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A Systematic Literature Review on Performance Evaluation of Power System From the Perspective of Sustainability

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Sustainability is a comprehensive concept that integrates at least three dimensions of environment, economy and society. The power system is the primary source of greenhouse gas emissions, adversely impacting environmental sustainability. It also generates necessary energy supplies, which promote economic and social sustainable development. Based on the sustainability nature of power system, this study puts forward an improved methodology, namely "Planning-Searching-Screening-Reporting-Reflecting" (PSSRR Cycle) to review the literature systematically on power system performance evaluation from a sustainability perspective over the past 20 years, with the aim of describing the current state of the whole performance evaluation system including the evaluation framework, evaluation indicators and evaluation methods, and providing research suggestions for future research. This study finds in the current literature that the Triple Bottom Line theory is the most commonly used theoretical evaluation framework; environmental and economic sustainability indicators are more emphasized; the DEA and MCDM methods are the more common evaluation methods. This study presents some future research notes, including improving the Sustainable Balanced Scorecard as a sustainable performance evaluation framework, emphasizing more social sustainability indicators, and using a combination of existing evaluation methods to make performance evaluation more efficient and accurate.

Keywords: sustainability, performance evaluation, power system, systematic review, evaluation framework, evaluation indicators, evaluation methods

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1 INTRODUCTION

Driven by the deteriorating ecological environment, social change, and the attendant public interest, sustainability is becoming a key topic of discussion among the general public, governments, enterprises and academic scholars. There are many definitions of sustainability, among which one of the most widely accepted preliminary definitions was presented in the 1987 United Nations report "Our Common Future," namely, "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED, 1987). Since then, many dimensions of sustainability have been developed and discussed. In the late 1990s, the British scholar Elkington coins the phrase Triple Bottom Line (TBL), which measures sustainability by integrating the three dimensions of economic, environmental and social sustainability. That is, organizations pursuing their development require balanced development in economic prosperity, environmental protection and social welfare (Elkington, 1997). The first dimension of sustainability is about the environment. Since the 1980s, environmental issues have become crucial to global sustainable development. Goodland (1995) puts forward the term environmental sustainability to refer to protecting human well-being by conserving natural resources and ensuring that the capacity to deal sustainably with human waste products is not exceeded. Diesendorf (2000) also states that environmental sustainability means that natural resources must be not harvested faster than regenerated. The second dimension of sustainability is about society. Social sustainability includes the concepts of equity, empowerment, accessibility, participation, cultural identity and institutional stability (Daly, 1992). Saith (2006) argues that appropriate healthcare, education, gender equality, peace, and stability need to be used globally to promote social sustainability. Economic sustainability is the third dimension. Lobo et al. (2015) regard economic sustainability as a system of production that meets current levels of consumption without compromising future demand. Sheth et al. (2011) identify two different aspects of the economic dimension of sustainability, i.e., traditional financial performance and external economic benefits.

Power system has a significant impact on environmental, social and economic sustainability. Firstly, in terms of environmental sustainability, the carbon emission of power system accounts for more than 40% of total global carbon emissions due to over-reliance on fossil energy (Climate Watch, 2021), which has had a massive impact on global climate change. Meanwhile, other gases produced by the power system also cause severe air pollution. For example, coal-fired power plants in China have caused severe pollution, resulting in large amounts of dangerous smog engulfing northern China (Spegele and Abkowitz, 2015). Secondly, as for social sustainability, the value brought by the power system has permeated all aspects of people's social life. Any failure of the power system will profoundly endanger the well-being of people and communities. For example, millions of homes and business entities were left without electricity, making millions of people live in the dark and cold due to a blizzard that devastated Texas in the United States (Tribune, 2021). Thirdly, with regard to economic sustainability, the power system provides the electrical energy necessary for modern economic development. There is also a clear causal relationship between the production and consumption of electricity and the country's economic development and prosperity (Shiu and Lam, 2004; Ayres et al., 2007). Due to the power system's impacts on sustainability and performance management requirements, it is crucial to understand the whole picture of performance evaluation of power system from the sustainability perspective. Therefore, a systematic literature review can be a suitable approach to acquire comprehensive knowledge and critical inspiration on the sustainability performance evaluation system of power system.

The notable difference from previous literature reviews is that this study evaluates existing literature on the performance evaluation system of power systems from three aspects, i.e. evaluation framework, evaluation indicators, and evaluation methods, which compose the whole performance evaluation system of the power system. Although there are a few existing literature reviews on the power system performance evaluation from the sustainable perspective, they only summarize one part of the performance evaluation system of the power system. For example, Wang et al. (2009) focus on an overview of Multi-Criteria Decision Making (MCDM) tools in sustainable energy decision-making. Martín-Gamboa et al. (2017) discuss the combined use of Life Cycle Assessment (LCA) and Data Envelopment Analysis (DEA) methods in the sustainability assessment of power system. Campos-Guzmán et al. (2019) conduct a comprehensive literature review of the sustainability assessment method of renewable energy system over the past decade (2007–2017), which suggest that a methodological framework combining LCA and MCDM is the appropriate method for the sustainability assessment of renewable energy system. Varun I. K. et al. (2009) also review the application of LCA methods for renewable energy generation systems. These above literature reviews make some distinct contributions for summarizing the evaluation methods of performance evaluation system of power systems. However, they are more concerned with the evaluation methods and less concerned with other vital parts of the performance evaluation system of the power system, such as the evaluation framework and evaluation indicators.

Therefore, in this paper, a systematic literature review concerning the whole performance evaluation system of power system, with the aim of describing evaluation framework, evaluation indicators and evaluation methods, has been performed from the sustainability perspective during the past 20 years (2000–2020). This paper presents not only a holistic and systematic literature review to fully understand the current research status on the power system performance evaluation, but it also provides some critical inspiration and discussion for future research on the performance evaluation of the power system.

The rest of the paper is organized as follows with **Section 2** spelling out a new systematic literature review methodology. **Sections 3–5** show some description and discussion on the evaluation framework, evaluation indicators and evaluation methods of the power system's performance evaluation system. **Section 6** presents a critical discussion for future research and a conclusion.

2 RESEARCH METHODOLOGY

This paper adopts a systematic approach to implement the literature review. A systematic literature review is defined as an objective, transparent and complete method (Tranfield et al., 2003; Cook et al., 1997). Precisely, a systematic literature review consists of a thorough search for outstanding contributions to a specific topic, which are assessed and synthesized according to a predefined and precise methodology. A series of specific stages are carefully

FIGURE 1 | The PSSRR Cycle of systematic literature review.

implemented to ensure the validity and reliability of the literature review. Based on the systematic literature analysis framework proposed by Tranfield et al. (2003), we put forward an improved methodology, namely "Planning-Searching-Screening-Reporting-Reflecting" (PSSRR Cycle, as shown in **Figure 1**), with five stages that form an integral logical loop.

2.1 Planning

The first stage of a systematic literature review is to plan. According to the study by Tranfield et al. (2003) and Zhang et al. (2019), we form a review team consisting of three scholars on power system's performance evaluation research and three senior practitioners on power system's performance evaluation and management. The review team define the research questions and solution ideas as follow after three-round discussions:

Q1. What are the current state and the trend of research on the performance evaluation of power system from the sustainability perspective?

This question will be answered through several steps: firstly, the existing literature will be searched by using appropriate keywords and methods in some databases as comprehensive as possible. Secondly, each article will be studied to find some features common to each piece of research literature and considered for inclusion in the thematic analysis. Thirdly, each article will be identified, and the research state of power system's performance evaluation from the sustainability perspective will be summarized. Furthermore, the evaluation framework, evaluation indicators, and evaluation methods for performance evaluation of power system will be critically discussed in detail.

Q2. What are the possible research notes of the power system performance evaluation from the perspective of sustainability in the future?

This question will be resolved according to the answer of the former question. Firstly, after a dedicated thematic analysis, what is valuable about each article (e.g. sustainable relevance, evaluation framework, evaluation indicators and evaluation methods used) will be identified and summarized. Then, after reading all the literature, each member of our review team will bring forward valuable conclusions and discussions from existing studies. Finally, after a consensus consultation of the review team, the different views will be consolidated. Then, some discussions and future research suggestions will be conducted and re-refined to stimulate and support the in-depth future research on the sustainable development of power system.

2.2 Searching

Tranfield et al. (2003) argue that comprehensive, unbiased literature searching is one of the fundamental differences between the traditional literature review and the systematic literature review, which means the literature searching requires considerable time, patience and attention to the details (Bom et al., 2019; Araujo et al., 2020). Our systematic literature searching begins with the identification of search keywords based on the scope of this study. Then, we decide on the searching keywords that were most appropriate for this study.

During the searching stage of this study, we make literature searching from Emerald, ELSEVIER Science Direct, SpringerLink, SCOPUS, JSTOR and Google Scholar, et al. The searching keywords include "performance assessment OR measurement OR evaluation" AND "power system OR energy system OR electricity system" AND "sustainable" which are limited to the article title, keywords and abstract. The searching is extended by using the Boolean search method (*) to identify all different forms of the above keywords. Finally, A total of 105 articles over the last 20 years are collected.

2.3 Screening

Tranfield et al. (2003) point out that the output of the literature searching should be a complete list of articles that is the basis of the literature review. Therefore, we screen those articles that meet all the inclusion criteria specified in the review protocol (Milanesi et al., 2020). More than one author conducts this stage of this systematic review because whether articles should be included or excluded is relatively subjective. The disagreements about the literature screening are discussed and resolved by the review team.

In the screening stage of this study, we carefully screen the articles for in-depth analysis based on our inclusion and exclusion criteria (as shown in **Table 1**). All articles are read carefully by every author. Conference papers, book chapter sections (8 articles), and literature reviews (9 articles) are excluded. Finally, after literature screening, the remaining 88 articles on the power system's performance evaluation are listed in an Excel workbook, which records all papers' data in detail. The searching and screening process can be summarized in the PRISMA flow chart (as shown in **Figure 2**).

Eighty-eight articles are finally identified as shown in **Figure 3**. After a plodding start, research on this topic is generally in a state of growth. Although there are some fluctuations, it is clear that

TABLE 1 | Inclusion and exclusion criteria of the literature.

Aspect	Inclusion criteria	Exclusion criteria
Subject area	Power generation enterprises Power generation technology Power sector/industry Power grid enterprises Power supply chain	Other areas (e.g., Pharmaceutical industry, Steel industry, Construction industry)
Literature type	Journals	Conference papers, Book chapters, Literature reviews
Language	English	Other languages

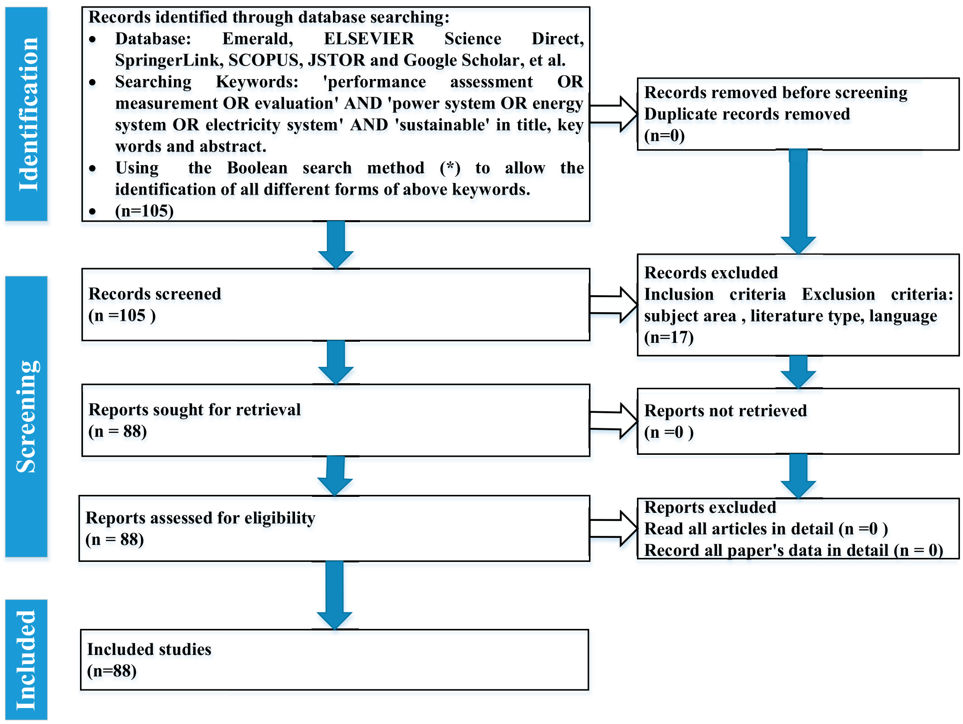

FIGURE 2 | PRISMA flow chart.

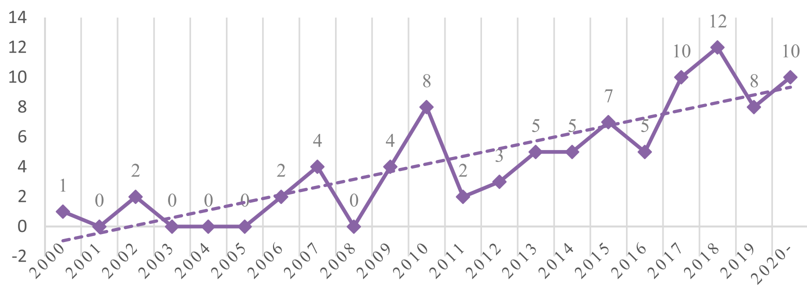

FIGURE 3 | Frequency distribution of publications by years.

academic interest in this issue has increased rapidly over the last few years. We may suggest at least three plausible reasons as follow. Firstly, in the light of the current carbon reduction targets proposed by countries around the world and the profound effect caused by climate change, there is a growing social awareness of the power system as a major source of carbon emission. Secondly,

TABLE 2 | Journals ranked by number of articles.

No.	Journals	Articles
1	Energy	17
2	Energy Policy	12
3	Sustainability	9
4	Renewable and Sustainable Energy Reviews	9
5	Journal of Cleaner Production	8
6	Applied Energy	3
7	Environmental Science and Pollution Research	2
8	Journal of Renewable and Sustainable Energy	2
9	Energy Economics	2
10	Process Safety and Environmental Protection	2
11	Sustainable Production and Consumption	2
12	Nature Communications	1
13	Frontiers in Energy Research	1
14	Renewable Energy	1
15	Journal of Enterprise Information Management	1
16	Energies	1
17	Renewable Energy	1
18	Sustainable Energy Technologies and Assessments	1
19	Processes	1
20	International Journal of Energy Research	1
21	Management of Environmental Quality: An International Journal	1
22	Asian Journal of Water, Environment and Pollution	1
23	Energy Sources, Part B: Economics, Planning, and Policy	1
24	Technological Forecasting and Social Change	1
25	Waste and Biomass Valorization	1
26	Expert Systems with Applications	1
27	International Journal of Green Energy	1
28	International Journal of Hydrogen Energy	1
29	Utilities Policy	1
30	Sustainable Cities and Society	1
31	Operational research	1
Total		88

due to the rapid development of new energy technologies, scholars pay more and more attention to the contribution of technology to the sustainability of power system. Thirdly, the power system has an irreplaceable role in the development of national economies and societies.

Table 2 displays an overview of the articles published by journals. Energy and Energy Policy are the two most published journals on the performance evaluation of power system from the perspective of sustainability, both of which have titles related to energy, consistent with their aim of addressing and discussing

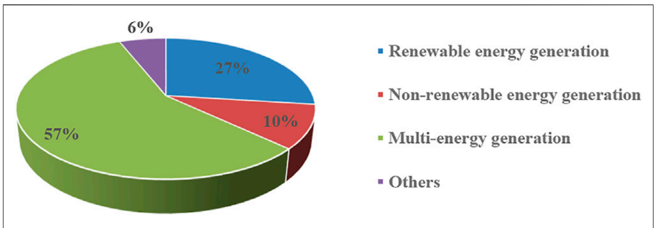

FIGURE 5 | Percentage of energy types studied.

sustainability issues. **Figure 4** illustrates our ranking of the number of specific research subjects within the power system. It can be observed that most of the existing studies focus on the sustainability evaluation of power generation technologies and power generation enterprises, while there are fewer studies on the sustainability evaluation of the power supply chain. **Figure 5** demonstrates the percentage of the screened literature that examines the number of different energy types. It is striking to see that the literature examining the sustainability of power generation from multiple energy sources is more predominant, followed by the literature examining the sustainability of power generation from renewable energy sources separately.

2.4 Reporting

A successful systematic review should produce a clear report which can make the research more accessible to the readers by synthesizing a wide range of original research papers. The report firstly focuses on identifying the key themes and the degree of consensus between these different themes. Furthermore, the report outlines what is already known and established from the existing literature Tranfield et al., 2003; Zhang et al., 2019; Milanesi et al., 2020. In this paper, we synthesize the selected articles so that the core contributions of the different articles. Then, the evaluation framework, evaluation indicators and evaluation methods as the three main themes of the power system's performance evaluation system are discussed in detail.

2.5 Reflecting

Based on the systematic literature analysis framework that Tranfield et al. (2003) proposed, we add a Reflecting stage to form an integral logical loop. There are two parts in this stage as

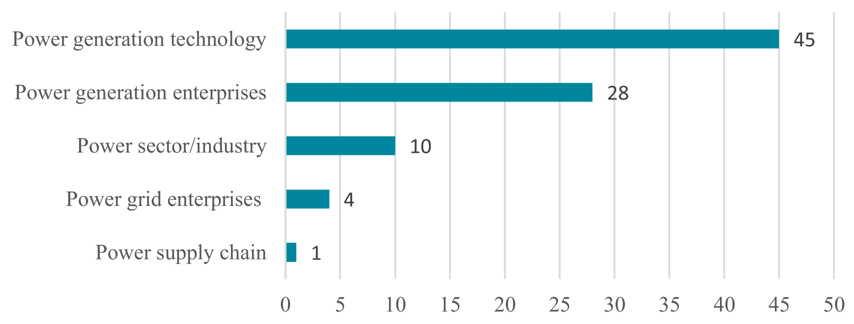

FIGURE 4 | Research subjects ranked by the number of articles.

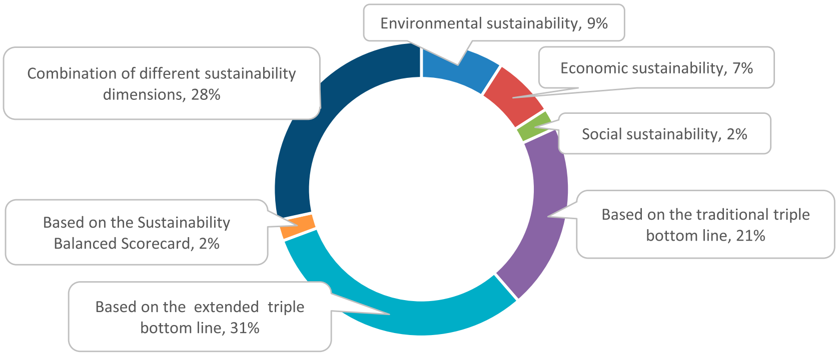

FIGURE 6 | Distribution of the evaluation framework.

TABLE 3 | Summary of these articles using the traditional triple bottom line.

No.	Author	Energy type	Research objects	Traditional TBL
1	Suomalainen and Sharp (2016)	Renewable energy	Power Sector	Economic, environmental, social
2	Khan (2019)	Multiple energy sources	Power Sector	Economic, environmental, social
3	Roinioti and Koroneos (2019)	Multiple energy sources	Power Sector	Economic, environmental, social
4	Atabaki and Aryanpur (2018)	Renewable energy	Power Sector	Economic, environmental, social
5	Tajbakhsh and Hassini (2018)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Economic, environmental, social
6	Akber, Thaheem, and Arshad (2017)	Multiple energy sources	Power Generation Technology	Economic, environmental, social
7	Büyüközkan and Karabulut (2017)	Multiple energy sources	Power Generation Technology	Economic, environmental, social
8	Wang et al. (2016)	Non-renewable energy (fossil fuels)	Power Generation Technology	Economic, environmental, social
9	Atilgan and Azapagic (2016)	Multiple energy sources	Power Generation Technology	Economic, environmental, social
10	Barros et al. (2015)	Multiple energy sources	Power Generation Technology	Economic, environmental, social
11	Santoyo-Castelazo and Azapagic (2014)	Multiple energy sources	Power Generation Technology	Economic, environmental, social
12	Serencam and Serencam (2013)	Renewable energy	Power Generation Technology	Economic, environmental, social
13	Dimitrijevic and Salihbegovic (2012)	Renewable energy	Power Generation Technology	Economic, environmental, social
14	Doukas et al. (2010)	Renewable energy	Power Generation Technology	Economic, environmental, social
15	Genoud and Lesourd (2009)	Multiple energy sources	Power Generation Technology	Economic, environmental, social
16	May and Brennan (2006)	Non-renewable energy (fossil fuels)	Power Generation Technology	Economic, environmental, social
17	Ong et al. (2019)	Multiple energy sources	Power Generation Enterprise	Economic, environmental, social
18	Li et al. (2013)	Renewable energy (wind)	Power Generation Technology	Economic, environmental, social

follow: firstly, reflecting critically on the current research state and the suggestion for future research; and secondly, reflecting on the limitations of this systematic review, with a focus on the comprehensiveness of the literature search and the accuracy of the understanding of the literature.

3 EVALUATION FRAMEWORK

The evaluation framework for performance evaluation refers to the conceptual dimensions of performance. Based on the existing literature, we have divided the evaluation framework into two categories from the sustainability perspective. The one is the evaluation framework with a single sustainability dimension, such as environmental, economic and social sustainability dimension. The other is the evaluation framework with multiple sustainability dimensions, which includes traditional triple bottom lines, extended triple bottom lines, sustainable balanced scorecards and a combination framework of different sustainability dimensions. As shown in **Figure 6**, the proportion of the articles based on the evaluation framework with a single sustainability dimension is about 18%. About 82% of the articles are based on the evaluation framework with multiple sustainability dimensions. Among them, papers based on TBL and expanded TBL account for more than 52%.

3.1 Evaluation Framework With a Single Sustainability Dimension

3.1.1 Single Environment Sustainability

About 9% of the articles adopt a single environmental sustainability evaluation framework. Firstly, some articles have made attempts in research methods. For example, Xie et al. (2021) use a Data Envelopment Analysis (DEA) game cross-efficiency model combined with a Malmquist index approach to study the dynamic environmental performance of Chinese power generators. Kouloumpis et al. (2015) present a combination of the life-cycle approach and scenario analysis to explore the impact of expected decarbonization of electricity supply on other environmental performance. Secondly, some scholars have explored the environmentally sustainable performance of

TABLE 4 | Summary of these articles using the extended triple bottom line.

No.	Author	Energy type	Research objects	Dimensions of the extended TBL
1	Rovere et al. (2010)	Multiple energy sources	Power Sector	Economic, environmental, social, technical
2	Yilan et al. (2020)	Renewable energy	Power Generation Technology	Economic, environmental, social, technical
3	Prete et al. (2012)	Unspecified energy	Power Grid Enterprise	Economic, environmental, social, technical
4	Angilella and Pappalardo (2020)	Multiple energy sources	Power Generation Enterprise	Economic, environmental, social, technical, market
5	Dong et al. (2019)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Economic, environmental, social, technical, market, governance
6	Bang et al. (2019)	Multiple energy sources	Power Generation Enterprise	Economic, environmental, social, technical
7	Zhao H et al. (2018)	Unspecified energy	Power Grid Enterprise	Economic, environmental, social, technical
8	Li T et al. (2018)	Renewable energy (photovoltaic power)	Power Generation Technology	Economic, environmental, social, technical
9	Li R et al. (2018)	Non-renewable energy (fossil fuels)	Power Generation Companies	Economic, environmental, social, technical
10	Bi et al. (2018)	Non-renewable energy (fossil fuels)	Power Generation Technology	Economic, environmental, social, technical
11	Bai et al. (2018)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Economic, environmental, social, technical
12	Dai and Niu (2017)	Unspecified energy	Power Grid Enterprise	Economic, environmental, social, technical
13	Finnerty et al. (2017)	Multiple energy sources	Power Generation Enterprise	Economic, environmental, social, technical
14	Sartori et al. (2017)	Multiple energy sources	Power Generation Enterprise	Economic, environmental, social, technical
15	Ahmad et al. (2017)	Renewable energy (nuclear)	Power Generation Technology	Economic, environmental, social, technical
16	Zhao and Li (2016)	Unspecified energy	Power Grid Enterprise	Economic, environmental, social, technical
17	Goldrath et al. (2015)	Multiple energy sources	Power Generation Technology	Economic, environmental, social, technical, politics
18	Sharma and Balachandra (2015)	Multiple energy sources	Power Generation Technology	Economic, environmental, social, institutional
19	Zhang et al. (2015)	Renewable energy	Power Generation Technology	Economic, environmental, social, technical
20	Matteson (2014)	Multiple energy sources	Power Generation Technology	Economic, environmental, social, technical
21	Dombi et al. (2014)	Renewable energy (nuclear)	Power Generation Technology	Economic, environmental, social, technical
22	Verbruggen et al. (2014)	Renewable energy (nuclear)	Power Generation Technology	Economic, environmental, social, governance
23	Ribeiro et al. (2013)	Multiple energy sources	Power Generation Sector	Economic, environmental, social, technical
24	Kurka (2013)	Renewable energy (biomass)	Power Generation Technology	Economic, environmental, social, technical
25	Kaya and Kahraman (2010)	Renewable energy (wind)	Power Generation Technology	Economic, environmental, social, technical
26	Begić and Afgan (2007)	Non-renewable energy (fossil fuels)	Power Generation Technology	Economic, environmental, social, resources
27	Afgan (2004)	Renewable energy (hydrogen)	Power Generation Technology	Economic, environmental, social, technical

TABLE 5 | Summary of these articles using the SBSC.

No.	Author	Energy type	Research objects	Dimensions of the SBSC
1	Sanjaranipour et al. (2018)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Economic, environmental, internal processes, learning and growth, sustainability
2	Zhao and Li (2015)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Economic, environmental, internal processes, learning and growth, sustainability

power systems in the context of energy policy changes. For example, Zhang (2019) and Kaygusuz (2011) discuss the environmental sustainability performance of the power system in the circumstances of energy policy changes in China and Turkey. In addition, some scholars have explored the environmental sustainability performance of power system under certain energy technologies. For instance, Greening and Azapagic (2013) have explored the environmental sustainability performance of micro-wind turbines and the potential role in helping the UK meet its climate change targets. Diniz da Costa and Pagan (2006) evaluate the environmental sustainability performance of coal power generation in Australia. Shah and Unnikrishnan (2018) assess the environmental impacts of natural gas-fired power generation in India. The sustainability performance of the electricity supply chain in 24 Chinese provinces are evaluated mainly from the environmental perspective in the study by Sun et al. (2020).

3.1.2 Single Economic Sustainability

Some articles directly use financial indicators to evaluate the economic sustainability performance of the power system. For example, Zhang and Qi (2020) use economic indicators such as carbon economic efficiency to evaluate the economic sustainability performance of the Chinese wind power industry. Si et al. (2020) utilize financial indicators such as short-term profitability, long-term profitability and RandD investment to evaluate economic sustainability performance. Employing financial metrics such as ROE and ROA, Schabek (2020) indicates solar power producers outperforms wind power by examining the economic sustainability performance of

TABLE 6 | Summary of these articles using the Combination of different sustainability dimensions.

No.	Author	Energy type	Research objects	Combination of different sustainability dimensions
1	Chai et al. (2019)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Environmental, social, technical
2	Cui et al. (2021)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Environmental, economic, technical
3	Bi et al. (2014)	Non-renewable energy (fossil fuels)	Power Generation Enterprises	Environmental, social, technical
4	Wang et al. (2020)	Renewable energy (biomass)	Power Generation Technology	Environmental, economic
5	Qin et al. (2019)	Multiple energy sources	Power Generation Enterprise	Environmental, economic, technical
6	Zhao C et al. (2018)	Multiple energy sources	Power Generation Enterprise	Environmental, social, governance
7	Stougie et al. (2018)	Multiple energy sources	Power Generation Technology	Environmental, economic, technical
8	Rafique and Ahmad (2018)	Multiple energy sources	Power Generation Technology	Environmental, economical
9	Ji et al. (2017)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Environmental, economical
10	Yang et al. (2017)	Renewable energy	Power Generation Technology	Economical, technical, social
11	Sueyoshi and Goto (2015)	Non-renewable energy (fossil fuels)	Power Generation Enterprise	Environmental, technical
12	Fallahi et al. (2011)	Multiple energy sources	Power Generation Technology	Technical, social
13	Han et al. (2012)	Renewable energy (nuclear)	Power Generation Technology	Environmental, economical
14	Jeswani et al. (2010)	Renewable energy (biomass)	Power Generation Technology	Environmental, economical
15	Verbong and Geels (2010)	Renewable energy	Power Sector	Technical, social
16	Tsai (2010)	Renewable energy	Power Sector	Environmental, economical
17	Gujba et al. (2010)	Multiple energy sources	Power Technology	Environmental, economical
18	Varun et al. (2009b)	Renewable energy	Power Generation Technology	Environmental, economical
19	Chatzimouratidis and Pilavachi (2009)	Multiple energy sources	Power Generation Technology	Economical, technical
20	Evans et al. (2009)	Renewable energy	Power Generation Technology	Environmental, technical, social
21	Diakoulaki and Karangelis (2007)	Renewable energy	Power Sector	Environmental, economical, technical
22	Heinrich et al. (2007)	Renewable energy	Power Generation Technology	Environmental, economical
23	Kannan et al. (2007)	Multiple energy sources	Power Generation Technology	Environmental, technical
24	Afgan and Carvalho (2002)	Renewable energy	Power Generation Enterprises	Environmental, economical, technical
25	Olatubi and Dismukes (2000)	Non-renewable energy (fossil fuels)	Power Generation Technology	Economical, technical

renewable energy companies from 16 emerging markets over the period 2000 to 2017. Paun (2017) also employs some financial indicators such as ROE and ROA to evaluate the economic sustainability performance of the renewable energy sector in Romania. Martí-Ballester (2017) applies ROE, Tobin's Q and other financial indicators to evaluate economic sustainability performance. Deng et al. (2020) construct a financial performance evaluation system for nuclear-related enterprises from a sustainability perspective.

3.1.3 Single Social Sustainability

Only two articles assess the social sustainability of energy systems. Botelho et al. (2016) evaluate the social sustainability of renewable energy production facilities by using social indicators such as public familiarity with renewable energy generation facilities, the visibility of renewable energy generation facilities, and public opinion of renewable energy generation facilities. Gallego Carrera and Mack (2010) evaluate the social sustainability of energy technologies from stakeholders' perspectives by applying some social indicators, such as security and reliability of energy supply, political stability and legitimacy, social and personal risk and quality of life.

3.2 Evaluation Framework With Multiple Sustainability Dimensions

3.2.1 Traditional Triple Bottom Line

About 21% of the selected articles are based on the Triple Bottom Line. For example, Suomalainen and Sharp (2016) describe the shift of renewable energy policy in New Zealand and assess the sustainability performance of the power sector based on the TBL. Khan (2019) evaluate the sustainability performance of the Bangladesh Power System Master Plan through a multi-criteria decision analysis model using the social, environmental and economic dimensions of the TBL sustainability framework. This article notes that energy policy design needs to balance all three dimensions to ensure a sustainable power generation system in the future. **Table 3** summarizes these articles using the traditional TBL to evaluate the performance of power system.

3.2.2 Extended Triple Bottom Line

Extended Triple Bottom Line is the most commonly used evaluation framework for power system performance evaluation. Extended Triple Bottom Line extends the TBL by adding some characteristics of power systems, i.e. technology, as a new extended dimension into the traditional TBL framework. For example, Rovere et al. (2010) extend the traditional triple bottom line framework by integrating four dimensions, i.e., social, economic, environmental and technological dimensions to evaluate the performance of small-scale hydro, wind, natural gas and nuclear power generation types. Similarly, for sustainable energy decision-making, Yilan et al. (2020) consider the economic, technical, environmental and socio-economic criteria to compare the performance of seven major power generation technologies in Turkey. In addition, some articles add to the traditional TBL framework by considering other dimensions such as Resources, Markets, Politics and Corporate Governance, etc. It describes these articles using the extended TBL to evaluate the performance of the power system in **Table 4**.

TABLE 7 | Summary of environmental sustainability indicators.

Environmental dimension	Indicator	Article
Emission of greenhouse gases	CO_2 direct emission, CO_2 emission per kWh, HC emission, NO_X emission	Afgan and Carvalho (2002); Ahmad et al. (2017); Angilella and Pappalardo (2020); Atabaki and Aryanpur (2018); Atilgan and Azapagic (2016); Bai et al. (2018); Bang et al. (2019); Begić and Afgan (2007); Bi et al. (2018); Bi et al. (2014); Büyüközkan and Karabulut (2017); Chai et al. (2019); Cui et al. (2021)
Ozone layer depletion potential	CFC direct emission, CFC emission per kWh	Atilgan and Azapagic (2016); Greening and Azapagic (2013); Gujba et al. (2010); Kouloumpis et al. (2015); Li T et al. (2018); Roinioti and Koroneos (2019)
Acidification potential	SO_2 direct emission, SO_2 emission per kWh	Atilgan and Azapagic (2016); Bai et al. (2018); Begić and Afgan (2007); Bi et al. (2018); Bi et al. (2014); Chai et al. (2019); Cui et al. (2021); Diakoulaki and Karangelis (2007); Dimitrijevic and Salihbegovic (2012); Diniz da Costa and Pagan (2006)
Photochemical oxidant	C_2H_4 direct emission, C_2H_4 emission per kWh	Atilgan and Azapagic (2016); Diniz da Costa and Pagan (2006); Greening and Azapagic (2013); Gujba et al. (2010); Jeswani et al. (2010)
Eutrophication potential	PO_4 emission per kWh	Atilgan and Azapagic (2016); Diniz da Costa and Pagan (2006); Greening and Azapagic (2013); Gujba et al. (2010); Jeswani et al. (2010); Kouloumpis et al. (2015)
Ecotoxicity	Freshwater ecotoxicity potential (kg Dichlorobenzene eq/kWh), Marine ecotoxicity potential (kg Dichlorobenzene eq/kWh), Terrestrial ecotoxicity potential (kg Dichlorobenzene eq/kWh), Waste hot water	Atilgan and Azapagic (2016); Büyüközkan and Karabulut (2017); Cui et al. (2021); Greening and Azapagic (2013); Gujba et al. (2010)
Human toxicity potential	PM10, Fume and dust, CO emission, HCL emission, Human toxicity potential	Atilgan and Azapagic (2016); Bai et al. (2018); Bi et al. (2014); Büyüközkan and Karabulut (2017); Chai et al. (2019); Genoud and Lesourd (2009); Greening and Azapagic (2013); Gujba et al. (2010)
Resource depletion	Abiotic resource depletion potential (elements) (kg Stibium eq/kWh) Abiotic resource depletion potential (fossil fuels) (Mega Joule/kWh)	Atilgan and Azapagic (2016); Greening and Azapagic (2013); Gujba et al. (2010); Kouloumpis et al. (2015); Santoyo-Castelazo and Azapagic (2014); Shah and Unnikrishnan (2018); Zhao and Li (2016)
Carbon dioxide emission reduction	Carbon Emissions Trading (CET), Carbon Capture and Storage (CCS), Carbon Trading Market Yield, Carbon Emissions Trading Pilot, Power System Emission Reduction, Renewable Energy Generation Rate, Green Certificate Purchase Rate, Green Patent	Bai et al. (2018); Dai and Niu (2017); Han et al. (2012); Qin et al. (2019); Xie et al. (2021); Zhao and Li (2016)
Visual, auditory and olfactory effects	Noise, Visual disturbance, Smog, Heat wave, Odor	Ahmad et al. (2017); Barros et al. (2015); Dombi et al. (2014); Doukas et al. (2010); Gallego Carrera and Mack (2010); Genoud and Lesourd (2009); Kaya and Kahraman (2010)
Resource consumption	Water consumption, Land use, Total energy consumption/Total power generation, Total water consumption/Total power generation, Coal use reduction	Afgan (2004); Afgan and Carvalho (2002); Ahmad et al. (2017); Büyüközkan and Karabulut (2017); Dai and Niu (2017); Doukas et al. (2010)
EPBT	Energy payback time	Genoud and Lesourd (2009); Li T et al. (2018); Varun et al. (2009b)
Others	Vegetation degradation, Effluent volume, Dust collection efficiency, Negative wattage (Electricity savings from reduced demand), Availability of renewable resources	Akber et al. (2017); Evans et al. (2009); Goldrath et al. (2015); Zhao and Li (2016); Zhao H et al. (2018)

3.2.3 Sustainable Balanced Scorecard

The Balanced Scorecard is a performance measurement and management system designed to balance financial and non-financial, short and long-term measures. A modification of the original Balanced Scorecard explicitly takes into account the environmental, social or ethical issues, which is referred to as Sustainable Balanced Scorecard (SBSC) (Hansen and Schaltegger, 2016). SBSC is widely used in sustainability performance evaluation (Deng et al., 2018; Mio et al., 2021). Only two papers are using the SBSC to measure the sustainable performance of power systems. For example, Sanjaranipour et al. (2018) measure the performance of the Iranian thermal power plant based on the SBSC framework. Based on the principles of the SBSC, Zhao and Li (2015) add the dimensions of Environment and Sustainability to the traditional BSC to assess and rank the performance of four power generation groups in China. A summary of these two articles using the SBSC is shown in **Table 5**.

3.2.4 Combination of Different Sustainability Dimensions

In this section, many articles assess the performance of power systems by relatively freely choosing an appropriate evaluation framework with a combination of different sustainability

TABLE 8 | Summary of economic sustainability indicators.

Economical dimension	Indicator	Article
Profitability	ROE, ROA, ROC, Sales Profit Margin, Total profit, Net profit, Return on risk, Gross margin, Capital expenditures divided by the natural logarithm of total revenues	Angilella and Pappalardo (2020); Bai et al. (2018); Bang et al. (2019); Dai and Niu (2017); Deng et al. (2020); Dong et al. (2019); Han et al. (2012)
Debt paying ability	Total debt ratio, Current ratio, Quick ratio	Angilella and Pappalardo (2020); Dai and Niu (2017); Paun (2017); Qin et al. (2019); Schabek (2020); Zhao H et al. (2018)
Operating Capacity	Inventory turnover ratio, Total asset turnover ratio	Angilella and Pappalardo (2020); Dai and Niu (2017); Deng et al. (2020); Qin et al. (2019)
Development capacity	Growth rate of total profit, Growth rate of net profit, Growth rate of earnings per share, Growth rate of total assets, Sustainable growth rate, Growth rate of total revenue	Dai and Niu (2017); Deng et al. (2020); Paun (2017); Schabek (2020); Si et al. (2020); Yang et al. (2017)
Power Operation Production and Maintenance Costs	Electricity production costs, Average cost of electricity generation, Unit transmission and distribution costs, Electricity loss costs, Fuel costs, Electricity supply costs, Operating costs, Maintenance costs, Emissions trading costs, Electricity trading rates, Collection costs, Transportation costs, Storage costs, Disposal costs, Extraction costs, Fuel and emission rights costs, Subsidies, RandD costs	Afgan (2004); Ahmad et al. (2017); Akber et al. (2017); Atabaki and Aryanpur (2018); Bai et al. (2018); Bang et al. (2019); Barros et al. (2015); Begić and Afgan (2007); Bi et al. (2018)
Electricity sales revenue	Electricity sales revenue, Unit sales revenue, Power generation price, Average electricity tariff, Annual revenue of grid enterprises, Gross industrial output value, Electricity sales, Fuel price	Bang et al. (2019); Chatzimouratidis and Pilavachi (2009); Li R et al. (2018); Sanjaranipour et al. (2018); Sun et al. (2020)
Investment Costs	Investment expenses, Cost of capital	Afgan (2004); Ahmad et al. (2017); Akber et al. (2017); Atilgan and Azapagic (2016); Begić and Afgan (2007)
Annualized cost, Average cost	Total annualized cost, Average cost	Akber et al. (2017); Atilgan and Azapagic (2016); Jeswani et al. (2010); Kaya and Kahraman (2010); Li T et al. (2018)
Project feasibility	Payback time, NPV, IRR	Finnerty et al. (2017); Goldrath et al. (2015); Kaya and Kahraman (2010)
Others	Growth rate of low carbon economic contribution, Carbon tax rate, Tobin's q, GDP per unit of total energy consumption, Percentage of imported inputs, Infrastructure investments and services provided primarily to generate public benefits/economic value	Deng et al. (2020); Martí-Ballester (2017); Qin et al. (2019); Rovere et al. (2010); Sartori et al. (2017); Tsai (2010)

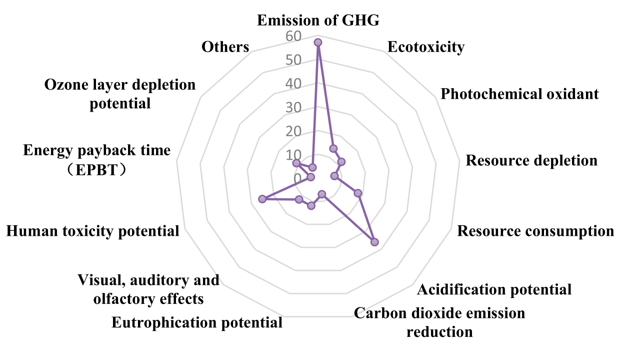

FIGURE 7 | Classification and frequency of environmental sustainability indicators.

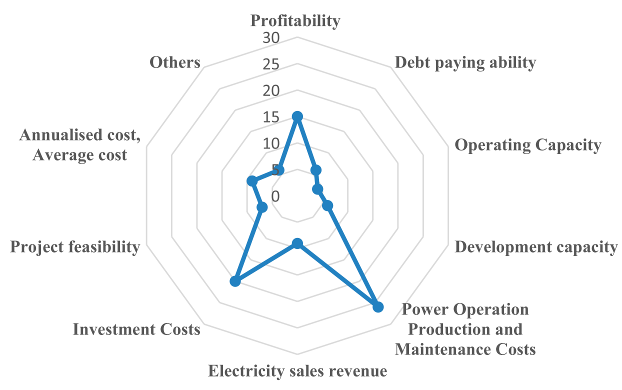

FIGURE 8 | Classification and frequency of economic sustainability indicators.

dimensions. This evaluation framework may include one or two sustainability dimensions of the TBL and other sustainability dimensions, such as technical sustainability, social sustainability, etc. For instance, Chai et al. (2019) evaluate the performance of listed companies in the thermal power sector by using an evaluation framework with the combination of different sustainability dimensions including the Technical dimension and the Environmental, Social dimensions, that stem from the traditional Triple Bottom Line. As shown in **Table 6**, few articles

TABLE 9 | Summary of social sustainability indicators.

Social dimension	Indicator	Article
Employment and job creation	Direct employment, Indirect employment, Total employment, Full-time employment	Atilgan and Azapagic (2016); Bang et al. (2019); Barros et al. (2015); Büyüközkan and Karabulut (2017); Chai et al. (2019); Doukas et al. (2010); Fallahi et al. (2011); Goldrath et al. (2015); Kaya and Kahraman (2010)
Customer	Customer satisfaction, Power supply contract signing rate, Average power outage time, Average repair time	Büyüközkan and Karabulut (2017); Dai and Niu (2017); Dong et al. (2019); Ong et al. (2019); Zhao H et al. (2018)
Employee care and development	Employee productivity, Employee equality, Annual employee training time, Talent equivalent density, Better working conditions, Number of employees, Number of people working in each energy technology, Average wage, Hours worked, Percentage of female employees, Percentage of disabled employees, Percentage of safety engineers to safety managers, Percentage of licensed safety managers, Average daily paid annual leave per employee, Social insurance rate, Annual employee training rate, Annual health examination rate	Ahmad et al. (2017); Bai et al. (2018); Begić and Afgan (2007); Bi et al. (2018); Bi et al. (2014); Dai and Niu (2017)
Risk	Public health risks, Number of injuries, Injury rates, Accident risks, Production safety, Occupational health and safety, Fatalities due to large accidents, Unplanned outages, Subjective expected health consequences of normal operations, Familiarity risks, The catastrophic potential of perception, Number of environmental safety accident cases, Total fines/Total generation, Electricity market risks, Nuclear Plant Risks	Atilgan and Azapagic (2016); Barros et al. (2015); Dong et al. (2019); Finnerty et al. (2017); Gallego Carrera and Mack (2010); Khan (2019); May and Brennan (2006)
Local development	Improvement of living standards, Development of new areas, Local economic development, Migration, Disruption of existing social infrastructure and services, Support for local production, Charitable contributions as a percentage of income, Support for vulnerable communities, Scale of lines under construction	Barros et al. (2015); Büyüközkan and Karabulut (2017); Goldrath et al. (2015)
Social acceptance	Social acceptance, Community and corporate philanthropy initiatives, Income sustainability of different income groups	Ong et al. (2019); Santoyo-Castelazo and Azapagic (2014); Sharma and Balachandra (2015); Yilan et al. (2020)
Others	Intergenerational issues, Entrepreneurship	Santoyo-Castelazo and Azapagic (2014); Sharma and Balachandra (2015)

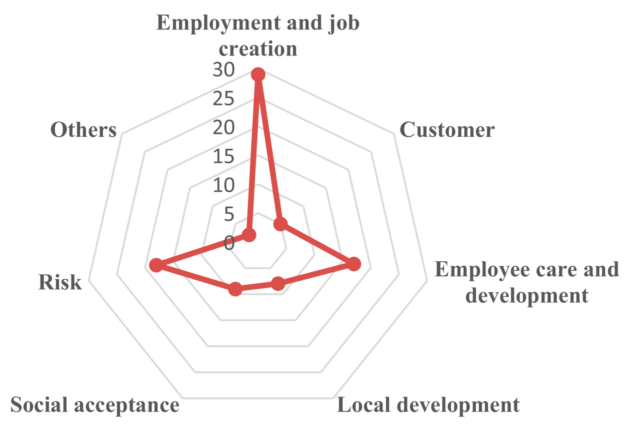

FIGURE 9 | Classification and frequency of social sustainability indicators.

deal with the social dimension in the combination of the different sustainability dimensions, while almost every article concerns environmental sustainability.

4 EVALUATION INDICATORS

4.1 Environmental Sustainability Indicators

The environmental sustainability indicators can be divided into 13 indicator categories, as shown in **Table 7**. In the articles selected in this paper, a total of 57 papers take Greenhouse Gas Emissions as their environmental sustainability indicator, which means Greenhouse Gas Emissions is the most considered environmental sustainability indicator. This finding is in line with the study of Campos-Guzmán et al. (2019). The next more considered indicator categories are Acidification Potential and Human Toxicity Potential. The former includes sulfur dioxide emissions and their impact on atmospheric acidification. The latter includes emissions of harmful pollutants to human health (e.g., respirable particulate matter, carbon monoxide, etc.). The summary of environmental sustainability indicators and the frequency of each indicator category are shown in **Figure 7**.

4.2 Economic Sustainability Indicators

The economic sustainability indicators can be divided into 10 indicator categories, as shown in **Table 8**. These indicators are mainly profitability indicators and cost-based indicators, which reflect how limited economic resources are allocated.

Figure 8 describes the summary of economic sustainability indicators and the frequency of each indicator category.

4.3 Social Sustainability Indicators

The social sustainability indicators can be divided into seven categories according to whether they are beneficial or harmful to humans, as shown in **Table 9**. These social sustainability indicators show the issues that directly or indirectly affect the human and society. In most cases, they are qualitative indicators, implying the involvement of the public, experts and authorities. Employment and Job Creation is the most common social sustainability indicator, followed by other indicators such as Employee Care and Development and Risk. The summary of social sustainability indicators and the frequency of each indicator category are shown in **Figure 9**.

4.4 Technical Sustainability Indicators

According to the indicators used in our selected articles, the technology sustainability indicators consist of 10 categories, as shown in **Table 10**. Among these indicators, Efficiency is in the leading position, followed by Technical Innovation, Installed Capacity, Technical Reliability. **Figure 10** illustrates the summary of technical sustainability indicators and the frequency of each indicator category.

4.5 Other Sustainability Indicators

According to the previous **Section 3**, there are some other sustainability dimensions in addition to environmental, social, economic, and technical sustainability dimensions. Therefore, it is necessary to summarize the other sustainability dimensions, as shown in **Table 11**.

5 EVALUATION METHODS

5.1 Data Envelopment Analysis

In the early 2000s, Olatubi and Dismukes (2000) apply DEA methods to measure the cost performance of coal-fired generation facilities. Rovere et al. (2010) incorporate socio-environmental, technical and economic aspects into the performance evaluation to decide the power generation expansion based on the DEA approach. Fallahi et al. (2011) utilize the DEA methodology to measure efficiency and productivity changes in power generation management companies. Tajbakhsh and Hassini (2018) propose a two-stage DEA model to assess the sustainable performance of thermal power plants. Furthermore, Sun et al. (2020) introduce an improved DEA model to analyze the sustainable performance of Chinese electricity supply chain. Deng et al. (2020) combine DEA methods with MCDM methods such as Analytic Hierarchy Process (AHP) and Preference Ranking Organization Methods for Enrichment Evaluations (PROMETHEE) to study the financial sustainability performance of nuclear power companies. DEA methods are also often used in conjunction with statistical methods, such as Slacks-Based Measure (SBM) analysis (Chai et al., 2019) and Tobit regression analysis (Bang et al., 2019). The summary of the use of DEA methods is shown in **Table 12**.

5.2 Multi-Criteria Decision Making Method

Due to the multidimensional nature of sustainability goals and the complexity of social, economic, and biophysical systems, Multi-Criteria Decision Making (MCDM) methods are becoming increasingly popular in performance evaluation for power system decision-making (Wang et al., 2009). Chatzimouratidis and Pilavachi (2009) evaluate the technical, economic and sustainability performance of ten types of power plants by applying an Analytic Hierarchy Process (AHP) and find that renewable energy power plants are the best solution for the future. Li R et al. (2018) establish a new hybrid MCDM model by using AHP and fuzzy Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method to evaluate the performance of four large power generation companies. Dong et al. (2019) apply the extended MCDM model combined with fuzzy Delphi, Analytic Network Process (ANP) and fuzzy Decision-making Trial and Evaluation Laboratory (DEMATEL) to identify the key influences on the sustainability performance of conventional power generation groups in the market. **Table 13** provides the summary of the application of MCDM methods.

5.3 Life Cycle Assessment Method

Life Cycle Assessment (LCA) is an essential environmental management tool. Life cycle refers to the entire process of a product (or service) from the acquisition of raw materials, production, application to disposal. Life Cycle Sustainability Assessment (LCSA) is well suited for assessing environmental, economic and social sustainability (Guinee et al., 2011). Stougie et al. (2018) assess the environmental and economic sustainability of five power generation systems: coal-fired power plants, coal-fired power plants including carbon capture and storage (CCS), biomass power plants, offshore wind farms, and photovoltaic parks. Li R et al. (2018) couple the LCA approach and sustainability theory to propose an integrated sustainability assessment model and then validated the model by applying it to a solar photovoltaics (PV) case study in the northeast of England.

LCA methods are often combined with MCDM methods. Atilgan and Azapagic (2016) combine the LCA approach with MAUT (Multi-Attribute Utility Theory) to assess the integrated life-cycle sustainability of power generators in Turkey. Genoud and Lesourd (2009) apply the LCA method and Elimination Et Choix Traduisant la R Ealité (ELECTRE) approach to evaluate the performance of power technology, such as Reservoir hydroelectricity, natural gas-fired power generation, etc. The articles using the LCA approach in combination with the MCDM approach are shown in **Table 14**.

5.4 Statistical Methods

The statistical method is a commonly used method of power system performance evaluation in some empirical research. For example, Si et al. (2020) employ factor analysis to investigate the interactive endogeneity relationship between RandD investment and financial sustainability performance and the moderate effect of executive incentives. Ong et al. (2019) conduct a self-administered questionnaire survey of 217 electrical and

TABLE 10 | Summary of technical sustainability indicators.

Technical dimension	Indicator	Article
Installed capacity	Installed capacity (growth rate), Power generation capacity growth rate, Power plant capacity	Bi et al. (2018); Bi et al. (2014); Chai et al. (2019); Chatzimouratidis and Pilavachi (2009)
(Net) power generation	Annual (net) power generation	Bai et al. (2018); Bi et al. (2014); Fallahi et al. (2011); Ji et al. (2017); Kannan et al. (2007); Rovere et al. (2010)
Technical reliability	Power supply reliability (reliability of power grid system, ratio of normal transmission lines, proportion of normal state of voltage transformers), Guarantee energy, Power available during peak load, Capacity factor, Annual load factor, Automatic power grid recovery capacity, Grid coordination, Number of distributed generators connected to the smart grid, Stability of supply, Performance of transmission systems, Average operating time	Dai and Niu (2017); Diakoulaki and Karangelis (2007); Dong et al. (2019)
Technical maturity	Technical maturity, Advanced level of production equipment and management, Comprehensive energy consumption of enterprises, Related industrial chain development, Future applicability, Lifetime	Afgan (2004); Ahmad et al. (2017); Dong et al. (2019); Finnerty et al. (2017)
Technical innovation	Percentage of new energy installations, Technological innovation, Investment in technological innovation, Investment in energy saving and emission reduction RandD, RandD expenditure/economic value generated, Investment ratio of energy saving and emission reduction equipment, Utilization rate of energy saving and emission reduction equipment, Application of advanced technologies, Establishment of IMS, Ash utilization rate, Proportion of clean energy installations, Installation rate of desulfurization facilities for coal-fired thermal power units, Installation rate of denitrification facilities for coal-fired thermal power units rate	Chai et al. (2019); Dong et al. (2019); Li R et al. (2018); Qin et al. (2019)
Technical flexibility	Flexibility, Integrated and innovative technological flexibility, Power generation flexibility, Resource availability and limitations, Energy independence	Finnerty et al. (2017); Gallego Carrera and Mack (2010); Khan (2019)
Technical security	Power supply safety (qualitative, complete waste disposal infrastructure), Security and diversity of supply, Supply risks, and Local energy use	Diakoulaki and Karangelis (2007); Gallego Carrera and Mack (2010); Genoud and Lesourd (2009)
Land demand	Land area requirements	Dombi et al. (2014); Evans et al. (2009); Genoud and Lesourd (2009)
Technical efficiency	Hours of use of power generation equipment, Efficiency, Average annual availability, Energy conversion efficiency, Efficiency coefficient, Electricity consumption efficiency, Net power plant efficiency, Thermal efficiency, Net generation efficiency, Line loss rate, Labor productivity, Net coal consumption rate, Plant electricity consumption ratio, Efficiency of power generation technology, Standard coal consumption, Power plant electricity consumption rate, Industrial water consumption added value, Industrial energy consumption added value, Fire use efficiency, Storage and extraction ratio, Fuel consumption rate, Energy utilization efficiency	Angilella and Pappalardo (2020); Bang et al. (2019); Begić and Afgan (2007); Bi et al. (2018)
Others	Construction period (year), Power structure share, Technology attributes (age, size, suitability), Fuel type	Cui et al. (2021); Fallahi et al. (2011); Rovere et al. (2010); Sanjaranipour et al. (2018); Yilan et al. (2020)

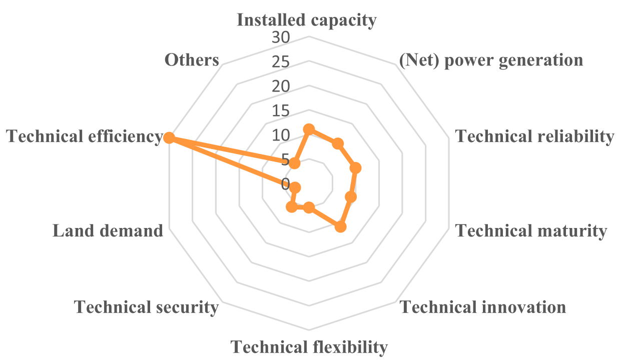

FIGURE 10 | Classification and frequency of technical sustainability indicators.

electronics companies and a hypotheses test through structural equation modelling (SEM) to identify critical success factors for sustainable performance measurement in Malaysian electrical and electronics companies. Yang et al. (2017) posit a new hybrid evaluation index system from sustainability and internal group management perspectives. In addition, the regression analysis method is more often applied to evaluate the economic sustainability performance of power listed companies, such as the articles studied by Schabek (2020) and Martí-Ballester (2017). The summary of relevant articles of application the statistical methods is shown in **Table 15**, Panel A.

5.5 Other Evaluation Methods

In addition to the above evaluation methods, some other evaluation methods are applied in some articles. For example,

TABLE 11 | Summary of other sustainability indicators.

Other dimensions	Other sustainability indicators	Article
Politics	The potential for conflict in energy systems, The need for participation in the decision-making process in the siting of energy systems	Gallego Carrera and Mack (2010)
Resource	Fuel index, Carbon steel index, Stainless steel index, Copper index, Aluminium index, Insulation index	Begić and Afgan (2007)
Market	Analysis of potential competitors, Market supply, Demand and price forecasting capability, Market tariffs, Pricing bidding strategy, Absolute market share, P/E ratio	Angilella and Pappalardo (2020); Dong et al. (2019)
Governance	Corporate governance status: number of nomination committee meetings per year, number of remuneration committee meetings per year, number of audit committee meetings, number of board meetings per year; Corporate governance response: annual training time for company secretaries, attendance of nomination committee, attendance of valuation and risk committee, attendance of board of directors, attendance of remuneration committee; Corporate culture and philanthropy, Top management awareness and commitment, Level of risk management	Dong et al. (2019); Verbruggen et al. (2014); Zhao H et al. (2018)
Institutional	Policies, Systems	Sharma and Balachandra (2015)

TABLE 12 | Summary of the use of DEA methods.

Author	DEA methods
Xie et al. (2021)	DEA game cross-efficiency model combined with Malmquist indicators
Sun et al. (2020)	Two-stage Directional Distance Function (DDF)-DEA model
Deng et al. (2020)	DEA, AHP, PROMETHEE
Sartori et al. (2017)	DEA-DDF model
Bi et al. (2018)	Two-stage DEA
Ji et al. (2017)	DEA combined with an exponential learning curve
Bi et al. (2014)	Two-stage DEA
Rovere et al. (2010)	DEA method
Tajbakhsh and Hassini (2018)	Two-stage DEA
Sueyoshi and Goto (2015)	DEA non-radial measure
Wang et al. (2016)	Non-radial Distance Function DDF
Olatubi and Dismukes (2000)	DEA method
Fallahi et al. (2011)	DEA method
Chai et al. (2019)	DEA -SBM method
Bang et al. (2019)	DEA-TOBIT method

Botelho et al. (2016) adopt the Contingent Valuation Method (CVM) to evaluate the social sustainability performance of renewable energy in power generation. Dombi et al. (2014) define seven sustainability attributes to describe the sustainability performance of each renewable energy-based power and heat technology. The weight of these attributes is achieved through a Choice experiment survey conducted among Hungarian professionals. A summary of the application of other evaluation methods is shown in **Table 15**, Panel B.

6 CRITICAL INSPIRATION AND CONCLUSION

Based on the above analysis, there are several research notes for future research on the performance evaluation of power systems. Firstly, under the circumstances of advocating global low-carbon development, research on performance evaluation of power systems is shifting from the traditional model to the sustainability model, which expands many research fields in the future. Especially, in order to explore the sustainable transformation and development of clean energy system from sustainability perspectives, performance evaluation of clean energy system is becoming a world research upsurge. Secondly, sustainable performance evaluation of power systems can adopt a combination of some management tools such as the sustainable balanced scorecard (SBSC). The SBSC combines the traditional balanced scorecard and the triple bottom line theoretical framework, combining strategy implementation tools, performance management tools and sustainability concepts. SBSC will vigorously promote sustainable performance evaluation and management practices in power systems. It should be noted that the difficulty of the SBSC lies in how to integrate the triple bottom line with the traditional BSC, which has two solution pathways requiring more rigorous theoretical and practical exploration. The one is to add more sustainability dimensions to the traditional four dimensions of the BSC, and the other is to integrate the sustainability concept into the four traditional BSC framework dimensions. Thirdly, while the environmental and economic sustainability performance of power systems has received widespread attention, the existing

TABLE 13 | Summary of the use of MCDM methods.

Author	MCDM methods
Qin et al. (2019)	D-IFAHP-RELM(AHP based on improved dynamic hesitation degree (D-IFAHP) and an improved extreme learning machine algorithm optimized by RBF kernel function (RELM))
Dong et al. (2019)	Fuzzy Delphi, Fuzzy DEMATEL, ANP
Atabaki and Aryanpur (2018)	AHP, Fuzzy affiliation function
Zhao C et al. (2018)	Fuzzy Delphi, Entropy Weight Method (EWM), Best Worst Method (BWM), VIKOR
Li R et al. (2018)	AHP, Fuzzy VIKOR
Dai and Niu (2017)	Delphi, EWM, Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS)
Büyüközkan and Karabulut (2017)	AHP, VIKOR
Finnerty et al. (2017)	AHP
Yang et al. (2017)	TOPSIS
Ahmad et al. (2017)	AHP
Khan (2019)	Simple Multi Attribute Rating Technique Exploiting Ranks (SMARTER)
Zhao and Li (2015)	Fuzzy Delphi, ANP, Fuzzy TOPSIS
Zhang et al. (2015)	Improved MCDM (Based on fuzzy measure and integral method)
Kurka (2013)	AHP
Begić and Afgan (2007)	Analysis and Synthesis of Parameters under Information Deficiency (ASPID)
Heinrich et al. (2007)	Multi Attribute Utility Theory (MAUT)
Kaya and Kahraman (2010)	AHP, Fuzzy VIKOR
Yilan et al. (2020)	MAUT, Weighted Sum Method (WSM)
Chatzimouratidis and Pilavachi (2009)	AHP
Doukas et al. (2010)	TOPSIS
Diakoulaki and Karangelis (2007)	PROMETHEE

TABLE 14 | Summary of the application of LCA combined with MCDM methods.

Author	LCA-MCDM methods
Wang et al. (2020)	LCA,BWM
Roinioti and Koroneos (2019)	LCA, MAUT
Atilgan and Azapagic (2016)	LCA, Multi Attribute Value Theory (MAVT)
Barros et al. (2015)	LCA, AHP, Modelo Integrado de Valor para una Evaluaciòn Sostenible or Integrated Value Model for Sustainability Assessment (MIVES)
Santoyo-Castelazo and Azapagic (2014)	LCA, MAVT
Genoud and Lesourd (2009)	LCA, ELECTRE

literature has paid relatively little attention to the issues of the social sustainability performance of power systems. The stability and safety of the power system have a significant impact on society. Furthermore, the social sustainability performance of the power system is also an essential expression of the power system's social responsibility. Fourth, given the multidimensional nature and the complexity of the sustainable development of power systems, the MCDM is the most suitable evaluation method for the sustainability performance of power systems. Therefore, finding a suitable MCDM method according to the characteristics of the evaluation object is the critical issue for the performance evaluation of the power system. Future research should pay attention to the hybrid and application of MCDM method and other methods. Finally, in terms of the geographical distribution of research on the performance evaluation of power systems, future research should focus on the sustainable development of power systems in underdeveloped regions such as Africa. Moreover, although solar power, hydroelectric power, wind power and even nuclear power are currently more common research objects, it can be noted that biomass and straw energy has less attention. Therefore, the research of sustainability performance evaluation of power systems can also be broadened into these new fields in the future.

To sum up, this paper put forward a systematic methodology, namely "Planning-Searching-Screening-Reporting-Reflecting" (PSSRR Cycle), to review the articles on power system's performance evaluation from a sustainable perspective. Some findings are revealed based on three main parts of the power system's performance evaluation system: Evaluation Framework, Evaluation Indicators, and Evaluation Methods, respectively. Firstly, regarding the evaluation framework, the Triple Bottom Line theory is the most commonly used theoretical framework for evaluating the performance of power systems from a sustainability perspective. Almost all of the articles deal with the environmental aspects, which shows that the environmental sustainability caused by power systems have attracted the attention of the vast majority of scholars. In the Expanded Triple Bottom Line framework, technical sustainability is the most commonly considered aspect. It is worth noting that Evaluation Frameworks of the power system's performance evaluation system are evolving ceaselessly. For example, a small number of studies have adopted the Sustainable Balanced Scorecard (SBSC) as the Evaluation Frameworks.

TABLE 15 | Summary of the application of statistical method and other evaluation methods.

Panel A

Author	Statistical methods
Schabek (2020)	Regression analysis
Si et al. (2020)	Factor Analysis
Ong et al. (2019)	Structural Equations Model (SEM)
Bai et al. (2018)	SBM-TOBIT Model
Zhao C et al. (2018)	Regression analysis
Yang et al. (2017)	Stochastic Transformation for Blended Information (STBI) method
Martí-Ballester (2017)	Regression analysis
Li et al. (2013)	Monte Carlo method

Panel B

Author	Other evaluation methods
Angilella and Pappalardo (2020)	Hierarchical Stochastic Multi-Attribute Acceptability Analysis (HSMAA)
Cui et al. (2021)	Global Change Analysis Model (GCAM-China)
Paun (2017)	Financial Ratio Analysis
Suomalainen and Sharp (2016)	Power Generation Technology Sustainability Index
Botelho et al. (2016)	Contingent Valuation Method (CVM)
Sharma and Balachandra (2015)	Hierarchical multidimensional framework based on indicators
Goldrath et al. (2015)	Comprehensive Sustainability Index
Matteson (2014)	Electricity Sustainability Index
Verbruggen et al. (2014)	Sustainability indicator approach
Dombi et al. (2014)	Choice experiment survey (CE survey)
Serencam and Serencam (2013)	Sustainability indicator approach
Prete et al. (2012)	Sustainability indicator approach
Dimitrijevic and Salihbegovic (2012)	Sustainability indicator approach
Gallego Carrera and Mack (2010)	Sustainability indicator approach
Tsai (2010)	Sustainability indicator approach
Diniz da Costa and Pagan (2006)	Sustainability indicator approach
Afgan and Carvalho (2002)	Sustainability indicator approach

SBSC is an organic blend of the traditional balanced scorecard and the triple bottom line. SBSC will be a powerful tool for evaluating sustainability performance and implementing the sustainable development strategy. For future research, the SBSC could be considered for sustainability performance evaluation of power systems, with continuous attempts to modify it so that the three dimensions of sustainability can be better balanced and expanded. Secondly, concerning the evaluation indicators, although the indicators used in each article are not the same, there are commonalities in these indicators that reflect which indicators are more commonly applied and valued. To a certain extent, the indicators used more frequently in articles are regarded as the more critical factors to evaluate the power system's performance. Current research has placed more emphasis on environmental and economic sustainability indicators while neglecting social sustainability indicators. For the future research, the selection of indicators should follow corresponding principles, such as the ease of access to data, the comprehensiveness of the measurement and the high relevance to the content of the measurement, thus enhancing the diversity of the evaluation content. Furthermore, although some indicators are somewhat specific and rare, it does not mean that they are not essential because of the specificity of the research objects, which may also provide a reference for the related research in the future. Finally, as for evaluation methods, the DEA and MCDM methods are the more common performance evaluation methods of power systems. Many scholars can improve the DEA method to make the evaluation process and results more accurate. Many MCDM methods are often selected and efficient combined according to the advantages of these methods. In addition, the LCA method is also essential because it is widely used alone or in combination with DEA or MCDM methods. Although LCA is suitable for the characteristics of the power system, the requirements of data availability and accuracy are very high, which limits the application and development of this method. In the future studies, the use of multi-criteria decision making methods is more strongly recommended. A combination of different evaluation methods can be explored and even more precise evaluation methods can be developed.

The evaluation framework, evaluation indicators, and evaluation methods are the main three aspects of the whole performance evaluation system of the power system. This study distinguishes itself from existing reviews of power system performance evaluation in that it not only focus more on the description of the evaluation methods (e.g., Varun I. K. et al., 2009; Wang et al., 2009; Martín-Gamboa et al., 2017; Campos Guzmán et al., 2019), and it is also more concerned with other aspects of the evaluation system, such as the evaluation framework and evaluation indicators.

Of course, this paper is subject to several limitations. Firstly, although this paper tries to summarize all the evaluation framework, indicators, and methods as far as possible in the thematic analysis section, it is impossible to avoid some omissions. Secondly, some methodological limitations need to be considered when interpreting the study results. For example, book chapters, conference papers and books were excluded in this paper, which potentially creates a bias in the selection of literature. Finally, the keywords choice and literature screening are performed under our subjective conditions in this paper, which may lead to unexpected uncertainty due to the limitations of our knowledge.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

AUTHOR CONTRIBUTIONS

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by DD, CL, and YZ. JZ, SW, and LL commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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