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Review article

Adoption of residential rooftop solar PV systems in South Africa: A scoping review of barriers

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ABSTRACT

Global sustainability challenges such as climate change are linked to carbon emissions from fossil fuel powered energy needed for commercial and household consumption. South Africa is highly depended on coal for energy production hence the transition to renewable energy sources such as solar PV is seen as a pathway towards emissions reduction and a sustainable future. Yet, despite the huge potential for solar PV technologies adoption remains very low. This scoping review examines the barriers to household solar PV adoption in South Africa to advance our understanding beyond case study level studies. We analysed all published literature on household solar PV in South Africa as a basis for finding themes, gaps, and trends on solar PV research. Review results show that key barriers can be grouped into financial, personal, institutional, technical and societal barriers, however there were no studies on barriers across an income gradient, a glaring omission given debates on just transitions. Given the complexity of the barriers ranging from personal, societal, to technical barriers, it is not reasonable to expect the government to facilitate transition to solar PV alone. Rather, collective approaches are needed to create enabling conditions for solar PV adoption such as the financial means and information availability. The private sector has a key role to play either in supporting state-initiated programmes or creating the means for solar PV adoption such as power purchase agreements. That said, the state remains a central player in facilitating an enabling economic and political environment to leverage responsiveness from other actors. Without an integrated approach to addressing barriers to solar PV adoption, solar adoption will remain a source of energy for the economically privileged, and the imperative to just transition to renewable energy a pipe dream, in a country characterised by large inequalities among households.

1. Introduction

Globally, the transition to renewable energy sources is rapidly growing in response to global energy crisis and sustainability imperatives [1,2]. Among renewable energy sources solar photovoltaic (PV) systems are rapidly growing in demand due to multiple factors including decreasing prices and considerable return on investments [1]. Further, geopolitical factors have negatively impacted the price of fossils fuels such as coal, petroleum, and gas, making dependence on fossil fuels for energy expensive and insecure [1]. For instance, the emergence of the Russian-Ukrainian war resulted in a sharp increase in crude oil by over 50 % in 2022 [3,4], translating into high fuel and energy prices as well as increased cost of living [5,6]. Generally, the price of energy sources from fossil fuel is on the

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increase thus the need for cheaper and affordable alternatives such as solar PV. Solar PV energy which is based on technology that converts sunlight into electrical energy is considered a cheap, reliable, profitable and clean energy source with low maintenance costs and a long lifespan [7–9]. The environmental benefits of solar PV adoption are arguably centred on carbon emission reduction from reduced coal use [2,10]. For example, previous studies have shown that solar PV adoption in Germany has reduced carbon emissions levels by more than 40 % compared to 1990 levels [4]. The bulk of these carbon emissions are at household level due to the fact that households are a major consumer of energy [11,12], thus the need to start investing in household solar PV energy [4]. However, the indirect environmental benefits are substantial, including reduced biodiversity loss and land degradation associated with open cast mining [13–15] and other downstream benefits beyond the mining site such as reduced water pollution and stream sedimentation. At the same time, although solar PV systems are recognised as a pathway towards halting climate change, there are environmental and equity concerns relating to renewable energy initiatives [7,9]. For example, Sonter et al. [15] caution that the technology and infrastructure needed for renewable energy production will lead to high demand for metals, which might rigger new mining ventures. Other environmental concerns of solar PV systems relates to manufacturing processes and disposal of hazardous substances, leading to land and water pollution [16]. Nonetheless, the environmental impacts are still considered minimal relative to fossil fuel energy sources, and future efforts on solar PV design improvements, sustainability and recycling might mean that the impacts will become less concerning [2,10]. Generally, the benefits of transitioning to renewable energy sources like solar PV seem to outweigh the costs, however, consistent with just energy transition debates, questions over who benefits from renewable energy are gaining traction with a view to avoiding the marginalisation of low income-households in renewable energy access [17,18]. For example, in South Africa, inequalities in access to renewable energy among marginalised communities have been reported in energy justice debates [19,20]. Also, in Germany monopolistic power distribution companies are responsible for setting prices of renewable energy that households sell into the energy grid, thus negatively affecting solar PV adoption if prices are not favourable [4].

Developed countries such as Australia and Germany have made some considerable strides in the adoption of solar PV [21]. For instance, in Australia solar PV now provides up to 20 % (6600 MW) of energy to households [21], whereas in Germany, estimates suggest that solar PV contributes around 10.5 % (around 15 TWh) annually to the country's energy mix [9]. In contrast, solar PV uptake in Africa remains low, yet the bulk of the African population does not have access to grid energy. For example, Burkina Faso has the lowest rate of grid connectivity with approximately 69 % of the population without access to the national energy grid [21]. African countries also face poor energy delivery, as the majority of power utility firms are unable to meet the rising demand for energy, resulting in power outages which result in negative socio-economic impacts [22] and mental health impacts [23]. For instance, Bwalya et al. [22], reported evidence of socio-spatial segregation in metropolitan settings in Zambia, with poorer residential areas suffering disproportionately negative effects of loadshedding compared to wealthy residential areas. These above-mentioned scenarios in Africa points to the need for investment in solar PV, both as a cheaper energy source and a means to provide energy for basic needs to the greater population. Interestingly, most African countries have climatic conditions favourable for solar PV adoption, yet they continue to lag behind. For instance, more than 80 % of the continent's landscape receives close to 2000 kWh/m^2 with most Southern African countries receiving an estimate of about 6 kWh/m^2 [24]. Despite these opportunities being available for solar PV adoption in Africa, efforts towards solar PV adoption remain slow [22,25,26].

The abundance of sunlight in Africa, coupled with the constant decrease of solar PV unit prices, makes the continent an ideal destination for solar PV energy generation [4,22]. Globally, several studies have outlined some of the barriers preventing solar PV adoption [27–29]. Generally, the most identified solar PV barriers are financial, personal, technical, and institutional barriers [30–34]. In general, barriers are factors or circumstances which prevent a person from accessing or using a desired service of interest. Financial barriers are money related factors that prevent access to solar PV. For example, the lack of pricing benchmarks for solar PV systems, which leads to high start-up costs has been reported in Pakistan [29] and German [31] as a key solar PV financial barriers. Personal barriers relate to factors that are personal to an individual that act as a hindrance to solar PV adoption. For example, lack of knowledge by adopters which lead to misconceptions and failure to operate and maintain the solar PV systems were reported in Netherlands [32] and Bangladesh [35,36] as key personal barriers to solar PV adoption. Literature also reports on technical barriers which are solar PV related technological factors that hinders use and adoption. For example, the lack of access to solar PV technology, manufacturing industries, service parts, and human technical expertise to install and maintain solar PV system has been cited in most developing countries as a key technical solar PV adoption barrier [27,37]. Institutional barriers relate to policies, laws, procedures, and situations that disadvantage solar PV users. For example, studies in Australia [38] and Malaysia [39] report that the reason why solar PV adoption was slow among households was due to the lack of comprehensive policies and feed-in tariffs. Besides these above-mentioned broad barriers, Lo et al. [40] indicated that barriers to solar PV adoption are complex, meaning they should be understood from a sociotechnical approach. This imply that barriers such as technical, social, economic, cultural, political, and historical factors could affect transition to solar PV individually or in combination. The study by Lo et al. [40] listed barriers based on the following categories; technical and environmental, economic and financial, market, policy and regulatory barriers. Regardless of how barriers to solar PV are categorised a systematic understanding of solar PV barriers in Africa, particularly amongst South African households is lacking.

The adoption of solar PV systems in South Africa is urgent due to several factors. Firstly, the energy tariffs in South Africa continue to increase beyond the reach of many poor households [41]. Although these energy tariff increase are meant to intensify energy generation capacity to meet demand and are also aimed at solving Eskom's financial challenges [41]. Between 2022 and 2023, the National Energy Regulator of South Africa (NERSA) approved about 18.7 % increase of energy tariffs, which negatively affects households, particularly those from low income groups [42]. Secondly, South Africa is currently experiencing a shortage in energy supply as evidenced by constant loadshedding. The effects of loadshedding are mostly felt by households and small businesses who do not have alternative forms of energy [43], thus solar PV adoption could be a solution for them. Thirdly, the bulk of South Africa's energy is from fossil fuels, with about 95.6 % coming from low quality coal [44]. The use of fossil fuels contributes up to 42 % of the country's carbon emissions, which is likely to have negative consequences on the environment [42]. Hence, the transition to solar PV is necessary if South Africa is to meet its international environmental climate change targets of reducing global warming to 1.5 °C [45]. Lastly, besides the residential sector in South Africa being one of the biggest consumer of energy, it is also the biggest carbon emitter, requiring the transition to solar PV for carbon emission reduction [45,46,47,].

Efforts towards solar PV adoption are underway in South Africa, although the pace is generally slow [43]. Firstly, the country initiated the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) aimed at increasing energy capacity through private sector investment in solar PV. To date solar PV projects have increased with close to 10 % of households having adopted solar energy for their day-to-day use [45]. Under REIPPPP, South Africa aims to install a solar PV generation capacity of about 8400 MW by 2030, a capacity that would benefit about 1.5 million households [21]. Secondly, to mitigate the impact of power outages, the South African government outlined a 10-point power crisis plan which amongst other things deals with licencing of energy generation. For example, the government waived the private power generation licencing requirements from 1 MW to 100 MW to allow independent power producers to generate more renewable energy [21,45]. Thirdly, the South African government is working towards enacting policies that are favourable for solar PV adoption. For instance, with effect from March 2023, rooftop solar panel installations are now eligible for tax refunds of up to 25 % of the cost of the panels [21]. Despite these supportive measures, the rate of solar PV adoption is still very low particularly by low households. Identifying and understanding barriers to adoption can help inform interventions for addressing the barriers and encouraging rapid intake of solar PV systems by the residential sector. Moreover, an understanding of the socially-embedded structural barriers that can perpetuate inequality in renewable energy is required for just energy transition. South Africa is a country that has high unemployment rate [43] and most households cannot afford solar PV systems. Therefore, this scoping review is motivated by the need to provide a comprehensive review of empirical studies on South African residential solar PV to gain insights into barriers affecting solar PV adoption. A review of barriers across a household income gradient can help policy makers to understand and address these barriers in equitable ways.

2. Methodology

We adopted a scoping review approach to identify barriers to household solar PV adoption in South Africa based on literature published between 2000 and 2023. Scoping reviews give a general overview of a field of study to determine the volume of literature and existing knowledge gaps [48]. Hence, in this research, literature was evaluated based on the extent of household solar PV search available and its focus, with reference to barriers of solar PV adoption among South African households. The scoping review was structured following the Reporting Standards for Systematic Evidence Syntheses (ROSES) which is a pro-forma flow diagram and a descriptive summary of the plan and conduct of environmental systematic reviews [49]. The ROSES provide a gold standard which assists reviewers with rich instructional information aimed at achieving certain levels of rigour [49]. In March 2022, the first author, with the help of a professional librarian commenced the initial search of literature. Papers were thoroughly and methodically searched using popular databases namely Scopus, Web of Science and Google Scholar, which are the most extensive databases comprising book chapters, books, journal articles and conference proceedings [50]. The databases cover a wide range of disciplines including humanities, physical sciences, biological sciences and social sciences [51]. The limitations of Google Scholar as a trustworthy source for reviews are recognised [50,51], especially its usage as the main search engine [52]. Key limitations include that some of the items retrieved in Google Scholar are not peer reviewed while the search engine has restrictions on subject indexing which can limit the findability of pertinent items [51]. Even though Google Scholar has restrictions, it offered relevant papers that were unavailable in other databases, as observed elsewhere [52]. All authors actively collaborated in crafting the search string, guided by a professional librarian from the Rhodes University library. The key search terms were categorised into three sections namely the focus area, keywords and search-scope (Table 1). The same key search terms were used on all the three databases following method employed by Ghaboulian-Zare et al. [53].

2.1. Scope and exclusion criteria

Exclusion keywords are used in scoping reviews to judiciously narrow the search findings to meet the scope [54,55]. All the three authors actively participated in developing the exclusion criteria. Articles that were clearly related to the subject of the study were carefully selected and analysed. The goal was to compile the most recent and most relevant articles that had been published, which included works from January 1, 2000 to December 2023. All articles which were not focused on the barriers of solar PV were excluded in the analysis as suggested by Ahmed et al. [54]. Article titles and abstracts were used to thoroughly screen the articles, and those that were not relevant were removed.

Table 1
Key search terms.

Focus area	Keywords	Search scope
Household	House* OR home* OR resident* OR dwelling* OR domestic ("Solar photovoltaic" OR "solar PV" and "South Africa")	Topic
Adoption	Adopt* OR diffusion OR uptake OR "take up" OR acceptance OR motiv* ("Solar photovoltaic" OR "solar PV" and "South Africa")	Topic (title-abstract-keywords)

2.2. Eligibility of articles

To assess eligibility, each article's full text was retrieved based on titles and abstracts and were then read (Fig. 1). To avoid leaving out relevant articles, references of the included articles were analysed to check for articles that may have been omitted by the three databases. Unpublished material, editorial notes and non-English publications were also excluded from the analysis. The potential limitation of the study is that it only considered articles written in the English language, which might have resulted in omission of relevant articles in other languages such as French. Nevertheless, given that English is the widely used medium of instruction in published South African literature, we do not think the language bias has huge implications for our analysis.

The first phase of the search returned 857 articles, however, after removing duplicates (532) and irrelevant articles based on title and area (e.g., non-South African papers = 55), only 270 articles were returned (Fig. 2). Duplicates were eliminated using Zotero software by adding the downloaded articles to the Zotero database which identified, highlighted, and removed repeated articles. A subsequent manual check was performed by all the authors to ensure thorough duplicate removal. After reviewing the abstracts, a further 237 articles were excluded for not meeting the criteria, leaving 33 articles. For instance, after reading the abstracts we note that a substantial number of articles focused on Concentrated Solar Power (CSP) while others focused on microgrids and mini grids and other non-residential sectors such as universities, industries, and businesses. The full text screening excluded an additional 16 articles since they were outside the scoping review focus. Therefore, 14 articles were returned because they focused specifically on the barriers to household solar PV in South Africa. After examining the remaining publications' reference lists, four more articles were added resulting in 18 being considered for the scoping review (See Appendix 1). The steps and procedure used to gather articles for the scoping review are summarised using the ROSES search chart (Fig. 2).

2.3. Data analysis

The research employed an inductive methodology, meaning that the research themes were not pre-selected and examined but emerged through the examination of pertinent articles following suggestions by Gusenbauer and Haddaway [52]. Thematic codes were created after multiple iterations of preliminary reading of the chosen publications, and the papers were then grouped into work packages in accordance with the theme codes to enable quantification of the results. As in most global solar PV literature, the packages included financial, technical, institutional, personal, and social barriers [27–30]. The distribution of articles was displayed descriptively using proportions and histograms based on the publishing type (grey literature including theses or journal articles), publication year, and the conceptual emphasis of the articles.

3. Results and discussions

3.1. Barriers to solar PV adoption among households

Review results show that 61 % (n = 11) of the reviewed articles focused on financial barriers ranging from high start-up costs and

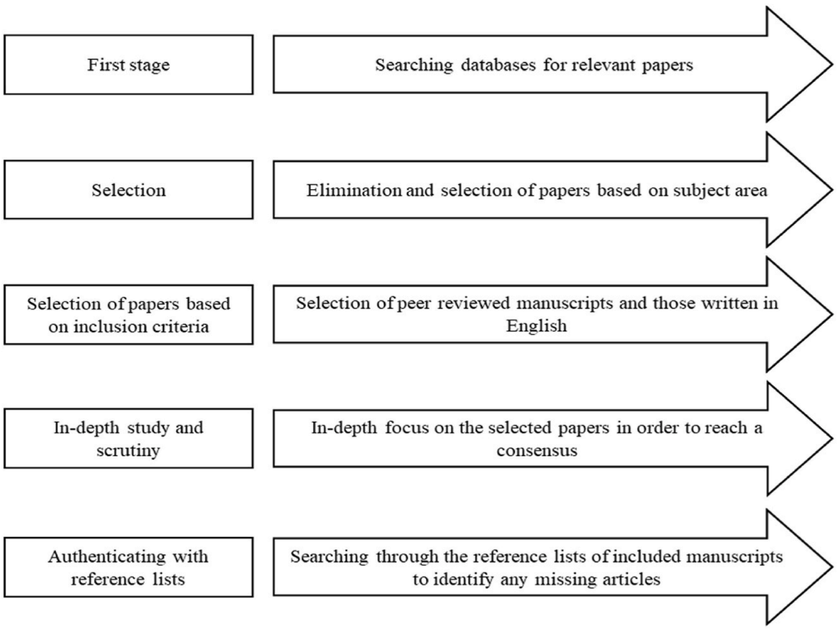

Fig. 1. Eligibility criteria of articles [53].

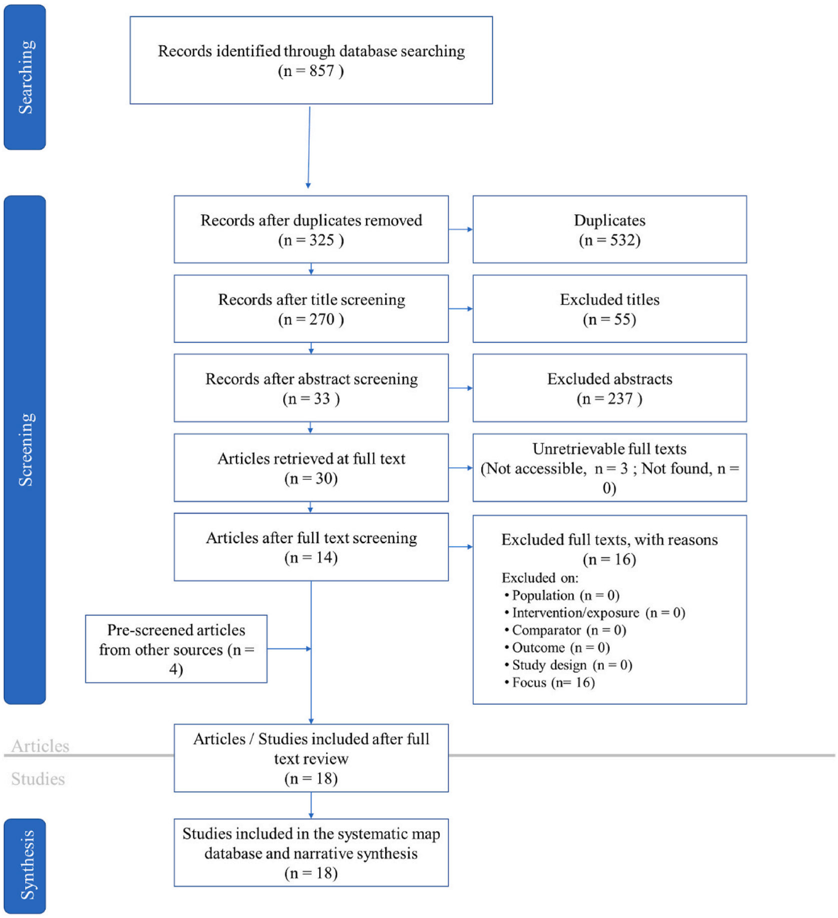

Fig. 2. The ROSES search chart.

non-availability of bank loans to support solar PV adoption [56–66] (Fig. 3). Similarly, 61 % (n = 11) of the articles [57–59,63–69] focused on personal barriers to solar PV adoption including lack of knowledge on how to operate the solar PV systems and dissatisfaction with the solar PV output quality. Half of the articles 50 % (n = 9) [57–59,64–67,70,71] reported institutional barriers ranging from lack of government and utilities support as to lack of grounded policies which can incentivise the adoption of solar PV among households. Only four articles (22 %) reported technical barriers - the lack of technical expertise to install and operate solar PV systems and non-availability of spares to repair faulty systems [67,68,72,73]. The least number of articles (17 %, n = 3) focused on societal barriers which were mainly related to theft of solar PV systems [57,67,72].

3.1.1. *Financial barriers*

A key financial barrier to solar PV adoption by households relates to high start-up costs and the availability of after sales

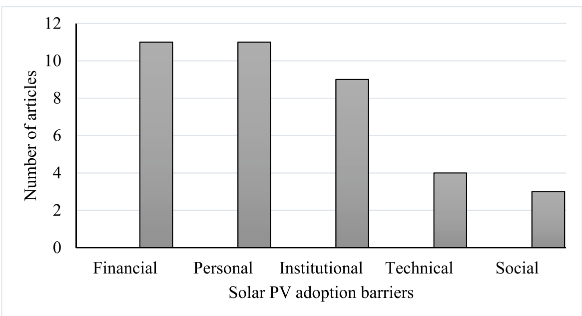

Fig. 3. Types of solar PV adoption barriers identified in South Africa.

maintenance support [56–61]. For instance, in a study exploring the hybrid models for comprehensive access to basic energy among informal households in Zimbabwe and South Africa, Conway et al. [56] found that solar home systems that are not subsidised have a lower chance of being accepted especially by marginalised societies because they are costly to purchase and maintain. Similar findings were also reported by Chidembo et al. [57] who found that most rural households in the Vhembe district of South Africa were reluctant to adopt solar PV because of the high capital investment needed but beyond the reach of many households. Hendricks [59] studied the determinants of solar PV adoption among high-income households in Parkhurst Johannesburg and found that they considered rooftop solar PV initiatives very expensive, and the investment to provide very slow and low returns. Parkhurst residents also felt it was not possible to include the cost of solar instalment in selling value of their property if they considered selling which constrained their willingness to adopt solar PV [59]. Similar perceptions were reported by Tang et al. [60] and Chang et al. [61] who found that most South African households perceived the adoption of solar water heaters as costly, and could only be achieved through government interventions such as donations or subsidies. Such government initiative includes the Solar Water Heating Rebate Programme which provides low-income households with access to hot water [74]. However, Tang et al. [60] and Chang et al. [61], noted that the number of existing government initiated solar PV subsidy programs in South Africa were not sufficient to support meaningful solar adoption. The consensus among studies on financial barriers is that solar PV is an expensive initiative which needs the intervention and support of governments to spearhead its adoption, especially among marginalised and low-income groups of households.

Barriers pertaining to high capital investment of solar PV have also been reported elsewhere. For instance, in Pakistan, Khattak et al. [29] report that market structures with no market control pricing benchmark resulted in high start-up costs which were beyond the affordability of many households. Studies in Germany [31] and Netherlands [32] have found that economic feasibility is one of the major factors hindering households' decision to move to solar PV. A study in India showed that more than 45 % of Indian households were failing to adopt solar PV due to cost related reasons [74].

Other financial barriers relate to the lack of credit facilities to promote solar PV purchases. Studies by Chidembo et al. [57,58] which reviewed the determinants of solar PV adoption among rural households in South Africa found that most rural households did not have a consistent income, hence, they did not have the disposable income to purchase solar PV systems. Further, most rural households did not have collateral security to get loans from banks for solar PV purchase. Similar sentiments were reported by Lemaire [66] who suggested that the low adoption of solar PV initiative in South Africa is due to the lack of financial arrangements between households and institutions that provide financial assistance for purchasing solar PV technology. Hendricks [59] argues that banks and other financing facilities generally take a conservative approach which leaves out marginalised households and societies when they provide funds for initiatives such as solar PV in South Africa.

Issues related to lack of credit facilities as a solar PV adoption barrier have also been reported in other countries, e.g., among US low-medium income households [75]. The above-mentioned study found that most low-to medium income households among the US household were typically excluded from financial arrangements for supporting solar adoption because they had low credit scores [75]. However the same study also reported that few households with high credit scores were financially excluded from for solar PV loans due to debt from cars loans and house mortgages [75].

These findings suggest that, financial barriers relating to solar PV installation remain one of the main reasons behind low solar PV adoption among households of varying economic status, though the marginalised households are likely to be disproportionately affected. These findings also suggest that policies supporting solar PV should be directed around regulating market structures so that solar PV products are not too expensive to purchase. Such initiatives have been implemented with success in the US, where the Solar Energy Technology Office (SETO) has set a benchmark guiding solar PV market to promote the adoption process among industries and households [76]. A study in Seychelles reported a high solar PV adoption (>40 %) rate and attributed it to financial support in the form of credit facilities [77]. This implies that solar PV adoption among households is expensive and may require financial support from credit facilities if solar PV adoption is to increase in less developed countries.

3.1.2. Personal barriers

Two key personal barriers were identified namely, lack of knowledge and personal satisfaction. Slightly below half of the articles (44 %) point to the lack of knowledge and skills needed to operate and repair faulty solar PV equipment as contributing to the low adoption of solar PV among South African households [57–59,63,66–69]. For instance, Bikam and Mulaudzi [67] found out that one of the factors which led to the failure of the solar energy pilot project in Folovodwe, South Africa was that households were never equipped with the skills to operate and maintain the solar PV systems, leading to lack of interest and dissatisfaction among households. Thobejane et al. [68] found similar observations in a review of the factors behind failures in the rolling out of solar geysers among South African households. They found that most solar geyser recipients were neither trained nor received any form of information on how the systems functioned, which resulted in wrongful use and ultimate damage to systems. A similar study of residential solar PV panels installed by international donors found that the solar PV panels were abandoned a few years after they were installed, simply because the recipients lacked knowledge, skills, and understanding of how the systems work [66]. Curry et al. [69] also report that solar geyser owners in the Tshwane district of South Africa lacked knowledge on how the system worked, leading to underuse and dissatisfaction. Chidembo et al. [57,58] also observed that solar home systems were not adopted as expected in South African households because the users lacked knowledge on how the systems functioned and, could not determine its potential risks and benefits. This lack of knowledge, in turn, leads to wrongful use resulting in negative attitudes when solar systems fail to meet the expected output. In a study by of solar PV systems in Parkhurst, Johannesburg, Hendricks [59] found that, householders generally sceptical of roof top solar PV because they were not fully informed about how the systems functioned and did not trust the suppliers. In light of knowledge barriers, Adams [63] argues that households should be educated about the benefits, functions, downslide of solar PV systems to allow them to make informed decisions about purchasing the solar systems, emphasising that knowledge of the systems can help potential consumers to ascertain the risk and the potential benefits.

Barriers relating to knowledge are quite prevalent among developing countries which are known to have limited resources to initiate solar PV knowledge and skills transfer programmes to the general public [33,78]. Thus, it is worth noting that until households are properly informed about the pros and cons as well as the technical aspects of solar PV technology, supportive efforts for the diffusion of solar PV systems might not yield optimum results. Hence, it is plausible in the South African context to argue that the government and key solar PV stakeholder like private companies need to direct more effort on educating households on solar PV systems functionality, particularly low-income households that often have limited access to such information. This could be in the form of awareness campaigns using existing community meeting forums and social media or through the school curriculum. For example, in the US, the Solar Energy Technologies Office (SETO) - a branch in the Department of Energy, launched a successful inclusive solar awareness campaign which sought to encourage solar adoption across a diverse audience [79]. The United States is also committed to advancing solar energy education through the creation of a comprehensive set of K-12 curriculum resources, assistance for outreach coordinators and teachers in implementing modules and lessons on solar PV science and engineering [80]. Similar initiatives can be implemented in South Africa through the Science, Technology, Engineering and Mathematics (STEM) education initiative, where solar PV studies can be integrated into the curriculum starting from elementary stages of learning.

Apart from lack of knowledge, dissatisfaction with the quality of solar energy was also reported as a key personal barrier to solar PV adoption [63,71]. For instance, Azimoh [71] found that households that were not connected to the grid and were put on the government solar PV scheme ended up shunning solar PV systems for fear of being pseudo-connected which could risk their exclusion from the perceived more reliable and efficient energy grid energy. The dissatisfaction relates to the quality of energy produced by solar panels as it could not support other household energy needs such as cooking and refrigeration. Adams [63] has also reported customer dissatisfaction as a barrier, describing renewable solar PV energy systems as a relatively new system whose rate of assimilation is solely dependent on customer satisfaction. A World Bank report similarly concluded that most South African solar PV recipients and adopters were dissatisfied with the systems due to its limited capability to support key household energy requirements [21]. Elsewhere, a study among rural Indian rural households found that solar PV performance had a significant positive impact on households' satisfaction [81]. Thus, solar PV suppliers and installers need to assess the energy needs of households to match them with the capabilities of solar PV systems. Further, information provision should include details about the size of solar PV systems needed to support household energy needs before the installation process starts. When households are equipped with enough information related to solar PV capacity, they can make informed decision about the solar packages that satisfies their needs. Kumar et al.'s [82] study on Indian solar customers, shows that pre-sales services ensured that consumers obtained comprehensive information about solar products as including operating principles, operational needs, advantages and disadvantages, usage restrictions, appliance efficiency, and quality principles.

3.1.3. *Institutional barriers*

Institutional barriers reported in the reviewed studies include lack of support in the form of feed in tariffs from local municipalities and the main power utility, Eskom [41,42]. The lack of support could be attributed to the fact that both municipalities and Eskom generate their revenue through selling conventional grid energy, hence, a transition to solar PV could compromise their income. For example, a study on the impact of grid connected solar PV on municipal revenue in Stellenbosch, found that municipality would lose about 0.6–2.4 % in revenue, if households transitioned to solar PV [83]. Municipalities in South Africa are responsible for selling about 40 % of energy and as part of diversifying the energy mix, efforts have been made to purchase energy from rooftop house-owners [84]. However, households expect municipalities to pay the same amount of money they pay for energy which could leave municipalities with no profits [84]. Hence, it plausible to argue that the limited support from local municipalities to support the transition to solar PV among households is linked to potential losses. Lack of institutional support from the government and companies that supply energy has also been reported in Japan, where monopolistic companies which sell energy do not prioritise renewable energy sellers as they compromise their fossil energy sales [85]. Elsewhere, the imbalance resulting from the feed-in tariff policy has also been reported [86]. For instance, in Germany, the feed in tariff policy has been so successful that it now threatens the financial viability of the energy providers [86]. Hence, energy providers should ensure that there is a balance between their energy supply and households' independent generation of renewable energy, for a mutually beneficial transition.

Other institutional barriers that were identified relate to inconsistent and under-developed policies on solar PV adoption within South Africa [66,67,70]. For instance, Donev et al. [70] suggest that the low adoption of solar water heaters results from lack of grounded renewable energy policies that foster adoption, describing the South African renewable energy policies as weak and dominated by conventional energy policies with little or no support for solar PV transition. For example, in 1999 the South African government launched a solar electrification programme called a Fee for Service Concession where it distributed solar PV systems in return for a very small monthly payment which was specifically directed towards maintaining the systems [66]. Lemaire [66] reported that the above-mentioned programme failed due to lack of an effective and transparent renewable energy policy. In addition, there were no guiding principles for dissemination such that the solar PV systems were allegedly distributed based on political affiliation. The lack of feasible policies for guiding adoption has also been reported by Bikam and Mulaudzi [67] who found that solar energy pilot project in Folovodwe failed because it was not guided by the cultural dynamics of the households. For instance, the local communities were culturally connected to traditional energy sources such as coal and firewood, which constrained adoption of solar PV systems [67]. Lack of policies that support transition to solar PV has been reported somewhere [87]. In Malaysia, lack of strong policies in solar PV transition explain the slow adoption by households of solar PV [39]. However, policy successes have been noted in Germany [31]. If the South African government is to succeed in just transitions to solar PV, there should be a shift in policy support conventional to renewable energy policies [88]. The country lacks grounded national policies which frame residential solar PV. Interestingly, the persistent power outages in South Africa have seemingly forced the government to develop and implement solar PV policies that could facilitate solar PV transition [89]. For example, the introduction of tax rebates linked to solar PV installation by households [90] is a welcome policy that could incentivise households to adopt solar PV. Although policies on selling excess solar energy to the conventional grid are now in place, some experts think the policy is still costly for many households as they are required to pay tax in order to sell back to grid [91].

Another institutional barrier reported relate to grid encroachment, which happens when conventional grid energy is introduced in areas that have been targeted for solar PV, thus slowing down the adoption process. Chidembo et al. [58] found that the grid expansion into areas targeted for solar PV was one of the main barriers to solar PV adoption in rural South African households. This is mainly because grid energy is usually government-funded and hence it is cheaper for low-income households. The impact of cheaper forms of conventional energy relative to solar PV adoption has also been reported to slow down the transition to solar PV in Nigeria [78], Sweden [92] and United States [93]. This implies that households maybe more concerned with affordability and access to energy than about the environmental impacts of the energy source.

3.1.4. Technical barriers

Technical barriers such as technical faults and non-availability of solar systems maintenance were identified by Bikam and Mulaudzi [67], Curry et al. [69] and Aigbavboa [94]. For instance, in Folovodwe, South Africa, a high rate of breakdown on the solar PV systems due to wear and tear was reported and non-availability of spare parts was the key factor behind the unsuccessful implementation of a solar PV pilot project [67]. The spares had to be imported which was very expensive and time consuming for households. Another pilot solar water heater project in the city of Tshwane, South Africa reported similar findings, where technical faults and non-availability of spare parts prevented the project from achieving its desired results [69]. Technical barriers have been reported in other countries, particularly in developing countries such as Guinea [32] and Nigeria [78] where inaccessibility to solar PV spares and logistical problems were linked to lack of robust solar PV markets. Unlike in most developing countries, the availability of spares was rarely mentioned among developed countries possibly because they have readily available industries which manufacture spares. For instance, countries such as China [95] and German [9] have invested in solar manufacturing plants, making it cheap to buy and service solar PV systems. The expectation is that a wide network of solar PV technology manufacturing industries can broaden the market, making parts affordable and accessible to many households. However, there is need for South Africa and other developing countries to invest in establishing solar PV industries and developing the human skills needed for establishing the industry.

Another technical barriers to solar PV adoption reported in the reviewed studies relates to the malfunctioning of appliances [94]. For instance, Aigbavboa [94] found that households reported malfunctioning of government installed solar water heaters including leakages, which discouraged other households from accepting the technology. The study also found that the solar water heaters produced an unpleasant noise during use of hot water taps, suggesting a lack of expertise in installation and maintenance. In the absence of government solar PV specialists, households tend to rely on private operators which are highly expensive and inaccessible to low-income groups. In developed countries, after the installation and commissioning of a solar system, suppliers continue to support the customer during routine maintenance appointments and solar system troubleshooting requests at no additional cost for the duration of the system's warranty [81]. This arrangement can boost adopters' confidence in using the solar PV systems as well as address technical challenges they may face after installation. Similar arrangements can increase the level of trust and chances of solar PV adoption in South Africa.

3.1.5. Social barriers

Social barriers reported in the reviewed literature include theft of solar PV appliances and spares [57,67,72]. For instance, Bikam and Mulaudzi [67] reported that some households in Folovhodwe village had discontinued investments in solar energy because of the high rate of theft in the area, including of solar PV appliances. In the Vhembe district of South Africa, Chidembo et al. [57] also found that though households perceived solar energy as environmentally friendly and cheap, they were unwilling to install solar PV systems because of fear of theft. Azimoh et al. [72] reported that adopters of solar PV used most of their energy towards lighting to prevent crime, which in turn, reduced the capacity of the solar systems to support the households' primary needs such as powering appliances. The issue of insecurity of solar PV systems as a barrier to adoption has been reported elsewhere. For instance, in Papua New Guinea, households opted not to invest in solar panels to avoid inviting criminals to their houses [33]. Similar findings were reported among British households where community concerns including security were noted as additional barriers to solar PV adoption among households [96]. However, improvements in solar PV technology such as security lighting in the form of floodlights connected to motion sensors and anti-theft fasteners can help reduce theft [97] but in low-income areas the costs of such measures should not be expected to be borne by households. Other security related solutions include the use of advanced alarm systems that can proactively warn users about intruders. These security technologies can be mainstreamed by South Africa through information campaigns to increase solar PV uptake amongst local households. However, it is important to acknowledge that these security features may come with extra costs which might limit some households from affording them.

In most cases, barriers reported in South Africa are comparable to those reported elsewhere [31,32]. For instance, financial barriers have been reported among developed countries such as Sweden [92], Germany [31], and the Netherlands [32], as noted in the analysis. However, while technical barriers are universal, they differ in nature based on geographic settings. For example, unlike South African households, which face barriers in the form of technical faults and non-availability of solar system maintenance, in developed countries such as the United Kingdom (UK) technical barriers relate to limited rooftop space for installing panels, rooftop suitability in terms of accessibility for maintenance, and rooftop shading caused by plant growth covering the solar panels [98]. In many European households, rooftop plants covering solar panels are common, making some homeowners unwilling to undergo constant rooftop maintenance to eliminate these plants [98].

4. Implications and recommendations

This scoping review provides useful insights on the barriers of solar PV adoption among South African households. It shows that barriers to solar PV adoption vary ranging from personal to institutional, with such barriers likely to affect households disproportionately, with more negative effects on low-than on high-income households. For instance, the results show that adoption of solar PV systems requires a high capital investment which is beyond the reach of many South African households, especially those located in low-income areas. Approximately 55 % of the people in South Africa are classified as low-income households, and 20 % are considered middle income [98], implying that these two income groups will struggle to move towards solar PV if these barriers were not addressed. Compared to high-income households, both low- and middle-income households lack access to credit facilities, have limited roof space for installation of solar panels as well as limited knowledge and awareness which might constrain their ability to adopt solar PV systems. Moreover, because of apartheid discriminatory spatial arrangements, most low-income households are in neighbourhoods with poor security which might discourage solar PV adoption due to theft concerns. Yet, it seems like there is an urgent need for low- and middle-income households to adopt solar PV given that they disproportionately incur the costs of power cuts because they cannot afford alternative energy sources such as generators. Further, the majority of low-income households are debt ridden, with more than 60 % having unsustainable debts [99] which disqualifies them from accessing loans. Therefore, there is a need to address barriers that directly affect low- and medium-income groups for a just transition to solar PV adoption in South Africa. The current government solar PV incentives (e.g., the 25 % solar PV rebate) will only benefit the high-income households as they have the means to purchase Solar PV systems through disposable income or bank loans.

A consideration of all these factors combined might explain the reason behind the low and slow adoption of solar PV among the low income households in the country as highlighted in the literature [62]. Hence, a socially just transition to solar PV energy in South Africa might be achievable through the introduction of equitable policy frameworks which support inclusive transitions. For instance, the government should put in place inclusive financial legislations which cater for low- and middle-income households. The government can also initiate or support power purchase agreements whereby solar PV systems are installed in homes at reduced costs, and the energy generated will be sold to the homeowner at a set contractual price. Power purchase agreements can address the lack of trust and perceptions of limited capacity of solar PV systems to produce sufficient energy and at the same time minimise start-up financial costs, which could in turn, encourage solar PV adoption. Power purchase agreements have proven to be effective among low- and medium income households in California, USA [100]. Californian households have also benefited from the government solar leasing exercise where the government contracts solar companies to lease solar panels to homeowners who pay for them over a long period of time [100,101]. These initiatives can be very effective in South Africa, given that most low- and medium income households in South Africa are debt ridden and hence, cannot qualify for loans [102]. Moreover, these initiatives can also cater for the low- and medium income households who are key consumers of energy in South Africa [103]. Alternatively, the government can also create financial institutions that offer loans or financial help to household adopters at zero or low interest rate for solar PV system adoption. Similar initiatives have been successful in Ghana [104] and Kenya [105], with solar PV adoption positively linked with various kinds of incentives and credit arrangements through the rural and community banks initiative. To reduce the financial burden of low- and middle-income households, the government can also promote adoption of solar PV by reducing import duties for solar PV products which can reduce the upfront costs of solar PV systems.

In discussing the challenges facing widespread adoption of solar PV technology, it is imperative to recognise that institutional, financial, social, and cognitive barriers are deeply interconnected and cannot be addressed in isolation. Institutional barriers such as outdated regulations or bureaucratic hurdles, often intersect with financial constraints, limiting access to necessary funding and investment. Moreover, social factors, including public perception and community acceptance, play a pivotal role in shaping the uptake of solar PV systems. Additionally, cognitive barriers, stemming from misinformation or lack of awareness, further hinder progress in this transition. Recognising and addressing these barriers holistically is essential for fostering a conducive environment for the widespread adoption of solar PV technology, unlocking its full potential in the global transition towards sustainable energy.

5. Research gaps and future recommendations

Although the reviewed articles provide useful insights, future research needs to focus on the comparisons between perceived and objective barriers as this can determine what solutions might be needed to address them. Perceived barriers refer to an individual's assessment of the challenges they may face in trying to change their behaviour [106]. In this context perceived barriers refer to households' assessment of the challenges associated with solar PV adoption. Objective barriers on the other hand refer to practical challenges encountered in solar PV adoption [99]. Although it was not the focus of this study, the majority of the work reviewed in this study focused on perceived barriers. Thus, future research needs to focus on objective barriers as these show an accurate reflection of factors deterring households from adopting solar PV. As already alluded to, available literature on barriers to solar PV adoption in South Africa provide limited insight into how barriers affect different income groups. This work is very important, but insufficient to capture the structural issues that shape access to renewable energy. Moreover, there is a need for studies on the barriers of solar PV among households, focusing on both adopters and non-adopters, and across an income gradient which might provide insights on what and how barriers are experienced. This can form the basis for drafting policy interventions for equitable transitions to solar PV, particularly in contexts of high levels of inequality.

6. Conclusion

Despite a growing unanimous agreement on the benefits of solar PV energy, there is a very low adoption rate among South African households attributable to diverse barriers including financial, institutional, technical, personal, and social barriers. Solar PV systems are still largely expensive and beyond affordability for most households in South Africa which has serious implications for energy security and environmental targets. Addressing the barriers remains important in promoting rapid uptake of solar PV systems but should be informed by up to date analysis of how barriers vary by income status, and distinction between perceived and objective barriers. Further collective efforts are needed to meaningfully address the barriers. Central to promoting local solar energy is creating a strong strategy that is inclusive of all households including those from marginalised societies. The government also needs to invest in educating households so that they can effectively ascertain the risks and benefits of solar PV to allow agency and informed decisions.

Data availability

Data will be made available on request.

Ethics and declarations

Informed consent was not required for this study because the study was focused on secondary data.

CRediT authorship contribution statement

Uzziah Mutumbi: Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Formal analysis. **Gladman Thondhlana:** Validation, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization. **Sheunesu Ruwanza:** Writing – review & editing, Supervision, Methodology, Investigation, Funding acquisition, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2024.e30937.

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