Future Energy
Open Access Journal
ISSN 2832-0328

May 2023| Volume 02 | Issue 01 | Pages 01-11

Journal homepage: https://fupubco.com/fuen

https://doi.org/10.55670/fpll.fuen.2.2.1

Future Publishing LLC

Review

An overview of renewable energy technologies for the simultaneous production of high-performance power and heat

Marziyeh Razeghi, Ahmad Hajinezhad*, Amir Naseri, Younes Noorollahi, Seyed Farhan Moosavian

Department of Renewable Energies and Environmental Engineering, University of Tehran, Tehran, Iran

ARTICLE INFO

Article history:
Received 04 October 2022
Received in revised form
03 November 2022
Accepted 05 November 2022

Keywords:
Combined Heat and Power,
Renewable Energy, Heating Demand,
Energy security, Cooling Demand

*Corresponding author
Email address:
hajinezhad@ut.ac.ir

DOI: 10.55670/fpll.fuen.2.2.1

ABSTRACT

Combining heat and power (CHP) technology, which uses renewable energy sources as fuel, will be a promising solution to increase energy security. This report aims to examine CHP technologies based on renewable energy, seek to increase their efficiency and reduce the unsustainable nature of renewable resources, and then examine the existing articles from an economic and technical perspective. Heat and electricity are generated simultaneously in CHP technology; heat is the limiting factor in this issue. Therefore, it should be installed in a place requiring heat and population density because transmission losses are reduced in this case. Among renewable energy sources used as fuel for CHP power plants, biomass has the largest share, and among fossil fuels, natural gas and coal have the largest share in CHP, respectively. The United States, Russia, and China have the largest shares in renewable power plants, respectively. All the articles reviewed mention the need for heat storage for CHP power plants. If regional heating and cooling using CHP technology are used, biomass consumption can be reduced by 31.4% compared to single heating, and this amount can be used more in value-added sectors.

1. Introduction

About 46% of the world's energy is heating and cooling [1]. In China, about 36% of the building sector's energy is for heating, and of this volume, 62.9% is provided by combined heat and power and district heating (DH) [2, 3]. Combined heat and power use several fuel sources at the requested or nearby location. In CHP designs, the limiting factor is heat generation, not electricity generation, because if there is excess electricity, it can be easily transferred, but if there is excess heat, it will be difficult to transfer. CHP power plants have an efficiency of about 75-80% [4-6]. Because CHP projects are built near the consumer market, transmission losses are lower in these projects. The main components of a CHP plant are the main drive (motor or drive system), power generator, heat recovery system, and control system. Almost any type of fuel can be used in CHP, which will increase energy security, and alternative fuel can be used when one type of fuel becomes expensive or unavailable [7]. Naturally, natural gas is mostly used among fossil fuels, coal and gas oil, and after fossil fuels, among the renewable energies of municipal solid waste and biomass [8, 9]. In terms of CHP power generation, their capacity is from 1 kW (electric kilowatt) to more than 500 MW (electric megawatt). The location of the CHP power plant affects the ratio of heat and power and its efficiency. The efficiency of CHP depends on technology, fuel source (energy), and location. Figure 1 compares the overall efficiency of CHP and the typical production of separate "heat and power" [10-12]. CHP schemes are used in industrial, commercial/institutional, and regional heating and cooling (DHC). One of the problems and concerns today is the economics of small-scale CHP schemes, and researchers are looking for solutions that make these schemes more efficient and can be used more in DHC systems. A summary of the applications of CHP technology is given in Table 1 [10]. CHP technology has not yet found a special place in most countries, but in three countries, the United States, Russia, and China, it has been able to find a good position, and in other European countries, such as Germany, it has been able to grow with incentive laws. Figure 2 shows current estimates for global CHP capacity [13-16]. In Finland, 50% of the heating needs are met by DH, more than half of which is met by CHP technology.

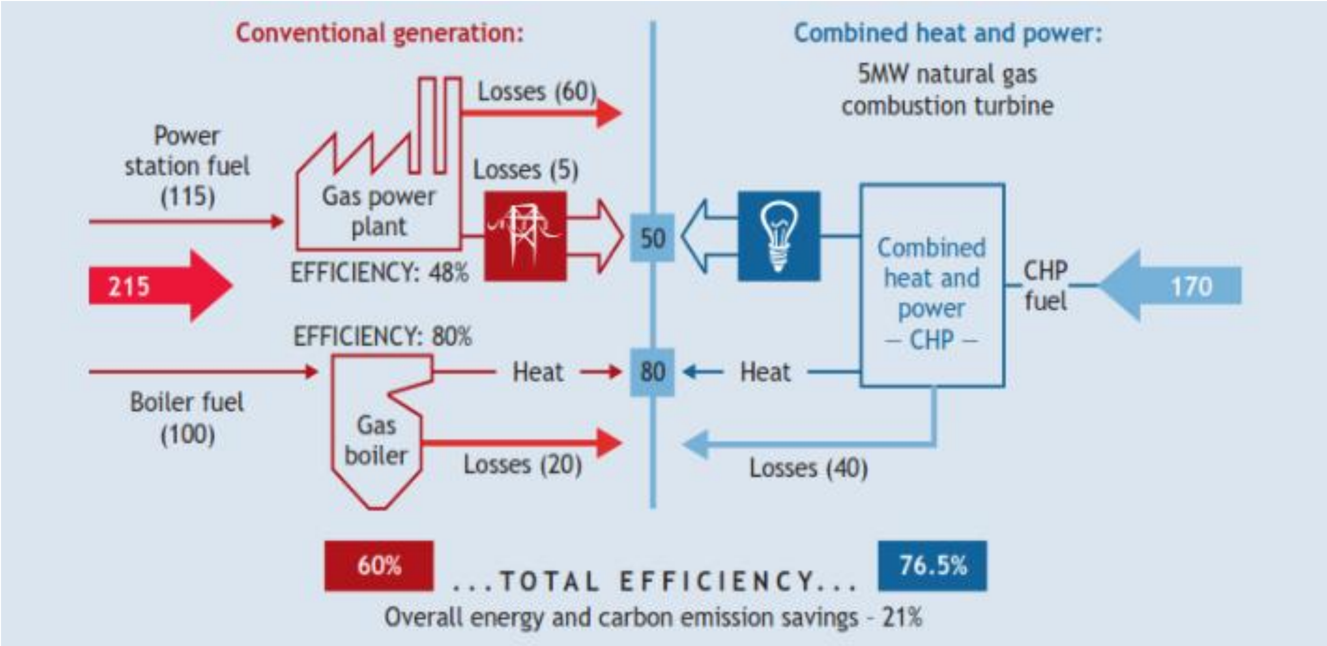

Figure 1. CHP efficiency (all HHV values) [10]

Table 1. Usage cases of CHP[10]

Property	CHP - Industrial	CHP - Commercial / Institutional	Regional heating and cooling
Common applicants	Chemical industries, paper industries, food industries, petrochemical industries	Commercial, service, and residential centers	Commercial, service, residential centers, as well as the industrial sector
Renewable energy utilization rate and energy sector losses	Medium-Much	little -medium	Much
Temperature level	Much	little to mediocre	little to mediocre
Common production capacity	Min=1MWe Max=500 MWe	Min=1kWe Max=10 MWe	Different capacities
The main transmitter	compression combustion, gas turbine, Steam turbine, combined cycle	fuel cells, Stirling engines, Reciprocating engines, microturbines	To burn waste, gas turbines, Steam turbines
fuel provenance	Solid, liquid, and gas phases of fuels, wasted combustion gases	liquid and gas phases	Every type of fuel

One of the common fuels in CHP technology, which increment the share of renewable, is biomass [17]. However, due to the low reliability of renewable sources and their inconsistent production, different renewable sources should be identified and used as CHP fuel. One solution that increases the reliability of renewable sources and reduces their volatile nature is thermal energy storage (TES) [18, 19]. Therefore, a system based on district heating and CHP technology that uses (TES) and renewable fuels is a solution to increase the share of renewables in the heat supply, and this combination of technology is one of the four categories of district heating system (4GDH) [20]. Due to the multifaceted nature of CHP-DH systems based on renewable fuels, modeling and optimizing these systems is necessary to increase their energy efficiency. According to the articles studied in this field, various measures have been taken to increase the use of renewable energy in CHP systems. For example, efforts have been made to determine the best dimensions of boilers, solar collectors, and TES, and thus the efficiency of the system in question increase and obtain the highest productivity when using renewable energies [21]. It has also been tried to increase the efficiency by using simulation and modeling, for example, using the Mixed Integer Linear Pro (MILP) command model, to minimize costs for a combination of CHP technologies, thermal power plants solar, boilers, and condensing chillers. The MILP algorithm uses a high-capacity power plant that uses CHP and TES technology [22]. In Finland, to increase the efficiency of CHP for domestic use by up to 65% theoretically, after calculating the total annual heat demand in the domestic sector, which generally includes heating demand for space and hot water, using the construction of different dimensions of CHP and storage unit was investigated. Finally, it was determined that a power of 300 kWth (250 kWe) for the non-modulating CHP and a storage unit of 800 kW h can have the highest efficiency [23].

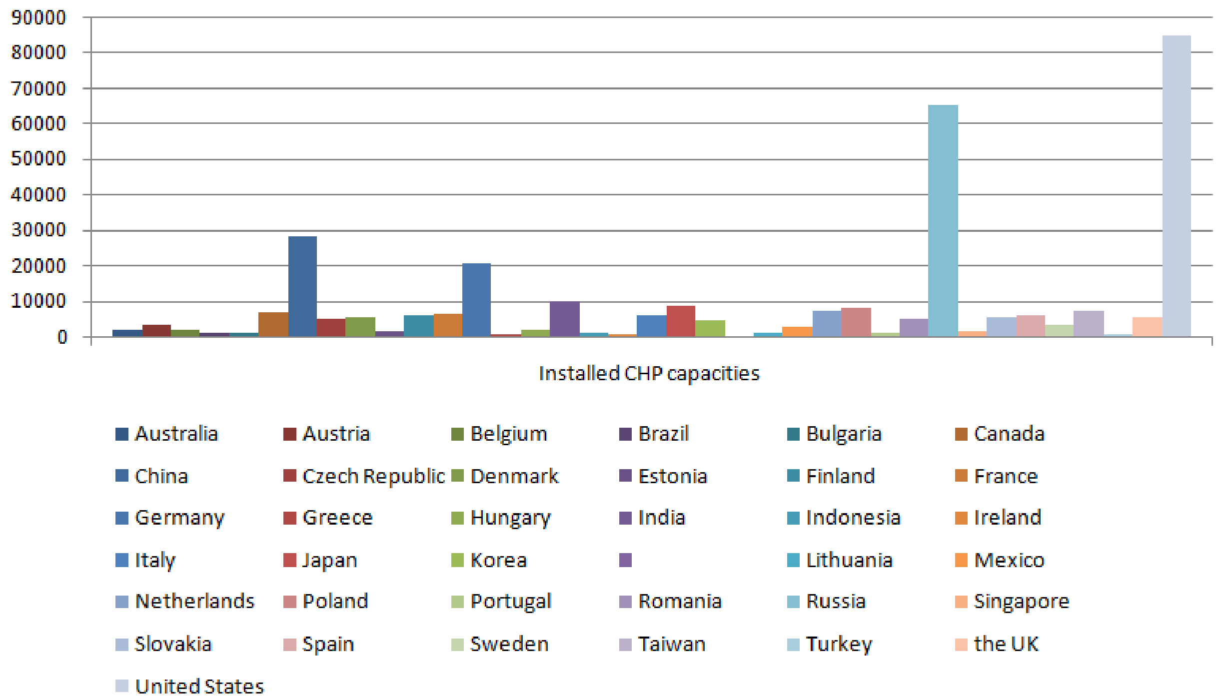

Figure 2. Installed CHP capacities (MWe) [65]

For markets where the price of electricity is variable and predictable, using the linear programming (LP) model, the Demand Response (DR) control of partial storage electric space heating was optimized, and the goal is to minimize the costs of customers and DR control is optimized using dynamic pricing, shifting electricity demand from peak price periods to the cheapest hours. As a result, it was found that using the optimized model, all multiple constraints can be met, such as:

- Maximum charging power
- Net storage capacity
- Quality of service
- Heating energy demand
- House cooling rate
- Maximum heat stored in the thermal masses of the building structures
- Maximum heat released from the thermal masses of the building structures

The studied area stored about 40% of the heat requirement for the whole day [24]. Also, to optimize the heat storage used in heating-cooling and power supply (CCHP) using renewable energy, TRNSYS unsteady model has been used [25]. A Model Predictive Control (MPC) was used to meet the thermal and electrical energy needs of a green building and integrate different renewable energies. The optimization model is used for a case study that uses electrical energy to pump water for domestic use [26]. This article is written to investigate the methods of increasing the use of renewable energy in CHP systems and increasing the sustainability of renewable energy when used in CHP systems during the day and night, and because different articles are based on the conditions of the region under review. They have presented various methods, and the need for an article that collects and examines most of the mentioned methods was felt. Therefore it was decided to write this article.

2. The relationship between District heating and cooling and combined heat and power

Regional heating meets moderate heating needs by reusing waste heat from CHP projects, industrial processes, and waste incineration. District heating and cooling (DHC) systems are one of the ways to use renewable sources in the discussion of heat and power supply. To provide cooling, the wasted heat can be converted to cold through absorption chillers or natural cooling sources such as deep water. One of the important points of DHC is to be used in areas with a population density because the shorter the distance between DHC and the consumer, the fewer losses will be [10]. The efficiency of area cooling systems is 5 and 10 times higher than traditional electricity-based equipment [15]. Due to the use of regional coolers from wasted energy sources, in the hot seasons of the year, there will be no pressure on power supply systems and no electricity shortage [14]. Figure 3 shows the energy sources that can be used in DHC.

3. Resources that can be used in CHP

3.1 Renewable resources

Because some renewable energy resources are predominantly alternating (wind, solar), placing such resources in a grid poses challenges. This is less likely to be the case for biomass, hydropower, and geothermal power plants. The most common renewable fuel used in CHP is biomass, which today has significant progress in meeting the need for heating or electricity, so Figure 4 and Table 2 show biomass conversion pathways to generate heat, electricity, or biofuels. Some of the main features of biomass thermal energy conversion to electrical energy and heat and combined energy (CHP) are presented in Table 2 [30-32].

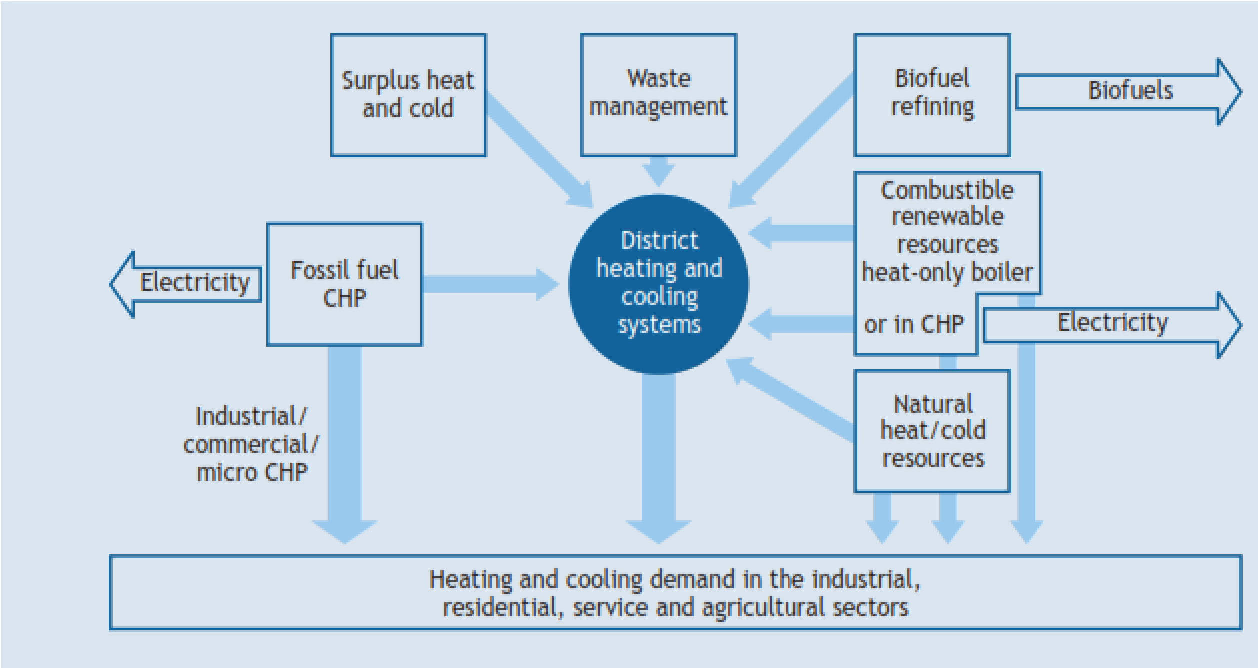

Figure 3. A variety of sources used DHC systems [27]

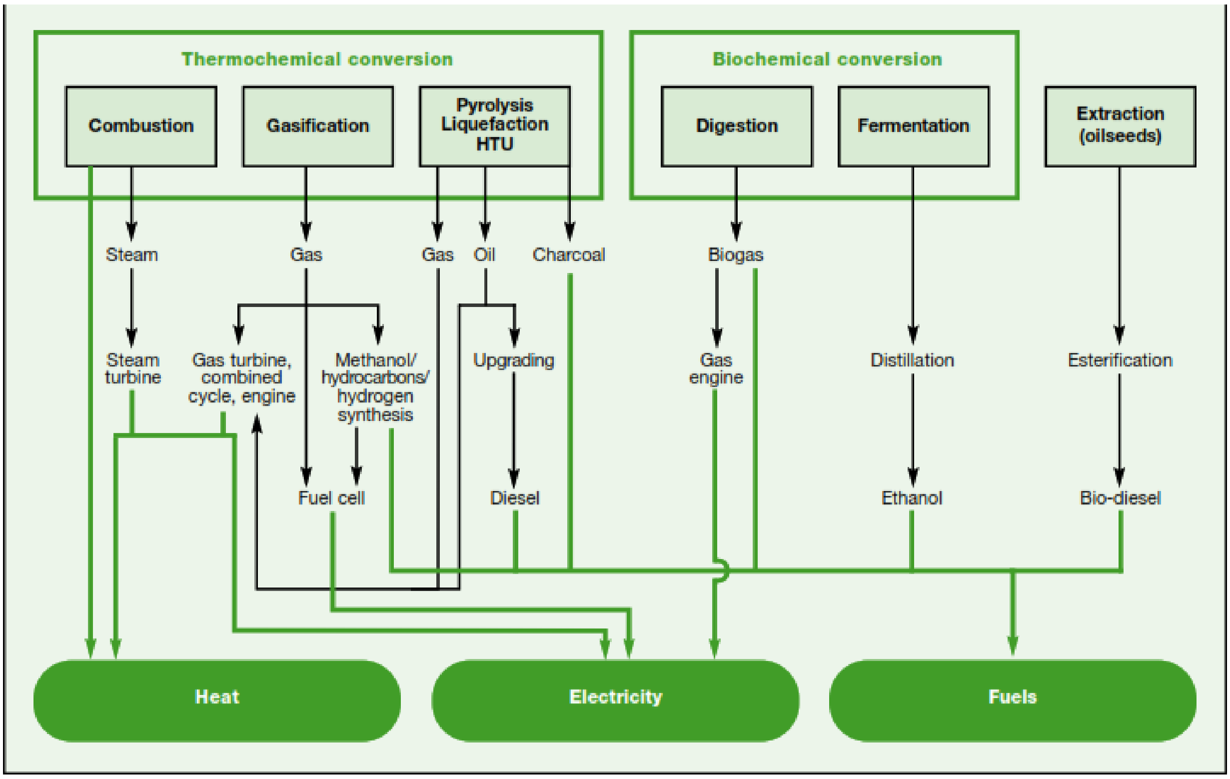

Figure 4. Main routes of biomass energy transfer [28, 29]

Table 2. Main routes of biomass energy conversion to heat and electricity [28, 33]

Conversion system	Domain		Net efficiency (percentage, LHV)		Investment cost ($/Kwe)	
	Min	Max	Min	Max	Min	Max
Ignition 1) Simultaneous generation of electricity and heat (CHP) 2) Standalone 3) Co-combustion	KWe100 1 MWe 20 MWe 5 MWe	1MWe MWe1- MWe100 20 MWe	60(overall) 80(overall) 20(Electrical) 30(Electrical)	90(overall) 99(overall) 40(Electrical) 40(Electrical)	2) 1,600	2)2,500 3) 250 plus the cost of the existing power plant
Gasification 1) CHP 2) Diesel 3) Gas turbine 4) BIG / CC	100 Kwe 1) 1 MWe 2) 30 MWe	1 MWe 1) 10 MWe 2) 100 MWe	15 (Electrical) 25(Electrical) 40(Electrical)	25(Electrical) 30 (Electrical) 55(Electrical)	1) 900 4) 1100	1) 3000 4) 2000 (when commerciali zing)

3.2 Fossil resources

Natural gas is the most common source of fossil energy used in CHP technology. One way to use natural gas is the use of high natural gas power to create shaft work and generate electricity while reducing natural gas pressure at the entrances to cities because the natural gas flux in transmission pipelines before city gate stations (CGS) is high (5e7 MPa), which CHP technology is one of the cost-effective solutions for this target and can produce a combination of heat and electricity (power) [34, 35]. Another way to use natural gas in CHP is to use it directly in internal combustion engines, but recently activities have been done to burn this fuel in CHP, such as enriching natural gas (methane) with hydrogen because the use of mixtures of Methane and hydrogen have a dual effect on the issuance of greenhouse gases. Higher H / C ratios reduce carbon dioxide issuance. The second effect, the enrichment of natural gas with hydrogen, improves the thermal effect of the engine, thus leading to a further reduction in carbon dioxide emissions [36]. In general, the amounts of CO and CO_2 resulting from the combustion of hydromethane are lower than in other gaseous fuels [37, 38]. Gas-based Micro-CHP systems have also recently received attention. These systems can be used with gas engines, Stirling engines, and fuel cells but currently can not be widely used on small scales such as residential due to the high cost of fuel cells and low internal efficiency (less than 5%) [39]. In addition, technologies such as gas boilers will be more cost-effective, but if Micro-CHP is reduced by about 50%, CHP technology can be widely used in residential areas instead of gas boilers [28]. Coal is another common fossil fuel used in CHP [38, 40, 41].

4. Discussion

4.1 CHP from a technical point of view

Salomón et al. [42] examine the technology used in CHP to use biofuels. In the range of 1-20 MW, ordinary Rankin cycle, gas turbine with HRSG, internal combustion engines, SOFCs, and MCFC can be used.

Various biofuels can be used in the typical Rankine cycle, although the solid phase is the most common biofuel. Changes must be made to use biofuels in gas turbines, especially its fuel system. On a smaller scale (50-1000 kW), microturbines, Stirling engines, fuel cells, and internal combustion engines are the most promising technologies. Of course, regarding the cost of using biofuels in CHP, Moreton et al. [43] Have a different opinion and believe that the use of liquid biofuels is more economical in terms of cost, resulting in shorter payback periods. However, in the normal Rankine cycle, the most commonly used biofuel has a solid phase. Jacimovic et al. [44] also have a different opinion from Salomón et al. [41] and believe that the typical Rankine cycle has low efficiency and high cost. This paper presents alternatives to the Rankine organic cycle in biomass power plants where the Kalina cycle is recommended. An overview of both Rankine and Kalina cycles is provided, along with the possibility of using biomass as a suitable energy source. Ammonia-water binary system analysis has been performed under different operating conditions for all proposed cycles based on published sources. The advantages of the Kalina cycle over the Rankin cycle are higher thermodynamic efficiency and lower capital costs with the possibility of using resources. Low-grade heat is like biomass or heat lost from exhaust gases. The inlet temperature of organic matter affects the performance of CHP. For this reason, the research in this field by Algieri et al. [45] to generate micro-scale heat and electricity (CHP), examined the performance of organic biomass ranking cycles (ORCs). Three organic substances were considered at the Expander input. The results show that the inlet temperature of organic matter and its type have a special effect on CHP performance. Algieri et al. [45] ORC systems using biomass are considered one of the solutions to increase efficiency and save the use of CHP on a residential scale. The results show that the evaporation temperature significantly affects the electrical power and efficiency of the ORC: the higher the temperature level, the higher the system performance. Heat recovery will increase ORC efficiency and power generation. Also, Sameti et al. [46] used MATLAB software and a genetic algorithm (GA) as an optimization method to determine the system's optimal behavior. The gas cycle's thermal performance based on the gas turbine has been simulated and optimized. To increase the economic efficiency and reliability of the micro CHP system, a micro gas turbine (MGT) is a promising solution. The results showed that increasing the inlet temperature of the gas turbine reduces the amount of exergy degradation in the combustion chamber (and receiver) and also saves fuel consumption. At 1000 K, the exergy efficiency increases from 67.69% to 71.52%, while the total cost rate increases slightly from 2.20 to 2.57 ($ / h).

One of the problems of renewable energies as an energy source is their instability and discreteness, which Hu et al. [47] have published an article in this field to increase stability, reliability, and flexibility. To increase reliability and flexibility, phase shift heat storage (HS) is introduced in the combined heat and power plant, using wind energy as the CHP energy source. Heat transfer processes in HS facilities are modeled as a thermal resistance network. To minimize wind energy loss, the integrated system operation plan is optimized using the linear programming (LP) method. The results show that installing HS facilities increases the flexibility of the power system and reduces wind energy loss from 18.7% to 11.2%. For maximum wind power consumption, the maximum temperature of the material phase change should be between 90 and 100 degrees. Other people also worked in excess heat storage. For example, Sartor et al. [48] examined the possibility of using excess heat storage at high temperatures to increase the flexibility of a combined heat and power plant. This article examines the economic, environmental, and energy aspects of CHP power plants that meet heating needs. And also, Stark et al. [49] provided a new simulation method to generate electricity from a CHP plant based on biofuel from a technical point of view. The new steam storage system integrates the boiler and steam turbine into the processes. According to the modeling results, flexible short-term power generation can be used for 15 minutes to several hours. As mentioned, biomass can be one of the best sources of energy supply for CHP power plants, and it benefits from better flexibility and reliability among other renewable energies. However, biomass can also have other applications. Sometimes instead of municipal solid waste, agricultural waste is used to provide heat and electricity in CHP power plants, which can be used for other purposes, such as providing fodder for livestock, producing biodiesel fuel, etc... For this reason, many articles worked on increasing the efficiency of biomass use and making it more cost-effective, such as Mathiesen et al. [50] finding ways to provide heating so that if it wants to use renewable sources as fuel, its biomass consumption will be reduced. One of the proposed solutions is to use district heating (DH) systems that use CHP and are more economical than individual heating methods. Because using this technology, other renewable sources such as solar heat, geothermal energy, and wasted heat can be used. Geothermal pumps are recommended for individual heating systems when the energy in the building is not sufficiently affordable for DH. Also, in this paper, for different amounts of wind energy, different technologies of home heating systems were examined. Mathiesen et al. [50] consider the role of heat storage when using CHP very effectively. Using a district heating system instead of individual heating reduces the use of biomass by 31.4%. Razmiet al [51]. Biomass is more reliable than other renewable energies because it is available for longer times. In this study, a new combined heat and power (CHP) system based on biomass gasification, compressed air energy storage (CAES), and gas turbine power plant has been introduced and analyzed using ASPEN PLUS. Three types of biomass materials, including wood chips, green waste, and municipal solid waste, are considered, and critical parameters' effects on system performance are carefully investigated. The results showed that the composition of syngas had no significant effect on temperature change and air vapor. A comparison of the effect of biomass material on efficiency shows that green waste is the least efficient, while the highest power plant efficiency can be obtained by using wood chips to produce syngas fuel. Ishikawa et al. [52]. The dynamic characteristics of biogas power plants with combined heat and power (CHP) systems were investigated, and the possibility of using these systems as a new source to regulate the supply-demand in the electricity network was evaluated. In addition, the emission characteristics of CHP engines were investigated. This paper examines CHP systems that use biofuels in Germany and Japan. Based on the results, biogas CHP systems have the potential to contribute to a long-term power equivalent adjustment, such as tertiary control reserve (TCR) in Germany. To operate efficiently, the biogas CHP system must equip a biogas bag with the capacity to supply power to restore the control reserve. Many biogas plants in Japan do not have adequate gas-bag capacity due to the FIT-specification power production strategy, so an upgrade is essential to provide adjustment capacity. The amount of methane and formaldehyde emissions are highest at the start of CHP systems, so the number of times you have stopped and started using CHP systems should be the lowest, and gas-bag capacity should be designed to reduce output fluctuations.

4.2 CHP from an economic perspective

Combined heat and power technology, as mentioned earlier, generate electricity and heat simultaneously because there is no continuous demand for electricity and heat simultaneously. For example, in the spring, a small heating load. In summer, the load of air conditioning is very high, and in winter, the demand for heat is very high, so managing the operation and duration of CHP plants is very efficient. In this regard, the use of optimization and simulation models helps. Yang et al. [53] believe that the use of heat storage to store the heat generated by the combined heat and power is very necessary because when the electricity rate is high, and the heat requirement is low, the combined heat and power activity, electricity is generated and injected into the network and at the same time the generated heat is stored. This source can be used during hours when electricity generation is not economical, but heat is needed. If this method is not used, using CHP at all hours of the day and night will not be economical. This study proposes a new method for measuring the combined heat and power unit production based on renewable energy in a combined energy microgrid [54]. A new model for micro-grid system planning was developed based on an hourly energy balance that can meet customer needs with the minimum annual cost of the system. Shao et al. [55] examined the possibility of encouraging consumers to use different energy sources to provide heating and the use of electricity to replace conventional heat supplied by district heating (DH). This paper aims to increase the flexibility of large-scale CHP projects when using renewable sources as an energy source, convert heating demand into electrical demand, and provide solutions to increase the heat storage of CHP projects. An optimization model is proposed to reduce costs while meeting the demand for CHP projects. The simulation result shows that 5% of the operating cost can be reduced due to the overall optimization of the integrated energy system. Because the demand for electricity and heat is different at different hours of the day and in different seasons, for this reason, it is necessary to convert heat and electricity sources to increase efficiency. The study found that government pricing of energy sources is one of the main reasons consumers use different energy sources to discuss heating and cooling. Fang et al. [56] optimized a model for the simultaneous generation of heat and electricity using heat storage proposed to minimize production costs and maximize revenue from electricity sales based on the time-sliding window method and the effect of time window width on the method's performance. In results show that revenue from the sale of electricity can increase [57]. Storage allows the production of large amounts of heat and power during off-peak hours while minimizing costs and maximizing energy efficiency. Moreton et al. [43] In the United Kingdom, a technical and economic modeling tool was presented to investigate the feasibility of biomass-based heat and power technologies for energy supply and Carbon dioxide demand in commercial horticultural greenhouses. The results show that the availability of initial capital can increase the reliability of the project by 25%. Increasing the thermal energy tariff at a minimum price of 10 pounds/megawatt-hour will improve the overall reliability of the project and reduce the sensitivity to rising fuel prices. Haghifam et al. [58], Based on the state space and a continuous Markov process, proposed a model for the electrical and thermal reliability of the heat and power generation systems using a frequency balance method. The mean time to failure index was also calculated for a combined heat and power case study in standby and parallel operation. By improving the reliability of gas and water transmission networks to combined heat and power and hot water transmission network to end users, system reliability and combined heat and power feasibility studies are improved. Several articles have worked on increasing the efficiency of renewable energy use in small-scale CHP power plants. For example, Lund et al. [59] seek a suitable method for using renewable sources such as wind, which are discontinuous in small-scale thermal power plants. This article aims to provide the pricing methods and tools that small businesses and service sectors, such as small CHP power plants, can perform independently, as large power plants do in the electricity market. The TRADE computer tool uses the above principles to calculate bidding prices. Goulding et al. [60] determine the optimal determination of biogas technology on a small and medium scale that is economically viable in Ireland. If there is heat demand in Ireland, biogas fuel use in CHP technology is justified. Otherwise, it is better to use this fuel in transportation or other sectors with more added value. Wang et al. [19] provide an energy system that provides intelligent hybrid renewable energy for communities (SHREC). This system considers the need for heating (heating and cooling) and electricity at the community level and emphasizes using electrical energy sources, CHP, and energy storage. A CHP-based linear programming (LP) algorithm has been provided for the SHREC system. Quick shutdown and commissioning combined heat and power plants will increase energy consumption and costs. Algieri et al. [45], an economic assessment has been made considering the Italian tariff scenario for the organic ranking cycle for domestic users in southern Italy. Results show that maximum temperature and heat recovery significantly affect the main functions of CHP. Wu et al. [61] optimized the MILP model for Microgrids, which includes CHPs, conversion equipment, and energy stores; it is proposed to combine heat and electricity based on renewable energy to reduce costs. Cormio et al. [62] reduce environmental damage and increase the economic efficiency of the simultaneous production of electricity and heat in industrial estates that use renewable sources such as wind or solid waste, a linear programming optimization method based on the energy flow optimization model (EFOM) was presented. The region of Apulia in southern Italy has been selected as the study area. The results showed that combining these resources to convert wind energy into electricity, extract biomass energy and waste, and use is better. Ahmadi et al. [63] optimized the multi-purpose combined heat and power plant in terms of thermodynamics and cost used in the paper mill in southern Iran, modeling using a genetic algorithm. Three exergies, cost, and emission rate functions are considered in multi-objective optimization. As exergy efficiency increases, purchasing equipment at the plant increases with the project's cost. In addition, the discharge temperature does not change fuel consumption and therefore does not affect emissions. Rezania et al. [64] study a variety of optimization methods that can improve the performance of integrated energy systems (IES), especially heat and combined energy (CHP) and cooling, heating, and combined energy (CCHP), using renewable energy sources; also it is shown by specifying the characteristics of each method along with accurate statistical reports. The results showed that classical optimization methods are no longer efficient for integrated energy systems and CHP, and innovative and modern optimization methods have been replaced. Each method has further contributed to a specific application among modern innovative algorithms. A genetic algorithm (GA) was considered for economical thermal optimization, and particle swarm optimization (PSO) was further used for economic recovery.

5. Conclusion

The use of fossil fuels in various sectors, especially those with fewer added values, has caused serious environmental problems. The heating and cooling sector is one of the major consumers of energy in the world, and now some governments are trying to lead people to use different energy sources to meet this need because by doing so, they will not rely on only one energy source, and energy security will increase. In return, if one source becomes more expensive and scarce, they will move to another source, which is cheaper. Using the technology of simultaneous electricity and heat production, which uses renewable energy sources as fuel, will be a promising solution to increase energy security and diversify the energy basket because, in this technology, a variety of renewable and fossil energy can be used. This report aims to review CHP technologies based on renewable energy and seek to increase their efficiency and reduce the volatile nature of renewable sources. CHP technology generates electricity and heat simultaneously, and heat is the limiting factor in this issue. Therefore, the main purpose of a CHP power plant is to provide heat, and it should be installed in a place where there is a need for heat and population density because, in this case, the transfer losses will be reduced. To increment the efficiency of these power plants and increase their flexibility, thermal storage should be used so that heat can be stored when only electricity is needed, and heat can be used if necessary. Management, mode of operation, and duration of activity of power and heat generation power plants have a great impact on their economy, so simulation models and optimization software can help a lot with these issues. In addition to activities such as modeling and optimization that increase the efficiency of CHP, the addition of some technologies to this area has also increased the efficiency of CHP because one of the problems of CHP systems now is economical when they are used on a small scale (commercial, residential). These technologies include micro gas turbine engines, ORC systems using biomass, and the possibility of storing phase change heat (HS). One of the current problems is that biomass is used more in value-added sectors, such as transportation, than heating and cooling as fuel. Researchers are now looking for solutions that, if biomass is used in the heating and cooling sector, reduce its consumption and give a higher efficiency, which was determined that if used the District heating and cooling that uses CHP technology is used, the biomass consumption can be reduced by 31.4% compared to individual heating. This amount can be used more in value-added sectors. The provision of a point market, an energy regulation market, and an initial storage market make small-scale CHP projects economical. Considering the electricity sector as part of a complete energy system where all the parts are interconnected is much more economical than considering it as a separate sector. Currently, using solid biofuels in power plants producing electricity and heat at a scale of less than 1 MW has a technological challenge that researchers are advised to work on in this field, as well as another sector that needs further research. The economization of CHP power plants is small-scale.

Data availability statement

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Conflict of interest

The authors declare no potential conflict of interest.

References

[1] A. K. Lotfabadi, A. Hajinezhad, A. Kasaeian, and S. F. Moosavian, "Energetic, economic, environmental and climatic analysis of a solar combisystem for different consumption usages with PSI method ranking," Renewable Energy, 2022.

[2] Riahi, K. , Dentener, F., Gielen, D., Grubler, A. , Jewell, J. , Klimont, Z. , Krey, V. , McCollum, D.L., et al. (2012). Chapter 17: Energy pathways for sustainable development. In: Global Energy Assessment: Toward a Sustainable Future. Eds. Team, GEA Writing, pp.1203-1306 (October 2012): Cambridge University Press and IIASA,http://www.globalenergyassessment.org

[3] H. Wang, W. Yin, E. Abdollahi, R. Lahdelma, and W. Jiao, "Modelling and optimization of CHP based district heating system with renewable energy production and energy storage," Applied Energy, vol. 159, pp. 401-421, 2015/12/01/ 2015, doi: https://doi.org/10.1016/j.apenergy.2015.09.020.

[4] Watch, Global Atmosphere. "World Meteorological Organization." WMO Reactive Gases Bulletin. Highlights from the Global Atmosphere Watch Programme. https://library. wmo. int/opac/doc_num. php (2003).

[5] Y. Noorollahi, A. Golshanfard, A. Aligholian, B. Mohammadi-ivatloo, S. Nielsen, and A. Hajinezhad, "Sustainable Energy System Planning for an Industrial Zone by Integrating Electric Vehicles as Energy Storage," Journal of Energy Storage, vol. 30, p. 101553, 2020/08/01/ 2020, doi: https://doi.org/10.1016/j.est.2020.101553.

[6] A. Gholami, A. Hajinezhad, F. Pourfayaz, and M. H. Ahmadi, "The effect of hydrodynamic and ultrasonic cavitation on biodiesel production: An exergy analysis approach," Energy, vol. 160, pp. 478-489, 2018/10/01/ 2018, doi: https://doi.org/10.1016/j.energy.2018.07.008.

[7] N. Azizi et al., "Critical review of multigeneration system powered by geothermal energy resource from the energy, exergy, and economic point of views," Energy Science & Engineering, 2022.

[8] M. Mohseni, S. F. Moosavian, and A. Hajinezhad, "Feasibility evaluation of an off-grid solar-biomass system for remote area electrification considering various economic factors," Energy Science & Engineering, 2022.

[9] F. Mohammadi, A. Hajinezhad, A. Kasaeian, and S. F. Moosavian, "Effect of Dust Accumulation on Performance of the Photovoltaic Panels in Different Climate Zones," International Journal of Sustainable Energy and Environmental Research, vol. 11, no. 1, pp. 43-56, 2022.

[10] T. J. R. f. I. Kerr, International Energy Agency website: https://www. iea. org/publications/freepublications/publication/chp_report. pdf, "Combined heat and power: evaluating the benefits of greater global investment," 2008.

[11] M. H. Katooli, R. Askari Moghadam, and A. Hajinezhad, "Simulation and experimental evaluation of Stirling refrigerator for converting electrical/mechanical energy to cold energy," Energy Conversion and Management, vol. 184, pp. 83-90, 2019/03/15/ 2019, doi:https://doi.org/10.1016/j.enconman.2019.01.014.

[12] A. Heidari, A. Hajinezhad, and A. Aslani, "A Sustainable Power Supply System, Iran's Opportunities via

Bioenergy," Environmental Progress & Sustainable Energy, https://doi.org/10.1002/ep.12937 vol. 38, no. 1, pp. 171-188, 2019/01/01 2019, doi: https://doi.org/10.1002/ep.12937.

[13] I. Staff, Energy Policies of IEA Countries: Austria 2002 Review. OECD Publishing, 2003. https://www.iea.org/reports/energy-policies-of-iea-countries-austria-2002

[14] International Energy Agency. Office of Energy Technology, R&D., and Group of Eight (Organization). Energy technology perspectives. International Energy Agency, 2006. URL:https://www.iea.org/topics/energy-technology-perspectives

[15] R. Verduci et al., "Solar Energy in Space Applications: Review and Technology Perspectives," Advanced Energy Materials, https://doi.org/10.1002/aenm.202200125 vol. 12, no. 29, p. 2200125, 2022/08/01 2022, doi: https://doi.org/10.1002/aenm.202200125.

[16] C. Henderson, "Fossil fuel-fired power generation. Case studies of recently constructed coal-and gas-fired plants," 2007. https://www.osti.gov/etdeweb/biblio/20968626

[17] K. Sartor, S. Quoilin, and P. J. A. E. Dewallef, "Simulation and optimization of a CHP biomass plant and district heating network," vol. 130, pp. 474-483, 2014.

[18] E. Carpaneto, P. Lazzeroni, and M. Repetto, "Optimal integration of solar energy in a district heating network," Renewable Energy, vol. 75, pp. 714-721, 2015/03/01/ 2015, doi: https://doi.org/10.1016/j.renene.2014.10.055.

[19] H. Wang, E. Abdollahi, R. Lahdelma, W. Jiao, and Z. Zhou, "Modelling and optimization of the smart hybrid renewable energy for communities (SHREC)," Renewable Energy, vol. 84, pp. 114-123, 2015/12/01/ 2015, doi: https://doi.org/10.1016/j.renene.2015.05.036.

[20] H. Lund et al., "4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems," Energy, vol. 68, pp. 1-11, 2014/04/15/ 2014, doi: https://doi.org/10.1016/j.energy.2014.02.089.

[21] D. Buoro, P. Pinamonti, and M. Reini, "Optimization of a Distributed Cogeneration System with solar district heating," Applied Energy, vol. 124, pp. 298-308, 2014/07/01/ 2014, doi: https://doi.org/10.1016/j.apenergy.2014.02.062.

[22] M. Giuntoli and D. Poli, "Optimized Thermal and Electrical Scheduling of a Large Scale Virtual Power Plant in the Presence of Energy Storages," IEEE Transactions on Smart Grid, vol. 4, no. 2, pp. 942-955, 2013, doi: 10.1109/TSG.2012.2227513.

[23] T. Nuytten, B. Claessens, K. Paredis, J. Van Bael, and D. Six, "Flexibility of a combined heat and power system with thermal energy storage for district heating," Applied Energy, vol. 104, pp. 583-591, 2013/04/01/ 2013, doi: https://doi.org/10.1016/j.apenergy.2012.11.029.

[24] M. Ali, J. Jokisalo, K. Siren, and M. Lehtonen, "Combining the Demand Response of direct electric space heating and partial thermal storage using LP optimization," Electric Power Systems Research, vol. 106, pp. 160-167, 2014/01/01/ 2014, doi: https://doi.org/10.1016/j.epsr.2013.08.017.

[25] A. Chesi, G. Ferrara, L. Ferrari, S. Magnani, and F. Tarani, "Influence of the heat storage size on the plant performance in a Smart User case study," Applied Energy, vol. 112, pp. 1454-1465, 2013/12/01/ 2013, doi: https://doi.org/10.1016/j.apenergy.2013.01.089.

[26] H. Dagdougui, R. Minciardi, A. Ouammi, M. Robba, and R. Sacile, "Modeling and optimization of a hybrid system for the energy supply of a “Green” building," Energy Conversion and Management, vol. 64, pp. 351-363, 2012/12/01/ 2012, doi: https://doi.org/10.1016/j.enconman.2012.05.017.

[27] R. Wiltshire, J. Williams, and S. Werner, "European DHC Research Issues," presented at the 11th International Symposium on District Heating and Cooling, Reykjavik, Iceland, August 31 – September 2, 2008, 2008, 2008. [Online]. Available: http://urn.kb.se/resolve?urn=urn:nbn:se:hh:diva-6036.

[28] J. Goldemberg, World Energy Assessment: Energy and the challenge of sustainability. United Nations Development Programme New York^ eNY NY, 2000.

[29] I. Gunnarsdóttir, B. Davidsdottir, E. Worrell, and S. J. E. P. Sigurgeirsdóttir, "Indicators for sustainable energy development: An Icelandic case study," vol. 164, p. 112926, 2022.

[30] R. Van den Broek, A. Van Wijk, and M. Trossero, "Electricidad a partir de eucalipto y bagazo en ingenios azucareros de Nicaragua. Costos, aspectos macroeconomicos y medioambientales," 1998.

[31] R. van den Broek, A. Faaij, and A. van Wijk, "Biomass combustion for power generation," Biomass and Bioenergy, vol. 11, no. 4, pp. 271-281, 1996/01/01/ 1996, doi: https://doi.org/10.1016/0961-9534(96)00033-5.

[32] H. Kargbo, J. S. Harris, and A. N. Phan, "“Drop-in” fuel production from biomass: Critical review on techno-economic feasibility and sustainability," Renewable and Sustainable Energy Reviews, vol. 135, p. 110168, 2021/01/01/ 2021, doi: https://doi.org/10.1016/j.rser.2020.110168.

[33] I. Gunnarsdottir, B. Davidsdottir, E. Worrell, and S. Sigurgeirsdottir, "Indicators for sustainable energy development: An Icelandic case study," Energy Policy, vol. 164, p. 112926, 2022/05/01/ 2022, doi: https://doi.org/10.1016/j.enpol.2022.112926.

[34] C. Li, S. Zheng, Y. Chen, and Z. Zeng, "Proposal and parametric analysis of an innovative natural gas pressure reduction and liquefaction system for efficient exergy recovery and LNG storage," Energy, vol. 223, p. 120022, 2021/05/15/ 2021, doi: https://doi.org/10.1016/j.energy.2021.120022.

[35] F. Kong et al., "A Novel Nitrogen Pipeline System for Recycling Pressure Energy: System Model and Energy Efficiency Economic Analysis."

[36] D. Faedo, "State of the art and environmental benefits using methane-hydrogen blends," Rivista dei Combustibili, vol. 61, no. 6, pp. 331-339, 2007.

[Online]. Available: http://inis.iaea.org/search/search.aspx?orig_q=RN:40049263.
[37] R. Sierens and E. Rosseel, "Variable composition hydrogen/natural gas mixtures for increased engine efficiency and decreased emissions," J. Eng. Gas Turbines Power, vol. 122, no. 1, pp. 135-140, 2000.
[38] S. De, M. Kaiadi, M. Fast, and M. Assadi, "Development of an artificial neural network model for the steam process of a coal biomass cofired combined heat and power (CHP) plant in Sweden," Energy, vol. 32, no. 11, pp. 2099-2109, 2007/11/01/ 2007, doi: https://doi.org/10.1016/j.energy.2007.04.008.
[39] S. F. Moosavian, D. Borzuei, R. Zahedi, and A. Ahmadi, "Evaluation of research and development subsidies and fossil energy tax for sustainable development using computable general equilibrium model," Energy Science & Engineering, 2022.
[40] J. Smrekar, M. Assadi, M. Fast, I. Kuštrin, and S. De, "Development of artificial neural network model for a coal-fired boiler using real plant data," Energy, vol. 34, no. 2, pp. 144-152, 2009/02/01/ 2009, doi: https://doi.org/10.1016/j.energy.2008.10.010.
[41] N. N. B. M. Nistah, F. Motalebi, Y. Samyudia, F. J. P. J. o. S. Alnaimi, and Technology, "Intelligent monitoring interfaces for coal fired power plant boiler trips: A review," vol. 22, no. 2, pp. 593-601, 2014.
[42] M. Salomón, T. Savola, A. Martin, C.-J. Fogelholm, and T. Fransson, "Small-scale biomass CHP plants in Sweden and Finland," Renewable and Sustainable Energy Reviews, vol. 15, no. 9, pp. 4451-4465, 2011/12/01/ 2011, doi: https://doi.org/10.1016/j.rser.2011.07.106.
[43] O. R. Moreton and P. N. Rowley, "The feasibility of biomass CHP as an energy and CO2 source for commercial glasshouses," Applied Energy, vol. 96, pp. 339-346, 2012/08/01/ 2012, doi: https://doi.org/10.1016/j.apenergy.2012.02.023.
[44] B. Jaćimović, S. Genić, and N. Jaćimović, "Application of modified Kalina cycle in biomass chp plants," International Journal of Energy Research, https://doi.org/10.1002/er.5570 vol. 44, no. 11, pp. 8754-8768, 2020/09/01 2020, doi: https://doi.org/10.1002/er.5570.
[45] A. Algieri and P. Morrone, "Energetic analysis of biomass-fired ORC systems for micro-scale combined heat and power (CHP) generation. A possible application to the Italian residential sector," Applied Thermal Engineering, vol. 71, no. 2, pp. 751-759, 2014/10/22/ 2014, doi: https://doi.org/10.1016/j.applthermaleng.2013.11.024.
[46] J. Pirkandi, M. A. Jokar, M. Sameti, A. Kasaeian, and F. Kasaeian, "Simulation and multi-objective optimization of a combined heat and power (CHP) system integrated with low-energy buildings," Journal of Building Engineering, vol. 5, pp. 13-23, 2016/03/01/ 2016, doi: https://doi.org/10.1016/j.jobe.2015.10.004.
[47] K. Hu et al., "Phase-change heat storage installation in combined heat and power plants for integration of renewable energy sources into power system," Energy, vol. 124, pp. 640-651, 2017/04/01/ 2017, doi: https://doi.org/10.1016/j.energy.2017.02.048.
[48] K. Sartor and P. Dewallef, "Integration of heat storage system into district heating networks fed by a biomass CHP plant," Journal of Energy Storage, vol. 15, pp. 350-358, 2018/02/01/ 2018, doi: https://doi.org/10.1016/j.est.2017.12.010.
[49] M. Stark, F. Conti, A. Saidi, W. Zörner, and R. Greenough, "Steam storage systems for flexible biomass CHP plants - Evaluation and initial model based calculation," Biomass and Bioenergy, vol. 128, p. 105321, 2019/09/01/ 2019, doi: https://doi.org/10.1016/j.biombioe.2019.105321.
[50] B. V. Mathiesen, H. Lund, and D. Connolly, "Limiting biomass consumption for heating in 100% renewable energy systems," Energy, vol. 48, no. 1, pp. 160-168, 2012/12/01/ 2012, doi: https://doi.org/10.1016/j.energy.2012.07.063.
[51] A. R. Razmi, H. Heydari Afshar, A. Pourahmadiyan, and M. Torabi, "Investigation of a combined heat and power (CHP) system based on biomass and compressed air energy storage (CAES)," Sustainable Energy Technologies and Assessments, vol. 46, p. 101253, 2021/08/01/ 2021, doi: https://doi.org/10.1016/j.seta.2021.101253.
[52] S. Ishikawa, N. O. Connell, R. Lechner, R. Hara, H. Kita, and M. Brautsch, "Load response of biogas CHP systems in a power grid," Renewable Energy, vol. 170, pp. 12-26, 2021/06/01/ 2021, doi: https://doi.org/10.1016/j.renene.2021.01.120.
[53] Y. Yanhong, P. Wei, and Q. Zhiping, "Optimal sizing of renewable energy and CHP hybrid energy microgrid system," in IEEE PES Innovative Smart Grid Technologies, 21-24 May 2012 2012, pp. 1-5, doi: 10.1109/ISGT-Asia.2012.6303122.
[54] S. Jahromi, S. F. Moosavian, M. Yaghoubirad, N. Azizi, and A. Ahmadi, "4E analysis of the horizontal axis wind turbine with LCA consideration for different climate conditions," Energy Science & Engineering, 2022.
[55] C. Shao et al., "Optimal Coordination of CHP Plants with Renewable Energy Generation Considering Substitutability between Electricity and Heat," Energy Procedia, vol. 103, pp. 100-105, 2016/12/01/ 2016, doi: https://doi.org/10.1016/j.egypro.2016.11.256.
[56] T. Fang and R. Lahdelma, "Optimization of combined heat and power production with heat storage based on sliding time window method," Applied Energy, vol. 162, pp. 723-732, 2016/01/15/ 2016, doi: https://doi.org/10.1016/j.apenergy.2015.10.135.
[57] M. Yaghoubirad, N. Azizi, A. Ahmadi, Z. Zarei, and S. F. Moosavian, "Performance assessment of a solar PV module for different climate classifications based on energy, exergy, economic and environmental parameters," Energy Reports, vol. 8, pp. 68-84, 2022/10/01/ 2022, doi: https://doi.org/10.1016/j.egyr.2022.05.100.
[58] M. R. Haghifam and M. Manbachi, "Reliability and availability modelling of combined heat and power (CHP) systems," International Journal of Electrical Power & Energy Systems, vol. 33, no. 3, pp. 385-393,

2011/03/01/ 2011, doi: https://doi.org/10.1016/j.ijepes.2010.08.035.
[59] A. N. Andersen and H. Lund, "New CHP partnerships offering balancing of fluctuating renewable electricity productions," Journal of Cleaner Production, vol. 15, no. 3, pp. 288-293, 2007/01/01/ 2007, doi: https://doi.org/10.1016/j.jclepro.2005.08.017.
[60] D. Goulding and N. Power, "Which is the preferable biogas utilisation technology for anaerobic digestion of agricultural crops in Ireland: Biogas to CHP or biomethane as a transport fuel?," Renewable Energy, vol. 53, pp. 121-131, 2013/05/01/ 2013, doi: https://doi.org/10.1016/j.renene.2012.11.001.
[61] Z. Pan, Q. Guo, and H. Sun, "Feasible region method based integrated heat and electricity dispatch considering building thermal inertia," Applied Energy, vol. 192, pp. 395-407, 2017/04/15/ 2017, doi: https://doi.org/10.1016/j.apenergy.2016.09.016.
[62] C. Cormio, M. Dicorato, A. Minoia, and M. Trovato, "A regional energy planning methodology including renewable energy sources and environmental constraints," Renewable and Sustainable Energy Reviews, vol. 7, no. 2, pp. 99-130, 2003/04/01/ 2003, doi: https://doi.org/10.1016/S1364-0321(03)00004-2.
[63] P. Ahmadi, A. Almasi, M. Shahriyari, and I. Dincer, "Multi-objective optimization of a combined heat and power (CHP) system for heating purpose in a paper mill using evolutionary algorithm," International Journal of Energy Research, https://doi.org/10.1002/er.1781 vol. 36, no. 1, pp. 46-63, 2012/01/01 2012, doi: https://doi.org/10.1002/er.1781.
[64] M. A. Bagherian et al., "Classification and Analysis of Optimization Techniques for Integrated Energy Systems Utilizing Renewable Energy Sources: A Review for CHP and CCHP Systems," Processes, vol. 9, no. 2, 2021, doi: 10.3390/pr9020339.
[65] T. J. R. f. I. Kerr, International Energy Agency website: https://www.iea.org/publications/freepublications/publication/chp_report. pdf, "Combined heat and power: evaluating the benefits of greater global investment," 2008.