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SUSTAINABLE ENERGY FOR BETTER SOCIAL, ENVIRONMENTAL AND ECONOMIC RETURNS

The solar end game: bibliometric analysis, research and development evolution, and patent activity of hybrid photovoltaic/thermal—phase change material

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Abstract
Solar photovoltaic-thermal hybrid with phase change material (PVT-PCM) emerges as an intelligent game changer to stimulate the clean, reliable, and affordable renewable energy technology. This PVT-PCM technology can be manipulated into generating both electricity and thermal energy that feature its practicality for residential and industrial applications. Hybridized of PCM into PVT design adds value to existing architecture with its capability to store excess heat that can be used during insufficient solar irradiation. Present work gives overview of the PVT-PCM system on technology innovation toward commercialization (viz, solar end game) subjected to bibliometric analysis, research and development evolution, and patent activity. A consolidation of these review articles was decluttered to focus on the performance and efficiency of PVT-PCM technology based on the fact that commercialization is ready once the technology is completed and qualified (at technology readiness level, TRL: 8). Economic review was conducted to understand the feasibility of the existing solar technologies and how it affects the PVT-PCM market price. Based on the contemporary findings, promising performance of PVT-PCM technology has underpinned its feasibility and technology readiness. China has predominant local and international framework and expected to be the PVT-PCM technology trendsetter in the next years through its strong international collaborative projects and pioneer in PVT-PCM patent filing. This present work underscores the solar end-game strategy and recommendation to create a path forward to achieve clean energy transition. Though, as to the date of submission of this article, no industry has found to manufacture/sell this hybrid technology in the market.

Keywords Solar · Bibliometric · Patent · End game · PVT-PCM

Introduction

Global demand for energy is growing briskly due to the increment of population index and rapid industrialization activities. This evident with the report from International Energy Agency that the energy sector was accountable for approximately 75% of global greenhouse gas (GHG) emissions. In accordance with that recent trend, The Net Zero Emissions by 2050 Scenario (NZE) is designed to provide pathway for the energy sectors to reach net zero CO_2 emissions by 2050, specifically to realize universal energy access and enhancement of air quality (IEA 2022b). Nevertheless, reaching net zero by 2050 demands huge leaps in clean energy innovation and holistic deployment of available renewable technologies along with the pre-commercial one.

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Solar and wind are forecasted to conquer nearly 70% of electricity generation by 2050, which highlight the important to evaluate the research progression and technology readiness of those renewable technologies (Bouckaert et al. 2021). Compared to wind, solar is more tangible and relevant toward sustainable energy and easily accessible to incorporate with decentralized electricity generation system. Rapid deployment of solar technologies is able to push energy sector (electricity) to the edge in the race to zero. This is in line with NZE's pathway, where rapid scale-up of solar system is required to accelerate energy transition (from fossil fuel to renewable).

At present, solar technologies can generally categorize into three. For instance, solar thermal collector, photovoltaic (PV) module, and the recent one are solar photovoltaic/thermal (PVT) panel. These three technologies are already at the commercialization phase while at different maturity stage. This scenario is influenced by the research and development evolution/dynamics and market demands which subject to the geographical location and investor's interest.

Solar thermal collector/system harvests heat from the sun for various application such as water heating system, heat pump, and district heating. Based on NZE Scenario 2050, the pathway calls for 400 million solar thermal systems dwellings by 2030, targeting standard and new emerging solar thermal technologies deployment (IEA 2022b). While for solar PV, 7 400 TWh of total power generation (from 2020 to 2030) is required by 2030 to align with the NZE Scenario 2050. Investment in solar rooftop distributed solar PV expansion as well as involvement in corporate power purchase agreements (PPAs) feature significant efforts to accelerate solar PV deployment while achieving net zero emissions (IEA 2022a). Based on NZE 2050 envision for solar thermal and PV cell, innovation of hybrid solar PVT would be able to reduce (or combine) the targeted installed capacity (for both systems).

Hybrid solar PVT was evolved based on the solar thermal collector and PV module application. Its dual operation with compact design enables the technology to penetrate real market effortlessly. As extreme solar radiation may reduce the electricity conversion of solar PV, hybridizing the solar thermal collector behind PV cell is able to cooling down the cell (Marsh 2010); thus maintaining the performance of solar PV while managing to harvest heat for other thermal applications. This PVT technology has proven to generate four times more energy compared with solar PV under the same surface area (Marsh 2010; Senthilraja et al. 2020). Furthermore, rapid reduction in solar PV cost has make the technology more sensible and relevant to be on par with the conventional fossil-fuel power plant.

Dramatic technological revolution and global demand toward renewable energy (viz solar PVT) and global pressure toward NZE 2050 have led to a ground-breaking discovery of a power couple; hybrid PVT with phase changes material (PVT-PCM). Where, coupling of solar PVT with PCM is able to resolve the existing challenges by bridging the gap between energy supply and demand and deals with the diurnal pattern. This advantage is based on the characteristic of PCM which enables to store excess solar energy in latent heat form. Besides absorbing excess heat, PCM also acts as a heat storage material. Therefore, the collected heat can be utilized during night-time when the sun is not available (Mofijur et al. 2019; Javadi et al. 2020). Additionally, PCM as a latent heat storage is capable of storing fourteen times more heat per volume unit than other sensible heat storage (Zalba et al. 2003). This property has become among the impressing factors for the researchers to incorporate PCM in their PVT designs. Moreover, when compared to standalone PVT technology, PVT-PCM shows higher electrical efficiency performance due to the PCM's enhanced cooling effect and reduction of PV plate backplane temperature (Yang et al. 2018; Fayaz et al. 2019). This power couple envision would be able to rationalize the solar energy application especially during cloudy and night time while concurrently minimize the geopolitical risk and securing access to energy (Avelar 2022).

Based on contemporary solar power market growth, technology readiness level (TRL) for solar thermal collector, PV panel, and PVT is at the TRL 8–9 (https://calssa.org/thermal-manufacturers, 2023; Marsh 2021; https://www.openpr.com/new, 2022), which demonstrate that the technology has been successfully evaluated, completed, and qualified in an operational environment in commercial layout. Contradict with PVT-PCM, this technology seems at intermediate prototypical stage, as supported by Jabar et al. (2021) where application of PCM as solar thermal energy storage is still at TRL 5–6.

Thus, to avoid premature technological lock-in for PVT-PCM technology, this work aims to provide systematic analysis of PVT-PCM research through a bibliometric approach underpin with patent analysis. With the intention to fill in the existing research gap by learning how networking, collaboration and patents filed can influence the progression of PVT-PCM commercialization. Ultimately, at the end of this work, solar end game strategy is proposed based on the consolidated reviewed articles. To the best of the author's knowledge, no similar studies have been conducted to mimic or surpass/compare present research findings thus highlight the novelty and significant contribution of this work to related stakeholders.

The structure of this paper is as follows: "Literature review" section reviews the existing works of solar thermal collector, PV cell, PVT at various scopes, and applications overspill to the PVT-PCM research works (research evolution). Research motivation and methodology is elaborated in "Motivation" and"Methodology" section, respectively. Result and discussion are presented in "Results and discussion" section continues with the proposed solar end-game strategy. This end-game (technology end-game) refers to time-span where technology is ready for commercialization setup.

Literature review

Research and market proof of solar technologies

This section elaborates performance of major solar technologies subsequently to provide insight on the pathway for solar end game, either it is ready or not. Comprehensive review on the solar plate collector and related standards was conducted by Evangelisti et al. (2019). According to them, approximately 17,000 research articles have been published in circa 2015–2019. Their review summarized fundamental design and improvement that have been done or could be done for the improvement of existing technology which include the innovative and low-cost solutions. The establishment of standards procedure consisting of durability, reliability, and safety requirements related to the solar thermal collector has proven the long-standing performance and technological stability of those solar system within the actual operational environment, for instance, EN12975-1: 2006 (British Standards Institute Staff 2006), EN12975-2:2006 (Fischer et al. 2004), and ISO9806 (Palmer 1930).

Flat plate solar collector is already at post-TRL 9; however, research and development (R&D) is still continuously growing. Ali et al. (2021) proved a satisfactory performance of flat plate solar collector based on the climatic condition at Duhok city, Iraq. The tested system was exhibited maximum energetic and exegetic performances at 70% and 4%, subjected to the variation of heat transfer coefficient and inlet water temperature. As reduction of water inlet temperature led to the enhancement of energy performance, their work suggested to combine PV cell on top of the existing system to provide alternative electricity supply to other devices.

Instead of the promising performance, economic value of solar technology plays a vital role to ensure the readiness of technology to penetrate the market (one of the criteria before reach endgame). Bahrami et al. (2022) calculated net present value (NPV) for different tracking system of solar plate collector (fixed and flexible solar tracker systems) in 66 cities in the northern hemisphere. The analysis utilized comprehensive meteorological data such as the latitude, longitude, irradiance (global, diffuse, and beam), wind speed, and ambient temperature. It was observed that the tracking system is the most feasible system compared to the fixed system. Full axis tracking system exhibited the best investment for solar plate collector at Larnaca, Cyprus with NPV of 19,813US$ (Bahrami et al. 2022). A façade mounted transpired solar air collector (TSAC) system was evaluated based on the location in Borlänge, Sweden. The system showed a positive NPV of € 5000 with 3% cost saving if compared with the reference case, without solar connector (Saini 2019). Parabolic trough thermal collector (PTC) demonstrated positive NPV at 2.198 based on location in Labuan, Malaysia. In their work, a PTC technology from Spain was adopted and showed viable investment and adaptable based on market and weather conditions in Labuan (Jailani et al. 2021). Similar technology was evaluated based on the location in Ouarzazate city, Morocco. It was observed that PTC plant indicated NPV of USD 20 million which prove that the technology is financially and economically feasible (Ouali et al. 2022). Apart from the NPV, there are other economic criteria that can be used to evaluate the technology feasibility such as payback period and levelized cost of electricity (LCOE). Nevertheless, we have not reviewed detail of that.

PV technology is evident to give advantage to power energy sector in Zakho city, Iraq. The simulated analysis showed that the cost of a PV plant was 10 times less than the other fossil fuel power plants with 7 years of payback period (Ali et al. 2023). Extending from the city to university campus in Iraq, solar energy cost for PV grid-connected system was 6.3¢/kWh with NPV value at 551,600US$ (Ali and Alomar 2023). Suparwoko and Qamar (2022) have conducted an evaluation pertaining to the economic value of solar PV system installed on the rooftop of the mosque at the Central Java, Indonesia. Five difference case study was deployed to identify the feasibility of rooftop solar PV technology implementation based on current/possible situation in Indonesia. It was observed that the technology is only viable and economically attractive at NPV value 144.44 US$ when enactment of non-subsidized electricity tariff was imposed. Otherwise, all fours cases exhibited negative NPVs. Contrary, rooftop solar PV has been installed on the roof of house at Diyala, Iraq. It was prevailed that the installation of solar PV rooftop was viable if only the electricity tariff is more than 0.1 $/kWh at NPV value around 2,500US$. Economic analysis on the commercial-scale PV systems for agricultural farms has been conducted in 5 major cities in Pakistan. For a small-scale agriculture farms, the installation of PV system exhibited positive NPV value of 22,332US$ located at Mutan. While, for large scale agriculture farm, a viable investment for PV system is at Mutan, with NPV of 210,515US$. This scenario was due to Mutan received high solar irradiance compared to other studied locations.

Herrando et al. (2023) reviewed the state-of-the art of PVT technologies encompasses of design, concept, application, and techno-economic criteria. On top of that, they uncovered present PVT market players and categorized the technology performance in term of electrical and thermal efficiency.

France was observed as a market leader with an installed solar PVT collector area of approximately 484,000 m^2 within the Europe, while Korea is the market leader with an installed area of ~280,000 m^2. Tiwari et al. (2018) reviewed the application of PVT/air in the process of agriculture drying and concluded that the technology was feasible and can provide better temperature controllability when compared to other drying systems. The forced convection mode of this application (greenhouse dryer) is more beneficial for high moisture content crops while its natural convection mode performed better for low moisture content crops. Additionally, this PVT air heater may be useful for multiple purposes such as contained space heating and solar drying. Herez et al. (2020) reviewed fundamental concept, pros, and application of PVT system with the end focus on the electrical efficiency of thermoelectric generators (TE) integrated with PVT system. Their study revealed that credibility of PVT-TE system is enhanced via spectrum splitting configuration. Moreover, they emphasized that PVT system outperformed the performance of independent thermal collector and PV system. Li et al. (2020) reviewed the application of PCM in building heating application, and they suggested that the utilization of PCM in active and passive building applications can meet the demand for enhancement of thermal comfort and better solar energy utilization. Besides that, Chauhan et al. (2018) reviewed the application of PVT-PCM in solar distillation and desalination industry and summarized that the commercial viability of this application provides huge potential for excessive emission mitigation. Further study on the aspects of efficiency, performance, and on economic points of view is required. As continuation of desalination process, PVT-PCM systems also hold potential in humidification and dehumidification application. George et al. (2019) reviewed this matter and suggested that this application is suitable for small scale usage and the designs need to be modular for easy production and set up capacity modification. Jia et al. (2019) summarized two major types of PVT systems (flat plate and concentrator) subjected to various working fluids (water/air) and commercialization applications. They highlighted that energy storage system, such as PCM, is significantly important to make the technology relevant in different climatic and geographical conditions. Based on to this fact, several studies have been done focusing on the adaptability of PVT and PVT-PCM technology under the one country.

Brottier and Bennacer (2020) conducted an analysis on thermal performance of 28 PVT systems that are set up for the purpose of domestic water heating in Western Europe (France, Switzerland, and Portugal). They discovered that PVT system provides twice the amount of energy for this purpose when compared to PV systems with similar module surface subjected to the climatic condition in Western Europe. Hamdoon et al. (2020) conducted a numerical investigation on PVT water heating system in Iraq climate environment and discovered that the system is capable of providing hot water between 61.7 to 83% required by a family of five. The system also managed to operate with thermal efficiencies ranging between 30 and 70% and electrical efficiency of 15%. Thus, justifying the suitability and adaptability of PVT system in domestic hot water system in Iraq. Yao et al. (2022) have fabricated a novel solar assisted PVT heat pump system as a co-generation in building sectors. The evaluation was conducted and tested under the real-time climate condition at Shanghai Jiao Tong University with average solar irradiation intensity of 771.4 W/m^2 and the average ambient temperature of 23.3 °C. Significant elevation in term of electrical and thermal efficiency was observed at 18 and 109%, if compared with the conventional heat pump. Those experimental outcomes evident that the proposed solar assisted PVT heat pump system has potential to stimuli “Carbon neutral” strategy in Shanghai. On the other hand, Menon et al. (2022) fabricated and tested an unglazed PVT system incorporation with water/copper oxide-based nanofluid based on the actual climatic condition in Kochi, India. Under those condition, nanofluid PCM based on PVT system outperformed the performance of water-based PVT system. Contrary, water-based PVT system featured superior performance under the weather conditions of Oman (Kazem 2019), which highlight that the penetration of solar technology is highly relied on climate condition (country-based), technology adaptability, and demand.

Comparative analysis between conventional PVT and improved PVT (with finned) system was conducted at University Campus of Bari, Italy, under the tropical climate conditions (Cetina-Quiñones et al. 2023). It was observed that the maximum value of NPV was obtained correspond to the installation of finned PVT technology at NPV value of 407.43US$. This result showed viable investment of finned PVT system compared to the conventional one. An actual PVT concentrator used for typical Swedish apartment was taken as a reference case for economic analysis. Two different approaches were applied via Monte Carlo case and normal case. It was observed that via normal case, NVP value is at 2,297.384 € which theoretically showed that the technology is profitable and viable to be opt for that country/location. Nevertheless, Gu et al. (2018) criticized on the result since in actual market (Sweden), PVT is unprofitable with scarce installation, which contradict with the result from their computational analysis. Based on the review, most of solar technology proposed exhibited positive NPV. This reflects that the investment on the selected solar technology is profit-making as the projected earnings exceed the anticipated costs. However, the decision making is not solely based on NPV but could be based on other economic criteria which enormously discussed elsewhere.

From the previous studies, it can be summarized that the R&D progression of solar technology which include solar thermal collector, PV cell, and hybrid PVT is well established and evolved. Contradict with the PVT-PCM technology status, its pathway towards commercialization is still vague, thus requires deep dive on the recent research and academic-industry collaboration to come out with the end-game strategy.

Bibliometric studies

Bibliometric analysis is a useful tool to assess and forecast research trend from different angle such as researchers profile, networking, collaboration, emergence topic, research gap, and contemporary research contribution (Donthu et al. 2021). Information obtained from the bibliometric analysis would be able to portray how much effort can be exerted to such technology (in this work, solar PVT-PCM) to achieve the end-game objective which in this context reflect by "fully commercialization with large scale capacity."

A number of bibliometric reviews have been conducted to analyze the development of solar technology research trend. Calderón et al. (2021) conducted an analysis of the past, present, and future trends of concentrating solar power (CSP) research, reviewing approximately 6300 related publications. It was found that China was dominated in the CSP research portfolios, while European countries and United States were more perceptible toward technology development. Their study forecasted that China and India will be the main player in the CSP development due to the abundant solar resources. Both countries agreed that consideration of thermal energy storage (TES) may enhance the viability of CSP based on the utility-scale power plant. Shen et al. (2021) explored solar rooftop PV research progress via bibliometric analysis based on 595 curated articles from the Web of Science. Their study appeared to contradict with the CSP research landscape (Calderón et al. 2021) where United States featured as a top country with active research activities related to rooftop PV compared to China (at rank number 3). From research and development (R&D) perspective, weakness in international and joint collaboration was identified to be the main discouragement of global progression and deployment of rooftop PV.

Previously, Liang and Liu (2018) conducted a bibliometric analysis focused on the evolution of government funding for a collaborative network pertaining to solar PV technology in China. It was observed that geographical proximity and government sponsored network exhibited negative impact to the solar PV research innovation. Their work also suggested that to achieve Solar PV's R&D endgame, government investment and funding is the crucial factor to boost the technological improvements and large-scale penetration of solar PV technologies. Saikia et al. (2020) performed a bibliometric analysis of solar cooling technology which covers about 3639 publications from Web of Science database. China featured as the most enthusiastic country participating in solar cooling R&D followed by the United States and European countries. Similar trends were observed in a study conducted by Calderón et al. (2021).

Azad and Parvin (2022) are the pioneer researchers who conduct bibliometric analysis on the PVT system. Their study indicated that R&D activities related to PVT system were at a peak after 2000 at progression rate 16.3% by referring to the 1659 published documents from Scopus database. China has consistently led in academic activities (reflected by number of publications and citations), followed by United States and Malaysia. Interestingly, Malaysia appeared to evolve in PVT technology rather than the research related to solar PV and thermal energy, which exhibited Malaysia as the most influential country in collaborative PVT drive research. Underpinning with the existing bibliometric studies, application of PCM (via nanofluids) enables the enhancement of electrical and thermal efficiencies (reflected by PV panel and thermal collector systems respectively) of PVT system subsequently to put the final battle of the PVT R&D.

Motivation

To address the suggestion from Azad and Parvin (2022) and to fill in the research gap on scientometric studies of solar technology, this paper performs a holistic bibliometric analysis and R&D evolution of PVT hybridized with PCM (PVT-PCM). To the best of the authors' knowledge, there is no bibliometric analysis that has been conducted focusing on the PVT-PCM technology. Additionally, to augment value of this work, patents landscaping is performed to analyze the progression and commercialization/technology strategies of PVT and PVT-PCM. Final verdict of this work will enable a decision on the technology endgame by means that either PVT-PCM system is ready for large scale commercialization and should move toward massive transition on renewable energy sector or vice-versa. Present work differs from traditional/conventional studies of bibliometric analysis which includes not only the historical and future research perspectives but also the relevant research themes and authors-affiliation networking and collaboration.

The motivation for this study is to encourage community including investors to assist in promoting the clean energy subsequently expedite the solar PVT-PCM technology penetration. Via this work, bibliometric research would be able to evaluate past research activities, trace transformation evolution, and knowledge structure and predict potential trends for end-game strategy. While patent analysis methods can be used to capture the evolution of technology topics since patents feature the innovation output of a company and can be viewed as a means of evaluating the technology trends in an industry.

Methodology

Data source and search strategy

Bibliometric analysis and maps

The publication year was set to be between 2011 and 2021. To be specific, selected publications were the ones published between January 1, 2011 until August 23, 2021. The authors then started to analyze the data in 2022. We believe the output from this bibliometric analysis is still relevant and up-to-date. The ten-year period was selected since the application of PCM in the PVT systems was relatively new (in the solar area) circa 2014 (Jabar et al. 2021). Web of Science (WOS) database was selected for this study due to its stability and established status as an international and multidisciplinary research database (Joshi 2016). It covers publications from various fields where over 15,000 journals and 50,000,000 classified publications in 251 categories are included (Merigó and Yang 2017). Furthermore, WOS database is also chosen as it provides data for various solar technologies that contributed to the development of solar energy research (de Paulo and Porto 2017).

Search phrase included ("photovoltaic thermal" OR "PVT") AND ("PCM" OR "phase change material*") AND (performance* OR efficiency*) was used to find the intended publications. The strategy of adding query string (performance* OR efficiency*) is to narrow down the scope of the searched documents which only covers the performance and efficiency of PVT-PCM technologies. The symbol "*" was used as a wildcard in order to retrieve radical variants of the word cell, and operator OR was used to retrieve abstracts that presented any of the words between this operator. Since we aim to determine the technology endgame, identification of those string would lead to the answer (performance and efficiency). Documents obtained from the phrase search were then used as the input to the VOSviewer (van Eck and Waltman 2010). VOSviewer is a software for bibliometric map construction and visualization that creates networks between the raw data obtained from the WOS database. Citation, bibliographical, and author keywords information were exported to this software and further analysis was done. In this study, the analyzed items are countries, participated institutions, authors, authors keywords, and research areas. The networks and connections between these items were then evaluated by means of the numerical value of the link strength and the pattern of bibliometric map produced by VOSviewer.

Patent collection

A patent is a type of legal document attesting the authorship of inventors (Intellectual Property Right, IPR), with the unique and discreet right of ownership for a process or product/prototype (Streletskiy et al. 2015). Patent searching is conducted in Derwent, Patent Inspiration based on Derwent World Patents Index (DWPI) database cooperated with Google Patents database. A search patents was executed with search string as follows: "hybrid PVT-PCM" OR "solar photovoltaic and thermal system and phase change material" OR "PV cell and solar thermal and PCM".

Results and discussion

Bibliometric perspective

Publication overview (growth and research interest)

A total of 255 publications were obtained when the search phrase ("photovoltaic thermal" OR "PVT") AND ("PCM" OR "phase change material*") AND (performance* OR efficiency*) was used in the WOS database. However, 56 review articles were then removed leaving only 199 publications to be analyzed, as present study only intends to focus on individual PVT-PCM technology researches. An increasing trend of publication was observed at average yearly rate of 24% as illustrated in Fig. 1. The analysis shows that the research related to the performance of PVT-PCM systems began to emerge in 2013, and publication is increasing steadily and reached its peak in 2020. As for the types of publications, the fraction consists of 177 research articles, 20 proceeding papers, and 2 early access articles. The increasing publication trend can be linked to the efforts of several countries to realize the 2015 Paris Agreement as an effort to combat climate change through the advancement and application of solar energy. The United Nation (UN) encourages its members to incentivize and facilitate participation in the mitigation of GHG emissions by a party through this agreement (UN 2015). Apart from that, the increasing number of publications is significantly influenced by the motivation to achieve Sustainable Development Goal (SDG)s launched by the UN. Among them are the affordable and clean energy (SDG 7), industry innovation and infrastructure (SDG 9), and sustainable cities and communities (SDG 11) goals. Apparently, NZE 2050 was announced in May 2021 where studies on the PVT-PCM are forecasted to increase in the coming years.

Leading countries, top institutions, and international collaborations

Figure 2 shows the top 20 of most prolific countries by taking account of the total number of publications and

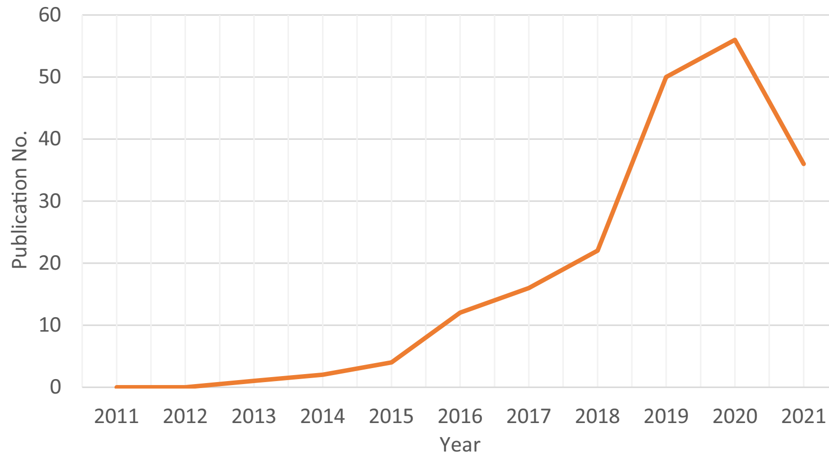

Fig. 1 The annual numbers of research articles on PVT-PCM indexed in WOS database from 2011 to 2021

citations, as they potrays positive and negative impact to the innovation performance (Liang and Liu 2018). Apparently, research of PVT-PCM evolved to 46 countries with 17 from that contributed to one article each (single-country publication). The most significant factors influencing the technology adaptation/adoption are based on the policy incentives or subsidies offer by the Government to promote innovation and new technology. In this analysis, we relate how the government's policy/planning would stimuli the country's domination in PVT-PCM research subsequently affect the innovation/commercialization process.

Rank	Country	NP	TC
1	China	46	831
2	Iran	41	686
3	India	35	454
4	Malaysia	31	697
5	England	24	361
6	Australia	16	417
7	Saudi Arabia	16	340
8	Turkey	13	64
9	Oman	12	432
10	Iraq	11	427

Rank	Country	NP	TC
11	USA	8	254
12	Egypt	6	14
13	Bangladesh	5	133
14	Italy	5	67
15	Canada	4	25
16	France	4	73
17	Pakistan	4	203
18	Vietnam	4	11
19	Ireland	3	158
20	Spain	3	11

Fig. 2 Top 20 publishing countries in PVT-PCM performance and efficiency study (note: NP, number of publications; TC, total citations)

China was the leading country with 46 total publications and 831 total citations, subsequently portraying China as big giant in the evolution of solar technology. A possible reason catalyzing the China's movement is the state-directed subsidies for renewable energy technology development initiated under the country's 12th Five Year Plan (Lewis 2011). The plan envisioned to set China as a global dominant in the solar and wind sectors in less than a decade. Apart from that, its convenient geographical conditions also enable solar harvesting process to be done, and solar energy is available in abundance in most of the areas in China (Gulzar et al. 2020).

The other countries, such as Iran, India, Malaysia, Oman, Iraq, and United States, are also productive as shown in Fig. 2. One of the drivers for Iran's progress in PVT-PCM technology development is due to the republic's Sixth Development Plan which aims at generating 5000 MW of energy from renewable sources by 2021 and an additional 2500 MW by 2030 (Gorjian et al. 2019). Additionally, Iran also provides Feed in Tariff (FiT) as an encouragement for private sectors to invest in its renewable energy sector. Under this effort, even small-scale solar farms with energy generation capacity less than 20 kW received a guarantee of electricity purchase (Ghorashi and Maranlou 2021). Via this incentive, it would indirectly motivate Iran to venture into an advance solar technology such as PVT-PCM due to the incentive provided by their Government.

Similarly, Malaysia employs FiT concept through its Renewable Energy Act 2011 to provide incentives for the generation of renewable energy up to 30 MW under the Sustainable Energy Development Authority Act 2011 (Act 726). Apart from that, the 10th and 11th Malaysia Plans were designed to support the development of new technologies. A 12th Malaysia Plan which outlines the growth and development for the period of 2021–2025 was launched and Theme 3 of the Plan discussed the green growth and enhancement of energy sustainability (Twelfth Malaysia Plan 2021). This contemporary plan encourages solar technology research underpinning with the supports from policy enabler to accelerate technology adoption and innovation that aims to align R&D towards commercialization, wealth generation, and economic growth (Twelfth Malaysia Plan 2021).

Another ASEAN country such as Vietnam has projected interests in PVT-PCM technology as an advancement in solar energy harvesting technology. Vietnam's renewable energy and energy efficiency target aims the country to have 21% renewable energy of 60 GW installed capacity by 2020, 13% renewable energy of 96 GW by 2025, and 21% renewable energy of 130 GW by 2030 consisting of 2.1% wind, 15.5% hydro, 2.1% biomass, and 3.3% solar (IRENA 2018). Therefore, the impact of these efforts can be seen in the first half of 2019 where Vietnam has experienced an increase in solar photovoltaic installation, with the installed capacity reaching 4450 MW (Do et al. 2020). While Oman has been ranked lower based on the total number of publications; however, contrary, it is one of the highly cited countries with 432 total citations as illustrated in Fig. 2. Most of the Middle East countries such as Saudi Arabia, Oman, Iraq, and Egypt focused on solar energy to supply the electricity as most of the Middle East countries view solar energy resources as one of the main alternatives to help meet part of the rising electricity demand (IRENA 2014).

European countries such as Italy, France, Ireland, and Spain have demonstrated their interests in PVT-PCM research. This can be linked to the European Union's targets of at least 40% domestic reduction in GHG emission by 2030 compared to 1990 and to become global leaders in renewable energies (Lacal Arantegui and Jäger-Waldau 2018). However, their number of publications is low, indicating that their interest in PVT-PCM is not as popular as other renewables such as hydropower and wind power (https://ec.europa.eu/eurostat 2021).

The academic collaboration networks between the associated countries in PVT-PCM studies are shown in Fig. 3. The minimum number of publications was set to be one in VOSviewer. Under these conditions, 46 countries have been identified. However, only 34 countries are included in Fig. 3, which shows the largest set of connected countries in term or co-authorship analysis. In this network, every circle represents a country. The size of the circle indicates the number of publications generated by a country, the bigger the circle, the higher the publication count. The thickness of the lines between two countries represents the number of publications the two countries has co-authored to publish. The co-authorship network represents an ideal indicator to analyze scientific collaboration and research direction (Azad and Parvin 2022; Liang and Liu 2018).

In PVT-PCM research, five main networks featured are led by China (blue cluster), Iran (green cluster), Malaysia (soft-blue cluster), England (purple cluster), and Saudi Arabia (yellow cluster). Similar to the analysis of leading countries, instead of the common bibliometric analysis by relating the cluster and link strength, this work is trying to relate the country's incentive/planning toward the establishment of research authorship. Since the fact that co-authorship can be reflected by the collaborative work which is usually supported by the government mutual fund/initiative.

Countries in the blue cluster are concentrating their efforts on the design and optimization of PVT system via experimental and computational approach. Authors in the blue cluster discussed PVT system via energy and exergy analysis. On top of that, they analyzed the thermal prediction of PCM application under various application. In the soft-blue and yellow clusters, both experimental and computational research are conducted related to the PVT-PCM and integrate with HVAC system. Whereas, research related to

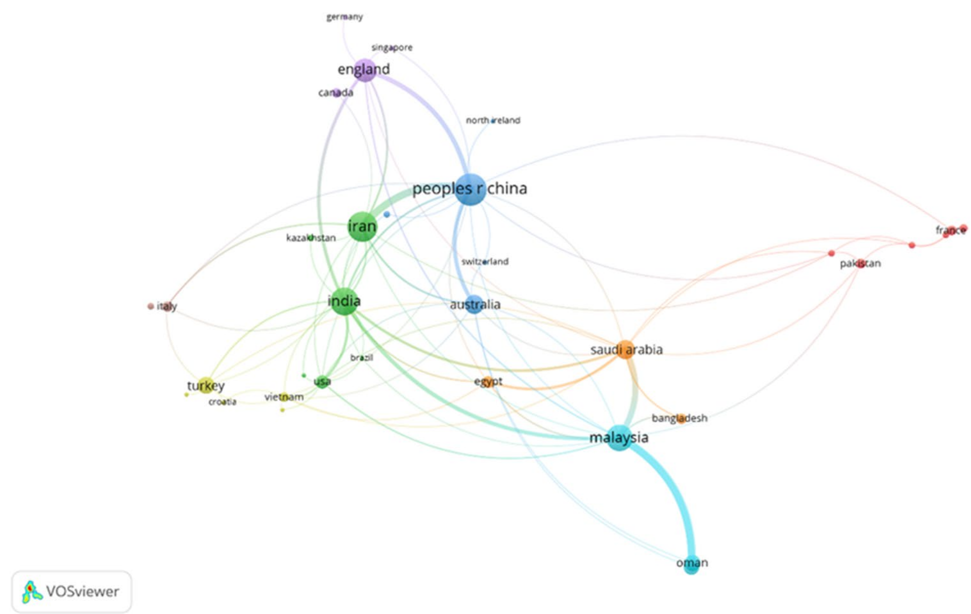

Fig. 3 Countries collaboration networks in PVT-PCM studies (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

the purple cluster encompassed of experimental and research of PVT in heat pump and power generation.

It is seen that China has the most publications and strong collaboration with Iran. This is because Iran collaborates with China to support its economic development and China engaged with Iran to accommodate their growing energy demand (Green and Roth 2021). The link strength between China and Iran is 11, which demonstrate that China and Iran have collaborated in 11 publications. Two documents out of the 11 focused on the performance optimization of PVT-PCM system. The two documents performed single and multi-objective optimization for the proposed system under different scenarios to obtain optimum values of control factors. Another strong collaboration found is China and England. This is mainly due to the UK-China Joint Strategy on Science, Technology, and Innovation Collaboration where both countries committed to further collaborate on the science and technology that was launched by UK and Chinese government in 2017 (Gaston and Mitter 2020). The link strength between China and England is 7; this means that China and England have collaborated to publish 7 documents focusing on the performance of Building Integrated Photovoltaic Thermal (BIPVT) system and comparison of PVT-PCM system with conventional PVT system.

On the other hand, China and Australia also have a noteworthy collaboration as Australian universities had 1,741 formal agreements with Chinese universities which is more than with universities in any other countries, and the agreement included academic or research collaborations (CWG 2019). In addition, the link strength between China and Australia is 6, which translated that China and Australia have collaborated to publish 6 documents, in which 3 documents focus on the performance optimization of a PV systems integrated with PCMs.

Furthermore, there is a remarkable collaboration between India and England. The collaboration can be linked by the joint UK-India flagship program, namely, Newton Bhabha Fund, which supports the UK and Indian scientific research that provide solutions to challenges faced by India's economic development and social welfare (Firmin and Heald 2018). The link strength between India and England is 5, indicating that India and England have collaborated to publish 5 documents, 2 of which focused on the fins integrated PCM for solar PV where fins embedded PCM can improve the performance of PV array. Another noteworthy collaboration exists between Malaysia and Saudi Arabia. Malaysia's economic relationship with Saudi Arabia is predominantly determined by energy resources as Saudi Arabia is the largest supplier of Malaysia's crude oil import (Abu-Hussin et al. 2018). Moreover, the link strength between Malaysia and Saudi Arabia is 9, where both countries have collaborated to publish 9 documents. As such, 4 of them discussed on the effects of nano-PCM to the performance of the PVT system.

According to the bibliometric analysis, 605 authors contributed to the PVT-PCM system database. Table 1 shows the top 20 most prolific authors on PVT-PCM research portfolio who have published more than three documents. The most productive author is found to be K. Sopian from Universiti Kebangsaan Malaysia, Malaysia, followed by Omani, H.A Kazem, and A.H.A. Al-Waeli in the top five places. In the aspect of research areas, 19 out of 20 authors have the most publications in energy fuels with the remaining one author, and M. Sardarabadi has the most publications in thermodynamics. In addition, mechanic, construction

Table 1 Authors with more than three publications

Author	Affiliation	NP	TC	PY_start
Sopian, K	Universiti Kebangsaan Malaysia	13	432	2017
Kazem, H.A	Sohar University	12	427	2017
Al-Waeli, A.H.A	Sohar University	10	413	2017
Chaichan, M.T	Sohar University	10	416	2017
Kazemian, A	Shanghai Jiao Tong University	9	173	2018
Ma, Z.J	University of Wollongong	9	271	2014
Ma, T	Shanghai Jiao Tong University	8	131	2019
Lin, W.Y	University of Wollongong	7	201	2014
Saidur, R	Sunway University	7	38	2018
Kasaeian, A	University of Tehran	6	119	2018
Pandey, A.K	Sunway University	6	65	2018
Zhao, X.D	University of Hull	6	204	2016
Mallick, T.K	University of Exeter	5	18	2019
Passandideh-Fard, M	Ferdowsi University Mashhad	5	278	2017
Sardarabadi, M	Ferdowsi University Mashhad	5	265	2017
Tyagi, V.V	Shri Mata Vaishno Devi University	5	69	2019
Zhou, Y.K	Hong Kong Polytechnic University	5	91	2017
Abdelrazik, A.S	King Fahd University of Petroleum Minerals	4	23	2019
Cooper, P	University of Wollongong	4	205	2014
Hasanuzzaman, M	University of Malaya	4	93	2019

NP, number of publications; *TC*, total citations; *PY start*, publication year start

building, and science technology are also the top research areas based on the top 20 authors' research areas analyzed resulted from the WOS database. Out of the 605 authors, 489 (80.83%) authors have only one publication. The reasons for the small number of publications related to the PVT-PCM are due to the questionable PCM economic feasibility, unviability of different PCMs, and lack of disposal technology of the used PCM and PVT-PCM systems which require more endeavors of research and development (Islam et al. 2016). As highlighted before, PVT-PCM is considered a new topic as most of the authors were actively published their work in 2017. Nevertheless, if looking from the practicality and technology maturity, combination of PVT with PCM has in place for 22 years but in a conventional and traditional way.

The collaboration network between the PVT-PCM research organizations has been obtained using VOSviewer software as shown in Fig. 4. The minimum number of publications by each organization is considered to be one document. Under this criterion, 264 organizations have been identified and the organization is clustered based on co-authorship relationship between them. There is correlation between country, and organization relationship as Shanghai Jiao Tong University (China) has co-authorship link with two Iran organizations which are Ferdowsi University Mashhad and Sharif University of Technology. University of Hull (England) has co-authorship links with three China organizations: Guangdong University of Technology, University of Science and Technology of China, and Southwest Jiao Tong University. University of Wollongong (Australia) has co-authorship links with two China organizations: China Resources Power Investment and Chinese Academy of Sciences. This also verified the strong collaboration China has with Iran, England, and Australia that are stated in country statistic segment. Two Malaysia organizations which are Sunway University and University of Malaya have co-authorship links with two Saudi Arabia organizations, King Fahd University of Petroleum Minerals, and King Abdul-Aziz University. This also verified the strong collaboration that Malaysia has with Saudi Arabia that are stated in country statistic segment.

Keywords analysis

The analysis of keywords used in the search of articles allowed identifying the frequency of each term in the documents as mapped in Fig. 5. The size of circle represents the frequency of the keyword's occurrence (Xie et al. 2020). Three major clusters are exhibited based on the keywords analysis by applying the same database. The highest co-occurrence keywords are "Phase change material" (50) followed by "solar energy" (33) and "nanofluid" (23). The connection between these three keywords can be interpreted as follows: solar energy represents PV and/or PV/T technology where integration of PCMs in PVT systems would help to increase the efficiency and performance of PVT systems. PCM is gaining interest among the researchers of

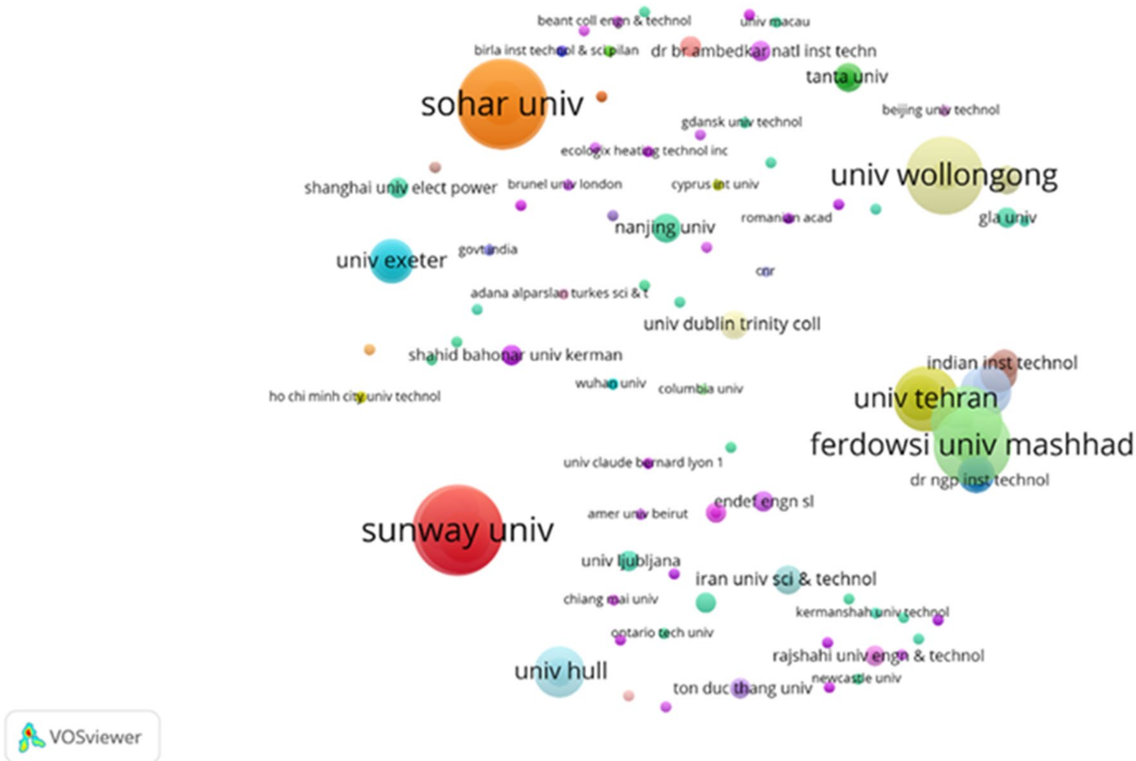

Fig. 4 Collaboration network between organizations (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

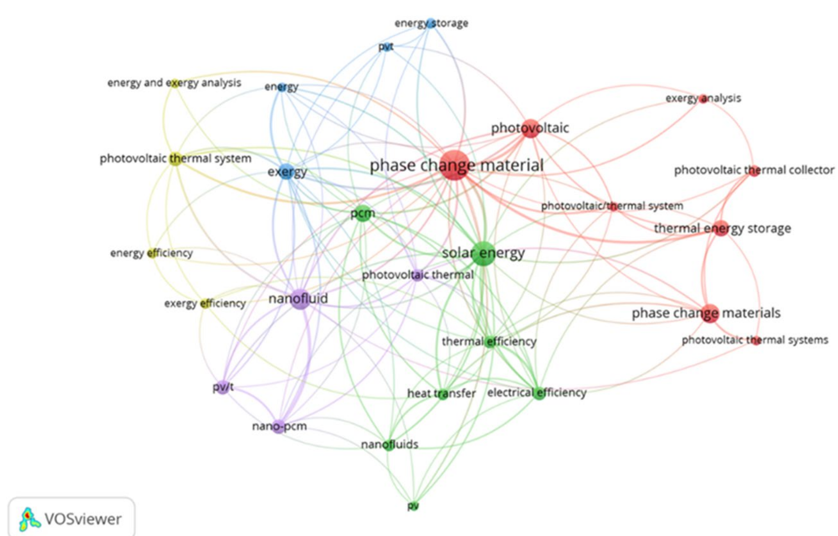

Fig. 5 Network connections between author keywords (for interpretation of the references to color in this figure legend, the reader is referred to the web version of this article)

solar technology due to its attractive properties. For organic PCMs, they usually piqued researchers' interests due to their ability such as chemically stable, non-reactive, change phases congruently, and availability in varied range of phase change temperatures. As for inorganic PCMs, they are commonly utilized due to high volumetric latent heat storage capacity, high thermal conductivity, and low purchasing (Kuznik et al. 2014). PCM also work as a nanofluid that can be applied as a cooling medium for solar technology. Furthermore, the utilization of PCM enables the usage of PVT system during night-time, where sun is absent to be the provider solar energy.

Table 2 shows the top 10 highest co-occurred keywords which reflect that research evolve from the application of

Table 2 Top 10 keywords in the co-occurrence of keywords analysis

Keyword	Occurrences	Total link strength
Phase change material	50	58
Solar energy	33	57
Nanofluid	23	40
Phase change materials	20	17
Photovoltaic	19	30
PCM	16	28
Thermal energy storage	14	20
Photovoltaic thermal system	12	20
Nano-PCM	11	23
Electrical efficiency	10	27

PCM as nanofluid up to the thermal and electrical performance of the hybrid system. Considerable total link strength can be observed where the connection between the clusters is closed and intersect.

Patent perspective

Patent overview

A total number of 8235 patent documents was obtained encompasses of all strings indicated in Sect. 4.1.2 (Patent collection). The patent documents were further screened by selecting patent which consists of only PVT and PVT-PCM keywords. A total number of 189 patents were obtained related to the PVT technology and 6 patents were PVT-PCM technology. The filtration was done due to the inclusion of non-relevant patents description (out of the scope of present work). Focus of this section is on patent landscape of PVT and PVT-PCM patent landscape to decipher the PVT and PVT-PCM technological transition/evolvement and freedom-spaces available for manufacturers/investor. In addition, innovation performance and technology diffusion can be evaluated based on the number of patent activities (Gao 2022), subsequently identifying the technology end-game of PVT-PCM from the industrial/commercialization perspective (via patent landscape).

Based on the 189 filled patterns application, China filled the highest number of patents (102) followed by Republic of Korea (25), United States of America (15), and World Intellectual Property Organization (WIPO) (13). There is a consistency in the trend from bibliometric and patent analyses. Whereby, China conquers in PV/PVT/PVT-PCM's R&D and patent pool (i.e., technology and market) evolutions. This phenomenon evident that country which invests heavily in R&D is expected to have a higher rate of innovation leads the technology diffusion. According to the patent pool (based on 189 patents), the most usable International Patent Classification (IPC) groups were F24/25 and H01/02, which are categorized by the heating, ventilating, heat pump system and basic electricity, and electricity generation and conversion (ipcpub.wipo.int 2022)

Table 3 delineates several PVT and PVT-PCM patents based on the Derwent World Patents Index (DWPI) database cooperated with Google Patents database (extracted from 189 patens). Five PVT technology patents (PCM type indicated as "Not Applicable") and 6 PVT-PCM technology patents are discussed to understand the status quo on solar technology evolution. Judging by the patent documentations, Anhui University of Technology is the pioneer in PVT technology, while Hohai University and Southwest Jiaotong University are the academic institutions which own patents on the PVT-PCM technology. Deciphering the PVT-PCM patents, landscape could help visualize the technology trajectories. This will subsequently facilitate in de-risking R&D activities in new technology development while avoiding technology lock-in (Song et al. 2018). This scenario deems wise formulation for PVT-PCM end-game strategy to ensure smooth transition to large scale installation of this new emergent solar self-sustaining energy.

End-game: global demand and realistic of PVT-PCM technology

In analyzing the end-game strategy (technology end-game) of PVT-PCM development, a thorough bibliometric and patent studies was done. Contemporary scenarios of global PVT market during and after COVID-19 pandemic and strategies taken by multiple countries to increase the general demand of solar technology are discussed in this section. Apart from academic field, the development of solar technology (specifically PVT-PCM) can also be observed from industrial point of view. Like other sectors, COVID-19 lockdowns disturbed the productivity of the general energy sector, and this includes global solar technology market. This affects all demographics, especially the lower income communities. For instance, communities in poorer regions in India are still struggling to meet the energy security they possess prior to COVID-19 pandemic and economic damage they face is much more severe than those of higher income regions (Aruga et al. 2020). This shows that lower income communities need to be taken under more serious observations and actions from the authorities.

One of the most prominent impacts of COVID-19 on solar energy sector is the slowdown of manufacturing activities of materials used in the fabrication of solar energy harvesting technology. This is due to heavily impacted Asian countries (China, Malaysia, Vietnam, Singapore, Thailand, and South Korea) that are the most active manufactures of these materials in this part of world (Vaka

Table 3 Summary of PVT and PVT-PCM patents based on inventors' country

No	Publication no ICP class	Inventor	Title	Type of PCM	Country
1	CN106788237A (2017) H02S004044 F28D002002 H02S004042	Changzhou Campus, Hohai University	High efficient PVT system with PCM storage	Crystal hydrous salt, paraffin, fatty acid, polyethylene glycol, high-density polyethylene, graphite, polypropylene or rubber	China
2	CN108233866A (2019) F24S001030 H02S001030 H01L00310216 H01L0031042	Changzhou Campus, Hohai University	Solar energy PVT energy output spectrum precipitation control device	Not applicable	China
3	CN104729108A (2016) F24J000200 F24J000240 F24J000246 F24J000252 F24S002370 H02S001010	Anhui University of Technology	A simple photovoltaic-thermal-thermoelectric comprehensive utilization system	Not applicable	China
4	CN104601085A (2015) H02S001000 F24J000252 F24S002030 H02N001100 H02S004044	Anhui University of Technology	A photovoltaic-photo-thermoelectric and baking integrated solar energy utilization device	Not applicable	China
5	CN103929117A (2014) H02S001012 F24H000118 F24H000120 F24H000900 F24H000920 H02N001100 H02S004042	Anhui University of Technology	A concentrating PVT-wind-thermoelectric integrated system	Not applicable	China
6	CN102117855A (2011) E04D001318 H02S004042 H02S004044	Tongwei Solar Energy Co. Ltd	PVT component for building	Disodium sulfate decahydrate/paraffin	China

Table 3 (continued)

No	Publication no ICP class	Inventor	Title	Type of PCM	Country
7	CN212992236U (2021) H02S001010 H02S001020 H02S004044	Hunan Sanli Energy Technology Co. Ltd	PVT power generation system	Not applicable	China
8	CN111750417A (2020) F24D001502 F24D001504 F24S001095 F25B001300 F25B003002 F28D002000 H02J000735 H02S004044	Southwest Jiaotong University	Heat pipe type PVT module-heat pump-phase change floor coupling (PCM storage) system and method	Not stated in the patent	China
9	KR2020032345A F25B002700 F24D001100 F25B004100 F25B004104 F25B004702 H02S001010	Tapsol Co. Ltd	Solar heat pump system with connected PVT collector and PCM heat storage tank	Not stated in the patent	Korea
10	KR2018103242A H02S001030 F24S001030 H01L00310216 H01L0031042	Tapsol Co. Ltd	Solar heat pump system with connected PVT collector	Not applicable	Korea
11	GB2490125A (2012) F24D000314 F24D001910	Caplin Solar Systems Ltd	Hydronic radiant heating and cooling system comprising a PCM	Not stated in the patent	United Kingdom

et al. 2020).The reduction of manpower due to deaths and lockdowns restrictions are observed to be the main cause of the slow down. Zhang et al. (2021) assessed the lockdown impacts in Japanese settings and concluded that two months of lockdown would impose a high-risk threshold value in solar industry, and when the period is exceeded, market demand would shrink by 78.69% and the monthly value-added loss would reach 67.69%. Conversely, the slowdown of market activity would also decrease emission reduction potential over the whole year by 64.2%. Therefore, it can be concluded that longer lockdown period imposes severe impacts on energy generation sectors, including solar industry.

Asian PV producers are observed to be the main players in solar technology industries as they made up to 95% of c-Si PV module production in 2020, and 67% of them are producers from China (ISE 2021). Besides producing the most publications regarding PVT-PCM technologies, China also ranked as the largest country in the world installing solar energy system. Therefore, one of the possibilities that might cause a spike in China's high number of PVT-PCM publications is due to the increasing production of scholars in academic field and their collaboration with demanding industries. Apart from that, its neighboring country, Taiwan, came out with the strategies to increase the demand for solar technology in their energy market. Lee et al. (2021) elaborated in their study that the Taiwan relies heavily on solar energy to achieve its target of generating at least 20% of electricity from renewable sources by 2025. This is due to the high dependence of the country on imported energy supply from abroad (98% of total energy supply). To reach this target, Taiwan has expanded its solar capacity to 20 GWh from only 4 GWh. The country also passed Two-Year Solar PV Promotion Plan in 2016 as an encouragement effort to promote the utilization of solar energy. As a result, governmental market intervention is perceived as an effective strategy to increase the market demand of solar harvesting technology.

Decarbonization of electricity sector also leads to the increase of market demand for solar energy harvesting technology. Following wind power in second, solar PV is estimated to supply approximately 25% of total electricity demand where it leads to an increase of over tenfold in its contribution to the generation mix by 2050 compared to 2016 levels (IRENA 2019). Europe for instance managed to increase their solar power production capacity from 130 MW to 110 GW in this century to meet the renewable energy demand (Madsen and Hansen 2019). Therefore, it can be expected that the enhancement of solar energy industry through the development of PVT-PCM technology can provide a fulfilling choice for customers in international and domestic solar market as an effort to combat carbon emissions and transition to renewable energy sources.

Commercially, PVT systems are observed to be in lower production when compared to stand alone PV and thermal collector systems. Furthermore, in comparison to academic field, the production of PVT systems in industrial setting is still limited and open for creative innovations. Das et al. (2018) came up with a list of PVT technology producers around the globe, and it is comprehended that most commercially available PVT systems are employed for the purposes of hot water production and space heating. When compared to the publication of PVT-PCM efficiency and performance studies, Asian countries besides China are seen to be less productive in manufacturing PVT systems for commercial purposes. This is due to the domination of western countries in the PVT market (Denmark, Turkey, Canada, USA, Bulgaria, Italy, and Germany), while China and Israel are found to be the sole global manufacturing countries. Therefore, it is suggested that as the main players in PV production industry, Asian PV producers need to increase their involvement in PVT technology production to be on par with western countries in term of clean renewable energy utilizations. However, when compared to single PV and solar thermal collector production, global commercialization of PVT systems production is still at a relatively low level. Therefore, more commercialization efforts of PVT-PCM technologies need to be done to ensure a more prominent presence in the global solar technology market.

Conclusion and significant takeaway

Present work provides descriptive bibliometric information about PVT-PCM technology based on 199 articles retrieved from the WOS database in the period of 2011 to 2021. A patent search was also conducted to see the current trend of PVT-PCM systems in solar industry targeting PVT and PVT-PCM technologies. A total number of 189 patents were obtained related to the PVT technology, and 6 patents were PVT-PCM technology covering patent pool from 1981 until 2020. Based on the contemporary profiling conducted in this study, the main conclusion can be drawn as follows:

1. China remains the primary actor of PVT-PCM technology in terms of R&D (academic perspective) and patent filing (industrial and commercialization perspective) and is forecasted to left behind other nations in the next 10 years. Similar verdict was predicted by Chandak 2021 and Xu and Stanway 2021.
2. The most often used keyword is "phase change material," followed by "solar energy" and "nanofluid." China is the leading country in this field in terms of overall publication and citations, followed by the Iran, India, and Malaysia. China has the most publications and strong collaboration with Iran with 11 joint publications

3. The major clusters in co-citation exhibits (i) design and optimization of PVT-PCM system via experimental and computational, (ii) PVT-PCM system via energy and exergy analysis, and (iii) PV/T-PCM integrate with HVAC system

The output from this work can be a quick guideline to the investors/industries and government in understanding and identifying the end-game strategy for PVT-PCM technology. Evidently, PVT-PCM is seen to have a huge potential for modern renewable energy due to its technical-social-environmental benefits for short and long terms. Nevertheless, PVT-PCM which features high-end technology requires expensive infrastructure and experts for commercialization; thus, single country might not be able to win PVT-PCM end-game strategy, which then demands for international collaboration, financial, and technical supports. This work meets the purpose by measuring the R&D evolution, understanding the organizations networking that can influence the success of R&D projects. Additionally, patent landscaping analysis added values on highlighting the essential patents that can be useful for firms and which perform vital purposes in the evolution of a PVT-PCM technology.

The study is subject to some limitations, which also open perspectives for future research. This work could be extended by employing exhaustive data from multiple sources. Analysis on the patent filing using empirical approach can be beneficial for future study.

Author contribution All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Muhammad Hussin Abdul Jabar, Norhuda Abdul Manaf, Rishita Srivastava, Suchithra Thangalazhy-Gopakumar, Farah Ezzah Ab Latif, Minh Tri Luu, and Ali Abbas. The first draft of the manuscript was written by Norhuda Abdul Manaf, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability Not applicable.

Declarations

Ethical approval The manuscript work is original.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interest The authors declare no competing interests.

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