Integrated Energy System Systems and Game Theory: A Review

Arief Ramadhan[1], Bhima[2], Tio Nurtino[3]
[1]University of Bina Nusantara, Jakarta, Indonesia
[2,3]University of Raharja, Tangerang, Indonesia
e-mail: ariefr amadhan@ieee.org, bhima@raharja.info, tio.nurtino@raharja.info

Article Info

Article history:

Received October 29, 2022
Revised November 23, 2022
Accepted November 27, 2022

Keywords:

Integrated Energy System,
Game Theory,
Energy Management,
Demand Response

ABSTRACT

As mankind expands quickly, there is a shortage of energy worldwide. Instead of focusing on the production, transmission, and provision of a particular power source, China has proposed an To address the energy crisis, an integrated energy system is being developed. This system links energy resources and utilizes their complementary benefits. With the development of integrated energy systems, involvement and Engagement is getting increasingly difficult. Game theory, which can successfully address issues arising from multi-agent commerce, is a natural application of the System of integrated energy. This publication gives in-depth information analysis of how the integrated power system has undergone game theory analysis. Initial game situations in integrated power systems are provided, followed by a brief introduction to the evolution of integrated energy, The design and deployment of interconnected power systems issues are outlined, along with game scenarios that take into account the energy production side, supply chain, demand side, and all of these factors. Second, a summary of the fundamental for the integrated energy system, use game theory models is provided. The last topic is examined along with the challenges involved in game theory's potential application to integrated power systems. When applying the newly created game models to the integrated power system, a mixed game is recommended to solve these issues. This study should prove to be an invaluable resource for upcoming scholars in the subject.

Corresponding Author:

Arief Ramadhan
University of Bina Nusantara, Jakarta, Indonesia
Email: arieframadhan@ieee.org

1. INTRODUCTION

Humans require greater energy assistance as civilization develops. When a sequence of separate electricity, gas, and heat are examples of energy sources, proved insufficient to fulfill society's present demands, energy systems that are integrated (IESs) arose . As in case, IESs have been examined by several researchers in China and other countries. Overseas, another method of addressing this issue was put up, as well as an approach based on conceivable situations was also suggested. The influence of energy consumption characteristics was taken into account when developing an extensive IES model for the rural setting. In order to encourage development, China has also given IES top priority and conducted a number of initiatives. Chinese scholars have recommended a strategic way of thinking that takes into account how energy, economy, and the environment are all interconnected, as well as how best to address energy-related problems and barriers. in IES. In order to find the best solution given CIES dispatching issues, IESs were investigated macroscopically in existing communities integrated energy systems (CIES). The issues with energy conversion and storage have also been studied by Chinese scholars. Both the use of and research into IES are expanding, as are the number of IES-related problems requiring speedy remedies (such as the connection between energy sources and interests across numerous themes). Theoretical game theory, that was frequently used to study single-phase devices, could thus be able to provide some direction. Game theory is frequently used. incorporated in the electricity market. A few domains where game theory has been used to address The electricity market is one example of a similar issue, deployment of power monitoring and management of power systems. It got increasingly challenging in the competition. proposed the idea of using game theory to achieve market equilibrium and should enhance every patient's objectives. To show how prudent market oversight should be, a fresh approach was suggested. To address issues with the smart grid, game theory was applied. Using a singular disk drive to obtain the most collaborating with consumers and reducing energy usage were the two scenarios that focused on shared storage in smart grids that were explored. It was modeled using cooperative game theory. When electric cars were incorporated into the smart grid framework, the research parameters were also raised in line with this, and the problem of energy management was approached through the use of a three-party game framework. This study also demonstrates how the addition of more components increases the complexity of a system's interactions. The problem may be solved using game theory, which yields twice as many results with half the work. Utilizing game theory, the distribution network may be expanded to include electric automobiles. According to, the distribution network has been greatly impacted by plug-in electric automobiles. A non-cooperative game strategy for creating a model and applying it for pricing driven was suggested in order to avoid jeopardizing the security of the distribution network.

Although the electricity system's demand uses game theory more frequently than the supply side, the The electricity state's supply and transmission ends saw the majority of applications. a review of the scholarly work on the use of behavioral economics to high-, medium-, and consumers of distributed energy The increasingly open electricity market and managerial structure were infused with game theory theories and tactics. The two previously mentioned sources make it abundantly evident how game theory may be used to improve the demand side of electricity networks. consumers of distributed energy increasingly intertwined as a result of the wide range of approaches and successful strategies employed uses game theory to deal with various transmission line difficulties.

IESs seem to be more intricate to comprehend than conventional power systems. The elements to take into account and challenges to solve for when coupling various types of energy are expanding in variety. The several fundamental kinds of energy should first be looked at in IES. Electricity, natural gas, cold energy, and hot energy are all examples of energy sources. are examples of conventional energy sources. To improve energy networks, these numerous energy sources are connected.

A paradigm for resilient Distributed generation technology with power process of adding was proposed due to the complexity and unpredictable nature of energy networks. Iteration accuracy was increased by this approach using staged iterations. While resolving conflicts between energy suppliers is important, the energy market also has to be taken into account. With With relation to IES, energy market participants, and their communication network, market difficulties are exceedingly sophisticated, as witnessed in the electrical market. The majority of IES internet companies and various categories of IES clients, electric pumped hydro transfer industrial companies control the industry's energy trading and commercial activities. In order to maximize the interests of all participants, a solution that enhances the several systems in this large energy market is required. Each stakeholder has its own starting position, interests, and expectations. There are many stakeholders. The use of combined energy based on unpredictability and a It was proposed that a regular leadership sending approach that relies on an ancillary service model be used. The interaction between a market for urban multi-energy systems and outside parties is crucial to consider as a last point comparable to the market and AI technologies. The equilibrium between the energy supply and the pricing strategy is one issue that has to be addressed as part of the ongoing reform of the energy markets. To estimate prices and increase prediction accuracy, artificial intelligence technologies must be used. A back propagation was created utilized to forecast Peak pricing hours, and a hybrid nonlinear regression and support vector machine model was produced for daily power price prediction.

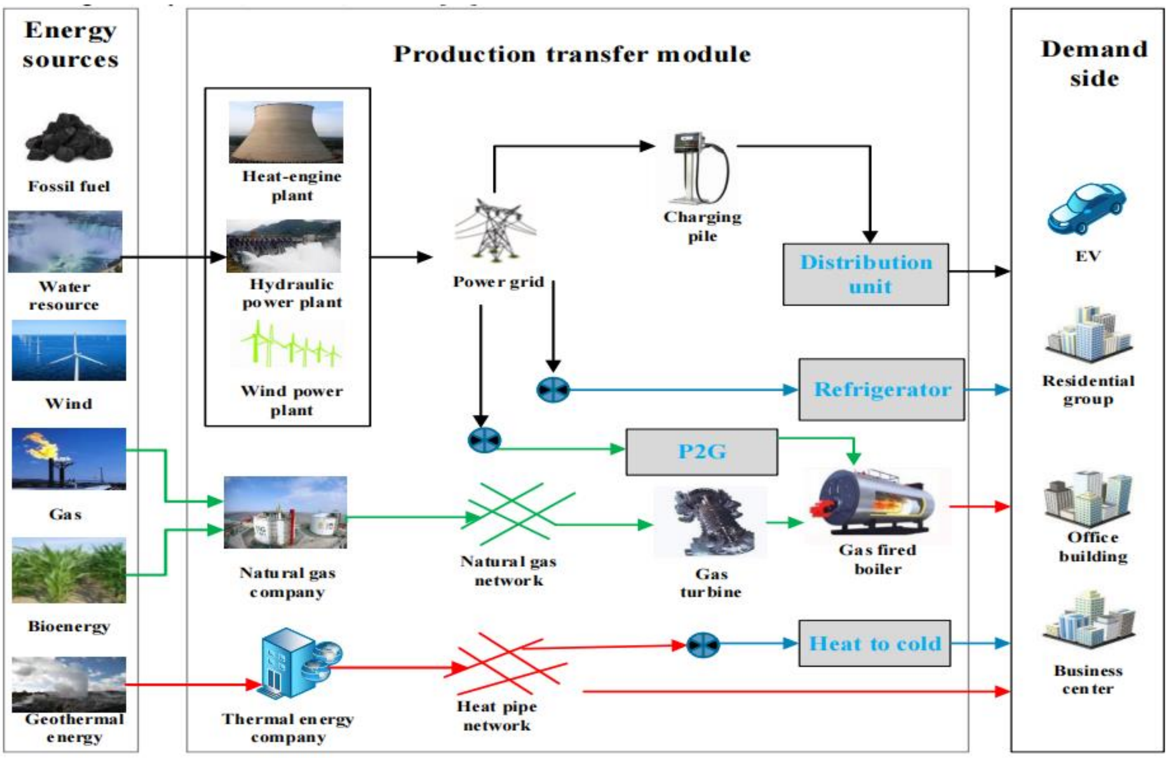
In order to manage the complicated aspects and interests, game theory must definitely be applied to IESs. This part of the issue is being investigated on a national and international level. Cooperative economic dispatching's potential in energy centers was looked into. It was suggested to use bargaining game theory to maximize justice in issue resolution while minimizing operational costs as an alternative to the conventional non-cooperative option. Using game theory to simulate the energy grid, it was recommended that intelligent energy hubs be deployed data storage while addressing the issue of energy usage on the hub's demand side. The wind power capacity was correctly predicted utilizing a game of collaboration simulate In a reduced economic climate, wind energy potential and solve it. An interactive game model was created for a system for sharing solar power generation and cogeneration. The partnership, using scattered activities, decreased the operational costs of the system. A fluid sending game system in the case of the natural energy systems and infrastructures is created with the goal of reducing power and gas load loss. An example was given to demonstrate the usefulness of the mixed integer linear model. Although IESs are a current hot issue, game theory hasn't been utilized much to handle them despite their significance. Game theory holds that each decision-maker When there are other options, he or she takes a soul choice regarding on his or her own talents or knowledge several decision-makers and conflicting interests. Because of their multi-stakeholder and polarizing characteristics, IESs make excellent candidates for game theory.

This page provides a brief summary based on the previous discussion, of IESs and game theory, lists game situations, matching game models, and IESs-specific algorithms, as well as the most recent IESs-related game theory applications. As a result, the second half of this article explains integrated energy, The interactive themes and accompanying scenarios in the IES are introduced in the third piece, which also introduces game theory. The fourth section contains a thorough presentation of the IESs game models and procedures. The important topics for additional study are highlighted in Section V, along with any possible drawbacks of applying game theory to the study of IESs.

2. INTEGRATED ENERGY SYSTEM SHORT DESCRIPTION

A. SYSTEM FOR INTEGRATED ENERGY IS DEFINED

The fourth section completely explains the IESs game models and procedures. The important research questions and potential drawbacks of using game theory to the study of IESs are both highlighted in Section V. An IES structure diagram is shown in Figure 1 and shows The evolution of Source-source IESs The transition from the supplier integrated operating paradigm is shown below. The energy-related raw resources production, distribution and transmission networks, end-to-end power generation, storage, and distribution consumers are all mentioned. In, it was demonstrated that incorporating renewable energy into the electrical system decreased environmental concerns while having no effect on economic development [2]. There are risks associated with renewable energy, including wind energy. The needs of all system components are met by IESs, which are continually upgraded, in addition to Work toward sustainable growth and properly utilize all resources available. The key component of an IES is the link between the electric-gas and cold-hot-electric systems [3].



B. COUPLING OF THE GAS-GAS SYSTEM, ELECTRIC

Despite being standard energy sources, electricity and natural gas both consume energy inefficiently. An integrated electric-gas energy system that is more energy efficient can be produced by merging the two independent energy sources. Electricity and natural gas, the two conventional energy sources, are mixed in order to create an integrated Network of generated electricity, which seeks to enhance energy efficiency. An essential foundation in the case of digital connection and sending of electricity was investigated, which involved coordinating the interdependent infrastructure for power and gas construction of natural gas, as well as the optimization of the applying several improvement approaches on a gas turbine. More investigation was required in order to develop the crucial mechanism and effectively carry out a switch to power-gas systems in the future [4]. The response was provided in, which examined how power and gas interacted (P2G) Future energy systems may find it advantageous to use transition processes. A variety of application approaches that are very beneficial for prospective strategic energy plans and strategies also received a lot of attention.

Fundamentally, the P2G technology and gas generators form the foundation of the power-gas energy system [5]. Over the course of more than 200 years, since its invention in 1791, the gas turbine has experienced a number of alterations. Gas units are commonly employed in industry, despite the fact that their proper application in IES is still under investigation.

A gas turbine boiler model based on the piecewise cooling model and the step-by-step superposition methodology was also developed, in addition to the medium-pressure cylinder exhaust technique. The system's existing power-gas coupling has a number of unresolved issues, as noted [6]. Coupled components that merely concentrate on traditional Compressed air powered by power plants or electricity, for example, cannot adequately depict the interplay of energy in both directions. Concurrent errors will occur between simulation modeling and real engineering [7]. A thorough and effective evaluation of power-gas coupling was carried out using power-gas modeling and the weighted minimum absolute value anti-difference estimate method. P2G technology is a more well-known research topic than gas turbines, and several articles have predicted breakthroughs [8]. P2G technology was examined, the economics were analyzed, and the profitability was calculated. To advance P2G technology in IESs, an innovative approach to online Lyapunov optimization is advised. The key goal of the idea is to balance the conflicting trends of growing operational expenses and rising wind energy consumption. The power-gas coupling system's architecture, operating mode, internal and external optimization, as well as many other components, all need to be optimized have developed through time, laying the groundwork for expanding renewable energy sources in the future.

C. THERMALLY COOLER– CONNECTION OF ELECTRONIC SYSTEMS

A solution that incorporates cooling, heating, and power system (CCHP) is achieved using a natural gas-based cold-hot power supply [9]. The majority of the CCHP system's components are found in the generator set, which can be made up of a gas turbine, an internal combustion engine, and other generator sets, likewise the refrigeration unit, as well as the heating unit , which comprises the gas boiler, heat exchanger, etc., is part of the heating to cooling group. A current focus of study and the most promising future direction for IESs is the combined operating mode of CCHP systems, which has significantly reduced energy consumption and increased operational efficiency. For the purpose of CCHP system improvement and enhancement, the research findings are currently available [10]. Economic operation, dynamic analysis, and environmental implications were all taken into consideration while optimizing the CCHP system. Incorporating weighted and fuzzy optimum selection methods with real use allowed for an evaluation of the CCHP system's operational strategy. With the addition of renewables and a thermal mass tank, the CCHP system was demonstrated to be excellent in the majority of circumstances [11]. Power load and heat load reliability, and combined The CCHP delivered to the grid load was investigated using a variety of techniques for use in business and home settings. In accordance with two distinct incentive programs (incoming tariffs and carbon emissions), the appropriateness of the CCHP system for various situations was established [12]. The CCHP system was successfully optimized at three levels: assortment of first-level components and connectors, configuration of second-level system capacity, and third-level functional variables. The system's ability to maximize energy savings, environmental protection, and financial gains was proved via the particle swarm optimization technique. A crucial component of IESs is how CCHP systems are connected [13]. Therefore, more creative research is necessary to understand how CCHP systems may contribute more to IES and how to use energy sensibly and effectively [14].

3. INTEGRATED GAME THEORY AND ENERGY SYSTEM SCENARIOS

A. THEORY OF GAME

Game theory seeks to maximize the interests of several players with certain constraints in a particular situation. Throughout the game, players rely on their own information and sequentially or simultaneously develop their own plans repeatedly to decide on the best strategy for playing the game. The players, the plan, and the prize are often the three elements that make up a complete game (This is known as the payout functional).

A player in a game is a group or person who has the power to choose a course of action.

N = {1,2..., n}

The game requires players to have a plan, and as they gain information and resources throughout the game, they can decide how many plans are viable and how many to use.

S = { S1, S2... Sn}

S= {S1, S2 ... Sn}

A plan of action determined by both a player's own regulations and a plan established made up of each player's unique strategy sets are both indicated by the formula above.

Profit, however there may be negative figures as well, describes the advantages that participants obtain following the game. Typically, this is the highest benefit they will receive.

U = {u1, u2,...un}

The advantage of all participants in the game is captured in the previous sentence.

The above three components are then combined to produce a complete game.

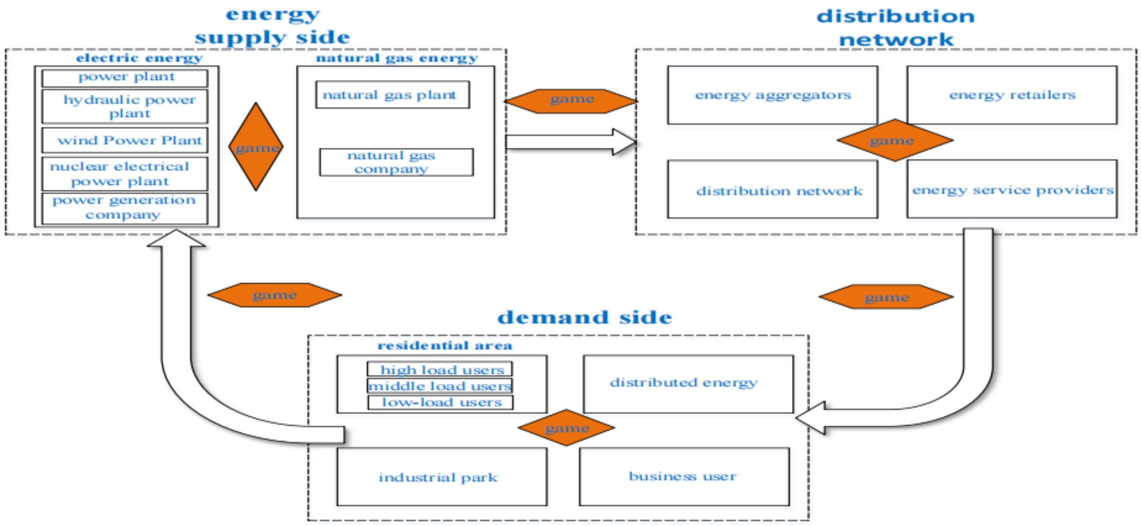
There are two categories of game models: traditional games and evolutionary games. The cooperative and non-cooperative, static and dynamic categories of classic games can be determined using a number of criteria [15].

The development of a cooperative link between the players distinguishes cooperative games from non-cooperative games [16]. The cooperative gaming process's two key components are the distribution of benefits and cooperation under predetermined conditions. The foundation of the non-cooperative game process is the Nash equilibrium [17].

The game's dynamic or static nature depends on the players' choice of activities [18]. Players choose strategies and act sequentially in a dynamic game as opposed to concurrently in a static game. It's thrilling to play Stackelberg [19].

B. A GAME'S USE IN A SCENARIO FOR INTEGRATED ENERGY SYSTEMS

Game theory has totally altered the power grid. Games must be employed to help students overcome IES challenges. First, the energy question is no longer a single supply-side topic. Game theory must be applied find the best solution since there is a connection mechanism among many energy types and participants They are optimizing their self preferences in the marriage. Along in regards to energy supply, a network of transmission also takes into account other aspects like market competitiveness. Individual homes, industrial parks, and distributed energy are all examples of demand. These considerations must be made not just for other demand-side customers, but also for energy firms and sales units. Figure 2 displays the internal game link between the three groups.



1) SIDE OF THE ENERGY SUPPLY

There will be a variety of game scenarios on the supply side because the game connection is primarily created by linking different energy sources. First, CCHP integrates the triple cooling, heating, and power supply, making it a major method for completing multi-energy optimization. This study develops a CCHP-based optimal energy management with several objectives system in the case of electricity and natural gas. This research extends the group's investigation of the framework and offers a management mechanism within certain restrictions. An IES using renewable energy is researched to develop a game scenario. When considering renewable, economical, and environmental elements, renewable sources of electricity are the main contributors to the energy system. In order to get the best results, the game is played within the parameters of the energy flow, overall operational price, CO_2 emissions reduction, and collaborative efficiency. Each garden is viewed as a player using the CCHP triple supplies in the game's dynamic electricity price system. A strategy pertaining to elements like the garden's producing power situation and operational costs To construct the non-cooperative game paradigm, sending is created. Both the peak-to-valley difference in grid load and the The garden's daily operational expenses are targets of the payment function. creates a challenge for optimal microgrid energy dispatching and CCHP reserve management. When creating Attention is paid to the concept to several aspects, including wind speed or light intensity for wind and PV energy production, gas turbine power, heating power, and others. The game's elements in the game scenario are the building, operating, and energy transaction costs in the system. Key players are found in the power and gas sectors. The game's strategy involves selecting the power and flow levels for the gas network and distribution line. By acquiring the best gas pipelines and distribution lines, the game's payment stored procedure goal is to increase the cost-effectiveness of the CCHP.

Combination heat and power (CHP) connections are another typical configuration that transmits both electrical and thermal energy to clients. establishes that the CHP system should optimize its benefits while also increasing the system's dependability, therefore the use of game techniques for this kind of issue may be taken into consideration. The dynamic game approach is used presented in this essay. Corporations are the primary stakeholders in CHP. that produce and distribute electricity, as well as retailers and energy service providers. They have a significant impact on the game by increasing system operating procedures, investment plans, and other tactics with the ultimate goal of maximizing benefits. While the PV output strategy is a participant-chosen choice, the pricing strategy for the microgrid is one that is predetermined by the game. Achieving the best pricing, optimizing load characteristics, reducing operational costs, and maximizing output characteristics are the game's reward functions.

Along with the two common types relating to coupling, There are some other game-like conversations situations of various energy sources. It investigates how benefits are divided across the many energy supplies in the PV cluster and advocates for multilateral energy conservation solutions. When energy companies set their own prices or when consumers devise demand-responsive strategies, non-cooperative game theories are applied. The producer's payoff function is to maximize overall benefit, whereas the consumer's payoff function would be to achieve a decent pricing and make efficient use of energy. For the swirling vapor of gas system built around Several efficiency methods for gas and steam turbines have been developed. These factors—energy consumption, operating costs, investment returns, and so forth—largely influence the operational strategy. While maximizing performance during peak hours, the objective is to reduce operational costs. These three components can be used to form a game scenario.

2) A NETWORK OF DISSECTION

Figure 1 illustrates how the energy market and delivery network's sales of energy are connected to the distribution network. Due to its connection to the economy, the distribution network is essential in IESs. To exchange and distribute energy, the distribution network needs function with both the supply and demand sides. Game theory is therefore essential in the distribution network. The gaming scenarios that are accessible through the distribution network are listed below.

The energy sector's businesses compete to get a sizable share of the market and advantageous conditions. The optimal aggregator bid strategy for electric vehicles is presented, and the scenario is represented. using the Monte Carlo simulation method. The efficacy of something like this system and the effect of bid The electricity market approach is displayed. In order to compete for better advantages, the natural gas market Many local delivery companies' rights have been questioned. The primary players in the literature's major game scenarios are large clients, retail businesses, suppliers, and manufacturers. A cooperative game can be played in two ways are presented in this scenario. One on only one side, by activating the collaborative pump and sharing cooperation network gas, the expenses may be efficiently combined to provide cost savings. The ultimate payout function, by contrast, looks to discover the greatest path inside the network of grid connection by minimizing supplier costs while maximizing consumer satisfaction. Each issue has certain responsibilities and objectives.

Along with A variety of gaming situations for power producing firms upon this natural gas system. and the grid. A unique It commodities trading platform's spacetime component and an interactive experience play were provided by the resultant game scenario of enormous renewable energy generation for power system integration. Every energy transfer between micro-grids in this game is done directly. The This game situations tactics is to guarantee the higher distribution energy market's operational quality while modeling the multi-energy connection and stutter stepping at the institution's bottom layer. The payment function of the game process maximizes each micro-earnings.

This study examines how power-generating companies behave in the energy market. In the game scenario, power producing companies are in the lead, while other service providers are in second place. Cleansing the market and setting transmission system and energy supply price are the goals of market managers. The method of playing the game aims to promote market-conscious competition and improve social welfare in the system. Without real-time measurement, exact data cannot be obtained due to oscillations in terms of system functionality, variations fluctuations in peak load, as well as increases in power stations. The The game's ultimate purpose is to help decision-makers in making the optimum repair method selection to enhance the recovery process' performance.

The distribution network contains more game scenarios than just one or two energy systems, such as the connection of the traditional natural gas and electricity systems, the rapid expansion of the coupling of traditional and renewable energy, etc. These are the situations for the game. Energy consumers and merchants In order to optimize profitability, a sound operational plan is required. Remember that the Connection of city electricity, water, and gas systems intensifies as they grow. In order to gather all of the useful as just a plan, data in the system, and eventually arrive at the optimum system design, the electricity, Players include water and gas delivery networks. The full optimization objective of CCHP triple supply is to minimize costs and carbon emission taxes while in operation, and the strategy is to co-optimize the CCHP system's capacity The local unit is the heat network created to participate in the game.

Lastly, the delivery service, resource storing, and other energy side game situations are discussed. developed source-network-load storage decision-making frameworks for a range of investors and stakeholders along with integrating generator energy. The game's three primary situations are as follows. An organization that offers renewable energy services comes first, followed by a microgrid PV system and equipment for power storage. Second, the energy service provider for the micro-grid system, CCHP, A game situation is created by the use of a gas-fired heat pump and an electric refrigerator. A user of an EV and microgrid charging and discharging devices are involved in the third scenario.

3) SIDE OF DEMAND

Demand-side consumers typically lack the opportunity to communicate directly with energy companies and service providers in the current energy system and are forced to acquiesce to their regulations in a passive manner. But since the energy structure is being changed, the energy market is gradually opening to the demand side, and distributed energy and industrial parks have been introduced, giving the demand side game scenarios with the supply side and distribution network as well as domestically. Thus, this section provides a summary of the demand-side game scenario.

The demand-supply side is the primary focus of the game situation. The topic of modern demand-side energy management is examined in relation to power and natural gas. On the demand side of integrated energy, the interaction between energy hubs is modeled as a game, and non-cooperative game theory is used to play the game. Not reducing power use during peak hours or shifting demand to off-peak times in response to higher electricity prices during peak hours is the ultimate goal of reaching people. The objective is to lower customer prices while raising energy and gas companies' profits. The objective is to lower customer prices while raising energy and gas companies' profits.

Participants include energy providers, gas companies, and consumers. The sequential number potential game provides the theoretical framework, and players choose the best course of action by simulating the real-world circumstances while playing the game. The appropriate renewable energy demand players participate in a game in an atmosphere where renewable energy is developing quickly. It bases its proposal on suppliers of fossil fuels and renewable energy, turns it into a game scenario involving energy firms and consumers, and, while accounting for the uncertainties of renewables, establishes the presence and distinctiveness of Nash equilibrium. This study offers a method for merging the choice of load dispatching and energy enterprises. For permeability of renewable energy and responsiveness of demand, a fully distributed optimization approach is proposed. This strategy has the advantage of being fully covered and dynamically open inside the game process; as a result, individual optimization drives overall optimization and ensures that each player in the game benefits. The problem of client base penetration of PV systems is examined using non-cooperative game theory. Customers and PV systems are the actors in the given game scenario. As the game progresses, various PV systems' installed capacity and cell capacity are evaluated, and various demand response options for the demand side are looked into. The game comes to a conclusion by stating that highly reactive consumers may accept large-capacity PV power generation, which can improve the economics of the

PV system with less batteries and satisfy the demand for energy at the lowest feasible cost, leading to greater advantages.

A hypothetical game scenario has players made up of energy generating companies, retailers, various types of clients, etc. playing a game with a focus on demand-side regulatory constraints. The pricing strategy is employed to determine if the system is positive or negative, while the game strategy is used to show the Nash equilibrium's singularity. The effectiveness of the game strategy is finally shown.

4. APPLICATION OF GAME THEORY TO THE PLANNING AND DISPATCHING OF INTEGRATED ENERGY SYSTEMS

Energy linkages and exchanges abound in integrated energy systems. Stronger resilience to natural disasters can be achieved with an effective interactive framework. Then, during system operation, all forms of energy must be planned and distributed in order to improve future energy system technology, the system's structure, and its resilience. Additionally, it encourages the use of game theory to the planning and dispatching of integrated energy systems. Game theory may be used to resolve planning and dispatching concerns. The study on integrated energy system planning and dispatching is covered in great detail in the next section.

A. INTEGRATED ENERGY PLANNING WITH GAME THEORY

Earth-shattering changes are occurring in the integrated energy system as a result of the current scarcity of fossil fuels and the rising trend of renewable energy. As a result, it is important to think about how to plan the energy in the system, and there is currently a lot of research being done on this topic. This research's findings are therefore summarized.

A planning model and an ideal output strategy are presented for the integrated system. Huge energy storage equipment may now enter the grid's sequence thanks to the integrated system, which blends wind power generation capabilities with technological advancements in energy storage equipment [20]. The costs and benefits of each segmented system are contrasted using the artificial fish swarm approach [21]. It is discussed how to coordinate natural gas and electricity networks stochastically, taking into account factors like interest rates, the increase of demand, and regulatory laws that limit the capacity of new renewable energy installations. The energy Internet still needs further study in order to be planned as an integrated energy system, despite great advances [22]. The difficulties with the integrated energy system and the network physical system are explored, along with the source-net-load integrated planning and transient process, and some methods for future planning studies are provided. Energy shortages and rising energy costs are causing problems with energy efficiency for many businesses [23]. To increase market competitiveness and profitability, energy efficiency should be given top priority in early energy planning. The intricate linkages between various renewable energy sources and home systems with regulated loads are suggested to be monitored and optimized by a multi-intelligent energy management system built on an ontology. The optimization technique has two components: demand response management and distributed effort coordination. To improve their relationship and collaboration, use certain tactics. Improve the system's functionality and effectiveness [24]. In order to study the best power system design, a theoretical framework is built based on the current low-carbon environment, which mandates growing usage of renewable energy in power systems. The study is split into two sections: the best renewable energy investments and the micro-grid that balances supply and demand for electricity to cut costs. The greatest renewable energy sources now available are solar and wind power, according to research. The same is true for the low-carbon economy, even if energy distribution is primarily the emphasis. Large-scale transmission systems and erratic renewable energy sources make energy supply unreliable.

What part of energy planning does game theory play and how does it integrate into it? This paragraph explains. By merging long-term energy planning investments, long-term and short-term energy planning using game theory incorporate energy management for a limited time, which explains stakeholders' goals. To address the multi-objective and multi-subject planning difficulty, two game frameworks for energy planning might reflect many, even contradicting models. With the aim of identifying the least reserve capacity while satisfying the highest load demand, a game model with minimal to maximum uncertainty is created. After that, the minimum-to-maximum game is resolved using the method. The effectiveness of the traditional expectation strategy in comparison to the Monte Carlo method is shown. To solve the intermittent issue with renewable energy, a number of different goals method for photovoltaics that use wind energy systems has been devised. Increased revenue and reducing heating from thermal cells are two aim functions that are taken into account by the model. The suggested method can also be used with different energy dispatching methods [25]. It is suggested to use a multi-area energy system to plan the expansion of power generation and transmission. Classical and enhanced game techniques are used to handle investment and operation planning difficulties, fostering competition among power grids, in order to adapt to market competition and generate the optimum investment plan. The architecture of gas and power systems is typically not well integrated, and Natural gas, which is the primary fuel for gas-fired power plants, is electricity networks. As a result, common planning is carried out using the multi-attribute decision-making technique.

B. USE OF GAME THEORY TO DISPATCH INTEGRATED ENERGY SYSTEMS

The dispatch of the system's various energy sources is just as important as designing the system's many different components, as is the case with an integrated energy system. The dispatch study is described along with how game theory may be used in an integrated energy system in the paragraphs that follow. It links the electricity and heat networks, going against the conventional wisdom of a single energy system. By optimizing the dispatching form and including the thermal power flow calculation method, it thus develops the thermal network and power analysis approach as a whole. Cogeneration combined heat and power is suggested as a solution to the problem of the regional heating network's lack of flexibility in order to ensure that everything runs smoothly the both the district heating system and the electrical system. According to the simulation, the usage of wind power and operational economy may be advantageous. The strategy tool allows the user to assign the necessary energy, followed by the dispersed energy that is accessible is dispatched for the purpose of maximization. This optimizes the energy service. The method has been tested in distribution systems with a variety of conditions, and the energy loss has been greatly minimized, according to the data.

Problems linked to distributing energy issue can be solved by applying game theory. The difficulty of dispersed economic dispatching is looked into intelligent grid An equilibrium state-based game method is offered for this subject. The stationary Nash equilibrium and optimal economic dispatching are combined. To get the optimum overall result, this method can handle challenging equations and unfair coupling constraints.

The thrill and fairness of player coordination and optimization may be enhanced by the optimum equilibrium approach, promoting the utilization of renewable energy sources and boosting customer profit. When faced with a sharply rising demand for energy, the conventional approach to expanding the power generation system may be prohibitively expensive and have a severe impact on the environment. The competitiveness and certain benefits are highly important as the power market becomes more open and more power producing companies take some dispatching initiative. As a consequence, a noncooperative Wind power, water storage, and thermal power are all generated using game theory. It was decided space is produced utilizing the output three-party dispatching characteristics. Because of how to play the game, the power system the act of dispatching optimal, and the impact of integrated optimization across seasons is also quite evident.

5. GAMES INTEGRATED ENERGY SYSTEMS THEORY MODELS

Numerous methods are required to confirm the effectiveness of the game model and workable, which is how game theory is now being applied to the whole energy system. The bulk of the cooperative game, non-cooperative game, and Stackelberg game were used in the integrated energy system's application of game theory utilizing the summary method. models are used in the current study. As a result, for each different game type and object, a suitable algorithm is selected in order to get the desired results, use efficiency and accuracy.

A. IMPLEMENTING A GAME ALGORITHM USED IN COOPERATIVE A COMBINATED ENERGY SYSTEM

This section outlines the cooperative game theory method in an integrated energy system.

TABLE I
CLASSIFICATION OF COOPERATIVE GAME ALGORITHM

The algorithm used to solve the model	Study	Issues addressed	Application scenarios
Shapley Value allocation	[93]	The phenomenon of abandoned wind and light in northwest China is serious and the development of new energy is limited	Wind light fire joint exchange
	[94]	Cost allocation and income distribution of the IES in an industrial park.	IES in industrial parks.
	[95]	Economic operation of energy management in energy networks	Energy networks
	[96]	To establish the energy management operation mechanism in micro turbine and a shared energy storage system to optimize its system	Transactions between operators and users
	[97]	The sharp price fluctuation of the integrated energy spot market brings great risk to the integrated energy service provider	Interaction between IES providers
Distributed alliance construction algorithm	[98]	Optimizing the IES, reducing wasted energy from wind and light, and improving the economy of the system	Interaction of energy hubs in IES
Iterative algorithm	[99]	The impact of demand-side and energy storage systems on the microgrid and the improvement of power reliability will lead to a decrease in PV permeability, thus affecting the economy	Demand side, energy storage system, PV micro-grid

An integrated energy system that incorporates cooperative game theory uses additional algorithms to implement Shapley's value allocation algorithm, and the advantage of the participants in the distribution process increases proportionately to their involvement. The Shapley value allocation method may fairly and appropriately share the profit and cost according to the marginal contribution of the alliance members in its cooperation, which may be the cooperative game's benefit over other value allocation methods. Each significant organization in the park has a unique cooperative game concept. The main participants are corporations involved in electricity grids, power production companies, and power sales organizations. The particular partnership excess should be related to the specific case study. Each player can receive a fair share of the cooperative surplus using the Shapley value technique. The size of the integrated energy quotient varies for all different types of service providers in the integrated energy system, and there will be power deviations during actual operations. This portion of the energy imbalance will then be bought or sold in the spot market, where energy market participants are free to bid and set their own prices, causing the market price to fluctuate erratically and posing a significant risk as well as losses. Not only should the subject of rewards be addressed, but also that of hazards in order to forge alliances. Each member must therefore take personal risk, which may be distributed using the Shapley value. If N members exist, A set of members is S, and the number of components S is N! Then assume the I member's Shapley value is as follows:

$$\varphi_i = \frac{1}{N!}\sum_{j=1}^{N!}\delta_i(s_j)$$

In the formula, φi is Shapley value of i integrated energy system service provider, sj is the j element in the set S, $ij()s$ is a change in the risk of joining the alliance in sj order. As a result, the Shapley value can be used to allocate the risk to player. Secondly is distributed alliance construction algorithm. In the cooperative game alliance, according to their own needs, cooperate with other members of the alliance to achieve the goal of win-win cooperation. Then distributed alliance construction algorithm is very suitable for solving cooperative game model. the alliance construction algorithm adopts two distributed rules, one is the merge rule, and the other is the split rule. In the cooperation rule,

$\{A_1, A_2 ... A_k\}$ is the set of k alliances, if $\{\bigcup_{i=1}^{k} A_i\} > \{A_1, A_2 ... A_k\}$

$\{A_1, A_2 ... A_k\}$ will merge into a new coalition $|\{\bigcup_{i=1}^{k} A_i\}$. Instead than splitting alliances into new ones, the split rule splits them. The rules must be chosen based on the real circumstances; It is necessary to unite a small and numerous alliance; Choosing the split rule and splitting up into new alliances is required if the alliance is larger. There are many various splitting and merging schemes, thus it is important to select the best one based on the requirement and benefit to create the best possible scheme.

Along with the aforementioned two algorithms, the cooperative game model will also employ the traditional iterative approach. In order to reach Nash equilibrium, a three-party cooperative game is employed, and the cooperative game can be maximized. Iterative search algorithms are necessary to reach Nash equilibrium because they allow players to determine the best course of action and maximize their gains. When using an we first input the original data and settings into an iterative algorithm to solve a cooperative game model in accordance with Each alliance separately optimizes the choice, continually considering the specific scenario, the cooperative game model, and the beginning value of the equilibrium point. chooses the optimal strategy, and continue sharing information at the same time. We then decide maybe one should try to locate the Nash equilibrium point, if it is achieved. In order to find the best answer, an iterative method might be utilized.

B. USE OF NON-COOPERATIVE GAME ALGORITHMS IN AN INTEGRATED ENERGY SYSTEM

This section summarizes the algorithm for solving the noncooperative game theory in integrated energy.

CLASSIFICATION OF NON-COOPERATIVE GAME ALGORITHM

The algorithm used to solve the model	Study	Issues addressed	Application scenarios
Nash Equalization algorithm	[100]	To reduce the power load on the distribution network during the early rush hour, so that distributed PV users can improve their market competitiveness	Integrated energy park
	[101]	Adjust energy structure by the market and seek an effective solution to wind power absorption from the supply side	Interactions between wind power plants, thermal power plants and grid companies
two-objective optimization algorithm	[102]	Hot and cool power supply micro-energy network optimization, optimization of power problems, optimization of power strategy.	Cool and hot power triple supply
	[103]	Optimization of the interests of the integrated energy park	Integrated energy park

Because players in a noncooperative game primarily care about maximizing their own interests, and because parties to a competitive relationship are rational states, the theory of noncooperative games is less applicable in an integrated energy system. The conflict between the parties is now at its height. In integrated energy systems, it is thus not frequently employed.

Because all participants must find an equilibrium point in a competitive setting to achieve balance, the Nash equilibrium method is frequently utilized in noncooperative game models. Likewise, the noncooperative game model does not take into account the Shapley value allocation discussed in the preceding section. To perform the fundamental criterion, choose the participants in the game, and determine each player's cost, transaction cost, and transaction revenue, one must adhere to particular market norms and the Nash equilibrium tripartite game theory. In accordance with a certain utility function, the equilibrium point is determined. In accordance with a certain utility function, the equilibrium point is determined.

The other is the two-objective optimization technique, and in non-cooperative games, these two are frequently in conflict with one another, This establishes the player's utility function, which comprises the advantages, disadvantages, and certain essential components. An optimization method is the fuzzy two-objective algorithm. At this point, the value for objective 2 is derived after first performing the optimization computation with regard to objective 1. The value of objective 1 at this time is determined in the same manner as the optimization calculation for objective 2, which is used to determine the optimization value at this time. The mapping is then created after blurring the ideal property of the objective function value. Finally, by linearly weighing two objective functions, it is possible to create the fuzzy double objective objective function.

C. INTEGRATED ENERGY SYSTEM USE OF STACKELBERG GAME ALGORITHM

The Stackelberg game theory approach for integrated energy is outlined in this section.

The foundation of both a game that is cooperative and one that is not covered above is the players' equality and the same quantity of knowledge acquired. However, there will be a hierarchy of authority, as well as active and passive information access, in the project as a whole. When it comes to decision-making authority, there is a master-slave connection, and the game's leader can take the initiative when formulating tactics and making choices. Additionally, the follower is limited to making judgments based on the facts that the leader has disclosed. So, a detailed introduction to the Stackelberg game algorithm is provided.

The inverse order induction approach, which is frequently employed to solve mathematical issues, may also be used to find the model's one-of-a-kind answer. The price of power ought to be decided by the operator in his capacity as the main figure on the basis of protecting using the user as a follower and its own interests should ensure the greatest advantage from its own power usage in accordance with the power rate that is publicly available. However, Demand reaction from the user have an impact on the Finding the equilibrium and unique solutions is important in order to maximize the operator's profit. The first operator's set electricity price may be used to directly demonstrate the uniqueness of the balance in the game's solution, therefore the inverse order induction approach is used to demonstrate this. Whenever a user changes how much power is used, the users of power purchases and sales have different upper and lower limit standards. Once the optimal power usage has been identified, a benefit parameter is created, and the appropriate value is added to improved performance of establish the ideal electricity price. It can be demonstrated because both the game's equilibrium solution and the after the best possible power price, a distinctive solution has been established is special, and in order to address the issue that the standard pricing demand management could raise the expense to the user, Distribution network and demand response are modeled as a Stackelberg game constructed. The dynamic response power pricing is restricted to maintain a level playing field between participating and non-participating customers' electricity costs and to increase the excitement of participating users. The active distribution network serves as the model's leader, while demand response acts as its follower. Until neither side changes their strategy, Current dynamic power prices are published by the leader, and followers follow develops the best a plan of action based on both the leader and his usefulness function chooses the individual's plan based on an observer's plan together with his useful role. This approach is clear and intended for solving the model's equilibrium isolution.

The optimization using a swarm of particles approach in addition show up in game model created by Stackelberg solution. An optimization strategy using particle swarms is appropriate for processing particular values because it offers quick search times, great efficiency, and a straightforward algorithm. It is suggested to employ an illustration of a Stackelberg game various topics, operators of energy hubs acting as captains of industry, users, and followers, and personnel working in energy storage acting as followers.

The exact models are created by players according to their personal interests; they are not duplicated. Because it is simple for particle swarm optimization to enter a local optimum, hierarchical processing is used in the Stackelberg game paradigm with several agents.

An upgraded algorithm built on genetic algorithms, NSGA-II is a type using a genetic algorithm. The Stackelberg game model was optimized using NSGA-II. It is a leader-multi-gaming model that emulates Stackelberg as well, with a gas-fired power plant acting being an adherent of a Stackelberg game model with a leader, three followers, and one follower. The model's particular operational flow is compatible with what was just said. Here is a quick introduction on how to utilize NSGA-II for optimization. By first entering the parameters and information for the initial load, creating in the form of a game with three leaders, and providing Nash with the equilibrium solution's starting value, and the optimization module for the followers can then be used to make independent decisions about the use of wind, water, electricity, and gas. If the optimal solution cannot be found, no return can be found. If you understanding the results of the Stackelberg equilibrium solution and go to the decision-making tool for the leader, you won't be able to discover the return. The final results should be produced following the equalization calculation.

6. THE IMPOSSIBILITY OF USING FUTURE INTEGRATED ENERGY SYSTEMS WILL USE GAME THEORY

A. TAKE INTO CONSIDERATION THE DEMANDS OF VARIOUS TYPES OF USERS ON THE DEMAND SIDE

The function of the demand side in IESs is typically less important than the supply side. In actuality, trade on the demand side will involve energy producers, energy distributors, and other stakeholders. In side searches, game theory is used so frequently. On the demand side, however, there are many different kinds of consumers, such as householders, office workers, those who work in industrial parks, and people who consume a lot of energy. As a result, while using game theory, we must take consumer needs into account.

Residential users make up a significant share of the demand side yet have a relatively low energy demand, making the state of the economy a crucial consideration for them. We must take into account the ability of the people in various places as well as if the pricing is affordable in favor of homeowners while developing model of the game. Additionally, We ought to take into account how much power is utilized in a particular location as well as the people' patterns of electricity use. When a pricing stage for electricity is set, assume the usual energy usage is surpassed, it cost may be raised, several users may be prohibited from squandering energy.

Second, business customers tend to employ concentrated loads; the majority of them rely on equipment with high energy requirements, thus the power load will remain at a reasonably high stage. A gaming paradigm that accommodates corporate users is thus necessary. For instance, in order to design suitable measures for regional conditions, energy sales businesses and commercial users must negotiate various policies with local inhabitants on pricing, energy and environmental protection, among other things. Each component must attain an equilibrium in order to provide outcomes that are agreeable to both parties.

Finally, even though industrial parks include many energy users, they are also productive units. In comparison to the other two user kinds, this one takes more initiative in the game and has the ability to bargain directly with the energy provider. Through the cooperative game, An energy supply unit or this type of user can communicate with one another for the benefit of both, or the energy sales unit. The fact that information is commonly marked as trade secret when customers contact with energy corporations should be addressed, This group of users can thus benefit from using a game with incomplete information.

B. EXPLORING VARIOUS GAME MODELS AND INTRODUCING INTEGRATED ENERGY SYSTEMS

The major focus of this essay is the integration of Stackelberg, non-Stackelberg, and cooperative games into IESs. The great majority of investigations in the present research have been based on these three game models. The repeating game and evolutionary game models, for example, are further game models that have been used in different domains to address issues. To address real-world issues We may include different game models in the integrated energy system under consideration. to maximize the integrated energy system, is built utilizing a repeating game. A possible scenario is the introduction of an evolutionary game if a group develops in a particular area of the integrated energy system and the members demonstrate limited rationality. Consequently, there is a method for solving real-world issues. more alternatives available. Therefore, to address associated issues, future study should investigate other game models.

C. THINK ABOUT HOW MIXED GAME IS USED LARGELY IN INTEGRATED ENERGY SYSTEMS

The creation of IESs is receiving more attention from nations, and IESs are involving more and more components. The issue cannot be effectively resolved by a single game model. Transactions for integrated energy commonly come from the source-networkload-storage mode, However, there will be an internal stage to the game as well; in this case, we have to think about incorporating the mixed game. A hierarchical game model is suggested in. While hybrid games are being used in other industries to better efficiently handle issues at various levels, there is currently little study being done in the integrated energy system.

D. TAKING CLIMATE FACTORS AND INTEGRATED ENERGY SYSTEMS INTO ACCOUNT

Since there are energy issues everywhere, researchers are looking into integrated energy systems. However, while looking into energy, it is important to consider the local climate. It has been researched and predicted how tropical climates operate. In order to conduct research and unite the local circumstances to create a matching integrated energy system, these characteristics are combined with the real local scenario. efficacy assessment of the local heating and cooling system. Urban multi-energy systems are thus subject to game theory.

7. CONCLUSION

In the future, more research will be conducted on IESs against a backdrop where the state promotes energy conservation, further questions, such as how to actualize the complimentary benefits between energy types, will be posed, along with emission reduction and the complementary energy advantages, How to increase the distribution network's ability to use energy efficiently and how to trade in a way that benefits all parties involved (demand, supply, and network) to the greatest extent possible. This paper gives an overview of the state of game theory research on IESs, with a focus on scenarios, models, and algorithms, in light of this problem. Three perspectives are considered, which fully take into account all of the integrated energy system's components as well as some competitive environments The energy supply side, the distribution network, and a summary of the game scenario challenges with planning, dispatching, and the demand side. The strategies for solving game model problems are also described. Future IESs challenges are proposed as a final effort to provide some references for further research in this field.

REFERENCES

[1] Z. Liu *et al.*, "Artificial intelligence powered large-scale renewable integrations in multi-energy systems for carbon neutrality transition: challenges and future perspectives," *Energy AI*, p. 100195, 2022.

[2] A. A. Alola, F. V. Bekun, and S. A. Sarkodie, "Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe," *Sci. Total Environ.*, vol. 685, pp. 702–709, 2019.

[3] J. Li *et al.*, "Optimization configuration of regional integrated energy system based on standard module," *Energy Build.*, vol. 229, p. 110485, 2020.

[4] C. Smith, J. Mouli-Castillo, D. Van Der Horst, S. Haszeldine, and M. Lane, "Towards a 100% hydrogen domestic gas network: Regulatory and commercial barriers to the first demonstrator project in the United Kingdom," *Int. J. Hydrogen Energy*, vol. 47, no. 55, pp. 23071–23083, 2022.

[5] Y. Huang, Q. Sun, N. Zhang, and R. Wang, "A multi-slack bus model for bi-directional energy flow analysis of integrated power-gas systems," *CSEE J. Power Energy Syst.*, 2021.

[6] T. Klatzer, U. Bachhiesl, and S. Wogrin, "State-of-the-art expansion planning of integrated power, natural gas, and hydrogen systems," *Int. J. Hydrogen Energy*, 2022.

[7] A. Angelopoulos *et al.*, "Tackling faults in the industry 4.0 era—a survey of machine-learning solutions and key aspects," *Sensors*, vol. 20, no. 1, p. 109, 2019.

[8] Ş. Kılkış, G. Krajačić, N. Duić, L. Montorsi, Q. Wang, and M. A. Rosen, "Research frontiers in sustainable development of energy, water and environment systems in a time of climate crisis," *Energy conversion and management*, vol. 199. Elsevier, p. 111938, 2019.

[9] Y. Wang *et al.*, "Capacity planning and optimization of business park-level integrated energy system based on investment constraints," *Energy*, vol. 189, p. 116345, 2019.

[10] J. Jia, G. Zang, and M. C. Paul, "Energy, exergy, and economic (3E) evaluation of a CCHP system with biomass gasifier, solid oxide fuel cells, micro-gas turbine, and absorption chiller," *Int. J. Energy Res.*, vol. 45, no. 10, pp. 15182–15199, 2021.

[11] E. Gholamian, P. Ahmadi, P. Hanafizadeh, and M. Ashjaee, "Dynamic feasibility assessment and 3E analysis of a smart building energy system integrated with hybrid photovoltaic-thermal panels and energy storage," *Sustain. Energy Technol. Assessments*, vol. 42, p. 100835, 2020.

[12] A. Bartolini, S. Mazzoni, G. Comodi, and A. Romagnoli, "Impact of carbon pricing on distributed energy systems planning," *Appl. Energy*, vol. 301, p. 117324, 2021.

[13] C. Mu, T. Ding, M. Qu, Q. Zhou, F. Li, and M. Shahidehpour, "Decentralized optimization operation for the multiple integrated energy systems with energy cascade utilization," *Appl. Energy*, vol. 280, p. 115989, 2020.

[14] J. Ramsebner *et al.*, "From single to multi-energy and hybrid grids: Historic growth and future vision," *Renew. Sustain. Energy Rev.*, vol. 151, p. 111520, 2021.

[15] J. Wang *et al.*, "Cooperative and Competitive Multi-Agent Systems: From Optimization to Games," *IEEE/CAA J. Autom. Sin.*, vol. 9, no. 5, pp. 763–783, 2022.

[16] S. Nazari, A. Ahmadi, S. K. Rad, and B. Ebrahimi, "Application of non-cooperative dynamic game theory for groundwater conflict resolution," *J. Environ. Manage.*, vol. 270, p. 110889, 2020.

[17] X. Cai, F. Xiao, and B. Wei, "Distributed generalized Nash equilibrium seeking for noncooperative games with unknown cost functions," *Int. J. Robust Nonlinear Control*, 2022.

[18] Z. Ni and S. Paul, "A multistage game in smart grid security: A reinforcement learning solution," *IEEE Trans. neural networks Learn. Syst.*, vol. 30, no. 9, pp. 2684–2695, 2019.

[19] P. De Giovanni, "Digital supply chain through dynamic inventory and smart contracts," *Mathematics*, vol. 7, no. 12, p. 1235, 2019.

[20] M. Mahmoud, M. Ramadan, A.-G. Olabi, K. Pullen, and S. Naher, "A review of mechanical energy storage systems combined with wind and solar applications," *Energy Convers. Manag.*, vol. 210, p. 112670, 2020.

[21] R. Yang and D. Li, "Adaptive wavelet transform based on artificial fish swarm optimization and fuzzy C-means method for noisy image segmentation," *Comput. Sci. Inf. Syst.*, no. 00, p. 39, 2022.

[22] D. Wang *et al.*, "Review of key problems related to integrated energy distribution systems," *CSEE J. Power Energy Syst.*, vol. 4, no. 2, pp. 130–145, 2018.
[23] H. Sun, B. K. Edziah, C. Sun, and A. K. Kporsu, "Institutional quality and its spatial spillover effects on energy efficiency," *Socioecon. Plann. Sci.*, vol. 83, p. 101023, 2022.
[24] J. Pacheco, S. Garbatov, and M. Goulão, "Improving Collaboration Efficiency Between UX/UI Designers and Developers in a Low-Code Platform," in *2021 ACM/IEEE International Conference on Model Driven Engineering Languages and Systems Companion (MODELS-C)*, 2021, pp. 138–147.
[25] M. J. Kim, T. S. Kim, R. J. Flores, and J. Brouwer, "Neural-network-based optimization for economic dispatch of combined heat and power systems," *Appl. Energy*, vol. 265, p. 114785, 2020.

BIOGRAPHIES OF AUTHORS

	**Arief Ramadhan, University of Bina Nusantara, Jakarta, Indonesia,** arieframadhan@ieee.org
	**Bhima, University of Raharja, Jakarta, Indonesia,** bhima@raharja.info
	**Tio Nurtino, University of Raharja, Tangerang, Indonesia,** tio.nurtino@raharja.info