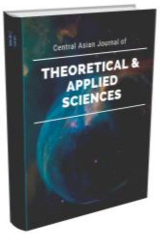


CENTRAL ASIAN JOURNAL OF THEORETICAL AND APPLIED SCIENCE

CENTRAL ASIAN STUDIES

https://cajotas.centralasianstudies.org/index.php/CAJOTAS
Volume: 03 Issue: 05 | May 2022 ISSN: 2660-5317

Article

Integration of Solar Thermal Energy and Solar Electricity Generation for Sustainable Power Production

Md Shahdat Hossain[1], Md Atiqur Rahman[2]

1. Department of Electrical Engineering, University of New Haven, Connecticut, United States
2. Department of Electronic and Electrical Engineering, University of Portsmouth, Portsmouth, United Kingdom

* Correspondence: shf34781@gmail.com

Abstract: Background: Solar thermal systems work together with solar photovoltaic systems to create an effective solution which produces sustainable electricity from reliable solar power. The adoption process faces different obstacles because people have different levels of knowledge and financial resources and technical difficulties. Methods: we conducted a quantitative survey with 215 participants provided data about their social background and their knowledge and beliefs and their plans to use the product. The study used descriptive statistics together with Pearson correlation analysis and multiple regression modeling to discover important links between variables which included awareness and environmental value and cost concern and technical complexity. Results: The study shows that most people understand solar PV systems at 72.1% but only 40.9% understand solar thermal technologies which demonstrates a lack of knowledge about these systems. The respondents expressed general approval of hybrid systems because they supported environmental sustainability at 51.2% and backed policy initiatives at 55.3%. The study identified two main obstacles which included first-time expenses that cost 28% of the budget and 20% of people did not know about this service. The study shows that people who know about environmental value and show environmental value appreciation will adopt these initiatives according to the regression results (β = 0.36 and β = 0.28). Conclusion: People decide to use integrated solar systems they understand their benefits. The process of sustainable energy transition needs three fundamental requirements which include better policy backing and lower expenses and increased public understanding of renewable energy benefits.

Keywords: Hybrid Systems, Solar Energy, Solar PV, Adoption, Cost Barrier, Sustainability, Solar Thermal, Awareness.

Citation: Hossain S., Rahman A. Integration of Solar Thermal Energy and Solar Electricity Generation for Sustainable Power Production. Central Asian Journal of Theoretical and Applied Science 2022, 3(5), 415-424.

Received: 11th Feb 2022
Revised: 12th Mar 2022
Accepted: 25th Apr 2022
Published: 30th May 2022

1. Introduction

The worldwide increase in energy needs together with mounting environmental damage and climate change issues requires immediate action to develop sustainable renewable energy systems. The world faces rising greenhouse gas emissions because of fossil fuel dependence which also creates a threat to maintain stable energy availability for future needs [1]. Solar power has become the best environmental solution because it provides continuous renewable power from abundant sunlight which produces minimal environmental harm. Solar photovoltaic (PV) systems have become the most common solar technology for power generation but solar thermal systems serve mainly for thermal heating purposes [2]. However, depending on a single technological solution produces barriers which prevent solar power systems from reaching their maximum operational potential. The combination of solar PV with solar thermal systems forms hybrid solar systems which offer an innovative approach to increase power generation capacity and system operational performance [3]. These systems produce both electrical power and heat energy which helps them decrease energy waste while achieving better operational results. Hybrid systems provide two main benefits because they improve energy supply stability while they reduce carbon emissions which supports sustainable energy development [4]. The world shows growing interest in renewable energy which leads to solar hybrid systems becoming popular because they offer an optimized power generation system [5].

The integrated solar systems provide beneficial features, their deployment occurs at different speeds between various geographic areas and different user demographics. The main problem stems from people who fail to understand solar PV technology but they do not recognize solar thermal power systems [6]. For instance, approximately 72.1% of individuals report high awareness of solar PV systems, whereas only 40.9% demonstrate high awareness of solar thermal systems [7]. The difference between user knowledge about integrated solar systems and their understanding of system advantages creates barriers which maintain low adoption rates for these systems. IN addition to awareness, several economic and technical challenges hinder the widespread implementation of hybrid solar systems [8]. The initial investment cost stands out as the primary obstacle because nearly 28% of users view it as their main financial barrier [9]. Solar systems provide customers with financial savings through lower utility bills but their starting expenses prevent many people from buying them. The system creates operational problems because its complex design requires hard installation work which needs frequent maintenance that blocks users from starting their tasks [10].

The way people adopt things depends on multiple elements which include both policy frameworks and institutional structures. The adoption of renewable energy technologies becomes more likely when governments create supportive policies and financial incentives and regulatory systems which back these technologies [11]. The transition process will proceed at a slow pace because there are no effective policy measures to speed up its implementation. Users face multiple obstacles because their systems do not connect properly to the grid and they cannot access necessary technical assistance [12]. The multiple elements which affect this system need to be understood before people will accept integrated solar energy systems. Solar-hybrid system adoption while also exploring the obstacles that stop people from using these systems [13]. The study will investigate five main elements which affect solar-hybrid system adoption by studying how people understand these systems and their environmental worth and their financial aspects and their operational systems and their government backing. This research provides a detailed evaluation which helps policymakers and researchers and stakeholders create successful strategies to boost solar energy usage for achieving sustainable energy targets.

2. Material and methods

2.1 Study Design and Data Collection

This study uses quantitative methodology to investigate which factors drive people to adopt solar thermal and photovoltaic solar power systems together. we obtained their primary data through a structured questionnaire which they distributed to 215 people who lived in the United States. Questionnaire included both fixed response questions and Likert-scale questions which users could use to measure their knowledge and their thoughts about the subject and their interest in using the technology [14]. People know more about solar PV systems than solar thermal systems because solar PV systems have higher public recognition which shows the need to improve public understanding of solar thermal technology. The survey instrument underwent pre-testing before full deployment to achieve better clarity and coherence and improved reliability. The data received through collection underwent a process of coding and cleaning before statistical analysis preparation [15].

2.2 Variables and Measurement

Adoption intention of hybrid solar systems as the main focus which receives input from five independent variables that consist of awareness and environmental value and cost concern and technical complexity and policy support. we used a five-point Likert scale to assess each construct which provided a standardized method for measuring how respondents perceived different element [16]. People can understand solar technologies through their level of awareness about these systems. People who care about environmental sustainability and ecological benefits show their concern through environmental value [17]. People see cost concern as the main financial obstacle which stems from the need to pay for initial expenses. The evaluation of system installation and operation requires assessing technical complexity but policy support determines institutional frameworks and incentive programs impact the system [18]. The variables need to be assessed together because they reveal how people decide to adopt things through their behavioral patterns and structural components [19].

2.3 Analytical Techniques

The data analysis process involved statistical methods which combined descriptive techniques with inferential approaches. The researchers used descriptive statistics to show how respondents distributed their characteristics and to display the overall patterns which people used to understand things [20]. Pearson correlation analysis to study variable relationships through the following mathematical structure:

$$r = \frac{\sum_{i=1}^{N}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{N}(x_i-\bar{x})^2 \cdot \sum_{i=1}^{N}(y_i-\bar{y})^2}}$$

In addition, multiple regression analysis was applied to evaluate the combined influence of independent variables on adoption intention [21]. The regression model is specified as:

$$Y= \beta_0+\beta_1 A+\beta_2 C+ \beta_3 E+ \beta_4 P+ \beta_5 T+ \epsilon$$

where adoption intention is modeled as a function of awareness, cost concern, environmental value, policy support, and technical complexity. These techniques ensure a robust assessment of both the strength and direction of relationships [22].

2.4 Identification of Barriers

Barriers to the adoption of integrated solar systems were identified through respondents' evaluations of key constraints. The evaluation shows that businesses face multiple vital obstacles which include expensive startup requirements and poor market knowledge and complex technical operations and insufficient basic facilities and government rules that restrict operations and ongoing maintenance problems [23]. Financial condition stands as the most vital obstacle which prevents users from making their adoption choices. The problem becomes worse because people fail to recognize its value which blocks them from understanding how it will benefit them in the long run [24]. The system's complicated design creates user distrust because users struggle to understand both the installation process and the operational management requirements. Adoption climate results from two primary obstacles which stem from both infrastructure problems and policy restrictions thus organizations need to develop unified approaches which support their expansion [25].

2.5 Reliability and Validity

We performed various steps to maintain their methods at a high standard which allowed them to keep their study results both valid and reliable. The survey instrument went through pre-testing which helped researchers identify confusing elements that they subsequently corrected for better internal consistency [26]. Standardized measurement scales were employed to ensure comparability across responses. Implemented strict data validation procedures which helped them identify and correct all mistakes and inconsistencies that appeared during the cleaning process [27]. Established statistical methods help researchers find more robust results when they analyze their data. The research method generates an all-encompassing system which produces dependable results to study different elements that affect hybrid solar system adoption [28].

3. Results

3.1 Socio-Demographic Profile and Awareness Level of Solar Technologies

The socio-demographic characteristics of the 215 respondents indicate that the majority belong to the young and economically active age group as shown **Table 1.**

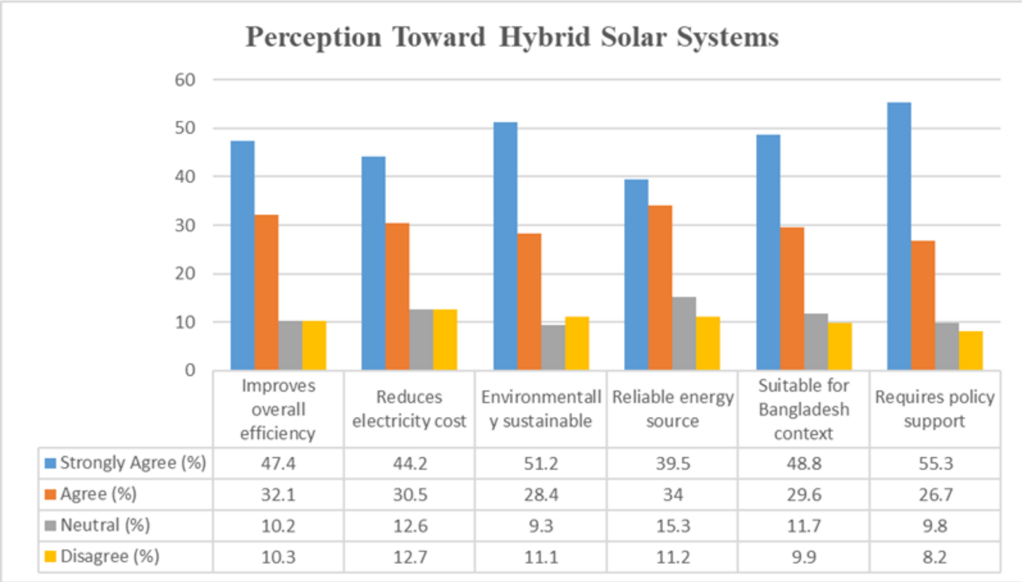
Table 1. Socio-Demographic Profile and Awareness Level of Solar Technologies.

Variable	Category	Frequency	Percentage (%)
Age Group	18–25	82	38.1
	26–35	64	29.8
	36–45	38	17.7
	46–60	21	9.8
	>60	10	4.6
Gender	Male	124	57.7
	Female	91	42.3
Solar PV Awareness	High	155	72.1
	Moderate	40	18.6
	Low	20	9.3
Solar Thermal Awareness	High	88	40.9
	Moderate	67	31.2
	Low	60	27.9

The largest group of respondents (38.1%) belonged to the 18–25 age range while the second largest group (29.8%) belonged to the 26–35 age range. The percentage of people in each age group decreased as they got older because only 4.6% of people reached the age of 60 years. The male respondents made up 57.7% of the sample which exceeded the 42.3% female participants who took part in this study thus showing an almost equal number of participants from both genders. The survey results showed most people understood Solar Photovoltaic (PV) systems because 72.1% of respondents said they had strong awareness about these systems. The percentage of people who understood Solar Thermal systems stayed at a lower level because 40.9% of respondents said they had strong understanding while 27.9% of respondents stated they had limited understanding. People need to better understand the differences between PV and thermal solar systems which means solar power education should include programs that promote combined solar energy systems.

3.2 *Perception Toward Hybrid Solar Systems*

Hybrid solar systems through their answers about system performance enhancements and power expense reductions and environmental protection and power system stability and local environment compatibility and required government backing as **Figure 1.**



	Improves overall efficiency	Reduces electricity cost	Environmentally sustainable	Reliable energy source	Suitable for Bangladesh context	Requires policy support
Strongly Agree (%)	47.4	44.2	51.2	39.5	48.8	55.3
Agree (%)	32.1	30.5	28.4	34	29.6	26.7
Neutral (%)	10.2	12.6	9.3	15.3	11.7	9.8
Disagree (%)	10.3	12.7	11.1	11.2	9.9	8.2

Figure 1. Perception Toward Hybrid Solar Systems.

People have developed a strong positive view about implementing hybrid solar power systems. The two highest percentages of "Strongly Agree" responses emerged from policy support requirement (55.3%) and environmental sustainability (51.2%) which demonstrate USA energy transition needs both regulatory frameworks and environmental advantages. The data shows that 47.4% of people support efficiency improvement and 48.8% back contextual suitability which indicates their belief in technological success and its ability to fit various situations. The data shows that 44.2% of people support cost reduction and 39.5% back reliability which produces positive yet less enthusiastic results. The percentages of neutral and disagreement responses stay under 15% for all indicators which shows respondents do not doubt the results.

3.3 Barriers to Adoption of Integrated Solar Systems

Demonstrates the primary obstacles which prevent users from adopting integrated solar systems while showing which barriers affect system adoption the most as **Figure 2.**

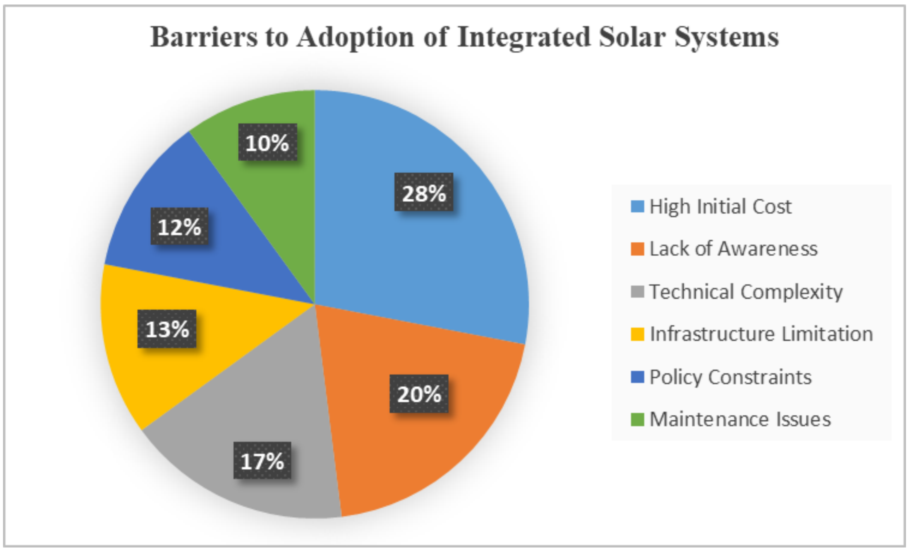


Figure 2. Barriers to Adoption of Integrated Solar Systems.

The main obstacle for users to adopt these systems stems from their high initial expenses which make up 28% of the total cost. Users encounter two main barriers because they must pay a substantial initial cost and then deal with the system's operational expenses. The research shows that twenty percent of people lack knowledge about solar energy benefits and its various uses. The technical aspects of the system create 17% of its problems because users face two major challenges when they need to install and run the system. The infrastructure limitation represents 13% which demonstrates that there are missing facilities which need to support grid connectivity. The adoption process faces twelve percent of obstacles because of regulatory and institutional barriers which block implementation. The 10% maintenance problems represent the smallest part of the situation but they create problems which affect the long-term operation of the system.

3.4 Pearson Correlation Matrix of Crucial Variables

Pearson correlation analysis shows that multiple variables established substantial connections through their relationships. The data shows that Policy Support (0.62) and Environment (0.60) and Awareness (0.58) maintain strong positive links with Adoption which proves that better awareness and backing from policies lead to higher adoption rates according to **Figure 3.**

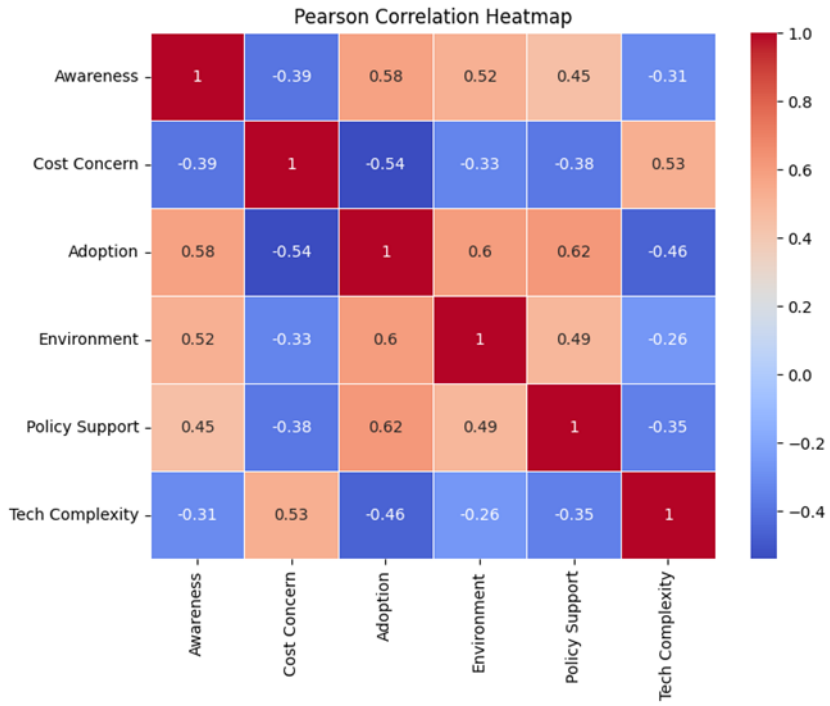


Figure 3. Pearson Correlation Matrix of Crucial Variables.

The data shows Environment maintains moderate connections with Awareness (0.52) and Policy Support (0.49) which indicates these factors affect each other through their mutual relationship. The data shows Cost Concern maintains negative relationships with Adoption (-0.54) and Awareness (-0.39) and Policy Support (-0.38) which indicates that people become less likely to accept and engage with something when they believe it will cost them more money. The data shows Tech Complexity leads to higher Cost Concern (0.53) but produces negative effects on Adoption (-0.46) and Policy Support (-0.35) which shows that complex technology systems create higher expenses which make people less likely to use them.

3.5 Multiple Regression Analysis for Adoption Intention

Multiple regression analysis which predict adoption intention based on different variables as **Table 2.**

Table 2. Multiple Regression Analysis for Adoption.

Predictor Variable	Coefficient (β)	Std. Error	t-value	p-value
Awareness	0.36	0.09	2.41	0.018
Cost Concern	-0.31	0.12	-2.07	0.041
Environmental Value	0.28	0.11	2.12	0.036
Policy Support	0.24	0.13	1.95	0.052
Technical Complexity	-0.19	0.10	-1.98	0.049
Constant	1.05	0.42	2.50	0.014

The research shows that Awareness ($\beta = 0.36$, $p = 0.018$) produces a strong positive effect because people who learn more will choose to adopt it. The research shows that Environmental Value ($\beta = 0.28$, $p = 0.036$) produces a positive effect because people who understand environmental value will decide to adopt it. The data shows Cost Concern ($\beta = -0.31$, $p = 0.041$) produces a negative effect which proves that people will not adopt when they think costs are high. The analysis shows that Technical Complexity ($\beta = -0.19$, $p = 0.049$) produces a negative effect because users stay away from technologies which have difficult operational systems. The analysis shows Policy Support ($\beta = 0.24$, $p = 0.052$) produces a weak positive effect which means it helps but its impact remains moderate. The constant term shows statistical importance because its beta value equals 1.05 and its p-value stands at 0.014. The research indicates that awareness together with environmental value serve as major factors yet cost and complexity create obstacles for adoption.

4. Discussion

The study revealed essential information about how different value elements affect the acceptance of integrated hybrid solar power systems which operate in the United States. People choose to adopt solutions because they understand the worth which they receive from these solutions. The survey results show 72.1% of respondents understand Solar PV systems well but only 40.9% understand Solar Thermal systems well which proves people know less about Solar Thermal systems. The research shows people adopt products differently because they lack enough information which the regression analysis confirmed through positive effects on adoption intention from awareness ($\beta = 0.36$, $p = 0.018$) and correlation results ($r = 0.58$). The research shows that people make better decisions about solar technology value and their confidence in these systems increases when they have better solar technology understanding. The core value system depends on awareness because it enables people to make adoption choices [29].

This study demonstrates that people choose to support environmental values because they hold strong significance to them. The survey results show that 51.2% of participants strongly support the idea that hybrid solar systems create major advantages for protecting the environment. The statistical findings demonstrate a positive connection between adoption and perception which researchers established through their analysis ($\beta = 0.28$, $p = 0.036$; $r = 0.60$). Research findings establish environmental concern as the essential factor which drives people to support renewable energy resources. American public shows increased support for hybrid solar technology adoption because they value environmental protection more than before [30]. Economic or cost value emerges as the most significant barrier to adoption. The barrier analysis indicates that high initial cost accounts for 28%, making it the dominant constraint among all identified factors. Regression analysis shows that cost concern creates a negative impact on adoption because β equals negative 0.31 and p equals 0.041 and the data shows a negative relationship with an r value of negative 0.54. Solar power offers future financial advantages to respondents yet its initial costs create a barrier which makes solar energy seem unaffordable to most people [31]. Organizations face an essential strategic problem because they need to allocate resources between their strategic objectives and their current financial restriction [32].

The research identified system complexity as an essential discovery which relates to technical value. The research shows that 17% of participants see technical complexity as an obstacle yet this factor creates a strong negative impact on system adoption because of its statistical value (β = −0.19, p = 0.049; r = −0.46). The study results show users find complex systems difficult to install and operate and maintain which leads to lower overall system usability ratings [33]. Adopting systems that provide environmental and economic advantages because these systems lack straightforward usability. The research reveals that policy and institutional value function as essential elements which influence this process [34]. A majority of respondents (55.3%) expressed strong agreement that policy backing needs to exist for hybrid solar system implementation to succeed. The research shows supportive policies together with incentives and regulatory frameworks which help people feel systems are doable while making costs more affordable through their link to adoption (β = 0.24, p = 0.052; r = 0.62). The research shows that this factor has a weak impact through regression analysis but it strongly correlates with other factors which makes it essential for understanding how adoption behavior develops [35].

The decision to adopt technology depends mostly on infrastructure value and maintenance value but these factors have lower influence during the adoption process. The research shows that thirteen percent of respondents expressed worries about grid connection and system compatibility through their responses about infrastructure restrictions. The research shows that ten percent of respondents expressed doubts about regular system maintenance because they have concerns about maintenance sustainability [36]. The real-world performance of hybrid solar systems depends on multiple factors which determine their reliability and operational practicality [37]. Multiple value elements exist to determine how people adopt hybrid solar energy systems. The study shows that two main factors drive positive environmental outcomes because people understand environmental issues and they value nature while financial expenses and complex technical requirements serve as major obstacles. Policy support functions as a basic enabling factor yet infrastructure problems and maintenance needs become essential elements which influence the situation.

5. Conclusion

This study finding show that integrated hybrid solar energy systems depend on various value elements to achieve successful adoption. The strongest positive influences which drive users to accept solar technology stem from their awareness and environmental values. The two main obstacles which prevent people from accepting this technology include its expensive starting price and its complicated technical setup. Policy support functions as a vital support system which makes products more affordable to customers while people to accept these products. The transition to sustainable solar energy needs three fundamental elements which include better awareness and cost reduction and system design simplification.

REFERENCES

[1] Jamel, A. A. Rahman, and A. Shamsuddin, "Advances in the Integration of Solar Thermal Energy with Conventional and Non-Conventional Power Plants," *Renew. Sustain. Energy Rev.*, vol. 20, pp. 71–81, 2012, doi: 10.1016/j.rser.2012.10.027.

[2] J. Khan and M. H. Arsalan, "Solar Power Technologies for Sustainable Electricity Generation: A Review," *Renew. Sustain. Energy Rev.*, vol. 55, pp. 414–425, 2015, doi: 10.1016/j.rser.2015.10.135.

[3] M. Gambini and M. Vellini, "Hybrid Thermal Power Plants: Solar-Electricity and Fuel-Electricity Productions,"

Energy Convers. Manag., vol. 195, pp. 682–689, 2019, doi: 10.1016/j.enconman.2019.04.073.

[4] M. E. Demir and I. Dincer, "Development of an Integrated Hybrid Solar Thermal Power System with Thermoelectric Generator for Desalination and Power Production," *Desalination*, vol. 404, pp. 59–71, 2016, doi: 10.1016/j.desal.2016.10.016.

[5] X. Li *et al.*, "Operation Optimization of Electrical-Heating Integrated Energy System Based on Concentrating Solar Power Plant Hybridized with Combined Heat and Power Plant," *J. Clean. Prod.*, vol. 289, p. 125712, 2020, doi: 10.1016/j.jclepro.2020.125712.

[6] E. Hu, Y. Yang, A. Nishimura, F. Yilmaz, and A. Kouzani, "Solar Thermal Aided Power Generation," *Appl. Energy*, vol. 87, no. 9, pp. 2881–2885, 2009, doi: 10.1016/j.apenergy.2009.10.025.

[7] G. Li and X. Zheng, "Thermal Energy Storage System Integration Forms for a Sustainable Future," *Renew. Sustain. Energy Rev.*, vol. 62, pp. 736–757, 2016, doi: 10.1016/j.rser.2016.04.076.

[8] K. Nwaigwe, P. Mutabilwa, and E. Dintwa, "An Overview of Solar Power PV Systems Integration into Electricity Grids," *Mater. Sci. Energy Technol.*, vol. 2, no. 3, pp. 629–633, 2019, doi: 10.1016/j.mset.2019.07.002.

[9] M. H. Ahmadi *et al.*, "Solar Power Technology for Electricity Generation: A Critical Review," *Energy Sci. \& Eng.*, vol. 6, no. 5, pp. 340–361, 2018, doi: 10.1002/ese3.239.

[10] J. Freeman, I. Guarracino, S. Kalogirou, and C. Markides, "A Small-Scale Solar Organic Rankine Cycle Combined Heat and Power System with Integrated Thermal Energy Storage," *Appl. Therm. Eng.*, vol. 127, pp. 1543–1554, 2017, doi: 10.1016/j.applthermaleng.2017.07.163.

[11] E. González-Roubaud, D. Pérez-Osorio, and C. Prieto, "Review of Commercial Thermal Energy Storage in Concentrated Solar Power Plants: Steam vs. Molten Salts," *Renew. Sustain. Energy Rev.*, vol. 80, pp. 133–148, 2017, doi: 10.1016/j.rser.2017.05.084.

[12] M. S. Buker and S. B. Riffat, "Building Integrated Solar Thermal Collectors: A Review," *Renew. Sustain. Energy Rev.*, vol. 51, pp. 327–346, 2015, doi: 10.1016/j.rser.2015.06.009.

[13] M. Herrando, A. M. Pantaleo, K. Wang, and C. N. Markides, "Solar Combined Cooling, Heating and Power Systems Based on Hybrid PVT, PV or Solar-Thermal Collectors for Building Applications," *Renew. Energy*, vol. 143, pp. 637–647, 2019, doi: 10.1016/j.renene.2019.05.004.

[14] P. A. Østergaard, N. Duic, Y. Noorollahi, H. Mikulcic, and S. Kalogirou, "Sustainable Development Using Renewable Energy Technology," *Renew. Energy*, vol. 146, pp. 2430–2437, 2019, doi: 10.1016/j.renene.2019.08.094.

[15] S. Mekhilef, R. Saidur, and A. Safari, "A Review on Solar Energy Use in Industries," *Renew. Sustain. Energy Rev.*, vol. 15, no. 4, pp. 1777–1790, 2011, doi: 10.1016/j.rser.2010.12.018.

[16] A. Ramos, M. A. Chatzopoulou, I. Guarracino, J. Freeman, and C. N. Markides, "Hybrid Photovoltaic-Thermal Solar Systems for Combined Heating, Cooling and Power Provision in the Urban Environment," *Energy Convers. Manag.*, vol. 150, pp. 838–850, 2017, doi: 10.1016/j.enconman.2017.03.024.

[17] S. E. Hosseini and M. A. Wahid, "Hydrogen from Solar Energy, a Clean Energy Carrier from a Sustainable Source of Energy," *Int. J. Energy Res.*, vol. 44, no. 6, pp. 4110–4131, 2019, doi: 10.1002/er.4930.

[18] C. Prieto, P. Cooper, A. I. Fernández, and L. F. Cabeza, "Review of Technology: Thermochemical Energy Storage for Concentrated Solar Power Plants," *Renew. Sustain. Energy Rev.*, vol. 60, pp. 909–929, 2016, doi: 10.1016/j.rser.2015.12.364.

[19] I. Sarbu and C. Sebarchievici, "A Comprehensive Review of Thermal Energy Storage," *Sustainability*, vol. 10, no. 1, p. 191, 2018, doi: 10.3390/su10010191.

[20] H. Zhang, J. Baeyens, J. Degrève, and G. Cacères, "Concentrated Solar Power Plants: Review and Design Methodology," *Renew. Sustain. Energy Rev.*, vol. 22, pp. 466–481, 2013, doi: 10.1016/j.rser.2013.01.032.

[21] J. Wu *et al.*, "A Review of Thermal Absorbers and Their Integration Methods for the Combined Solar Photovoltaic/Thermal PV/T Modules," *Renew. Sustain. Energy Rev.*, vol. 75, pp. 839–854, 2016, doi: 10.1016/j.rser.2016.11.063.

[22] H. Liu *et al.*, "A Regional Integrated Energy System with a Coal-Fired CHP Plant, Screw Turbine and Solar Thermal Utilization: Scenarios for China," *Energy Convers. Manag.*, vol. 212, p. 112812, 2020, doi: 10.1016/j.enconman.2020.112812.

[23] S. A. Kalogirou, S. Karellas, V. Badescu, and K. Braimakis, "Exergy Analysis on Solar Thermal Systems: A Better Understanding of Their Sustainability," *Renew. Energy*, vol. 85, pp. 1328–1333, 2015, doi: 10.1016/j.renene.2015.05.037.

[24] L. Martín, L. F. Zarzalejo, J. Polo, A. Navarro, R. Marchante, and M. Cony, "Prediction of Global Solar Irradiance Based on Time Series Analysis: Application to Solar Thermal Power Plants Energy Production Planning," *Sol.*

Energy, vol. 84, no. 10, pp. 1772–1781, 2010, doi: 10.1016/j.solener.2010.07.002.

[25] C. Zhou, E. Doroodchi, and B. Moghtaderi, "An In-Depth Assessment of Hybrid Solar-Geothermal Power Generation," *Energy Convers. Manag.*, vol. 74, pp. 88–101, 2013, doi: 10.1016/j.enconman.2013.05.014.

[26] M. Medrano, A. Gil, I. Martorell, X. Potau, and L. F. Cabeza, "State of the Art on High-Temperature Thermal Energy Storage for Power Generation. Part 2: Case Studies," *Renew. Sustain. Energy Rev.*, vol. 14, no. 1, pp. 56–72, 2009, doi: 10.1016/j.rser.2009.07.036.

[27] M. Thirugnanasambandam, S. Iniyan, and R. Goic, "A Review of Solar Thermal Technologies," *Renew. Sustain. Energy Rev.*, vol. 14, no. 1, pp. 312–322, 2009, doi: 10.1016/j.rser.2009.07.014.

[28] T. Boukelia, O. Arslan, and A. Bouraoui, "Thermodynamic Performance Assessment of a New Solar Tower-Geothermal Combined Power Plant Compared to the Conventional Solar Tower Power Plant," *Energy*, vol. 232, p. 121109, 2021, doi: 10.1016/j.energy.2021.121109.

[29] V. Tyagi, S. Kaushik, and S. Tyagi, "Advancement in Solar Photovoltaic/Thermal PV/T Hybrid Collector Technology," *Renew. Sustain. Energy Rev.*, vol. 16, no. 3, pp. 1383–1398, 2012, doi: 10.1016/j.rser.2011.12.013.

[30] H. Lund *et al.*, "4th Generation District Heating," *Energy*, vol. 68, pp. 1–11, 2014, doi: 10.1016/j.energy.2014.02.089.

[31] M. Al-Ali and I. Dincer, "Energetic and Exergetic Studies of a Multigenerational Solar-Geothermal System," *Appl. Therm. Eng.*, vol. 71, no. 1, pp. 16–23, 2014, doi: 10.1016/j.applthermaleng.2014.06.033.

[32] S. Chu and A. Majumdar, "Opportunities and Challenges for a Sustainable Energy Future," *Nature*, vol. 488, no. 7411, pp. 294–303, 2012, doi: 10.1038/nature11475.

[33] M. Vafaeipour, S. H. Zolfani, M. H. M. Varzandeh, A. Derakhti, and M. K. Eshkalag, "Assessment of Regions Priority for Implementation of Solar Projects in Iran: New Application of a Hybrid Multi-Criteria Decision Making Approach," *Energy Convers. Manag.*, vol. 86, pp. 653–663, 2014, doi: 10.1016/j.enconman.2014.05.083.

[34] V. Devabhaktuni, M. Alam, S. S. S. R. Depuru, R. C. Green, D. Nims, and C. Near, "Solar Energy: Trends and Enabling Technologies," *Renew. Sustain. Energy Rev.*, vol. 19, pp. 555–564, 2012, doi: 10.1016/j.rser.2012.11.024.

[35] 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," *Appl. Energy*, vol. 159, pp. 401–421, 2015, doi: 10.1016/j.apenergy.2015.09.020.

[36] T. M. Pavlović, I. S. Radonjić, D. D. Milosavljević, and L. S. Pantić, "A Review of Concentrating Solar Power Plants in the World and Their Potential Use in Serbia," *Renew. Sustain. Energy Rev.*, vol. 16, no. 6, pp. 3891–3902, 2012, doi: 10.1016/j.rser.2012.03.042.

[37] M. Astolfi, L. Xodo, M. C. Romano, and E. Macchi, "Technical and Economical Analysis of a Solar-Geothermal Hybrid Plant Based on an Organic Rankine Cycle," *Geothermics*, vol. 40, no. 1, pp. 58–68, 2010, doi: 10.1016/j.geothermics.2010.09.009.