricity to provide energy for a ground source heat pump (GSHP) using fuel cells at night, thereby heating the greenhouse. The disadvantage was that the system was substantially affected by climate and the efficiency was only 11%. Photovoltaic agriculture involves both power generation and heat storage. Cao et al. [53] mentioned the use of photovoltaic heat storage to provide heat energy for a greenhouse in winter or at night to prevent crop frostbite. Photovoltaic agriculture in China is often combined with irrigation and pump water for several reasons. First, China is a large agricultural country, but it is also a country with a water shortage. The amount of water consumed by agriculture, which requires a large amount water resources, can be reduced by improving the utilization rate of irrigation water. Second, irrigation and pump water are closely related to agriculture and photovoltaics are closely related to agriculture because of the requirement for land. The combination of photovoltaics, irrigation and pump water adapts to the trend of combining agriculture and energy. Third, photovoltaic power generation is mostly suitable for areas far away from the grid, such as arid areas in Northwest China, which often have a limited water supply. The combination of photovoltaic, pumping and irrigation systems will not only solve the problem of power generation in these areas but also reduce the waste of water resources to achieve an optimal situation. Fourth, photovoltaic power generation is characterized by its intermittent nature, which exerts a very adverse effect on the stability of the power grid, while the irrigation and pumping system can be used as buffer to improve the stability of power grid. In the long term, the development of photovoltaic agriculture is very important for the agricultural transformation of China; in the short term, photovoltaic agriculture is an effective measure to solve the current plight of the photovoltaic industry in China to some extent.

4. Biomass Energy for Agriculture

The demand for crop residues should not affect food production due to the trends in bioenergy and crops should be planted for food production rather than energy [54]. The research status of agricultural biomass energy in China is initially introduced. Amaducci et al. [55] comprehensively evaluated the biomass energy potential of China. In 2016, the total potential of biomass energy resources in China reached 32.69 EJ, which is equivalent to 27.6% of the domestic energy consumption and the development of biomass energy substantially reduced emissions in China. The available biomass energy of Heilongjiang Province doubled from 2003 to 2013 and it was very important to strengthen the regional practice of water resource management and irrigation in agricultural systems for the effective utilization of agricultural biomass resources [56]. This study confirmed the potential of developing biomass energy in China. Liu et al. [57] discussed the relevant policies on biomass energy and the future trends in biomass energy in China. Guan et al. [58] analyzed the current status and industrial policy of biomass briquette in China and discussed the problems and challenges in the standard system, legislation, development plan, incentive policy and other aspects of the biomass briquette industry. This study was related to the development of a policy for biomass energy regulation. Sun et al. [59] established the mechanism for supplying crop residues and the value-added process model. Monte Carlo and risk tolerance methods were used to explore the interactions among the transportation cost rate, unit cost of crop residues, basic price of crop residue sales and coal price, which provided a reference for feasibility planning and policy making related to biomass energy projects in China. Wang et al. [60] proposed that the direct economic cost of straw power generation was 0.45 yuan/kwh, of which 89% was attributed to fuel purchase and transportation costs. Compared with coal power generation, its economic competitiveness was at a disadvantage, but coupled with external costs, it was at an advantage. The price of biomass waste was the most sensitive factor affecting the economic benefits of biomass power generation. This paper mainly expounded on the development of biomass energy in China from the perspective of the economy. Wei et al. [61] summarized five stages of agricultural waste energy utilization in China and indicated that agricultural waste utilization in China was changing from planting wastes to breeding wastes.

Many studies have examined agricultural biomass energy technologies related to biomass gasification in China that produces hydrogen, methane, ethanol and other clean gases and strives to improve the gas production rate. Dai et al. [62] studied the effects of straw ingredients and surface properties on biogas production. The methane production potential of typical straw ranked as follows: corn > wheat > sweet sorghum > rice straw. The mineral composition of straw was closely related to methane production and silicon inhibited the production of methane from straw. These results provided theoretical support for improvements in the gas generation rate of agricultural wastes. Hydrogen and methane were recovered in a two-stage biological process using the waste residue from bioethanol fermentation as materials. The COD removal rate reached up to 81% and 0.3% H2 and 72.8% CH4 were converted. The process improved the energy utilization rate through secondary utilization and produced more clean gas [63]. The feasibility of a low temperature alkali/urea pre-treatment of rice straw to improve the hydrogen production rate was studied. After the pre-treatment, the maximum hydrogen production was 22.08 mmol/L and the energy transformation ratio was 9.76%. Compared with the control group without the pre-treatment, these parameters were increased by 161.92% and 56.91%, respectively [64]. Most studies of biomass technology in China have focused on biomass gasification technology, while biomass briquettes and other related technologies that utilize biomass energy have rarely been investigated, which is also a limitation of the development of agricultural biomass energy in China.

References

1. Cao, X.; Wu, M.; Guo, X.; Zheng, Y.; Gong, Y.; Wu, N.; Wang, W. Assessing Water Scarcity in Agricultural Production System Based on the Generalized Water Resources and Water Footprint Framework. Sci. Total Environ. 2017, 609, 587–597.
2. Zhang, W.; Cao, Y.; Zhu, Y.; Zheng, J.; Ji, X.; Xu, Y.; Wu, Y.; Hoitink, A. Unravelling the Causes of Tidal Asymmetry in Deltas. J. Hydrol. 2018, 564, 588–604.
3. Fei, R.; Lin, B. Energy Efficiency and Production Technology Heterogeneity in China's Agricultural Sector: A Meta-Frontier Approach. Technol. Forecast. Soc. Chang. 2016, 109, 25–34.
4. Mostashari-Rad, F.; Nabavi-Pelesaraei, A.; Soheilifard, F.; Hosseini-Fashami, F.; Chau, K.W. Energy Optimization and Green-House Gas Emissions Mitigation for Agricultural and Horticultural Systems in Northern Iran. Energy 2019, 186, 115845.
5. Qureshi, M.I.; Awan, U.; Arshad, Z.; Rasli, A.M.; Zaman, K.; Khan, F. Dynamic Linkages Among Energy Consumption, Air Pol-Lution, Greenhouse Gas Emissions and Agricultural Production in Pakistan: Sustainable Agriculture Key to Policy Success. Nat. Hazards 2016, 84, 367–381.
6. Jat, H.; Jat, R.; Nanwal, R.; Lohan, S.K.; Yadav, A.; Poonia, T.; Sharma, P.; Jat, M. Energy Use Efficiency of Crop Residue Management for Sustainable Energy and Agriculture Conservation in NW India. Renew. Energy 2020, 155, 1372–1382.
7. Aydın, B.; Aktürk, D. Energy Use Efficiency and Economic Analysis of Peach and Cherry Production Regarding Good Agricultural Practices in Turkey: A Case Study in Canakkale Province. Energy 2018, 158, 967–974.
8. Talukder, B.; Vanloon, G.W.; Hipel, K.W. Energy Efficiency of Agricultural Systems in the Southwest Coastal Zone of Bangladesh. Ecol. Indic. 2019, 98, 641–648.
9. Agathokleous, E.; Calabrese, E.J. Hormesis Can Enhance Agricultural Sustainability in a Changing World. Glob. Food Secur. 2019, 20, 150–155.
10. Liu, C.; Zhang, Z.; Liu, S.; Liu, Q.; Feng, B.; Tanzer, J. Evaluating Agricultural Sustainability Based on the Water–Energy–Food Nexus in the Chenmengquan Irrigation District of China. Sustainability 2019, 11, 5350.
11. Alam, M.; Murad, W.; Noman, A.H.M.; Ozturk, I. Relationships Among Carbon Emissions, Economic Growth, Energy Consumption and Population Growth: Testing Environmental Kuznets Curve Hypothesis for Brazil, China, India and Indonesia. Ecol. Indic. 2016, 70, 466–479.
12. Tjandra, T.B.; Ng, R.; Yeo, Z.; Song, B. Framework and Methods to Quantify Carbon Footprint Based on an Office Environment in Singapore. J. Clean. Prod. 2016, 112, 4183–4195.
13. Bekhet, H.A.; Othman, N.S. Impact of Urbanization Growth on Malaysia CO2 Emissions: Evidence from the Dynamic Relationship. J. Clean. Prod. 2017, 154, 374–388.
14. Reynolds, T.W.; Waddington, S.R.; Anderson, C.L.; Chew, A.; True, Z.; Cullen, A.C. Environmental Impacts and Constraints Associated with the Production of Major Food Crops in Sub-Saharan Africa and South Asia. Food Secur. 2015, 7, 795–822.
15. Lin, B.; Fei, R. Analyzing Inter-Factor Substitution and Technical Progress in the Chinese Agricultural Sector. Eur. J. Agron. 2015, 66, 54–61.
16. Liu, Q.; Liu, B.; Ambus, P.; Zhang, Y.; Hansen, V.; Lin, Z.; Shen, D.; Liu, G.; Bei, Q.; Zhu, J.; et al. Carbon Footprint of Rice Production Under Biochar Amendment—A Case Study in a Chinese Rice Cropping System. GCB Bioenergy 2016, 8, 148–159.
17. Xue, J.; Huo, Z.; Huang, Q.; Wang, F.; Boll, J.; Huang, G.; Qu, Z. Assessing Sustainability of Agricultural Water Saving in an Arid Area with Shallow Groundwater. Irrig. Drain. 2018, 68, 205–217.
18. Cherni, A.; Jouini, S.E. An ARDL approach to the CO2 Emissions, Renewable Energy and Economic Growth Nexus: Tunisian Evidence. Int. J. Hydrogen Energy 2017, 42, 29056–29066.
19. Rodriguez, C.M.; Rodas, C.F.; Munoz, J.C.; Casas, A.F. A Multi-Criteria Approach for Comparison of Environmental Assessment Methods in the Analysis of the Energy Efficiency in Agricultural Production Systems. J. Clean. Prod. 2019, 228, 1464–1471.

20. Abson, D.J.; Termansen, M.; Pascual, U.; Aslam, U.; Fezzi, C.; Bateman, I. Valuing Climate Change Effects Upon UK Agricultural GHG Emissions: Spatial Analysis of a Regulating Ecosystem Service. Environ. Resour. Econ. 2014, 57, 215–231.
21. Glenk, K.; Eory, V.; Colombo, S.; Barnes, A. Adoption of Greenhouse Gas Mitigation in Agriculture: An Analysis of Dairy Farmers' Perceptions and Adoption Behavior. Ecol. Econ. 2014, 108, 49–58.
22. Pan, H.; Liu, Y.; Gao, H. Impact of Agricultural Industrial Structure Adjustment on Energy Conservation and Income Growth in Western China: A Statistical Study. Ann. Oper. Res. 2012, 228, 23–33.
23. Tieppo, R.C.; Romanelli, T.L.; Milan, M.; Sorensen, C.A.; Bochtis, D. Modeling Cost and Energy Demand in Agricultural Machinery Fleets for Soybean and Maize Cultivated Using a No-Tillage System. Comput. Electron. Agric. 2019, 156, 282–292.
24. National Bureau of Statistics. China Statistical Yearbook; China Statistics Press: Beijing, China, 2018.
25. Kocaman, A.S.; Ozyoruk, E.; Taneja, S.; Modi, V. A Stochastic Framework to Evaluate the Impact of Agricultural Load Flexibility on the Sizing of Renewable Energy Systems. Renew. Energy 2020, 152, 1067–1078.
26. Wu, J.; Ge, Z.; Han, S.; Xing, L.; Zhu, M.; Zhang, J.; Liu, J. Impacts of Agricultural Industrial Agglomeration on China's Agri-Cultural Energy Efficiency: A Spatial Econometrics Analysis. J. Clean. Prod. 2020, 260, 121011.
27. Chau, J.; Sowlati, T.; Sokhansanj, S.; Preto, F.; Melin, S.; Bi, X. Economic Sensitivity of Wood Biomass Utilization for Green-House Heating Application. Appl. Energy 2009, 86, 616–621.
28. Qiao, H.; Zheng, F.; Jiang, H.; Dong, K. The Greenhouse Effect of the Agriculture-Economic Growth-Renewable Energy Nexus: Evidence From g20 Countries. Sci. Total. Environ. 2019, 671, 722–731.
29. Zorrilla-Munoz, V.; Petz, M.; Agullo-Tomas, M.S. GARCH Model to Estimate the Impact of Agricultural Greenhouse Gas Emissions per Sociodemographic Factors and Cap in Spain. Environ. Dev. Sustain. 2021, 23, 4675–4697.
30. Ridzuan, N.H.A.M.; Marwan, N.F.; Khalid, N.; Ali, M.H.; Tseng, M.-L. Effects of Agriculture, Renewable Energy, and Economic Growth on Carbon Dioxide Emissions: Evidence of the Environmental Kuznets Curve. Resour. Conserv. Recycl. 2020, 160, 104879.
31. Zhang, L.; Pang, J.; Chen, X.; Lu, Z.M. Carbon Emissions, Energy Consumption and Economic Growth: Evidence from the Agricultural Sector of China's Main Grain-Producing Areas. Sci. Total Environ. 2019, 665, 1017–1025.
32. Martinho, V.J. Energy Consumption Across European Union Farms: Efficiency in Terms of Farming Output and Utilized Agricultural Area. Energy 2016, 103, 543–556.
33. Raeeni, A.A.; Hosseini, S.; Moghaddasi, R. How Energy Consumption Is Related to Agricultural Growth and Export: An Econometric Analysis on Iranian Data. Energy Rep. 2019, 5, 50–53.
34. Feng, J.; Feng, L.; Wang, J.; King, C.W. Evaluation of the Onshore Wind Energy Potential in Mainland China—Based on GIS Modeling and EROI Analysis. Resour. Conserv. Recycl. 2020, 152, 104484.
35. Li, J.; Liu, P.; Li, Z. Optimal Design and Techno-Economic Analysis of a Solar-Wind-Biomass off-Grid Hybrid Power System for Remote Rural Electrification: A Case Study of West China. Energy 2020, 208, 118387.
36. Scarcioffolo, A.R.; Perobelli, F.F.; Chimeli, A.B. Counterfactual Comparisons of Investment Options for Wind Power and Agri-Cultural Production in the United States: Lessons from Northern Ohio. Energy Econ. 2018, 74, 299–309.
37. VanderWende, B.; Lundquist, J.K. Could Crop Height Affect the Wind Resource at Agriculturally Productive Wind Farm Sites? Bound. Layer Meteorol. 2016, 158, 409–428.
38. Rehman, S.; Sahin, A.Z. Wind-Solar PV Hybrid Power System with Battery Backup for Water Pumping in Remote Localities. Int. J. Green Energy 2012, 13, 1075–1083.
39. Mostafaeipour, A.; Rezaei, M.; Moftakharzadeh, A.; Qolipour, M.; Salimi, M. Evaluation of Hydrogen Production by Wind en-Ergy for Agricultural and Industrial Sectors. Int. J. Hydrogen Energy 2019, 44, 7983–7995.
40. Mekhilef, S.; Faramarzi, S.Z.; Saidur, R.; Salam, Z. The Application of Solar Technologies for Sustainable Development of Agricultural Sector. Renew. Sustain. Energy Rev. 2013, 18, 583–594.
41. Tyagi, V.; Panwar, N.; Rahim, N.; Kothari, R. Review on Solar Air Heating System with and Without Thermal Energy Storage System. Renew. Sustain. Energy Rev. 2012, 16, 2289–2303.
42. Fabrizio, E. Energy Reduction Measures in Agricultural Greenhouses Heating: Envelope, Systems and Solar Energy Collection. Energy Build 2012, 53, 57–63.
43. Chaysaz, A.; Seyedi, S.R.; Motevali, A. Effects of Different Greenhouse Coverings on Energy Parameters of a Photovolta-IC–Thermal Solar System. Sol. Energy 2019, 194, 519–529.

44. Li, C.; Wang, H.; Miao, H.; Ye, B. The Economic and Social Performance of Integrated Photovoltaic and Agricultural Green-Houses Systems: Case Study in China. Appl. Energy 2017, 190, 204–212.

45. Wu, G.; Yang, Q.; Zhang, Y.; Fang, H.; Feng, C.; Zheng, H. Energy and Optical Analysis of Photovoltaic Thermal Integrated with Rotary Linear Curved Fresnel Lens Inside a Chinese Solar Greenhouse. Energy 2020, 197, 117215.

46. Zhou, Y.; Chang, F.; Chang, L.; Lee, W.D.; Huang, A.; Xu, C.; Guo, S. An Advanced Complementary Scheme of Floating Pho-Tovoltaic and Hydropower Generation Flourishing Water-Food-Energy Nexus Synergies. Appl. Energy 2020, 275, 115389.

47. Feng, C.; Zheng, H.; Wang, R. Development of Transparent Greenhouse Cover with Function of Generating Electricity by Surplus Light and Photovoltaic. Trans. Chin. Soc. Agric. Eng. 2014, 30, 135–141.

48. Xue, J. Photovoltaic Agriculture—New Opportunity for Photovoltaic Applications in China. Renew. Sustain. Energy Rev. 2017, 73, 1–9.

49. Liu, K.; Wu, P.; Zhu, D.; Dai, W.; Li, D.; Cai, S. Design and Test of Driving Power and Photovoltaic Power Matching for So-Lar-Driven Sprinkler Irrigation Unit. Trans. Chin. Soc. Agric. Eng. 2017, 33, 96–103.

50. Li, G.; Jin, Y.; Akram, M.; Chen, X. Research and Current Status of the Solar Photovoltaic Water Pumping System—A Review. Renew. Sustain. Energy Rev. 2017, 79, 440–458.

51. He, W.; Zhang, S.; Hu, Z.; Zhang, J.; Liu, X.; Yu, C.; Yu, H. Field Experimental Study on a Novel Beehive Integrated With Solar Thermal/Photovoltaic System. Sol. Energy 2020, 201, 682–692.

52. Anifantis, A.S.; Colantoni, A.; Pascuzzi, S. Thermal Energy Assessment of a Small Scale Photovoltaic, Hydrogen and Geothermal Stand-Alone System for Greenhouse Heating. Renew. Energy 2017, 103, 115–127.

53. Cao, K.; Xu, H.; Zhang, R.; Xu, D.; Yan, L.; Sun, Y.; Xia, L.; Zhao, J.; Zou, Z.; Bao, E. Renewable and Sustainable Strategies for Improving the Thermal Environment of Chinese Solar Greenhouses. Energy Build. 2019, 202, 109414.

54. Ferrari, G.; Pezzuolo, A.; Nizami, A.-S.; Marinello, F. Bibliometric Analysis of Trends in Biomass for Bioenergy Research. Energies 2020, 13, 3714.

55. Amaducci, S.; Yin, X.; Colauzzi, M. Agrivoltaic Systems to Optimise Land Use for Electric Energy Production. Appl. Energy 2018, 220, 545–561.

56. Wang, W.; Ouyang, W.; Hao, F.; Liu, G. Temporal-Spatial Variation Analysis of Agricultural Biomass and Its Policy Implication as an Alternative Energy in Northeastern China. Energy Policy 2017, 109, 337–349.

57. Liu, D.; Liu, M.; Xiao, B.; Guo, X.; Niu, D.; Qin, G.; Jia, H. Exploring Biomass Power Generation's Development Under en-Couraged Policies in China. J. Clean. Prod. 2020, 258, 120786.

58. Guan, Y.; Tai, L.; Cheng, Z.; Chen, G.; Yan, B.; Hou, L. Biomass Molded Fuel in China: Current Status, Policies and Suggestions. Sci. Total. Environ. 2020, 724, 138345.

59. Sun, J.; Chen, J.; Xi, Y.; Hou, J. Mapping the Cost Risk of Agricultural Residue Supply for Energy Application in Rural China. J. Clean. Prod. 2011, 19, 121–128.

60. Wang, C.; Zhang, L.; Zhou, P.; Chang, Y.; Zhou, D.; Pang, M.; Yin, H. Assessing the Environmental Externalities for Biomass-and Coal-Fired Electricity Generation in China: A Supply Chain Perspective. J. Environ. Manag. 2019, 246, 758–767.

61. Wei, J.; Liang, G.; Alex, J.; Zhang, T.; Ma, C. Research Progress of Energy Utilization of Agricultural Waste in China: Bibliometric Analysis by Citespace. Sustainability 2020, 12, 812.

62. Dai, X.; Hua, Y.; Liu, R.; Chen, S.; Li, H.; Dai, L.; Cai, C. Biomethane Production by Typical Straw Anaerobic Digestion: Deep Insights of Material Compositions and Surface Properties. Bioresour. Technol. 2020, 313, 123643.

63. Cheng, H.-H.; Whang, L.-M.; Chung, M.-C.; Chan, K.-C. Biological Hydrogen and Methane Production from Bagasse Bioethanol Fermentation Residues Using a Two-Stage Bioprocess. Bioresour. Technol. 2016, 210, 49–55.

64. Dong, L.; Cao, G.; Zhao, L.; Liu, B.; Ren, N. Alkali/Urea Pretreatment of Rice Straw at Low Temperature for Enhanced Biological Hydrogen Production. Bioresour. Technol. 2018, 267, 71–76.