Future Study on The Hybridization of Concentrated Solar Power Technologies with Fossil Power Plants and Development Scenarios for Iran.

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Considering Iran's lack of development and proper planning in the solar thermal industry, a future study is conducted with the aim of combining Concentrated Solar Power (CSP) and fossil fuel power plants based on development scenarios in Iran by gathering the opinions of experts and researchers in the field based on the Delphi method. The findings demonstrate that Iran has a high potential for solar thermal technologies due to high Direct Normal Irradiation (DNI) and suitable terrain. This technology can be used in both power plant and non-power plant applications. The results also indicate that in power plant applications, parabolic trough CSP technology is a suitable option for hybridization with fossil fuel power plants. In this regard, changes in the combined cycle, especially in the Heat Recovery Steam Generator (HRSG) section, are necessary. In addition, it should be noted that reducing fuel consumption is the most important advantage of hybridizing CSP systems with Combined Cycle Power Plants (CCPPs) for Iran. The findings indicate that there is a potential for a 1۹% cost reduction if equipment manufacturing is localized. Additionally, in the non-power plant sector of the solar thermal industry, there is potential for the technology to be utilized in desalination, steel, and petrochemical industries.

Keywords: *Concentrated solar power, Future study, Government policy, Delphi method, Fossil fuel hybridization*

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Nomenclature

CSP	Concentrated Solar Power
DNI	Direct Normal Irradiation
HRSG	Heat Recovery Steam Generator
CCPPs	Combined Cycle Power Plants
PV	Photovoltaic
ISCC	Integrated Solar Combined Cycle
LCOE	Levelized Cost of Electricity
NGCC	Natural Gas Combined Cycle
COPRAS	Complex Proportional Assessment
NRI	Niroo Research Institute

1. Introduction

Due to the growing energy demand and environmental pollution, renewable energy will be one of the most important sources of energy in future energy systems [1,2]. Studies show that in 2022, the total renewable energy production capacity in the world reached 3372 gigawatts [3]. Solar energy has the most significant potential for supplying electricity among renewable energy sources [4]. Solar electricity generation is currently dominated by Photovoltaic (PV) systems; however, electricity storage remains a bottleneck due to its cost [5].

On the other hand, Concentrated Solar Power (CSP) systems have proper storage capabilities, making CSP systems with storage more cost-effective than those without storage [6]. Recently, CSP systems have been used in various applications, such as hydrogen production, desalination, and electricity generation, in combination with other energy sources [7-9]. Direct normal irradiation (DNI) is one of the main parameters necessary for building a CSP plant. DNIs between 1900 and 2100 kWh/m2 per year are considered a threshold at which building a CSP plant is economically feasible [10]. CSP systems consist of four technologies: solar tower and parabolic troughs, which are the most developed, and linear Fresnel and solar dish technology, which are less developed [11]. One of the obstacles to the further development of this technology is its cost. However, studies show that

the popularity of the CSP industry is increasing due to thermal storage and its decreasing costs over time [12].

In the context of the CSP industry's advancement, there has been a recent focus on hybrid designs because the CSP system is suitable for integration with other energy technologies to generate electricity [13,14]. Investigations show that CSP offers several advantages, such as reducing costs and fossil fuel consumption, and increasing efficiency [15-17]. According to Williams et al. [18] and Nathan et al. [19], CSP hybrid systems can be divided into two categories: fossil and non-fossil. Studies show that among the different combinations, the combination of fossil fuel power plants with CSP technologies generally has higher efficiency and capacity factor and lower cost compared to other combined plants, such as wind and geothermal CSP hybrids [14].

Studies have shown that the Integrated Solar Combined Cycle (ISCC) plant is one of the most efficient options for utilizing fossil and solar resources [20]. In ISCC power plants, solar energy can be utilized in two main ways: 1. Preheating the air entering the gas cycle combustion chamber; 2. The mixing of exhaust gases from the gas turbine and the injected steam generated by the solar field into the Heat Recovery Steam Generator (HRSG), which only affects the steam cycle of the ISCC [21]. In the majority of cases in the literature, the steam produced by the solar field is reinjected into one of the HRSG sections and is mentioned as the most efficient method [22,23]. The location of solar energy injection into the HRSG is a critical design parameter, as it directly enhances the solar-to-electric conversion efficiency [24].

A major challenge in hybridization is properly sizing the relevant HRSG sections and estimating the costs to retrofit conventional combined cycle power plants (CCPPs), including the steam turbine modifications needed to accommodate the additional injected steam [23,25]. The HRSG can be designed to handle both fossil-fuel-derived and solar-generated steam, or it can be sized solely based on the fossil-fuel contribution [23]. It should be pointed out that higher solar shares in ISCC plants can be achieved by employing a larger steam turbine [26]. However, due to the intermittent nature of solar energy, performance optimization is essential for economic viability; therefore, retrofit strategies are typically adopted to minimize modifications to existing equipment such as the steam turbine and HRSG [26]. In some studies, the sizing of the HRSG and steam turbine is based on half of the surplus thermal output from the solar field rather than its entirety, as the CSP system and steam turbine do not operate simultaneously at nominal design conditions throughout the year [20].

1.2. Comparative studies and literature review of ISCC systems

Currently, Spain, the United States, and China are the leading countries in the field of CSP industry [11]. Also, investments in Middle Eastern countries have increased in recent years. These countries have taken steps towards lowering dependence on oil, gas, and other fossil fuels for electricity production with the aim of reducing fuel consumption and carbon dioxide production [27]. India also has plans to expand its renewable energy sector and has taken significant steps to promote CSP as part of its renewable energy mix, resulting in a CSP deployment capacity of 200 MW by 2021 [28]. One of the main barriers limiting the development of this industry in India is the lack of research and development, along with high costs, which reduce investor motivation due to the country's reliance on imported technology [28]. Research on this topic shows that countries can significantly reduce costs by localizing the manufacturing of components required for CSP technology [29]. For example, Sharma et al. [30] showed that a 15% reduction can be expected for CSP part manufacturing localization in India.

Proper policies and planning are necessary for the development of the CSP industry in a country [31]. For example, with the recent government policies in China, it has become one of the most prominent countries in this field, unlike in the past. Xu et al. [31] suggested that in order to promote the development of the CSP industry in the country, the government should focus on implementing preferential loan policies, tax incentives, and R&D funding support. Furthermore, Spain implemented a series of regulations that led to the rapid expansion of the CSP industry between 2004 and 2013 [32].

According to the literature about ISCC systems, some articles generally discuss the benefits of these power plants, such as cost reduction compared to other types of power plants, like CSP or standalone fossil fuel power plants. For example, Akroot et al. [33] modelled a hybrid power plant consisting of gas, steam, and organic Rankine cycles. They considered an existing 283 MW gas power plant located in the Libyan desert as the reference power plant. The capital investment cost of the proposed ISCC model varies between 52.59 and 58.19 USD/MWh. Additionally, they achieved a power output of up to 452.7 MW, along with a 46% reduction in fuel consumption compared to the reference gas power plant. AlKassem [34] conducted a techno-economic analysis for an ISCC system using solar tower technology in Saudi Arabia and showed that this design can achieve an annual efficiency of 53-59%, which is higher than other renewable energy technologies of a similar intermittent nature. In this analysis, the Levelized Cost Of Electricity (LCOE) of the ISCC system with 220.89 GWh annual generation of the solar tower field is found to be 12.71 cent/ kWh. Furthermore, Alqahtani et al. [35] showed that the integration of CSP technology with an integrated combined cycle with natural gas reduces the LCOE by 35-40% compared to a stand-alone CSP system. They also indicated that the advantages of an ISCC over a Natural Gas Combined Cycle (NGCC) are clearer when CO2 emissions are considered. Talal et al. [36] performed a thermal analysis on the combination of solar tower CSP technology with NGCC, which resulted in an increase in power and efficiency for the combined cycle system. In their analysis, the ISCC system's maximum power production is about 575 MW, and the maximum power production of NGCC is about 520 MW. Dersch et al. [37] compared the techno-economic performance of an ISCC power plant in Egypt, India, Mexico, and Morocco with a stand-alone CSP project in California. The results showed that hybridization leads to longer daily working hours and a reduced LCOE. They noted that an ISCC plant with thermal storage can yield higher utility, as the solar levelized energy cost is about 10–15% lower with thermal storage. Boretti et al. [38] conducted a case study on an ISCC power plant in Trinidad and Tobago. They used a novel application of a validated model for an ISCC system with solar irradiance input. Their results showed the benefits of adding a small solar field in terms of fuel conversion efficiency. They mentioned that relatively high cloud coverage does not prevent the ISCC system from delivering a few percentage points better fuel conversion efficiency than the standalone combined cycle gas turbine plant at affordable costs. Hosseini et al. [39] analysed different power plants, including a gas turbine power plant, a CCPP, a standalone CSP system with parabolic technology, and an ISCC power plant with parabolic technology of 33 MW and another 67 MW in Iran. The ISCC power plant with parabolic technology of ١7 MW achieved the lowest LCOE. They added that the best project for constructing the first CSP power plant in Iran is the ISCC project. Amani and Ghenaiet [40] examined the ISCC power plant with solar tower technology, and they showed that this power plant is a suitable and practical option in terms of economic and technical aspects, considering the savings in fuel consumption and reducing the production of pollutants during the life of the power plant. They concluded that an ISCC power plant could achieve fuel cost savings of approximately 7.07 million dollars over a 30-year operating period. Binamer [41] studied the performance of an ISCC power plant in Kuwait. He found that the efficiency of this power plant can exceed 66%, which is 20% higher than that of the current conventional power plants in Kuwait. Amesri et al. [42] examined the thermodynamic, economic, and life cycle assessment of

an ISCC power plant, demonstrating its minimal environmental impact.

Some studies have investigated various CSP technologies to combine with fossil power plants. For example, Petersheim et al. [43] investigated which CSP technologies are suitable for combination with fossil power plants. The results of the study showed that the parabolic technology is more efficient than the solar tower when combined. Bravo et al. [44] compared solar tower and parabolic trough technologies in a CCPP with a standalone NGCC system. The result of the study showed that the parabolic technology is more efficient than the solar tower in combination. Elmorsy et al. [45] made a comparison of various types of CSP technology with an integrated CCPP located in Aswan, Egypt, and showed that integration with linear Fresnel technology has the lowest LCOE. In another study, Manente et al. [46] examined the most suitable CSP technology for integration with CCPPs. Their analysis revealed that the solar-to-electric efficiency of parabolic trough technology is higher than that of linear Fresnel and central receiver systems. Gülen [47] investigated the integration of three CSP technologies—central receivers, parabolic troughs, and linear Fresnel—into CCPPs and performed a thermodynamic analysis of ISCC configurations. Gülen identified parabolic trough technology as the most appropriate option for hybridization, mainly because of its technological maturity. As noted by Kelly et al. [22], ISCC power plants offer an efficient pathway to sustain the advancement of parabolic trough technology .The list of ISCC power plants currently operating worldwide is outlined in Table 1 [48]. As observed in Table 1, the majority of existing ISCC plants are based on parabolic trough collectors.

Table1. List of operational ISCC power plants worldwide

Project	Location	Nominal Capacity	Technology	Start Year
Dadri	India	14MW	Fresnel	2019
Agua Prieta II	Mexico	12MW	Trough	2017
City of Medicine Hat	Canada	1.1MW	Trough	2014
Ain Beni Mathar	Morocco	20MW	Trough	2011
Green Duba 1	South Africa	43MW	Trough	2023
Kuraymat	Egypt	20MW	Trough	2011
Waad Al Shamal	Saudi Arabia	50MW	Trough	2018

As discussed in the preceding section, the ISCC power plants face several technical challenges. Consequently, the thermodynamic configuration plays a critical role in the performance of ISCC plants [44]. Abdelhalim et al. [49] investigated various configurations for integrating a CSP system with an existing CCPP in Alexandria, Egypt. For instance, they considered adding the solar field either before the combustion chamber or before the steam turbine inlet. Their results showed that each configuration could be suitable depending on the desired objectives, such as reducing fuel consumption or improving efficiency. Younis and Amori [50] evaluated two distinct HRSG configurations for an ISCC plant: a single-pressure HRSG without a duct burner, and a multi-pressure HRSG equipped with a duct burner. Their findings demonstrated that the multi-pressure configuration with a duct burner yields higher thermal efficiency. Iglesias-Varela et al. [51] considered five different integration points in the HRSG section of a CCPP to evaluate the effect of solar-generated steam injection on the plant's power output and fuel consumption. Their results indicated that the optimal option for steam injection is in the last high-pressure superheating section before the steam turbine. Mohammadzadeh et al. [52] investigated the most effective integration point for adding solar thermal energy within the HRSG. Their results showed that introducing solar heat into the high-pressure superheater section increases the pinch point temperature, thereby raising the high-pressure steam mass flow rate and ultimately improving both the thermal efficiency and overall plant performance.

1.3. Iran's status regarding the CSP industry issue

Iran has vast oil and gas reserves, but due to population growth and the increasing demand for electricity, developing renewable energy has become a necessity [53]. According to Afsharzade et al. [54], the country faces serious problems regarding the development of renewable energies. To counter these challenges, a mix of policy changes, such as the gradual elimination of fossil fuel subsidies and using the funding for incentive mechanisms needed for developing renewable energies or increasing social awareness of the negative impacts of fossil fuels instead, is needed.

Atabi [55] identified the lack of policy frameworks as a major challenge to promoting renewable energy in the country and added that the government can implement programs to complement and strengthen renewable energy companies with the participation of the private sector. Fadai et al. [56] stated that appropriate government policies are the main influencing factor on market and industrial development, accelerating the growth of competitive businesses. In addition to the aforementioned research articles, which were primarily conducted by engineers focusing on the development of renewable energy, Payam and Taheri [57], scholars in the field of political humanities, examined the main political barriers to the development of renewable energies. They categorized the obstacles hindering development into governmental, academic, industrial, and other sectors. For example, in the governmental sector, they identified excessive bureaucratic procedures that lead to the waste of time and resources, ultimately reducing private-sector motivation, as well as the absence of a competitive market as key political impediments to the expansion of renewable energy. In the academic sector, they highlighted the lack of clear programs guiding university researchers toward specific topics and predefined goals. Payam and Taheri [58], in another study, pointed to the structural problem arising from the involvement of multiple governmental institutions, including the Ministry of Energy, the Ministry of Agriculture, the Fuel Consumption Optimization Organization, and others in renewable energy affairs, which results in fragmented and parallel activities. They further emphasized the need for elite consensus in policymaking to prevent time loss and reduce decision-making complexities. Accordingly, they argued that national elite-development models should be designed based on existing conditions and without requiring fundamental structural or institutional changes. Towards energy planning for Iran, Mousavi et al. [59] conducted a study on selecting the best renewable energy source for Iran. They established a group of experts to evaluate renewable energy sources with the hierarchical Complex Proportional Assessment (COPRAS) method. Results showed affordable acquisition and exploitation of solar energy as the first, rank requires information gathering on the basis of radiation levels in each region. To analyse and identify the most appropriate strategies for the deployment of solar energy in Iran, Molamohamadi and Talaei [60] conducted a study using SWOT analysis, examining four strategic approaches: aggressive, conservative, competitive, and defensive. The results of their analysis indicated that the aggressive strategy, namely the expansion and strong development of solar energy technologies, is the most effective approach for advancing solar energy development in Iran. Regarding CSP, although there is good potential for it in Iran, the industry is not well developed in Iran. In fact, the main composition of Iran's energy depends on crude oil and natural gas sources, such that 81.4% of the production power is from fossil power plants, of which 38.5% is CCPPs [61,62]. Iran is located in an area

where a large part of the central and southern areas are arid and semi-arid, with measured DNI in the range of 2100-2400 kWh/m^2, with some locations exceeding this range; therefore, Iran has high economic potential for solar power considering the high solar radiation intensity [11,63]. Additionally, Iran is among the countries that have produced high-quality articles in CSP technology [64]. So far, nearly three decades of academic research activities and the construction of laboratory samples, as well as two decades of relatively few executive activities, have been carried out in the field of CSP systems in Iran. Among the implemented cases, the following can be mentioned:

1. Designing, building, and technical research on a 10-kilowatt CSP system in the Niroo Research Institute (NRI) [65].

2. The design and construction of a 250kW parabolic trough site next to the Shiraz CCPP [66].

3. Construction of a 30 kW Fresnel in the Taleghan site and a plan to build a 1 MW solar tower in Taleghan [67].

Mohammadi & Khorasanizadeh [68] demonstrated the current obstacles to the development of CSP projects in Iran, which include the low price of oil and natural gas, a lack of sufficient knowledge about CSP technologies, and the absence of long-term policy frameworks. They concluded that serious policy settings are necessary for the development of this industry in the country. Additionally, Fakharizadehshirazi et al. [69] recently conducted a comprehensive study on the optimal locations for the deployment of solar power plants in Iran, including CSP facilities. In their analysis, multiple criteria were considered, such as solar irradiance, distance from roads and transmission lines, land slope, and other relevant geographic and infrastructural factors. The study resulted in a comprehensive suitability map identifying both appropriate and unsuitable areas for solar power plant development across Iran. Their findings indicated that approximately 14.5% of Iran's land area is suitable for PV installations and 7.5% for CSP systems (with moderate to high suitability), primarily concentrated in the central regions of the country. Iran has good fossil power plant infrastructure; additionally, these power plants are located in places with good direct solar radiation; therefore, integration of CSP systems with fossil power plants, especially CCPPs in Iran, represents a promising strategy for the country. Iran's DNI map has been extracted from SolarGIS [70]. Then, according to Figure 1, the locations of Iran's CCPPs with solar radiation levels above and below 1900 kWh/m² are shown. According to the estimates derived from [71] and [72], the potential adds up to about 3500 MW.

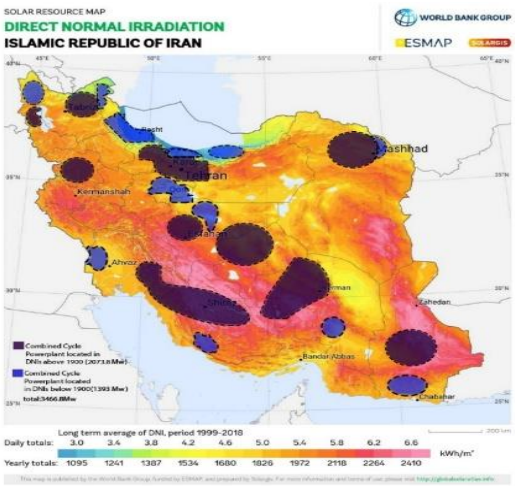

Fig. 1. Distribution map of Iran's CCPPs, the first priority of radiation above 1900 (kWh/m^2 year) (purple) and the second priority of radiation below 1900 (kWh /m^2 year) (blue)

Considering that the efficiency of the thermal power plant decreases with the increase in ambient temperature [73], this power plant can also be used to compensate for the power loss of the country's fossil power plants. Due to the lack of policies and plans for the development of the CSP industry in the country, in this article, gathering experts' opinions using the Delphi method and gathering a questionnaire according to the opinions of the country's experts have been used finally to present the development scenarios of the combination of CSP plants with fossil power plants.

2. Methodology

As mentioned earlier, this article aims to investigate the future scenarios of combining various CSP technologies with fossil fuel power plants and their development in Iran. Therefore, the Delphi method was used in this study for future research. The name of Delphi is derived from the name of the Oracle of Delphi, the priest of the temple of Apollo in ancient Greece, known for his prophecies [74]. Therefore, the first application considered for this method was future research and prediction. This method was first used for analysis and future research in the US military industry, but gradually became more widespread. The Delphi method is a structured method with a framework for group communication among experts. It is used for forecasting, decision-making, and analysis in ambiguous conditions. The results, derived from expert consensus, are expected to be highly reliable with minimal error. This method is a structured process for collecting and classifying the knowledge available to experts. It is used to distribute questionnaires among these people and control the feedback of the answers and opinions received in order to "identify" and "screen" the most important decision-making indicators.

The questionnaire used in this study is a researcher-made questionnaire that was adjusted and validated in interaction with the primary core of experts of this study. This questionnaire consists of 18 open- and closed-ended questions (Likert scale), which were divided into four categories related to "Perspective", "Technical Discussions", "Economic Matters," and "Executive Policies". The objectives of the research subject were examined and confirmed in interaction with the primary core of experts. The experts participating in the questionnaire include managers, faculty members, researchers, and experts in the field of energy. Selection was based on a minimum of 5 years of professional experience in renewable energy/power plant systems, holding relevant academic qualifications, or serving as policy managers in institutions such as SATBA, Niroo Research Institute (NRI), and key energy universities (Figure 2). A panel of 44 experts was invited. Among the participants, 48% held a doctoral degree (n=21), 43% held a master's degree (n=19), and 9% held a bachelor's degree (n=4). Consensus was defined as the majority of expert responses converging on a single score or category option across two consecutive rounds.

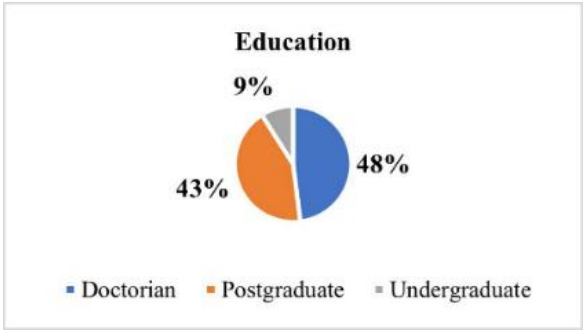

Fig. 2. Statistics of experts' education involved in the questionnaire

In order to reach consensus and conclusions, the questions were distributed among the target experts in several rounds, and finally, the results were analysed using quantitative analysis in Excel software. The process flowchart of this research is illustrated in Figure 3 [75].

The main questions that this study aims to answer are as follows: 1- What is the CSP outlook in Iran and the MENA region? 2- How do you evaluate the technical issues of CSP in combination with fossil fuel power plants? 3- What are the economic issues for developing CSP technology in combination with fossil fuel power plants? 4- How do you evaluate the impact of energy storage in CSP systems? 5- What are the procedures and policies of the Ministry of Energy, as well as the implementation strategies for the development of CSP technology in combination with fossil fuel power plants in Iran?

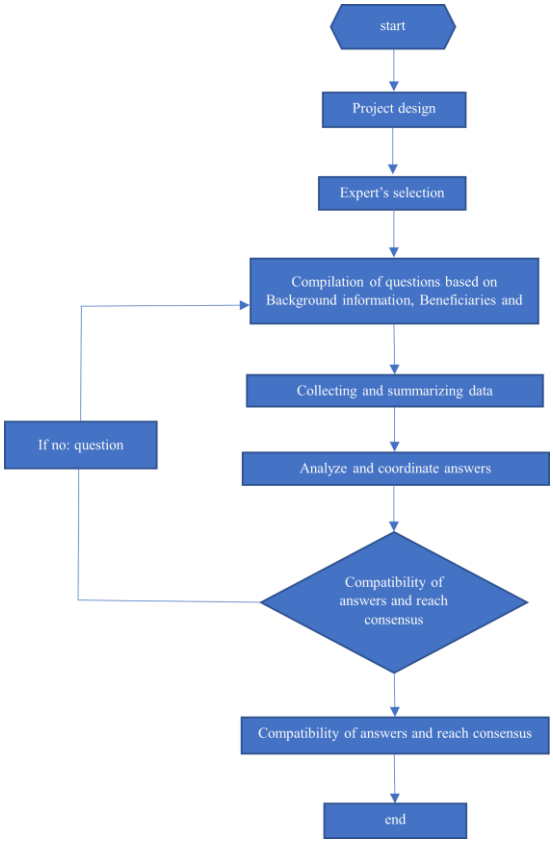

Fig. 3. The method of conducting future research using the Delphi method

3. Results

3.1. Main question number 1. "What is the CSP outlook in Iran and the MENA region?"

To answer this question, the experts were asked the following questions: A- How do you evaluate the future horizon until 2030 for the development of CSP systems worldwide, especially in the Middle East region? As seen in Figure 4, 66% of experts believe that, compared to PV, CSP plants will have limited development in the world and the Middle East due to the total cost. This price disparity with PV power plants is expected to persist and may even widen. B- At what stage of development do you see Iran in the field of combining CSP plants with fossil fuel power plants? Based on Figure 5, 55% of experts believe that Iran should prioritise the following areas in its focus on CSP issues: researching and manufacturing experimental samples, developing tech start-ups, preparing necessary infrastructure, and constructing an executive model of CSP combination with fossil power plants. They also recommend careful planning and implementation of appropriate measures. C- What is the biggest challenge faced when operationalizing the combination of CSP plants with CCPPs in Iran? According to the experts' opinions and Figure 6, 62% of experts consider the biggest challenge of operating CSP plants with CCPPs in Iran to be the high construction cost and the lack of domestic experts in this field.

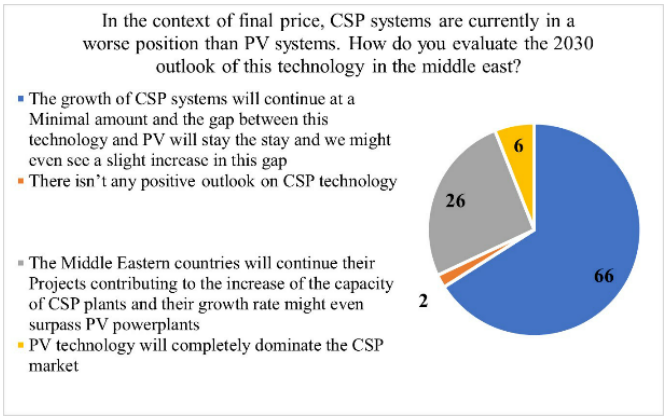

Fig. 4. Comparison of the total costs of PV and CSP systems

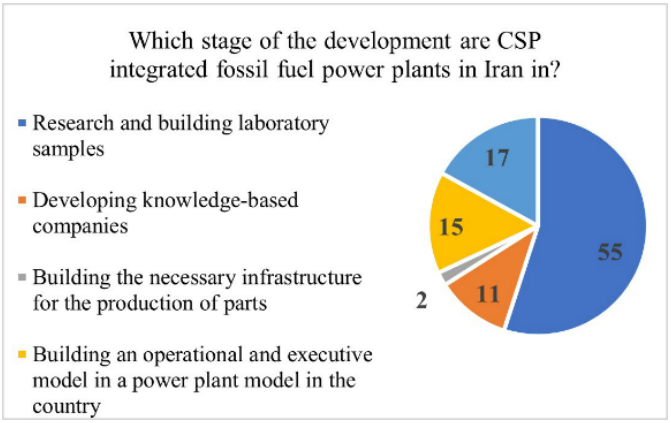

Fig. 5. Experts' opinion on the development stage of CSP and fossil power plants combination in the country

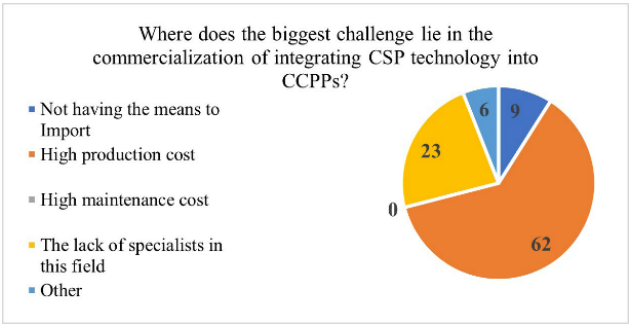

Fig. 6. Experts' opinion regarding the challenges of CSP development in Iran

Based on the findings, considering the high cost of CSP plants and the lack of domestic experts, it seems that the prospects for developing the CSP industry in Iran will be focused on the study and construction of university test samples as well as pilot projects for power plants in the next five years.

3.2 Main question number 2. "How do you assess the technical issues of CSP plants in combination with fossil fuel power plants?"

To answer this, experts were asked the following questions: A- which combination of CSP technology with a CCPP is more appropriate to increase efficiency? As seen in Figure 7, 64% of experts believe that parabolic technology is the best option for improving the efficiency of the country's power plants. Followed by Solar tower technology and Fresnel technology. B- What are the most important

challenges ahead in the design phase of combining CSP systems with fossil fuel power plants? According to Figure 8, 58% of the country's experts believe that the primary challenge in modifying the combined cycle's design to enable integration with CSP is that most of these modifications should be made in the HRSG part. C- Which technology is considered more appropriate to combine with the HRSG section of the power plant? According to Figure 9, 66% of experts believe that parabolic trough technology is the best option for incorporation in the CCPPs' HRSG section.

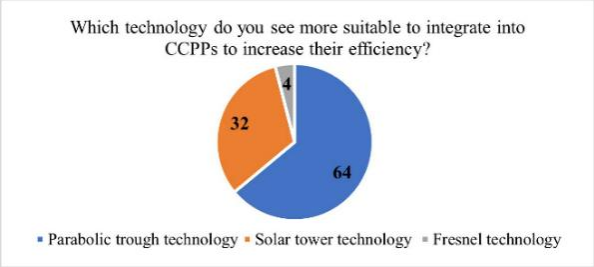

Fig. 7. The best technology to increase efficiency in CCPPs

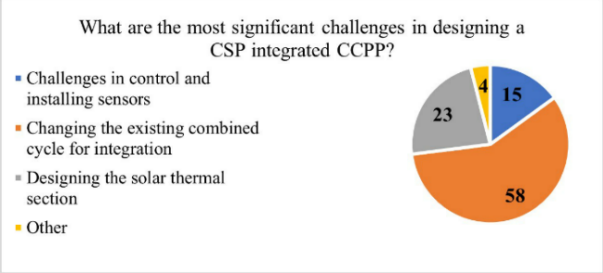

Fig. 8. The most important technical challenge in combining CSP plants with CCPPs

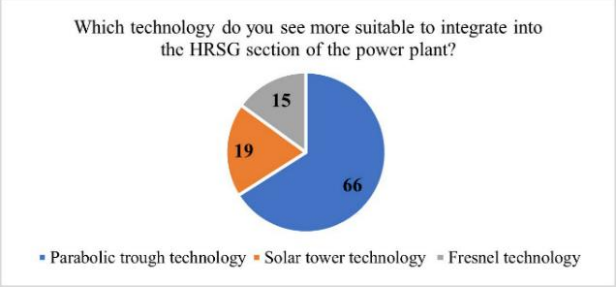

Fig. 9. Combination of the most suitable CSP technology in the HRSG sector

Based on the opinions in this section, it can be concluded that the best way to improve the efficiency of the country's fossil fuel power plants is to integrate parabolic CSP technology with the existing plants. The main challenge in this regard is to make the necessary modifications in the combined cycle of the HRSG section to integrate it with the solar thermal sector.

3.3 Main question number 3. "What are the economic issues for developing CSP technology in combination with fossil fuel power plants?"

To answer this question, the experts were asked the following questions: A- What is the most significant advantage of combining CSP technologies with fossil fuel power plants? According to Figure 10 and the opinion of experts, reducing fuel consumption and emissions by using CSP technology is the most important advantage of combining with CCPPs in the country. B- What percentage of cost reduction can be expected for the construction of CSP plants and their combination with fossil fuel power plants in the country, considering the localization of their manufacturing, compared to foreign counterparts? 68% of the experts speculate a price reduction between 10 and 20% for CSP technology compared to international conditions. By fitting a normal distribution function, we see that the maximum point lands near a 19% cost reduction according to opinions (Figure 11). C- What is the best method to attract private sector investors to construct and combine CSP plants with fossil fuel power plants? According to Figure 12 and experts' opinions, the most critical parameter in attracting private sector investors to build solar power plants is the government setting an appropriate electricity purchase tariff and providing loans to the private sector for the development of CSP technology.

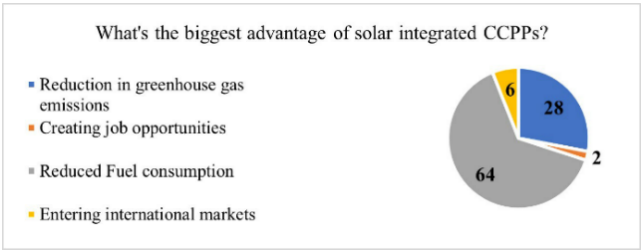

Fig. 10. The most important strength of combining CSP technology with CCPP

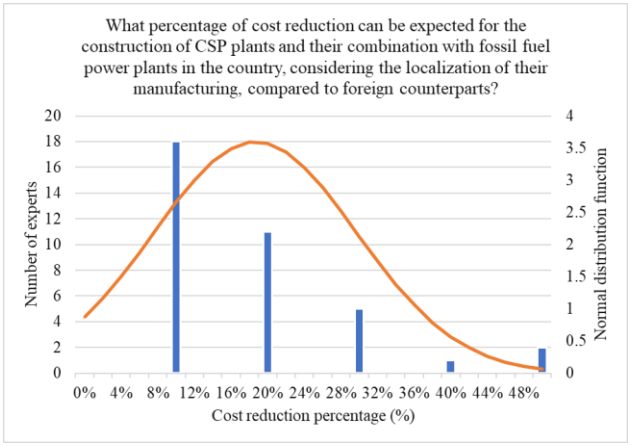

Fig. 11. Expert opinion on localization and cost reduction of CSP in the country

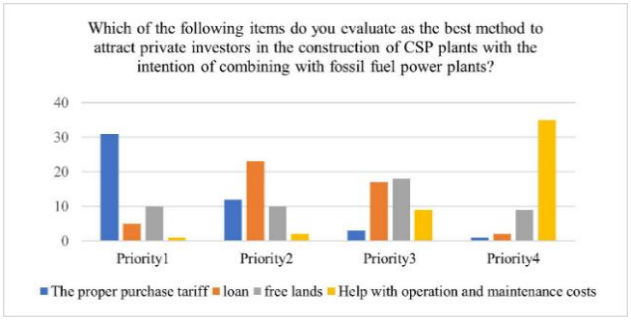

Fig. 12. Expert opinion on the best method to attract private investors to build a CSP plant with the intention of combining it with a fossil power plant

In response to this question, it can be concluded that combining CSP systems with CCPPs in the country has the most important advantage of reducing fuel consumption and emissions. Additionally, localizing the production of CSP technology could reduce the price by almost 19%. Findings also state that in order to attract private sector investors in the construction of these power plants, the appropriate purchase tariff by the government and lending are important parameters that must be considered.

3.4 Main question number 4. "How do you evaluate the impact of energy storage in CSP systems?"

To answer this question, experts were asked about their opinions on the thermal storage aspect of CSP systems. Most experts believe

that having the ability to store energy can have a significant effect on these systems during non-solar hours. However, some experts argue that the high cost of thermal storage, especially when combined with CCPPs, makes them not economically feasible (Figure 13).

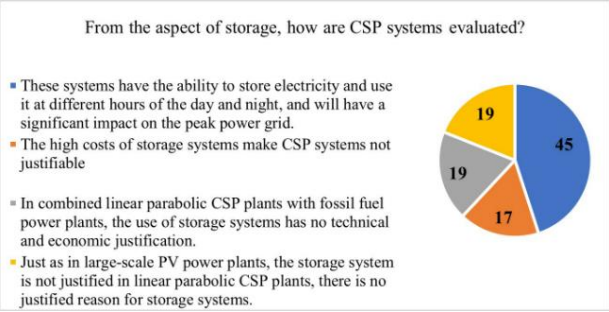

Fig. 13. Expert evaluation regarding the storage aspect of CSP systems

3.5 Question number 5. "What is the procedure and policy of the Ministry of Energy and executive policies for the development of CSP technology in combination with fossil fuel power plants in the country?"

Based on the opinions of CSP experts and specialists, we can mention some general issues regarding the use of CSP in addition to other renewable energies as follows: 1- Significant reduction in greenhouse gas emissions, 2- Protecting the environment and reducing water consumption, 3- Moving towards sustainable renewable energy development using appropriate tariff mechanisms, free land, and loans, 4- Increasing the productivity of fossil fuel resources and reducing the share of natural gas in the country's energy mix by developing renewables, 5- Increasing employment in the CSP industry. Based on the opinions of experts in this field, the actions outlined in Table 2 represent key practical steps in the initial phase of advancing this technology and legitimizing CSP technology in Iran. Based on the analysis of the questionnaire results and the conclusions drawn by the project research team, the suggested scenarios for national implementation are summarized in Table 3 as a general outcome:

First Scenario: Considering Iran's climate, as well as the existing power plants and the available technology in this field, most experts suggest connecting parabolic CSP plants to the HRSG section in fossil fuel power plants. This approach can be regarded as a practical and achievable scenario for the country.

Table 2. Proposed general programs and policies

Type of Policy	Administrator	Suggested Policy
Knowledge Development	Universities and Niroo Research Institute	Research and development of experimental models
Legitimization and Knowledge Development	Private sector, supported by the Ministry of Energy	Research and entry into competitive markets with support from knowledge-based companies
Technology Advancement	Ministry of Energy	Completion of the Shiraz Parabolic Power Plant
Legitimization	Energy Research Institute and CSP Technology Comprehensive Development Center	Development and implementation of a comprehensive support program for CSP technology
Technology Advancement	Ministry of Energy	Consultation for the pilot implementation of CSP plants connected to fossil fuel power plants

Table 3. Suggested scenarios

Priority	Executive Title	Subject Area	Period
1	Parabolic system connected to a fossil fuel power plant in the HRSG section	Power Plant Sector	Short-term (1–5 yrs)
2	Application of solar thermal energy in water desalination industries as an additional benefit from the knowledge obtained in the power plant sector	Non-Power Plant Sector	Mid-term (5–7 yrs)
3	Application of solar thermal energy in key national industries, including steel, petrochemical, and aluminium production	Non-Power Plant Sector	Long-term (7–10 yrs)

Second Scenario: Given the challenges of freshwater shortages in the country, CSP technology can also be seen as an extension of knowledge from the power plant sector. By implementing a comprehensive pilot project and training suitable personnel in CSP technology, there is hope for its expansion to support projects aimed at freshwater production, addressing the country's needs.

Third scenario: In recent years, the shortage of electricity and gas has affected the production planning of key industries such as steel and petrochemicals, leading to reduced output and increased costs in these sectors. Therefore, considering the thermal energy requirements in these industries, CSP systems can be effectively utilized.

4. Conclusions

Iran has a high potential for the application of CSP technologies due to its significant DNI. However, the development of this sector requires planned and long-term policies. Given that the cost of CSP power plants is significantly higher than combined-cycle and PV power plants, and given the lack of domestic experts for the development of CSP system technology in Iran, it can be predicted that the development outlook of the CSP industry in the next five years will be based on research projects and the construction of research models and pilot samples. Studies show that among various hybrid designs, combining CSP systems with fossil fuel-based power plants is a more effective solution than using this technology independently. Therefore, the aforementioned hybrid approach will improve the existing infrastructure of fossil-fuel-based power plants, thereby reducing costs and fuel consumption.

According to the studies conducted in this research, it can be concluded that to improve the efficiency of fossil power plants in Iran, combining parabolic trough technology CSP with fossil fuel power plants is considered the preferred option based on expert consensus, which is aligned with the literature [22,39]. In this regard, the biggest challenge is to make the necessary changes in the combined cycle (especially in the HRSG section) in order to combine it with the CSP system. It should be noted that one of the most important advantages of combining CSP systems with fossil fuel-based power plants (CCPP) is the reduction in fuel consumption. Also, by localizing CSP technology (hybridized with CCPPs), costs could be reduced by about 19%. To attract private sector investment to build these power plants, setting appropriate tariffs for electricity purchases by the government and providing low-interest loans are important factors that should be given special attention by electricity and energy policymakers.

Based on the general suggestions made in this study and the strategies related to CSP technologies mentioned in the related articles, the practical conclusion can be identified in the following three parts: 1- Considering the electricity production and integration of CSP systems with CCPPs, which is supported by most experts, the use of energy storage systems can have a significant impact on reducing the peak load of the Iranian electricity grid. 2- The use of CSP technology leads to an increase in the efficiency of existing

CCPPs. Therefore, this hybridization leads to the production of more electricity during peak hours, and the excess electricity produced can be stored in storage systems to be used at night. 3- Many industries in the country, such as the steel and petrochemical industries, require thermal energy as a vital medium in their production processes. CSP systems have great potential in this regard. Therefore, the support of the Ministry of Energy in promoting the use of CSP systems, especially in the heat production sectors, will bring significant benefits to the country. In addition, CSP capabilities can be used in practical freshwater production plants.

Given that the Ministry of Energy is responsible for ensuring a stable electricity supply in the country, the utilization of diverse technologies at the lowest possible cost should be prioritized. The LCOE of standalone CSP technology is relatively high; therefore, integrating CSP with fossil fuel power plants can play a significant role in reducing the LCOE and bringing it closer to that of other power generation technologies. To initiate the development of CSP technology in the country, the implementation of a pilot ISCC project within a 5-year timeframe is recommended. Furthermore, integrating CSP with desalination units can serve as another suitable application for developing this technology domestically and is proposed as a medium- to long-term strategy. This study is subject to several limitations, including a constrained sample size and the potential for expert selection bias toward local and domestic contexts. Furthermore, the inherently qualitative nature of expert consensus derived from the Delphi technique differs methodologically from quantitative thermodynamic simulations.

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