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Socio-technical challenges and prospects of residential solar PV diffusion in Ghana: Insights from regime and intermediary actors

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ABSTRACT

This study seeks to broaden the understanding of factors influencing the diffusion of residential solar PV in Ghana by examining the socio-technical challenges confronting this sector from the perspective of regime and intermediary actors. Semi-structured interviews were conducted with focal persons at the Energy Commission, Land Use and Spatial Planning Authority (LUSPA), 18 licensed solar home system (SHS) companies, and 15 real estate developers in Accra. The study uncovers compliance and mediation-based interactions between the intermediary and regime actors. Significant regime support for residential solar PV exists through incentives such as capital subsidies, net-metering schemes, and partnerships with financial institutions to provide soft loans for residential solar investments. Nonetheless, policy-regulation incoherence, a sectoral dichotomy between energy and urban planning, fragmented institutional efforts, inadequate access to long-term finance, and limited awareness/technical know-how of SHS emerged as the key challenges to residential solar PV diffusion in Ghana. Resolving these challenges requires synergies between the regime and intermediary actors to enact conducive regulatory frameworks and coordinate the activities of all actors to facilitate residential solar PV uptake in Ghana. The study also posits that the transition from a fossil-dependent regime to a low-carbon one not only requires a re-direction of financial incentives to technological niches but also to user-based intermediaries.

1. Introduction

Economic growth and a growing middle class are expected to increase households' ability to purchase more electric appliances in developing countries such as Ghana, potentially raising their electricity consumption and carbon footprint [1–3]. Nonetheless, a budding middle class coupled with declining solar PV costs provides an opportunity for increased investments in renewable energy (RE) technologies such as solar home systems (SHS). Through their integration into buildings, SHS offers significant opportunities to transition to clean energy and reduce households' carbon footprint from electricity consumption. While the cost of SHS is often cited to be too high for many households in developing countries, existing research suggests that cost is not the only major challenge impeding the diffusion of RE technologies such as SHS [4–6]. A transition to clean and sustainable energy requires positive transformations in socio-economic, technical, political, and socio-cultural systems for investors, governments, and end-users [7,8]. Bridge et al. [5] recount that while RE technologies such as SHS are becoming more technically and economically viable, their widespread uptake depends on the extent to which these systems can be integrated into the built environment. Akrofi and Okitasari [4], for instance, demonstrate how urban form could impede the uptake of rooftop SHS in Ghana, highlighting the need for a more integrated approach to urban planning and greater collaboration between various actors.

Like many sub-Saharan African countries, achieving universal access to modern, affordable and reliable energy is a top priority on Ghana's development agenda. Despite having one of the highest electrification rates (86.3 %) in the region [9], the reliability of supply remains a major challenge, with frequent load shedding occurring from time to time. The government's commitment to stabilize supply, particularly by increasing the share of electricity from renewable energy sources, is enshrined in several policy documents, such as the Renewable Energy Master Plan and the Renewable Energy Act [10,11]. Boosting the uptake of residential solar PV systems forms an integral part of this plan, with the launch of the National Rooftop Solar PV program in 2015. The aim of the program is to reduce the peak load on the national grid by 200 MW by providing a capital subsidy for the uptake of residential rooftop solar PV systems. As of 2023, non-hydro renewables constitute 2 % of Ghana's

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installed generation capacity [12]. Solar energy contributes the largest share of these renewable energy sources, accounting for about 90 % of non-hydro renewables [12].

While most of this solar energy comes from ground-mounted solar plants such as the Volta River Authority's (VRA) Navrongo, Kaleo, and Bui solar plants, among others, residential solar PV such as rooftop solar are also contributing (though not so significant at the moment) to Ghana's solar PV growth. Even though official and up-to-date statistics on installed residential rooftop solar PV systems are difficult to come by at present, some 200,000 installations of such systems were planned under the National Rooftop Solar PV program in 2016, and by 2017 around 727 applicants benefited from the program in Accra alone [13]. These residential solar PV systems (classified among distributed PV in Table 1) are expected to play a key role in reaching Ghana's renewable energy goal by 2030 as seen in Table 1.

More recently, Ghana has launched the Ghana Mini Grid and Solar Photovoltaic Net Metering Project with financial support from the African Development Bank. Some 12,000 rooftop net-metered solar PV systems are also planned to be installed across households and institutions in the country under this program. The foregoing demonstrates the importance of residential solar PV in Ghana's clean energy transition and the increasing popularity of this residential solar PV not only in Ghana but in many other sub-Saharan African countries [14]. Policies, regulations and market dynamics are instrumental in transitioning to such systems, prompting the need for understanding how both state and non-state actors influence this transition process. Interactions between regime and intermediary actors, in particular, are instrumental to facilitating the transition to clean energy technologies. Regimes refer to formal and informal institutions and rules that guide or regulate activities within the energy sector while intermediaries connect users to new energy technologies (e.g., SHS sales and installation companies) and influence policy decisions through interactions with regime actors and technological niches [15,16]. Laborgne [17] provides an example of how such intermediaries are facilitating low carbon transitions in German cities by bridging gaps between niche and regime actors. Similarly, Martiskainen and Kivimaa [15], and Bush et al. [18] recount how intermediaries empower innovations and shape incumbent institutional frameworks toward low carbon homes and district heating systems in the United Kingdom. Similar examples can be found in Spain [19], Finland [20], and the Netherlands [21], among others.

Nonetheless, Ehnert et al. [22] highlight that there is still a research gap regarding the ways in which these intermediaries are integrated into local governance frameworks and how the political dynamics involved in urban sustainability transitions unfold. This gap is evident in Ghana where existing studies on residential solar PV uptake (see Section 2) mostly focused on adoption intentions and its related challenges from the perspective of households. Thus, to broaden the understanding of both prospects and challenges of facilitating residential solar PV uptake in Ghana, this study focuses on regime and intermediary actors involved in policy formulation as well as marketing and installation of residential solar PV systems. The key questions that the study seeks to address are: 1) what are the institutional, regulatory, and market prospects and challenges to accelerating residential solar PV uptake in Ghana, and 2) what is the nature of interactions between regime and intermediary actors and how can these interactions be leveraged to address the existing challenges?

Our analysis includes both public and private sector actors and extends beyond socio-demographic challenges to include institutional, regulatory, and market challenges, thus presenting a more comprehensive and nuanced understanding of the challenges in Ghana's residential solar PV landscape. The study makes two key contributions to the existing work on residential solar PV in Ghana by: 1) unveiling and characterizing the nature of interactions between the regime and intermediary actors in Ghana and 2) extending the standpoint on redirecting financial flows to technological niches as a pre-requisite for transitioning to clean energy technologies [23]. In the Ghanaian context, we argue that such redirection of financial flows, particularly incentives for solar PV adoption, needs not only to focus exclusively on technological niches but also on user-based intermediaries. The rest of the paper is organized as follows: Section 2 presents an overview of current challenges to residential solar PV uptake in Ghana and sets the context for our focus on regime and intermediary actors. A detailed discussion of the regime and intermediary actors in the context of this is provided in Section 3. The methods of data collection and analysis are discussed in Section 4 while the results, discussion and policy implications are presented in Section 5, and conclusions and future research recommendations are outlined in Section 6.

Table 1
Solar energy technology targets in the renewable energy master plan.

Technology/ intervention	Unit	2015 (Reference year)	2020	2025	2030
Utility Scale Solar	MW	22.5	152.5	347.5	447.5
Distributed PV	MW	2	20	100	200
Standalone PV	MW	2	10	15	20
Street/ Community Lighting	MW	3	7	11	25
Water Heaters	Units	4700	20,000	70,000	135,000

Source: Energy Commission [10]

2. Challenges to residential solar PV uptake in Ghana

Previous studies on residential solar in Ghana have mostly focused on social groups (mostly households), often exploring the factors influencing households' willingness to adopt SHS [24–26]. Table 2 provides an outline of these studies and some of the identified challenges to SHS uptake in Ghana.

Socio-demographic factors such as income level, educational attainment, occupancy status, and perceived benefits from the SHS [25,26] are commonly cited as the major determinants of SHS investments in Ghana. The cost of SHS from one of Ghana's major solar energy companies (Nocheski Solar) ranges from 1177.99 USD (14,018 GHS) to 2100 USD (24,990) for mini off-grid solar systems with capacities of 250 watts, 1.2kWh battery storage and 500 watts, 2.4kWh battery storage, respectively. These are only backup systems that provide 5 to 8 h, respectively, of electricity to power some basic appliances. Thus, higher capacity systems are expected to be more costly. Existing studies have shown that these backup systems are largely unaffordable

Table 2
Challenges to SHS uptake in Ghana.

Challenges to SHS investments	Type of actors	Authors
Occupancy status—renters are unwilling to invest in SHS.	Social groups (households)	[24,25]
Policy-regulation incoherence—current planning regulations do not necessitate the consideration of solar PV systems in the planning process.	Regime actors (energy and urban planning authorities)	[27]
Skepticism about the ability of SHS to support household electric appliances	Social groups (households)	[24,25]
Effects of urban form attributes—building's/neighborhoods' design, density, etc.	Regime actors (energy and urban planning authorities)	[4,27]
High costs of purchasing, installing, and managing SHS	Social groups (households)	[24,25]
Notions of entitlements to electricity from the national grid	Social groups (households)	[28]
Limited awareness of the capital subsidy program for SHS (National Rooftop Solar Program)	Social groups (households)	[26]
Limited awareness of SHS	Social groups (households)	[29]

for most households [28]. The government of Ghana has initiated a capital subsidy scheme through its National Rooftop Solar PV program with the aim of making SHS more affordable to households. Nonetheless, beneficiaries still bear around 70 % of the cost, which remains a significant challenge, particularly for low-income households [24]. A recent study showed that households aware of this capital subsidy scheme are more likely to invest in SHS, yet around 32 % of households are unaware of it [26].

Apart from costs, other key challenges include notions of entitlement to the grid, where households feel that, as citizens, they have the right to be connected to the grid, and it is the government's responsibility to ensure that they are connected. This notion is typically demonstrated during election periods where the slogan "no electricity, no vote" is commonly seen in signposts in areas without grid connection. Urban settings in Ghana are dominated by renters who are often reluctant to invest in SHS due to the possibility of relocating to different areas and the immobile nature of SHS systems [30]. From Table 1, it is apparent that existing studies have mostly identified challenges related to costs and socio-demographic factors.

Nonetheless, a previous study [4] highlights the need for a more comprehensive assessment of factors affecting investments and the uptake of SHS in Ghana beyond the costs and commonly cited socio-demographic determinants. The study showed that even beyond households' decision to invest, and with government subsidies to lower SHS costs, the socio-spatial configuration and characteristics of the built environment pose significant challenges to the feasibility of residential solar PV systems, especially rooftop solar in Ghana [4]. For example, urban form attributes such as building density, buildings' roof type, roof shape, neighborhood compactness and landscaping have been affirmed to affect the feasibility and performance of residential rooftop solar PV systems in Accra, Ghana [27]. Addressing these challenges requires not only energy sector reforms but also urban planning and private sector reforms. It is against this background that this paper seeks to provide a broader understanding of the challenges to residential solar PV diffusion, emphasizing policy and regulatory bottlenecks from the perspective of regime and intermediary actors.

3. Actors and intermediaries in sustainable energy transitions

There is growing evidence that intermediaries whose primary activities may not be in the renewable energy domain play a significant role in facilitating the diffusion and uptake of renewable energy technologies [31–33]. Intermediaries are actors and platforms that serve as positive catalysts in the transition process by building bridges between actors, activities, skills, and resources in order to create momentum for socio-technical system change [34]. Thus, such actors may not be directly involved in the invention of new RE technologies or the enactment of new regulations for RE development and deployment, but they can catalyze the diffusion of such technologies through their marketing, and by influencing policy decisions or creating channels through which new RE technologies are adopted [15,16,35].

Five typologies of intermediaries are identified in the literature—systemic intermediaries, regime-based intermediaries, niche intermediaries, process intermediaries, and user intermediaries (see Kivimaa et al. [34] for details on each type). The focus of this study is on regime actors, regime-based intermediaries and user intermediaries. Regime actors are typically government agencies/institutions that could facilitate sustainable energy transitions by enacting conducive regulatory and policy environments for innovation processes [36]. On the other hand, Kivimaa et al. [34] recount that regime-based intermediaries are "actors in transitions that are part of the established institutions in the prevailing socio-technical regime but yet inclined or mandated to work towards transformative change" (p.1070). These actors also often interact with niche actors or the wider system.

Two actors involved in this study fit into the regime actors and regime-based intermediary categories. These are the Ghana Energy Commission (EC) and the Land Use and Spatial Planning Authority (LUSPA). Of these, the EC is the main regime actor, whereas the LUSPA could be described as a regime-based intermediary, given that its primary function is not energy regulation and planning. The EC is primarily responsible for regulating and managing the development of all energy resources (renewable and non-renewable) in Ghana. It provides legal, regulatory, and supervisory frameworks for licensing and sale of energy services [37]. The commission also develops national energy policies and oversees specific plans/programs for renewable energy, energy efficiency, and the supply, marketing, and sale of renewable energy products [37]. It oversees the implementation of key renewable energy legislations such as Ghana's Renewable Energy Act and specific programs such as the national rooftop solar PV program [38].

On the other hand, the LUSPA is Ghana's premier agency for planning and regulating land use and spatial development. It is responsible for development control in Ghana, issues building permits, and enforces Ghana's building code, including energy codes in buildings. Building professionals and urban planners are classified as regime-based intermediary actors [34]. Fischer and Guy [39] cite an example where architects assumed an intermediary role in simplifying energy efficiency mandates within construction codes, making them more comprehensible to clients and other stakeholders in the construction industry, thus facilitating the transition to more energy-efficient buildings. Table 3 presents a summary of the various actors and their roles in Ghana's solar energy landscape.

The second category of intermediary actors considered in this study is *user intermediaries*. According to Kivimaa et al. [34], user intermediaries "translate new niche technologies to users and user preferences to developers and regime actors, qualifying the value of technology offers available" (p.1070). These intermediaries connect users to new RE technologies, a function that sometimes involves modifying the technology to suit users' contexts. Such actors provide information on new technologies to users, configure technical and social elements, and convey useful user feedback to both niche and regime actors, thus serving as the interface between regimes and niches [15,40]. In this study, we classify real estate developers and licensed solar home system installation companies as user intermediaries. By including SHS as backup electricity systems in their housing, real estate developers play a mediating role in bringing SHS to homeowners. Real estate developers in Ghana are primarily private entities specializing in the

Table 3
Actors involved in the study.

Type	Name of institution	Level	Role
Government (Regime)	Energy Commission	National	Responsible for planning and regulating both RE and non-RE energy resources in Ghana. It also oversees specific solar PV interventions such as the rooftop solar PV and net-metering programs.
Government (regime-based intermediary)	Land Use and Spatial Planning Authority (LUSPA)	National/ Local	Responsible for spatial and urban planning in Ghana. It also oversees the enforcement of Ghana's building code and issues building permits for developers.
Private (user-based intermediary)	Real Estate Developers	Local	They are primarily involved in the design and construction of estate housing, which they sell/ rent to the public.
Private (user-based intermediary)	Licensed SHS Companies	Local	Responsible for the sale, installation, and maintenance of solar home systems.

design and construction of estate housing, often in gated communities. The design decisions made by these estate developers have significant implications for the integration of solar PV systems into buildings by homeowners who purchase houses in such estates [27].

SHS companies also bring the technology to users' doorsteps and have first-hand knowledge of user needs, preferences and challenges. They provide information on new RE technologies to users through advertisements and configure such technologies to fit different contexts. Previous studies on SHS in Ghana report how SHS installers design special mounting racks or mobile structures for solar PV panels. For example, in their study of SHS in Ghana, Boamah and Rothfuß [24] quoted one of their interviewees saying: "*… I have constructed a mobile structure housing batteries, regulator and inverter. It has wheels and, so I can easily move it around in my apartment. … I only have to pull out the solar PVs when relocating* [*to a new apartment*]. *… I design similar ones for customers upon request.*" (p.7). In Ghana, SHS installers are licensed by the EC upon passing an aptitude test. They are usually contracted to install SHS systems for users who benefit from Ghana's rooftop solar PV program, which the EC is implementing. Thus, they also serve as an important conduit, passing user feedback to the EC.

Inferring from the existing literature, the nature of interactions between intermediary and regime actors could be described as cooperative, competitive or transformative. In terms of cooperation, intermediary actors often work in collaboration with regime actors to implement clean energy projects. This collaboration can involve sharing resources, knowledge and expertise, and joint action to achieve common goals [18,34,41]. For example, municipal governments (regime actors) may partner with local NGOs (intermediaries) to promote community solar projects, as seen in various urban sustainability initiatives [42]. On the other hand, resource scarcity, pre-existing interests and ideological differences may create competitive interactions between these actors. According to Geels [43] there can be competition for resources such as funding, land, and political support between regime and intermediary actors.

A previous study [44] highlights such competitive interaction in Ghana where the Electricity Company of Ghana fears revenue losses due to the uptake of net-metered SHS, which the company will have to compensate SHS owners for their excess electricity supplied into the grid. Also, regime actors, driven by profit and efficiency and constrained by material and ideological forces, might resist changes proposed by intermediaries focused on sustainability and community engagement, an ideological clash that can slow down the transition process [22,45,46]. Nonetheless, where regime actors are open to innovation, they can adopt and scale up solutions driven by intermediaries to facilitate clean energy adoption, creating a transformative interaction between them [42,47]. Understanding these dynamics is essential for effectively managing the transition to clean energy.

4. Methods

4.1. Study setting and scope

This research focuses on Ghana's capital city, Accra, which was chosen for its central role as an administrative and commercial hub. The choice of Accra, thus, allowed a broader reach of all actors involved in the residential solar PV sector since the headquarters and ventures of most regime and intermediary actors, respectively, are located here. It is worth noting that this study is part of a broader study that focused on integrating residential solar PV considerations into urban planning practice in Ghana. As such, only actors whose primary activities fall within the domain of energy policy and regulation, urban planning, and residential solar PV systems are covered in this study. These actors are the EC, LUSPA, real estate developers, and licensed solar home system companies. Plausibly, other intermediary actors, such as unlicensed/informal SHS installers and architects that can be considered as process-intermediary actors, and niche-intermediary actors (e.g., solar communities) are omitted. These intermediary actors are either currently not present (solar communities) or difficult to reach during data collection (e.g., informal SHS installers). Nonetheless, as outlined in Section 3, many of the existing studies on the challenges and prospects of SHS diffusion in Ghana have focused on households, providing a substantial body of knowledge in that regard. While other intermediary actors are not covered in this current study, we believe that their perspectives are equally important for a much broader understanding of the socio-technical challenges to residential solar PV diffusion in Ghana. We acknowledge this as a limitation and provide recommendations for future research in the concluding section of the article. In the ensuing section, we discuss the methods of data collection and analysis, which are also outlined in Fig. 1.

4.2. Sampling and data collection methods

Respondents for this study were purposively sampled based on their expertise and roles in either regulating, planning or promoting the uptake of residential solar PV systems in Ghana. The sampling was done in two stages. First, key agencies in government and private sectors whose activities are within the scope of the study were identified through government reports such as Ghana's Renewable Energy Master Plan, and websites of state energy agencies, such as the Energy Commission of Ghana. Google searches were primarily conducted to identify real estate developers. For the licensed SHS companies, a list comprising 106 companies was obtained from the Ghana Energy Commission's website, and 30 companies that are based in Accra were selected for the study. A list of real estate developers in Accra was compiled through Google search and verified with their locations on Google Maps and their websites. From this search, a list of 20 real estate developers was compiled. All 20 real estate companies and 30 SHS companies, alongside the EC and LUSPA, were targeted for interviews.

In the second stage, initial contacts were made with the selected entities, with an informed consent form and ethical clearance form for the research. The target respondents for interviews were focal persons whose positions and roles at their respective organizations make them knowledgeable about this study and, thus, able to respond to the interview questions. The informed consent form detailed the research objectives and the specific information needed from each actor. While establishing contacts, it was discovered that about 12 of the SHS companies were no longer operational, while contact could not be established with 5 real estate companies. Hence, 18 SHS companies and 15 real estate developers were contacted, alongside the EC and LUSPA, who all consented to participate in the study, bringing the final sample size to 35. Each respective organization scheduled an appointment with their focal person for the interviews.

Face-to-face interviews were the main method of data collection with the aid of an interview guide. The interview guide entailed open-ended questions spanning a brief description of the organizations' roles, their interactions with other actors and their perspectives on the challenges and prospects of SHS diffusion based on their experiences. A research data collection firm[1] with trained research assistants was employed to conduct the interviews. The interview guides were pre-tested for validity and reliability in the first week of September 2022, with the main data collection occurring from mid-September to mid-October 2022. As indicated earlier, this study is part of a larger one; hence, the interview guide was administered alongside a questionnaire designed to gather data on SHS and urban planning in Ghana. Interviews were conducted using iPads, which allowed for audio recording of the responses. For a few SHS companies (2) and real estate developers (4), the interviews were conducted via phone since in-person interviews could not be arranged due to their schedules. The method of data analysis is explained in the ensuing sub-section.

[1] https://www.thinkdataservices.com/.

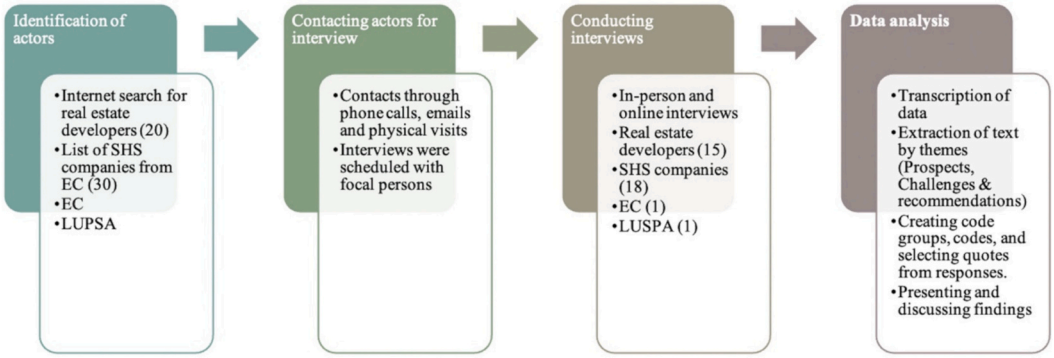

Fig. 1. Outline of the research methodology.

4.3. Data analysis procedure

The interview responses were transcribed into text with the help of the contracted data collection firm. The text pertaining to three key questions about the actors' views of the prospects of SHS diffusion, challenges of SHS diffusion, and recommendations to address these challenges were extracted into separate Microsoft Word files for each actor category. These questions formed the broad themes under which the data were analyzed, presented and discussed. The files were imported into *Atlas.ti* software and analyzed in four steps. In the first step, the interview responses were carefully read, and specific codes that represented the themes (prospects, challenges, and recommendations) were created. In the second step, the codes were applied to texts aligned with their respective themes. Once the code is applied, the corresponding text is automatically marked as a quotation in *Atlas.ti*. Next, the codes and their respective quotations were examined to identify relationships between them. This process led to the creation of three sub-themes (by grouping the codes into regulatory and institutional, market/financial, and socio-technical) under the prospects, challenges, and recommendations. These sub-themes and their codes and code frequencies can be found in Appendix A. In the final step, codes and their associated quotations were exported and presented in table format in Microsoft Word. These tables can be found in Appendices B, C, and D. For brevity, we select and present only the most elaborate quotations in the discussions. The *Network* tool in *Atlas.ti* was also used to visualize the codes created and presented as Figures. The results were discussed, and quotations were presented verbatim where necessary to support the findings. For anonymity, generic code names were created for respondents from various institutions and were used instead of respondents' names or positions in the discussions. These code names are *EC_Res* (Energy Commission), *LUSPA_Res* (Land Use and Spatial Planning Authority), *SHS_Res* (Solar Home System Companies), and *RED_Res* (Real Estate Developers).

5. Results and discussion

5.1. Interactions among the actors

Interactions among actors are essential for the transition to low-carbon energy systems given that the actions of key actors could facilitate or hinder the development, deployment and uptake of clean energy technologies [34]. Our analysis suggests that interactions between the regime and intermediary actors involved in this study can be described as cooperative where they interact on a compliance and mediation basis. Intermediary actors are required to comply with rules and regulations set by the regime actors regarding the conduct of the intermediaries' activities. The SHS companies, for example, indicated that the primary basis for their interactions with the EC is to obtain licenses for operating their businesses. In Ghana, SHS installers must pass an aptitude test conducted by the EC in order to obtain a license to start their business operations. Similarly, real estate developers need to obtain the necessary building permits from the LUSPA to ensure compliance with Ghana's planning standards and building codes [48]. Nonetheless, some SHS installers have also tried to engage the EC to reduce the cost of SHS imports through incentives such as duty-free imports or lower import tariffs. This engagement highlights the mediating role that SHS companies play, given that import costs will often translate to higher SHS costs for end-users. Thus, by trying to lobby the EC (a regime actor) to lower import tariffs, SHS companies are conveying the challenge of users to the regime actors.

On the other hand, SHS companies also actively engage real estate developers. However, this is mainly to secure contracts for installing solar PV systems on their properties or for households living in their estates. A *SHS_Res* highlighted that one of their principal reasons for interacting with the real estate developers is "*negotiation to incorporate solar system as a backup in houses or building for Real estate developers.*" This form of interaction may be described as commerce-based interaction. Interactions among the regime actors appear to be minimal and take the form of compliance-based interaction. When queried on their engagement with the LUSPA, the *EC_Res* recounted, "*Yes, we do engage them when it comes to licenses, but the sector is young, and they don't play a major role in this.*" The licenses in perspective here are typically licenses for large-scale and often ground-mounted PV arrays, which inherently fall in the domain of land use, hence the need to engage with the LUSPA. This ensures that such installations conform with planned development and safety standards. No specific direct interactions could be established between EC and real estate developers. Previous studies suggest that engagement between these two actors could be vital for making Ghana's rooftop solar PV program more effective through, for example, making SHS the main electricity backup system in their properties [4].

5.2. Prospects for residential solar PV diffusion in Ghana

The prospects for residential PV diffusion from the perspectives of the regime and intermediary actors in Ghana range from regulatory incentives such as net-metering schemes to private efforts made by real estate developers to integrate residential solar PV systems into their properties. Fig. 2 presents a summary of the prospects for residential solar PV diffusion in Ghana.

These prospects are discussed in detail under the sub-themes of regulatory and institutional support and financial and market prospects. The quotations associated with these sub-themes from the excerpts of the interviews with various actors are outlined in Appendix B. The following sub-section presents a more detailed discussion of the prospects with inference to the MLP and wider literature on intermediaries.

5.2.1. Regulatory and institutional support

Regime support for residential solar PV through regulations and incentives is a critical factor for residential solar PV investments in African countries, including Ghana [49]. Such support is observed in Ghana,

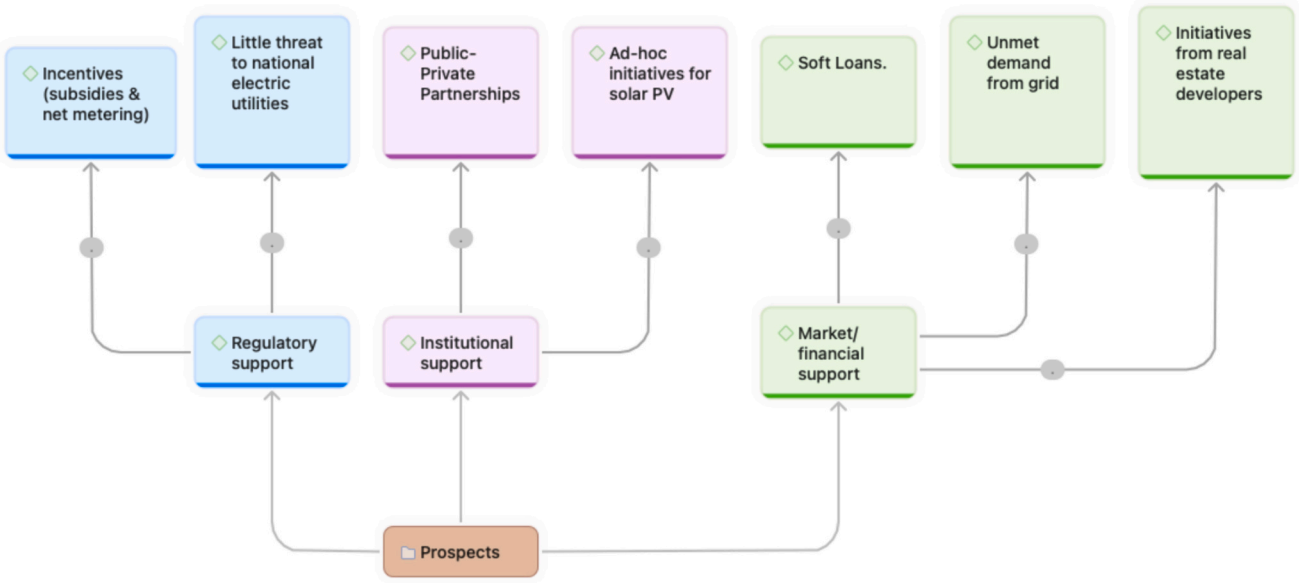

Fig. 2. Prospects for residential solar PV in Ghana.

where the government, through the EC, is rolling out several incentives for residential solar PV uptake in the country. The *EC_Res* acknowledges the need for a wider diffusion of residential solar PV systems in Ghana, noting, "*This* [*residential solar*] *will, to a minimum, solve issues of the high cost of tariffs and provide continuous supply*." A crucial regime support for residential solar PV diffusion in Ghana is the initiation of a net-metering strategy. This strategy addresses a key challenge regarding residential solar in Ghana, where SHS owners are unable to store excess electricity produced by their PV systems, partly due to the high cost of storage batteries [49]. Net-metering helps residential PV owners receive credit for the excess electricity their systems supply into the grid, set off against their electricity tariffs from the distribution utility. The *EC_Res* recounted that "*Currently, we are gazetting the net metering code for users who are on the program* [*and engaging*] *the installers (vendors), and ECG for the metering issues on how to pay* [*solar*] *generators which give out excess*." Once this net-metering initiative comes into force, it can incentivize many homeowners to opt for residential solar PV systems.

A key regulatory hurdle to residential solar PV diffusion in Ghana is the fear that wider adoption of residential PV systems could dwindle the revenues accruing to power utilities such as the Electricity Company of Ghana (ECG) and the Volta River Authority (VRA) [28]. This fear has been a major challenge to enacting favorable regulations for residential and off-grid solar PV systems, generally in Africa, given that most power utilities are state-owned [28]. However, the *EC_Res* revealed that this would not be much of a problem in Ghana, noting that electricity consumption from the residential sector poses a lower risk of financial loss to the utilities than consumption from the industrial sector. Aside from the regulatory support from the EC, the LUSPA equally backs the need to speed up the diffusion of residential solar PV systems in Ghana, noting that such systems will reduce the pressure on electricity usage from the national grid. The *LUSPA_Res* recounted that if real estate developers integrate residential solar PV systems into their properties, "*Their estate housing can sell faster when residents who purchase their homes are assured of cut in* [*the*] *cost of energy usage*." The *LUSPA_Res* also noted that a decentralized approach through public-private partnerships (PPP) would be ideal for facilitating residential solar PV diffusion in Ghana. In addition to regulatory and institutional support, there are market prospects for SHS diffusion in Ghana.

5.2.2. Financial support and market prospects

Geddes and Schmidt [23] argue that redirecting financial capital from incumbent to new technologies and practices is a major prerequisite for socio-technical transitions, noting that finance is crucial for interactions between niches and regimes. Such interaction is conditional upon the readiness of niche actors to comply with the regime's expectations or the regime's readiness to accept and finance niche technologies [23]. In the stage of supported commercial and fully commercial, governments' incentives, risk capital provision and regulatory roles are crucial for advancing clean technology markets [36]. In the context of Ghana, we find that finance-based interactions exist between regime and intermediary actors as well as end-users. Through Ghana's Rooftop Solar PV capital subsidy program, licensed SHS installers are either contracted and financed by the EC to install rooftop solar PV systems for households that meet the program's requirements, or free solar PV panels are given to the households both of which are intended to lower the cost of SHS for homeowners [13]. In addition to this program, efforts are underway to reduce SHS's upfront costs by partnering with banks to provide soft loans to homeowners (see an excerpt from the *EC_Res* in Appendix B). For example, a partnership between the EC and the African Development Fund (AfDF) seeks to complement the government's ongoing national rooftop PV program to lower the costs of SHS [38]. As identified by previous studies [14,50], the cost of residential solar PV systems is the most common challenge hindering their uptake by homeowners in developing regions like Ghana. Thus, creating financing options that lower the cost of such systems could significantly boost their diffusion in Ghana.

On the part of real estate developers, market forces are already compelling some to consider integrating SHS into their properties. One *RED_Res* recounted, "*We already have some solar homes, and we believe that will help lower electricity bills, lower carbon footprint, and potentially higher home values.*" As seen from the excerpts of the interviews, some real estate developers are already rethinking how they design their properties to allow for the effective integration of solar PV systems. This consideration implies a significant prospect for residential solar PV investments from real estate developers since they are already modifying their housing designs to effectively integrate PV systems. The emergence of such considerations on the part of real estate developers also addresses one of the key challenges identified by Kanters and Wall [51], who noted that solar energy did not have a high priority in urban planning processes in part because it is unclear whose task it is to provide such information. Despite these prospects, several challenges remain to be resolved to speed up residential solar PV diffusion in

Ghana. These challenges are thematically drawn from the interview data, presented, and discussed in the next section.

5.3. Challenges to residential solar PV diffusion in Ghana

Three key thematic challenges were identified from the interviews with regime and intermediary actors. These sub-themes are regulatory, market, and socio-technical challenges. Specific challenges identified under these sub-themes and their respective quotations from the interviews are outlined in Appendix C.

5.3.1. Regulatory challenges

Two main regulatory challenges were unearthed: a policy-regulation lapse between energy and urban planning and non-compliance with residential solar PV standards. The sectoral divide between energy and urban planning, which has traditionally constrained the integration of solar PV in the built environment [52], is evident in Ghana's current policy and regulatory frameworks. The actors acknowledged that urban form attributes affect the feasibility and performance of residential solar PV, particularly rooftop solar PV. SHS companies, in particular, gave a detailed account of how such urban form attributes affect residential solar PV systems (see excerpts of their interviews in Appendix C). Akrofi and Okitasari [4] found that these urban form attributes in Ghana not only affect the rooftop solar PV potential but also have implications for rolling out subsidies for residential solar PV in that such subsidies may be more effective in some neighborhoods than others based on urban form attributes. However, the *LUSPA_Res* recounted that such attributes are currently not being configured to maximize solar PV potential in the built environment because current urban planning regulations do not provide for the incorporation of solar energy considerations into the preparation of urban and spatial plans.

Thus, while energy regulators such as the Energy Commission are taking several initiatives to boost the uptake of residential solar PV systems, a gap remains in the urban planning domain on how the eventual diffusion of these PV systems can be maximized and facilitated through urban planning. It is worth pointing out that section 32.11 of the building code provides guidelines and standards for integrating solar PV systems into buildings [48]. However, there is currently no legislation that mandates the integration of such systems into building plans. The standards need to be followed only when individuals or developers opt to integrate solar PV systems into their buildings; a decision that often comes after the building has been constructed. Apart from this sectoral divide, the *EC_Res* recounted that there are still regulatory bottlenecks regarding how to effectively integrate excess electricity from residential solar PV systems into the national grid. Real estate developers also decry a lack of favorable regulations for investments in residential solar.

A second regulatory issue identified was the problem of non-compliance with regulations and standards. This challenge aligns with general challenges regarding development control in Ghana, where compliance with building and planning standards is seldom achieved [53]. The *EC_Res* revealed that some residents, in a bid to offset more of the power they purchase from the national grid, tend to install excess solar panels than the set standards. In the broader literature, Iwaro and Mwasha [54] noted that energy building codes are largely ignored where they exist, while a substantial number of African countries do not have such codes. In the case of Ghana, the Ghana Building Code spells out specifications and standards for integrating solar PV into buildings [48]. However, as recounted by the *LUSPA_Res*, these building codes regarding solar PV integrations are not considered at the planning stages of neighborhoods and houses.

5.3.2. Market challenges

Two main market challenges were reported, and in line with expectations, these challenges revolve around the cost of residential solar PV systems and access to financial capital. For real estate developers, despite some of them already making efforts to incorporate residential solar PV systems into their properties, they find access to long-term finance, on the one hand, as a key challenge to their investments. On the other hand, they also noted inadequate access to finance for end-users, adding that the cost of installation and maintenance is relatively high for households. SHS companies particularly emphasized this challenge. Key efforts such as the capital subsidy granted through the national rooftop program and partnerships with banks to provide soft loans could address this financial challenge. However, one *SHS_Res* recounted that high interest rates on such loans often discourage their uptake, noting that "*the high rate of interest also affects loans and makes it difficult for clients to go for loans*." These findings affirm those by Boamah and Rothfuß [24], who noted that high-interest rates on loans for residential solar PV often discouraged their uptake by homeowners.

For SHS companies, additional challenges include the high cost of importing solar home systems, inadequate information on user needs and preferences, inadequate incentives from the government, and unbalanced competition from electric utilities. Overall, SHS companies feel the government is not doing enough to support their industry. When queried on how the government is supporting the SHS industry, one respondent simply remarked that "*the government doesn't care about us*." Regarding competition from electric utilities, there have been fears in the past that a wider proliferation of residential PV systems could dwindle revenues accruing to the electric utilities, which are mostly state-owned.

However, these fears have been allayed by the *EC_Res*, who recounted that more SHS use in the residential space does not pose any significant financial risk to the national power utilities, noting that "*also, if residents intend to generate power for home use it has little contribution since residents can sell the excess power to ECG*". This assertion is plausible given that the electricity tariff in Ghana at the time of this research is much higher for industries/businesses ($0.74/kWh) than for households ($0.34/kWh). Thus, reducing household grid electricity consumption means that electric utilities will have excess power to sell to the industries at a higher tariff or export to neighboring countries such as Togo and Burkina Faso [55], in addition to ensuring a more reliable domestic supply in the country.

5.3.3. Socio-technical challenges

Limited technical know-how, limited awareness about SHS systems, and urban form-related constraints emerged as the key socio-technical challenges to residential solar PV investments in Ghana. The regime and intermediary actors pointed out that many households are still unaware of the benefits of SHS, and they do not have the requisite knowledge of how SHS operates. This limited technical know-how is not only on the part of end-users but also technicians in the SHS industry. One *SHS_Res* pointed out that there is apathy towards acquiring more technical skills on SHS, noting that "*we do not have enough technicians who are willing to learn.*" On the part of households, another *SHS_Res* indicated that clients' reluctance to read product manuals is a key reason for low technical knowledge of SHS. This low level of awareness and technical know-how aligns with the findings of previous studies, which identified the same issues as constraints to the diffusion of residential solar PV systems in Ghana [25,26].

Urban form-related challenges dominate as the major technical problems that specifically affect the installation of SHS, hence, their effective diffusion. These urban form-related challenges are a knock-on effect of the design decisions of urban planners and architects who fail to make considerations for building integrated solar PV (BIPV) during the design stages. SHS companies feel these effects during the installation of the SHS for households, as seen in the excerpts from their interviews in Appendix C. This finding affirms the sectoral divide between energy and urban planning in Ghana and reinforces the need for an integrated approach to solar energy and urban planning, given that such hurdles are better checked during the planning and design stages of neighborhoods and houses, respectively [4].

Urban planners and real estate developers who can better resolve the urban form constraints of residential solar PV systems have little knowledge of how their design decisions affect such PV systems. On the other hand, SHS companies with first-hand experience of how urban form attributes can facilitate or hinder residential PV diffusion play no part in planning neighborhoods and designing buildings. This finding also highlights the gap between private and public sector stakeholders in Ghana's energy and urban planning sphere, given that SHS companies and real estate developers are private entities whose activities are regulated by the Energy Commission and LUSPA, respectively. Bridging this divide will require engaging all these private and public entities, as noted by the *LUSPA_Res*, who suggested that "*They* [*private sector actors*] *should engage the government on issues of sustainable energy and the environment. A proposal which will benefit the populace will give the government of the day great relief and score them political points*." This quote implies that the compliance and mediation-based interactions identified between the regime and intermediary actors need to transcend obtaining licenses and permits or lobbying for monetary incentives to include the enactment of new regulations that integrate and harmonize the activities of all the actors towards a common goal of facilitating SHS diffusion. The interviewees have suggested some solutions to this effect, which are discussed in the next section.

5.4. Discussion and the way forward

Despite uncovering significant regime efforts to promote the diffusion of residential solar PV systems in Ghana, the study also finds critical challenges confronting this sector. A summary of these challenges and the actors' recommendations on the way forward is provided in Fig. 3.

Overall, while we do not find any specific trade-offs between the regime and intermediary actors, synergies among their activities are minimal and evident, for example, in the policy-regulation lapse between urban planning and solar PV considerations in the planning process. With formal regulations necessitating the consideration of solar PV in the urban planning process laid out by the LUSPA, real estate developers, planners and architects could serve as different types of intermediaries, translating these regulations into practice for end-users through the design of their properties. However, this is presently not the case. As noted by Fischer and Guy [39], planners and architects play an intermediary role in the transition to low-carbon energy systems by simplifying energy efficiency mandates within construction codes, making them more understandable to homeowners. Regarding such regulations, a *RED_Res* was of the view that mandating the integration of residential solar PV systems into new homes will facilitate their diffusion. However, the respondent added, "[*the government should*] *supply new estate developers with subsidized solar suppliers*" before mandating solar PV integration into new homes.

This viewpoint reflects current efforts in some countries, such as Japan, where the Tokyo Metropolitan government seeks to make solar PV integration mandatory in all new homes for real estate developers. This approach could prove particularly effective in Ghana, given that most of the inhabitants in the gated estates (designed and constructed by private real estate companies) are renters reluctant to adopt SHS [30]. Even for homeowners in such estates, properties are typically designed and constructed by real estate developers, and considerations for solar PV integration often come after they purchase the already constructed house. Consequently, they have little to no say about SHS integrations, especially at the crucial design stages of the neighborhoods and houses. It may be more effective for Ghana's capital subsidy program for rooftop solar PV to target real estate developers in such estates as an incentive to ensure compliance, should residential solar PV be made mandatory for new homes. Thus, to complement the notion that a redirection of financial capital from incumbent technologies to new ones (in this case, SHS) is crucial for socio-technical transitions to low carbon energy technologies [23], our results suggest that in the context of Ghana, a redirection of such capital needs not only focus on technological niches but also user intermediaries such as real estate developers.

As a second solution, the actors propose a decentralized approach where all stakeholders actively participate in the decisions and planning process for residential solar PV as an effective strategy to facilitate investments in residential solar. This approach should be easier to implement given that Ghana already has an elaborate decentralized urban planning system [56]. Ensuring effective participation in such an approach requires that all stakeholders understand and see its need [57]. The interview results from the actors suggest a low awareness of residential solar PV systems for households. Consequently, many of them recommend more sensitization of households on the need for and benefits of SHS and the basic knowledge of its operation and maintenance

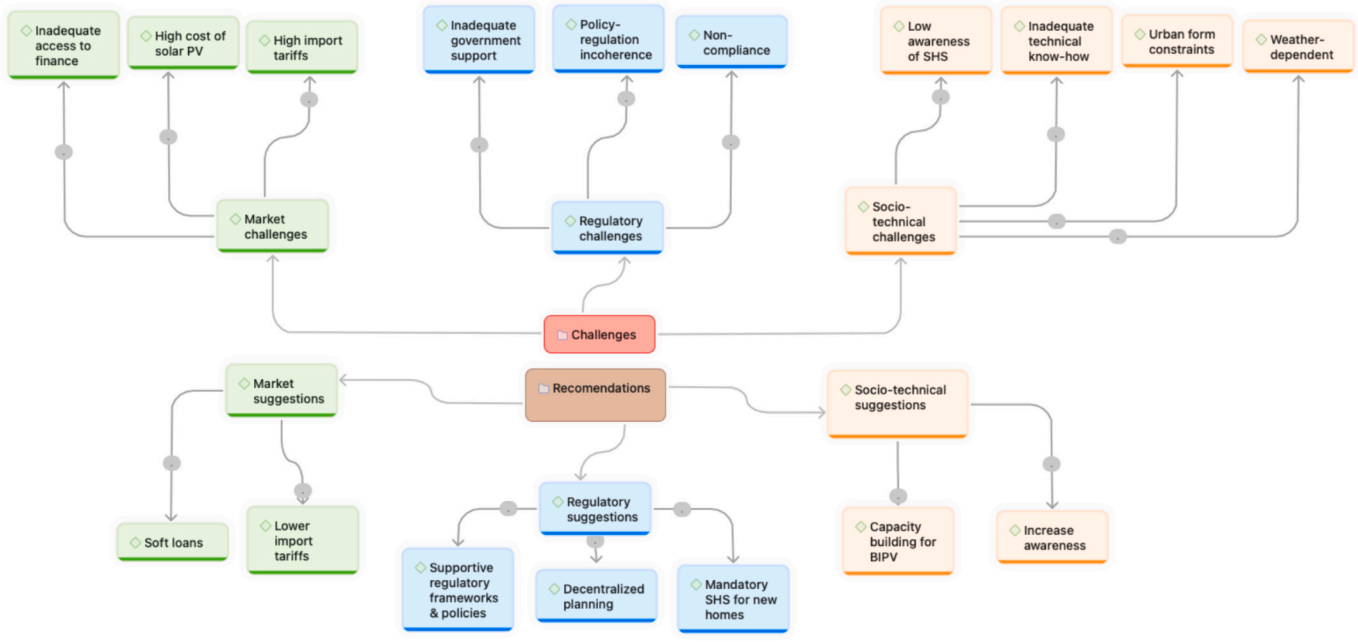

Fig. 3. Summary of challenges and actors' recommendations.

(see quotes from their interviews in Appendix D). The high cost of residential solar PV systems and inadequate access to long-term capital emerged as significant market challenges to the diffusion of residential solar PV systems in Ghana. Consequently, the most recommended solution by the actors is to provide subsidies and create access to soft loans and other financial assistance.

In particular, SHS companies decried the high cost of import duties on solar PV systems. One respondent remarked that "*Governmental interventions would help with the import charges*," noting that the high import charges are a major constraint to their operations. On the part of households, further actions to address the high interest rates on loans could include ensuring the implementation of net-metering scheme, which is currently underway in Ghana. Net metering can help households sell excess electricity to the grid, providing an additional income stream to offset loan costs. Ongoing partnerships with financial institutions such as the AfDB can also be leveraged to address this challenge through encouraging, particularly, local banks to create green financing and loan programs with favorable terms for solar installations. Another key strategy to overcome not only high interest rates but also the overall high upfront cost of residential solar PV installation is to initiate solar leasing programs. This can be achieved through private-public partnerships where regime actors could partner with private solar companies to offer leasing options where homeowners pay a monthly fee instead of a large upfront cost for PV installations.

Inferring from the broader literature on residential solar PV diffusion in Ghana, it is essential to note that while a regime actor such as the EC is making efforts to drive the uptake of residential solar PV systems, other regime actors like the state electric utility—the Electricity Company of Ghana (ECG) appear resistant to such solutions, particularly when it comes to compensating SHS owners who feed their excess electricity into the national grid. Boamah et al. [44], for instance, recount how the state electric utility failed to compensate both domestic, industrial and commercial users for the electricity that they fed into the grid on the basis of a lack of agreeable tariff structure. Hence, even though the *EC_Res* recounted that private production of electricity should not be a threat to the state utility, the ECG does not see this as the case and seems to want to maintain a monopoly over the electricity sector. This appears not to be a problem confined to Ghana alone but also in other African countries such as South Africa.

Mirzania et al. [58] provide an example from South Africa, where private solar PV users are unable to feed their excess electricity into the grid due to the state utility—ESKOM's reluctance to integrate such prosumers. Resolving this challenge in the context of Ghana, for example, will require deeper engagements between the principal regimes such as the EC, ECG and the Public Utilities Regulatory Commission (PURC) to settle on effective tariffs and allay the fears of the ECG. One way of allaying these fears is to ensure that SHS users comply with the set standards in terms of SHS system sizes, one of the key regulatory challenges identified. To address the urban form-related challenges, one *SHS_Res* echoed the need for *solar urban planning* by suggesting that the LUSPA unit should have staff knowledgeable on the interface between solar energy and urban planning. Such staff could check to ensure that the pre-conditions necessary for effectively integrating solar PV systems into the buildings are met before issuing building permits. Hence, the current prospects for residential solar PV in Ghana could be leveraged to address some of the challenges.

6. Conclusion

Drawing from the literature on regime and intermediary actors in sustainable energy transitions, this study presented key prospects and challenges to residential solar PV diffusion in Ghana. The study unveils three forms of interactions between these actors—compliance-based interactions, mediation-based interactions, and commerce-based interactions. The EC and LUSPA, Ghana's regulatory bodies for energy and urban and spatial planning, respectively, both showed support for residential solar PV. Regime support, which emerged as a key prospect for residential solar PV diffusion, manifested in the form of capital subsidies, net-metering initiatives, and lobbying financial institutions to provide soft loans to end-users. Nonetheless, greater collaboration is needed between the regime actors to enact regulations that will embed residential solar PV considerations into Ghana's urban planning system. This collaboration needs to extend beyond the actors considered in this study to include other regime actors like the ECG, given the potential friction between them and the large-scale uptake of residential solar PV systems in Ghana. User-based intermediaries, such as real estate developers and SHS companies, equally see the need for increased investments in residential solar PV and feel that the regime actors could do more to facilitate their role in facilitating the diffusion of these systems through the enaction of regulations to mandate SHS uptake and incentives to lower the costs of SHS.

Nonetheless, key challenges in the form of policy-regulation incoherence resulting in inadequate synergies between regime actors and intermediary actors, high cost of solar PV systems, inadequate access to long-term finance, limited awareness and technical know-how of residential solar systems emerged as the key challenges to residential solar investments in Ghana. Prospects such as net metering, capital subsidy, and access to soft loans could be leveraged to address challenges such as the high cost of SHS. On the other hand, technical challenges regarding urban form constraints could be addressed by real estate developers and the LUSPA through an integrated approach to solar energy and urban planning or solar urban planning. Such an approach requires an increased engagement of all actors on the need for new reforms and forming synergies between regime and intermediary actors to enact comprehensive institutional and regulatory frameworks that provide a conducive environment for niche actors and homeowners to invest in residential solar PV systems.

Relating our findings to the clean energy transition literature, a key contribution of our study lies in its position that the transition from a fossil-dependent regime to a low-carbon one, at least in the Ghanaian context, not only requires the direction of financial capital to technological niches but to also user intermediaries. We find that SHS uptake could be greatly facilitated, for example, in affluent neighborhoods, if subsidies for SHS are targeted to the developers instead of households in such neighborhoods. Our findings show that the regime actors in this study are ready to support the transition to residential solar PV, while the user intermediaries are equally supportive of this transition and are willing to synergize with the regime actors to reach this goal. Nonetheless, drawing from existing literature on the SHS transition in Ghana, we find that potential friction remains between this transition and the ambitions of other regime actors, such as the ECG. It is, thus, worth acknowledging that while this study has elucidated the perspectives of the key regime and intermediary actors in Ghana's residential solar PV transition efforts, not all the actors related to this issue have been covered in our study.

Resolving the challenges regarding the friction between state utilities and SHS users, for example, will require eliciting the perspective of the ECG on this matter. Further research incorporating the perspectives of other actors, including power producers such as the Volta River Authority and regulators such as the Public Utilities and Regulatory Commission would be beneficial in expanding on our findings. There is also a need for further research on how to harmonize the activities of all actors in the residential solar PV sector towards an integrated regulatory and policy environment for residential solar PV diffusion. Research on the integration of solar-specific building codes into Ghana's current urban planning system, as well as synchronizing the activities of real estate developers and SHS companies with those of the EC and LUSPA, will be instrumental in realizing a seamless transition to solar PV in the built environment.

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CRediT authorship contribution statement

Mark M. Akrofi: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization, Funding acquisition. **Mahesti Okitasari:** Writing – review & editing, Supervision, Funding acquisition. **Benjamin C. McLellan:** Writing – review & editing, Funding acquisition.

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.

Data availability

Data used in this research and their associated research instruments will be made available upon reasonable request.

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Appendix A. Code frequencies under each theme and sub-themes

Code	Frequency
● **Prospects**	**11**
● ***Institutional support***	***2***
○ Ad-hoc initiatives for solar PV	1
○ Public-Private Partnerships	1
● ***Market/financial support***	***6***
○ Initiatives from real estate developers	4
○ Soft loans	1
○ Unmet demand from grid	1
● ***Regulatory support***	***3***
○ Incentives (net-metering)	1
○ Little threat to national electric utilities	2
● **Challenges**	**31**
● ***Market challenges***	***14***
○ High cost of solar PV	7
○ High import tariffs	2
○ Inadequate access to finance	5
● ***Regulatory challenges***	***5***
○ Inadequate government support	1
○ Non-compliance	1
○ Policy-regulation incoherence	3
● ***Socio-technical challenges***	***12***
○ Inadequate technical know-how	4
○ Low awareness of SHS	3
○ Urban form constraints	4
○ Weather-dependent	1
● **Recommendations**	**24**
● ***Market suggestioins***	***12***
○ Lower import tariffs	2
○ Soft loans	3
○ Subsidies	7
● ***Regulatory suggestions***	***4***
○ Decentralized planning	1
○ Mandatory SHS for new homes	1
○ Supportive regulatory frameworks & policies	2
● ***Socio-technical suggestions***	***8***
○ Capacity building for BIPV	1
○ Increase awareness	7

Appendix B. Actors' perspectives on the prospects of residential solar PV in Ghana

Theme	Prospect	Quotations	Actor
Regulatory support	Incentives	"*The commission intends to use the net metering strategy to promote the adoption of renewable energy, and incentives will be given out to encourage the users to offset excess.*"	*EC_Res*
	SHS poses little threat to national electric utilities	"*Very little is happening in the residential home supply to have a threat; rather, a regulatory guide to help with connecting to the grid is our concern towards adoption of renewable energy.*"	*EC_Res*
		"*The consumption from residents does not pose a high financial loss compared to industrial use. Also, if residents intend to generate power for home use, it has little contribution since residents can sell the excess power to ECG. However, more sensitization is required since most homes don't use a lot of power compared to the industrial sector.*"	*EC_Res*
Institutional support	Opportunities for public-private partnerships	"*They [private sector actors] should engage the government on issues of sustainable energy and the environment. A proposal which will benefit the populace will give the government of the day great relief and score them political points.*"	*LUSPA_Res*

(*continued on next page*)

(*continued*)

Theme	Prospect	Quotations	Actor
		"*Yes. The PPP should be decentralized to the district level to ensure active participation in the process to switch to sustainable energy.*"	*LUSPA_Res*
	Ad-hoc initiatives for solar PV	"*We recommend they* [*households and private sector actors*] *take advantage of the initiatives available or since what the sector has would not last. All the initiatives are in phases*".	*EC_Res*
Financial support and market prospects	Soft loans for SHS	"*The commission is looking to promote residential solar by offsetting the initial cost with* [*a*] *partnership with AfDF* [*bank*] *to loan out funds to support renewable energy, and we are in the third phase. Hopefully, this will be implemented next year.*"	*EC_Res*
	Support and initiatives from real estate developers	"*Provisions are made in the building for rooftop solar energy, which is usually installed by the house owners to serve as an alternative source of energy for their homes.*"	*RED_Res*
		"*Our roofing is flat and friendly to any homeowner who has* [*an*] *interest in using solar systems on their roof.*"	*RED_Res*

Appendix C. Actors' perspectives on challenges to residential solar PV adoption in Ghana

Theme	Challenges	Quotations	Actor
Regulatory	Policy-regulation incoherence	"*We don't consider renewable energy in the preparation of our spatial plans because it* [*is*] *not part of requirements for the preparation of such plans.* ***There are no regulations that specify the incorporation of renewable energy in the preparation of spatial plans.***"	LUSPA_Res
		"*Very little is happening in the residential home supply to have a threat,* ***rather, a regulatory guide to help with connecting to the grid is our concern towards adoption of renewable energy***."	EC_Res
		"[*There is*] *lack of policy amendment or new laws that are not of benefits to investors.*"	RED_Res
	Non-compliance	"*…in the past,* ***residents put up a lot of panels, which was against the standard guide for homes*** *with the aim to offset more power to ECG.*"	EC_Res
Market	High cost of solar PV	"*High installation and maintenance costs, lack of access to long-term capital finance, access to affordable consumer finance.*"	RED_Res
		"*Funding is the major challenge confronting the industry.*"	RED_Res
		"*Cost of purchase and maintenance of solar panels on homes*"	LUSPA_Res
	Access to finance/available incentives	"*Lack of access to finance and long-term capital tends to discourage clients because of high capital injection needed for solar installation.* ***The high rate of interest also affects loans and makes it difficult for clients to go for loans.*** [*The*] *low purchasing power of households is high because solar products are expensive for the average household.*"	SHS_Res
Socio-technical	Awareness and technical know-how	"*…****clients not ready to learn and understand the operation of the solar system****, feel reluctant to take charge of simple products services or maintenance, neither ready to read product manuals. Lots of people are ignorant about the complete solar system, most feel you just need the panels, and you* [*are*] *good to go.*"	SHS_Res
		"*Solar energy is a very efficient source of power, most of the population in Ghana is not well educated on this fact, therefore the demand for solar is low, and because of this fact,* ***we do not have enough technicians who are willing to learn***."	SHS_Res
		"*Lack of knowledge on how to use it* [*solar PV system*]"	RED_Res
	Urban form elements	"*…the type of roofing materials also affect installation and cause delays, especially slate roofing, since one needs to be extra careful not to create cracks which may lead to leakages.*"	SHS_Res
		"*The type of roof is highly important for mounting the panels. The shape of the roof is also important for determining which materials to use for fixing the panels. Just as the shape of the roof, the material is also useful because of the weight of the panels.*"	SHS_Res
		"*The* ***heights of neighboring buildings can affect the positioning of the Panels because of the shadows*** *from the neighboring buildings.*"	SHS_Res
		"*We have not had such issues when it comes to installation except for trees, which we had to trim a bit.*"	SHS_Res

Appendix D. Actors' proposed solutions to the challenges to residential solar PV adoption

Theme	Suggested solution	Quotations	Actor
Regulatory	Mandatory SHS for new homes	"*…it should be a must for all new home builders to install solar. Hence releasing the pressure on the power grid to some extent.*"	*RED_Res*
	Decentralize energy planning	"*The PPP should be decentralized to the district level to ensure active participation in the process to switch to sustainable energy.*"	*LUSPA_Res*
Market	Subsidies for solar PV	"*Government should* [*give*] *a capital subsidy on solar installation projects.*"	*RED_Res*
		"*Subsidization of solar panels by the government will encourage people to switch to sustainable energy.*"	*LUSPA_Res*
	Lower import tariffs for PV products	"*To collaborate with the government and make solar system items duty-free.*"	*SHS_Res*
	Soft loans for SHS	"*Offering financing programs through AfDB and set standards for soft loans to encourage real estate developers* [*to*] *connect with solar companies to implement a lower cost.*"	*EC_Res*
Socio-technical	Capacity building on BIPV for urban planning officials	"*Town and Country planning department should have staff members who are knowledgeable in solar irradiation and positioning of the panels before issuing building permits.*"	*SHS_Res*
	Increase awareness of solar PV among households.	"*…more sensitization is required since most homes don't use a lot* [*of*] *power compared to the industrial sector.*"	*EC_Res*
		"*Enlighten individuals on the essence of solar.*"	*SHS_Res*

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