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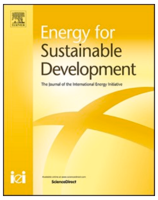

Stakeholders' awareness of urban form effects on rooftop solar photovoltaic in Ghana: Implications for integrated solar energy and urban planning

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ABSTRACT

Integrating solar energy considerations into urban planning practices, a socio-technical and multi-stakeholder approach known as solar urban planning, is essential for maximizing solar photovoltaic (PV) potential in the built environment. While the need for such an approach is articulated in solar energy studies and urban planning, very few research explore the extent to which key stakeholders critical to this process are aware of the connections between urban form and rooftop solar PV and its implication for solar urban planning. This study examines stakeholders' awareness of the effects of selected urban form attributes on residential rooftop solar PV and its implications for solar urban planning in Ghana. Primary data were collected using surveys and interviews of households, real estate developers, licensed solar home system (SHS) installation companies, and government agencies responsible for energy and urban planning. SHS installation companies affirmed that buildings' roof type and shape, roofing material, the height of neighboring buildings, and the trees' position significantly affect rooftop solar PV installation and performance in Ghana. However, households have a low awareness of how these urban form attributes affect rooftop solar PV. Despite the affirmed effects of urban form on rooftop PV, current planning legislations do not necessitate considering such systems in preparing urban and building plans. A robust institutional collaboration is necessary among urban planning authorities, energy regulators, and real estate developers to develop effective strategies for solar urban planning in Ghana.

Introduction

More ambitious strategies for embracing renewable energy in urban areas demand attention to particular built environments and local contexts (Akrofi & Okitasari, 2023; Feng et al., 2023). Several studies have consistently shown that successfully integrating solar photovoltaics (PV) into the built environment requires an integrated approach to solar energy and urban planning or solar urban planning (Akrofi & Okitasari, 2022; Lundgren & Dahlberg, 2018; Wall et al., 2017). Solar urban planning integrates solar energy into city planning through new developments or urban renewal (Lindner & Müller, 2014). It involves early considerations for building integrated solar PV (BIPV) in all urban plan preparation stages, from setting broad visions for a metropolitan area to preparing detailed land use and structural plans (Akrofi & Okitasari, 2022). BIPV involves integrating solar PV products into a building's envelop, such as its rooftop (which is the focus of this study), façade, or windows (Strong, 2016). Solar urban planning depends on technical, economic, and socio-political considerations (Akrofi et al., 2022; Lobaccaro et al., 2019;Lundgren & Dahlberg, 2018; Wall et al., 2017). Technical factors include technology, architectural integration, and characteristics of the built environment, like urban form, while economic factors deal with the costs of PV systems, payback period, and investment returns (Lundgren & Dahlberg, 2018; Wall et al., 2017). Socio-political factors involve policies, regulations, user acceptance, and the influence of demographic factors such as educational level, age, and gender (Lundgren & Dahlberg, 2018; Wall et al., 2017).

Most existing studies on solar energy integration in urban planning have focused on the technical considerations where the effects of urban form on rooftop solar PV have been examined (Akrofi & Okitasari, 2022). A list of studies examining the impact of urban form on rooftop solar PV is outlined in Appendix A. While several such studies on the technical and financial aspects of solar PV integration in the built

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environment exist (e.g., Alrawi & Al-Ghamdi, 2020; Boccalatte et al., 2022; Garabitos Lara et al., 2023; Lobaccaro, Carlucci, et al., 2017; Mohajeri et al., 2016), there are very few studies that explore the actual implementation of solar energy in urban planning (Lobaccaro et al., 2019). Adequately capturing diverse challenges related to technology, stakeholder interests, and social acceptance calls for a more nuanced and desegregated understanding of solar PV implementation (Lobaccaro et al., 2019). The participation of different stakeholders in integrating solar energy into urban planning has been considered an essential determinant in the literature, given that stakeholders influence the planning process (Lindkvist et al., 2019). For instance, a multi-stakeholder approach with citizen participation successfully integrated solar energy and bioclimatic parameters into neighborhood design on Reunion Island in France (Lobaccaro et al., 2019).

Mirakyan and De Guio (2013) recount that the evolution of integrated energy planning in cities has been influenced by a growing community awareness of environmental issues, renewable energy technologies, and the interests of actors participating in the planning process. The government of Ghana aims to significantly increase the share of renewable energy in its electricity generation mix. It has initiated several policies and programs to achieve this goal (Energy Commission, 2019), such as the Renewable Energy Act 2011 (ACT 832), the Renewable Energy Master Plan, and the national rooftop solar PV program (Energy Commission, 2019; Hagan, 2015). It also has a long history of urban planning with a well-laid-out decentralized planning system (Cobbinah et al., 2020). Ghana's energy and urban planning have traditionally been treated as separate sectoral issues. Although existing studies demonstrate the need to integrate solar energy considerations into urban planning and design (Akrofi & Okitasari, 2023), studies that explore the extent to which various stakeholders are aware of these interrelationships and their implications for formalizing solar energy considerations into urban planning are scarce.

Against this backdrop, this study aims to examine the extent to which key stakeholders (e.g., the urban planning authority, real estate developers, solar home system (SHS) companies, and households) are aware of the dynamics and interrelationships between solar energy and urban planning. The term awareness used in this study is based on the Cambridge dictionary definition, which describes awareness as “knowledge that something exists, or understanding of a situation or subject at present based on information or experience” (Cambridge Dictionary, 2023). We argue that stakeholders' awareness of the effects of urban form on solar PV potential in their cities is essential for advancing an integrated approach to urban planning toward low-carbon development. Based on this assessment, we discuss practical policy implications and recommendations for solar energy in urban planning, highlighting how institutional collaboration and harmonizing the activities of all stakeholders into an integrated urban planning process is critical for realizing solar urban planning in Ghana. The paper is structured as follows. Section 2 synthesizes existing research on the intersectionality between the role of stakeholders and solar urban planning. Section 3 outlines the analytical framework for the study. The methodology adopted for the study is presented in Section 4. The study results are presented in Section 5, while the discussion of findings forms the focus of Section 6. Finally, the conclusion, limitations, and recommendations for future research are outlined in Section 7.

The importance of stakeholders' participation in solar urban planning

Stakeholders play a crucial role in any planning process since their actions and inaction can affect the success of the process. Urban planning and design involve several decisions and regulations that influence and are influenced by the stakeholders involved. The literature has shown that existing regulations that do not facilitate the integration of solar energy in urban plans constrain stakeholders' efforts to promote the widespread diffusion of BIPV in urban environments (Kanters & Wall, 2018; Lobaccaro et al., 2019; Wall et al., 2017). For example, the existing building regulations omit requirements for installing solar PV systems on buildings and prevent municipalities from imposing such requirements on real estate developers, posing a challenge to the diffusion of BIPVs in Sweden (Kanters & Wall, 2018). Similarly, Lobaccaro et al. (2017) recounted that integrating solar energy into urban planning was challenging within the context of existing regulations and highlighted the importance of close collaboration between all stakeholders in the success of an integrated solar energy and urban plan for the Aspern development project in Vienna, Austria (Lobaccaro, Lindkvist, et al., 2017).

To identify effective strategies for solar urban planning, the International Energy Agency (IEA) funded a wide range of case studies through action research to identify the best approaches and methods for integrating solar energy into urban planning and overcoming regulatory and planning bottlenecks (Lundgren & Dahlberg, 2018; Wall et al., 2017). Among these case studies, the most successful were those where stakeholders understood the planning process and the need to optimize solar energy potentials through urban planning. In the FredericiaC project in Denmark, the participation of both public and private stakeholders was instrumental in realizing the carbon-neutral urban district with private sector partners developing the aims and objectives of the area's sustainable master plan (Lobaccaro, Lindkvist, et al., 2017). The project led to a conclusion that “*if solar energy is to become a fully integrated element when developing a new urban area, it is crucial that the developer/land owner, as well as the complete design understands that solar and daylight optimization is to be considered at the very beginning of the planning phase*” (Lobaccaro, Lindkvist, et al., 2017, p. 141). The case of the eco-neighborhood of Ravine Blanche, Reunion Island, shows that project success was determined by public participation through consultations and information campaigns. The involvement of different stakeholders with different capacities and rights led to the success of the photovoltaic village project in Alessandria, a residential neighborhood in Italy where authorities sought to produce 100 % and 70 % of solar PV electricity for common areas and flats, respectively (Lobaccaro et al., 2019; Lobaccaro, Lindkvist, et al., 2017). Bossi et al. (2020) ranked stakeholder involvement as the prime success factor for integrating solar energy into urban districts. Incorporating solar considerations into the urban planning process yields optimal outcomes. It creates economic and social opportunities, such as reducing heating and lighting costs (Derkenbaeva et al., 2022) while fostering social cohesion by creating avenues for citizen engagement and public participation in the planning process (Lobaccaro et al., 2019; Lobaccaro, Lindkvist, et al., 2017; Lundgren & Dahlberg, 2018).

The active participation of all stakeholders in the planning and implementation hinged on their awareness of the project's goals and objectives. The authorities behind the successful projects above employed public consultations, information campaigns, and local workshops to increase stakeholders' awareness about the need for integrated solar energy and urban planning (Lobaccaro et al., 2019; Lobaccaro, Lindkvist, et al., 2017; Lundgren & Dahlberg, 2018). More often, after the successful implementation of several projects, new regulations that favored solar integration in urban planning were enacted in areas where they were previously not available. At the same time, areas with existing regulations modified the regulations to encourage urban solar energy integration. For instance, after the zero-emissions commercial building project implementation in Norway, local regulations were amended to allow rooftop solar PV system installation in the city (Lobaccaro, Lindkvist, et al., 2017).

Configuring stakeholders' awareness in the solar PV transition

Stakeholders are individuals, groups, or organizations that are interested in or are affected by a particular issue or decision, and their actions or inactions can have either positive or negative consequences on the issue or decision (Graff et al., 2018; Kleanthis et al., 2022).

Existing research on energy transition focuses on stakeholders' awareness concerning different aspects of energy transitions, such as the acceptance of clean energy technologies (Hargreaves et al., 2022; Walker et al., 2021), the diffusion of renewable energy technologies (e.g. SHS (Malik & Ayop, 2020; Opiyo, 2019; Urpelainen & Yoon, 2015), large-scale solar projects (Oudes et al., 2022), national and local policies, and institutional arrangements (Graff et al., 2018; Kleanthis et al., 2022; Koasidis et al., 2022). It shows that interventions are more likely to succeed when stakeholders are highly aware of the benefits of renewable energy (Graff et al., 2018; Walker et al., 2021). In other words, stakeholders' awareness is vital to the success of clean energy transition initiatives. Thus, an in-depth evaluation of people's awareness of renewable energy interventions is crucial as it helps identify possible hindrances in the implementation process and key agents of change who could be targeted with specific strategies to ensure a successful implementation of change initiatives (Jimmieson et al., 2010). Recent work on the phenomenology of awareness has also explored how a holistic view of people's awareness requires understanding their characteristics (Merleau-Ponty, 2013).

This study bases its premise that stakeholders' level of awareness of urban form effects on rooftop solar PV could influence the extent to which they see the need for integrating solar energy planning and urban planning, a move that often requires enacting new regulations or modifying existing ones (Lobaccaro, Lindkvist, et al., 2017). Integrating solar energy considerations into the early stages of the urban planning process ensures that urban form parameters, such as building density, heights, type of roofs, and building orientation, are optimized for the best outcomes in terms of energy efficiency and solar power generation from BIPVs (Lundgren & Dahlberg, 2018; Oh & Kim, 2019). This study examines the awareness of selected urban form attributes' (building density, height, orientation, neighborhood layout, buildings' roof type, roof shape, roofing material, and position of trees) effects on rooftop solar PV from the perspective of real estate developers, licensed solar home system installation companies, urban planning authorities, and households.

The level of awareness is anticipated to vary depending on the type of institutions and the nature of their engagement in solar energy and urban planning-related activities, while households' awareness will vary by socio-demographic characteristics such as age, gender, and educational attainment (Malik & Ayop, 2020; Opiyo, 2019). The Land Use and Spatial Planning Authority (LUSPA) is the agency responsible for spatial and urban planning in Ghana. It also oversees the enforcement of Ghana's building code and issues building permits for developers. Real estate developers are primarily involved in designing and constructing estate housing, which they sell to the public. In contrast, licensed SHS companies are involved in selling and installing solar home systems. Fig. 1 illustrates the analytical framework formulated based on the discussions above.

Methods

Study area

The study area for this research is the city of Accra in the Greater Accra Region of Ghana. It is located between latitudes 5.556°N and longitude 0.169°W and shares boundaries with the Eastern, Central, and Volta regions and the Gulf of Guinea to the North, West, East, and South, respectively. The city lies within the dry equatorial climatic zone, with an average annual rainfall of about 730 mm and an average daily temperature between 20 and 30 degrees Celsius (Ghana Statistical Service, 2014). It has an average Direct Normal Irradiation (DNI) of 3.174kWh/m^2 per day and 1158.5kWh/m^2 per year, with monthly DNI ranging between 70.2kWh/m^2 in January to 137.3kWh/m^2 in October (World Bank, 2022). As the capital and economic hub of the country, the cityscape of Accra is rapidly expanding, with new residential developments springing up across the city and its urban fringes. The cityscape comprises a mix of formal and informal settlers. Often, old and informal neighborhoods are in the inner city areas, while formal and highly well-planned neighborhoods are in the middle to outer parts of the city (Ehwi et al., 2019). Accra has a high electrification rate, with 96.5 % of households in Accra connected to the national grid (Ghana Statistical Service, 2019). However, frequent power outages are common. Homeownership in Accra is below the national average (42.1 %), with only 18.3 % of households in Accra owning their homes (Ghana Statistical Service, 2019). However, 32.4 % of households live in rent-free housing (e.g., family houses), while 48.6 % are renters (Ghana Statistical Service, 2019).

Two neighborhoods, namely, Regimanuel Gray Estate (high-income, gated estate) and Dansoman (mostly middle-class neighborhood), are the primary study sites for this research. These neighborhoods were

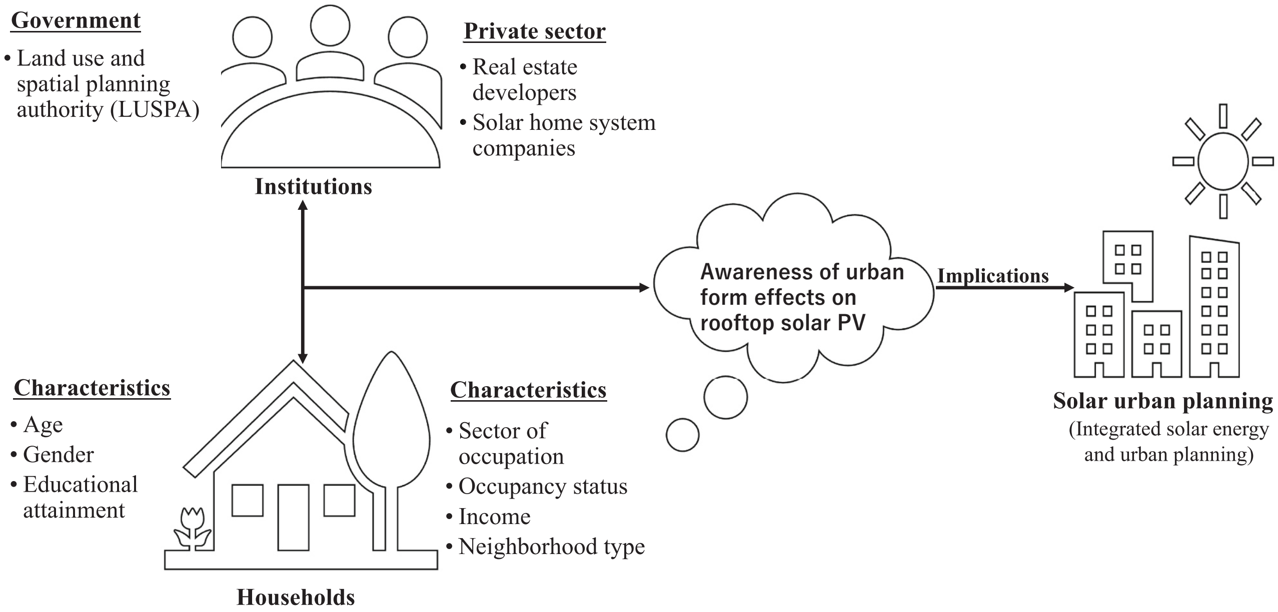

Fig. 1. Stakeholders' awareness of solar PV transition.

selected based on their urban form and socio-demographic characteristics. Regimanuel Gray estate is a well-planned neighborhood along the Spintex road in Accra, characterized by exceptionally planned layouts and consists predominantly of detached and semi-detached houses. The building designs are almost uniform, with identical shapes, roofing types, and heights. Dansoman, on the other hand, is a planned neighborhood comprised of mostly middle to upper-income dwellers, with a mix of housing types such as detached, semi-detached, and condominiums (Ehwi et al., 2020). These neighborhoods' distinct physical characteristics (urban form) allow for comparing urban form and rooftop solar PV. On the other hand, their socio-demographic characteristics in terms of educational attainment, occupation, income, and homeownership, among others, allow for examining the prospects of solar urban planning, considering the influence of socio-demographic factors. Previous studies suggest that residential solar PV adoption prospects are higher in such neighborhoods (Boamah & Rothfuß, 2020; Mensah & McWilson, 2021). Fig. 2 shows the location of the study area and the specific neighborhoods where data collection occurred.

Sampling and selection of household participants

The target population for the household survey is all households in Dansoman and Regimanuel Gray Estate. The specific population for these neighborhoods is unknown. However, Regimanuel Gray Estate is located in the Ledzokuku Municipal District, which has 72,382 households, while Dansoman is situated in the Ablekuma West District, which has 49,031 households (Ghana Statistical Service, 2020). Since the specific number of households in the two neighborhoods studied is unknown, the following formula proposed by Smith (2013) was used. This formula is used when the sample frame or sample population is unknown and is given by

$$N = \frac{(Z - score)^2 X\ StdDev\ X\ (1 - StdDev)}{(marging\ of\ error)^2}$$

with a confidence level of 95 %, standard deviation of 0.5, a 5 % margin of error and a corresponding Z-score of 1.96 (Smith, 2013), where N is the sample size. The resultant sample size is 384.5. Smith (2013) and Israel (Israel, 1992) noted that a sample of at least 200 is generally adequate for statistical analysis.

Regarding the selection of the participants for the household survey, the sample size was first split into approximately 192 for the Dansoman and Regimanuel Gray Estates. Each neighborhood was then divided into 10 clusters of houses based on physical landmarks such as roads. Approximately 19 households were expected to be selected from each cluster to determine the total sample size. This selection was based on the availability of a suitable respondent for the survey in each household, with household heads being the main targets for the survey. However, when the household head was unavailable, any adult household member (aged 18 years and above) with adequate knowledge to address the survey questions was recruited. To ensure that respondents have sufficient knowledge to address the survey questions, the field enumerators first present the informed consent form and explain the purpose, nature, and objectives of the survey, including specific information needed.

If the individual acknowledges that they can provide the information needed, enumerators ask for their consent to participate in the survey. If agreed, the participant must sign the informed consent form before administering the questionnaire. Since the questionnaires were preloaded on iPads, a check box was provided for participants to tick, indicating that they had consented to participate in the survey. If no consent is given or a suitable respondent is not found, the enumerators skip that household and select another until the desired number of households per cluster is reached. Enumerator training was conducted before the primary data collection. It was a joint effort between the researcher, enumerators, and the survey firm to make sure all enumerators were familiar with the survey protocols, objectives, and their roles and duties. This is to ensure the quality of the data collected.

Selection of institutional participants and interview protocol

Only institutions whose primary activities fall within urban planning, energy policy planning/regulation, and residential solar PV systems were selected as respondents. Thus, institutions were purposively sampled based on their direct engagement in activities related to the subject of study. Institutions selected for this study are the Land Use and Spatial Planning Authority (LUSPA), real estate companies, and licensed solar home system installation companies in Accra. A list of real estate developers in Accra was compiled from 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. For the licensed solar home system companies, a list comprising 106 companies was obtained from the Ghana Energy Commission's website, and companies based in Accra were selected for the survey.

From the list, 30 companies based in Accra were identified. All 20 real estate companies and 30 SHS companies were targeted for the institutional survey. In addition to these surveys, a key informant interview was conducted at the LUSPA. Participants for the institutional surveys and interviews were focal persons whose positions and roles at their respective organizations make them knowledgeable on the subject of this study and, thus, able to respond to the interview questions. In recruiting participants for the interviews, initial contacts were made with the organizations with an informed consent form and ethical clearance form for the research. The informed consent form detailed the research objectives and the specific information needed from each organization/institution.

When making the contacts, it was discovered that about 12 SHS companies were no longer operational, while contact could not be established with five real estate companies. Hence, 18 SHS companies and 15 real estate companies were contacted, alongside the LUSPA, which all consented to participate in the study. Each respective organization scheduled an appointment with their focal person for the interviews (LUSPA and energy commission) and surveys (SHS and real estate companies). The enumerators for this study visited the organizations to conduct the interviews and surveys. For some SHS companies and real estate developers, the surveys were administered online since they could not arrange in-person surveys due to their schedules.

Data collection, treatment, and analysis

The research instruments were preloaded on iPads using the Poimapper data collection tool during the fieldwork. Poimapper is a mobile data collection tool with advanced features such as audio/video recording, taking photos, and using Bluetooth to capture data. It has a Global Positioning System (GPS), which allows for live tracking of data points during fieldwork and provides the final data in several file formats. The field data collection was subcontracted to Think Data Services Limited,[1] a registered data collection agency in Ghana. The research instruments were pre-tested for validity and reliability from September 5th to 9th, 2022. No significant issues were found with the research instruments after the pre-testing. The primary data collection exercise was carried out over one month, from September 12th, 2022, to October 10th, 2022. The survey data were downloaded in SPSS file format from the Poimapper tool and imported into IBM SPSS version 24 for treatment and analysis. The data were cleaned by first specifying the appropriate variable types (i.e., numeric, string, currency, and date) since they all appear as string variables from the Poimapper app by default. All identifying information, such as the enumerators' names and GPS

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[1] Find more information on their website at https://www.thinkdataservices.com/

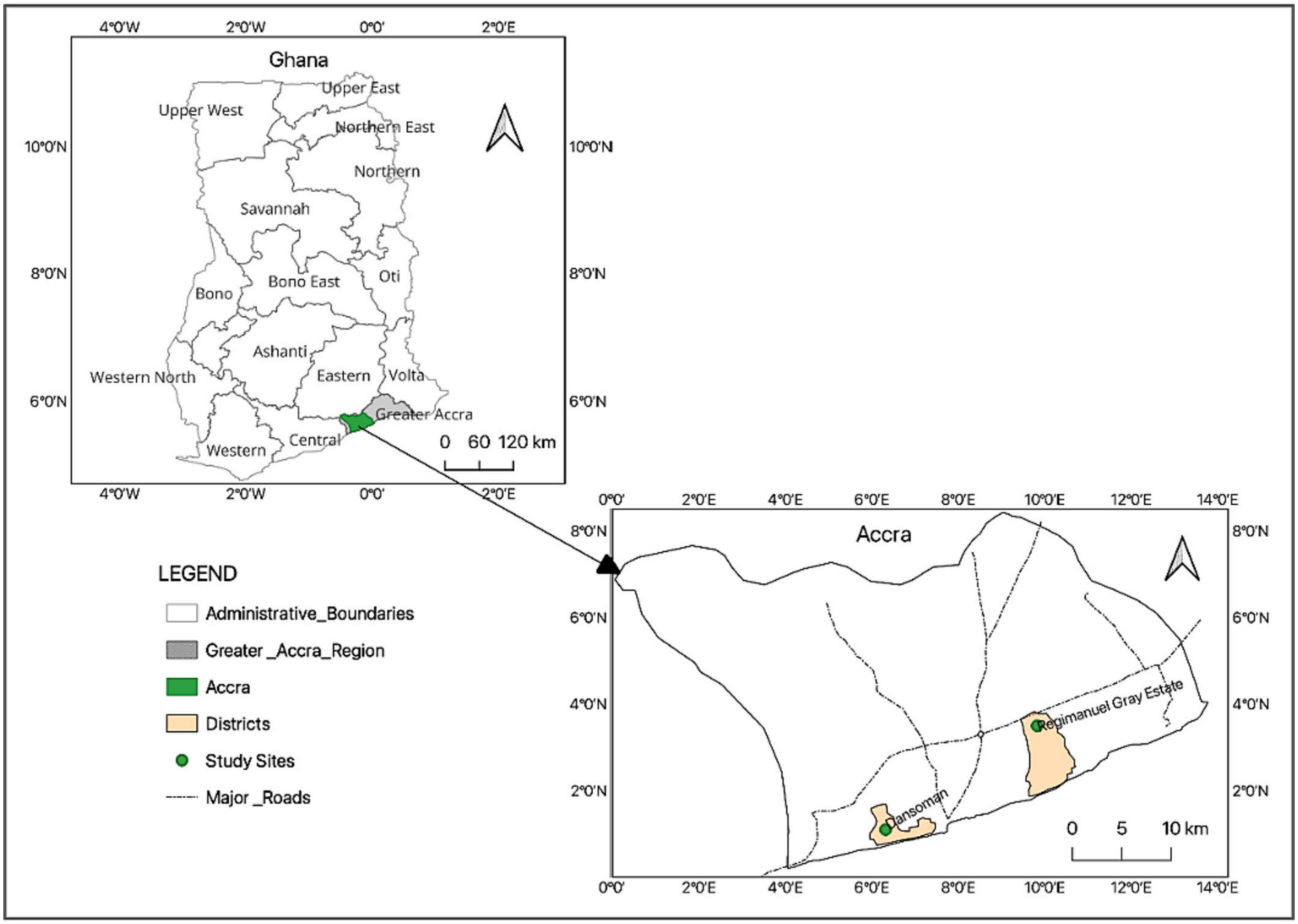

Fig. 2. Map showing the study sites.

coordinates of the houses and institutions surveyed, were removed to ensure anonymity following the ethical principles of this research. The data were checked for duplicates using the *identify duplicate cases* tool in SPSS, and structural errors such as typing mistakes in the variable names, question labels, and defined values were checked to ensure consistency.

Descriptive statistics alongside analytical methods such as chi-square tests were used. The results were visualized in the form of graphs and tables. Thematic analysis was used for the qualitative data, where the transcribed interview responses were carefully read and organized into themes based on the research objectives. Thematic analysis entails the in-depth reading of the text to identify patterns within the data in line with the research questions/objectives, and the patterns identified are categorized for analysis (Fereday & Muir-Cochrane, 2006). Quotations were marked and coded within the dataset. The results were discussed, and quotations were presented verbatim to support the findings. Codes were created for the various institutions; hence, the codes were used instead of institution names where quotations are presented. These codes are *LP_Res* (LUSPA), *SHS_Res* (Solar Home System Companies), and *RE_Res* (Real estate developers).

Data and sample characteristics

The largest proportion of our household survey respondents was between the ages of 18–34 years (45.4 %), had attained tertiary and post-tertiary education (59.7 %), was employed in the private (either formal or informal) sector (50.4 %), and earned between GHS 2000–3000(USD 160–240)[2] per month (31 %). The high proportion of respondents in these categories is explained by the neighborhood types (high-income and middle-class) inhabited mainly by highly educated and wealthier households. These demographic characteristics are also consistent with previous studies in similar neighborhoods in Accra (Ehwi et al., 2019). Also, similar to the homeownership rate reported by the Ghana Statistical Service (2019), about 40 % of the respondents were homeowners. Significant variations exist between gated and non-gated community dwellers. Regarding income, 87 % of gated community dwellers earn at least GHS 3000 (USD 240) monthly, while only 5.2 % of non-gated community dwellers earn at least the same amount.

Regarding homeownership, 46.6 % of non-gated community dwellers own their homes, while this proportion is 32 % for gated estate dwellers. The gated estate also has more long-term (more than two years) renters (32 %) than the non-gated estate, which has 15.2 % long-term renters. These findings reflect those made by Ehwi (Ehwi, 2019), who noted that high-income households inhabit gated estates in Ghana and that many of these houses are owned by expatriates who build or buy houses and rent them out since they do not reside in the country. Most respondents from the real estate developers (73.3 %) and SHS companies (87.5 %) were males, indicating a gender imbalance in these

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[2] GHS 1 = USD 0.08 in October 2022 (https://www.bog.gov.gh/economic-data/exchange-rate/)

sectors. More young people (18–34 years) are engaged in SHS companies (44.4 %) than in real estate companies (37.5 %). It is worth pointing out that the respondents from these organizations are mostly those in managerial positions, and their roles in the organizations are directly linked with the subject of this study. A table showing the demographic profile of household respondents is provided in Appendix B.

Results

Effects of urban form attributes on rooftop solar PV in Accra

The interviews with SHS companies revealed specific effects of urban form attributes on rooftop solar PV in Accra. Due to their primary function being the installation of SHS, respondents from these companies had first-hand experience from their activities. As a result, they were able to explain how each urban form attribute affects rooftop solar PV. Building-specific attributes such as the type of roof, roofing material, shape of the roof, and orientation of the building have the most significant influence, as deduced from the interviews with the SHS companies. These building-specific attributes mainly affect the architectural integration of rooftop solar PV systems into buildings. One *SHS_Res* recounted that the type of roofing material might cause delays in installing the panels because materials such as slate are delicate and could be easily damaged during installations. Hence, extra care is required when mounting rack brackets to hold the panels firm. The type of roofing material also affects the number of panels that can be installed, given the additional weight that the PV panels exert on the roof. Previous studies (Boccalatte et al., 2022; Morganti et al., 2017) have shown that the position and orientation of the solar panels on the rooftop are critical to ensure that the panels receive adequate solar irradiance to produce more electricity.

Our interviews with the SHS companies in Accra show that the shape of the building’s roof (e.g., round, rectangular, and conical) and the type of roof (e.g., flat and pitched) affect the positioning and orientation of the solar PV panels. No specific effects were reported for the buildings' orientation; however, one *SHS_Res* recounted that the orientation could affect the laying of cables during the PV system installation. Regarding neighborhood-level features, the height of neighboring buildings was reported as having the most significant effect on rooftop solar PV. Consistent with the findings made by related studies (Boccalatte et al., 2022; Mahaya et al., 2022; Oh & Kim, 2019), the SHS companies interviewed affirmed that the height of neighboring buildings causes shading effects, which not only affects the positioning of the PV panels but also limit the amount of solar irradiance reaching them, and consequently affecting the performance of the PV system. On the contrary, numerous studies (Lobaccaro & Frontini, 2014; Mohajeri et al., 2016; Sarralde et al., 2015), including a recent one in Accra (Akrofi & Okitasari, 2023), have shown that building density is one of the most significant urban form attributes affecting rooftop solar PV, the *SHS_Res* assert that building density has no significant effects on the rooftop PV. The same assertion was made for the neighborhood layout, as seen from the quotations in Table 1.

Similar to the shading effects caused by neighboring buildings, landscape elements such as the position of trees are reported to pose the same effects. One *SHS_Res* noted that trees may cast shadows and cause shading on buildings' rooftops, reducing the amount of solar irradiance that reaches the PV panels. Among the eight urban form attributes, the SHS companies reported the building density and the neighborhood layout as having no significant effects. Nonetheless, studies examining the effects of these attributes on rooftop solar have conclusively noted that they significantly affect rooftop solar PV. For instance, Akrofi and Okitasari (2023) found that Accra neighborhoods with higher building density have lower rooftop PV potentials than those with lower building density. Similar findings were made by related studies in Switzerland (Boccalatte et al., 2022), Sweden (Kanters & Wall, 2014), and Algeria (Mahaya et al., 2022).

Table 1
SHS companies' affirmation of urban form effects on rooftop solar PV.

Category	Attribute	Effect	Stakeholders' quotation
Building-specific features	Type of roof (e.g., flat and pitched)	Affects the positioning of the PV panels on the rooftop	*“…the shape of roofing affects position or orientation of panels on the roof…”* *“Steep roofs affect PV installations, however, considering azimuth angles become necessary to avoid shading when mounting structures are used.”*
	The roofing material	Affects the architectural integration of the PV panels on the rooftop and the number of panels to place on the rooftop	*“…the type of roofing materials also affects installation and causes delays, especially slate roofing, since one needs to be extra careful not to create cracks which may lead to leakages. One needs to design a special mounting bracket to suit and hold firmly the panels installation on the roof. Aluminum roofing materials are easy to just rivet, and most importantly brackets are easy to fix.”* *“Just like the shape of the roof, the material is also useful because of the weight of the panels.”*
	The shape of the roof (e.g., round and rectangular)	Affects the positioning of the PV panels on the rooftop	*“…the shape of roofing affects position or orientation of panels on the roof…”* *“The shape of the roof is also important for determining which materials to use for fixing the panels.”*
	Building's orientation	Could affect the laying of cables	*“The building orientation is not too important because (you) can still manage to lay out cables for the work.”*
Neighborhood features	Building density	No serious effects, but it could affect the number of panels needed.	*“Points…, 15 [layout of the neighborhood], and 17 [building density] have no serious influence over rooftop solar PV installation.”* *“The building density is important because of the number of panels needed.”*
	Height of neighboring buildings	Causes shading and affects the position of panels	*“The heights of neighboring buildings can affect the positioning of the Panels because of the shadows from the*

(continued on next page)

Table 1 (*continued*)

Category	Attribute	Effect	Stakeholders' quotation
			neighboring buildings." *"...the height of buildings and trees provide shade on the panels which affect its output performance."*
	Neighborhood layout	No specific effect identified	*"Points..., 15 [layout of the neighborhood], and 17 [building density] have no serious influence over rooftop solar PV installation."* *"The layout of the neighborhood might not matter much."*
Landscape features	Position of trees relative to buildings	Causes shading, which affects the performance of PV panels.	*"The positioning of trees is important because the sun is needed, and there must not be shadows of the trees to prevent the panels [from] receiving maximum sunlight."* *"... trees provide shade on the panels which affect its output performance."*

Stakeholders' ratings of urban form effects on rooftop solar PV

The stakeholders' ratings of the extent to which urban form attributes influence rooftop solar PV reflect our assertion that the stakeholders' awareness of urban form effects on rooftop solar is linked with the nature and level of their engagement regarding rooftop solar PV systems. The respondents from SHS companies demonstrated a higher level of awareness and knowledge because they are primarily the installers of SHS systems. This higher level of awareness is seen in their quotations in Table 1 and in their ratings of the extent to which each urban form attribute influences rooftop solar PV, as seen in Figs. 3 and 4. The type of roof, shape, height of neighboring buildings, and the building's orientation and density were rated as "not at all influential." In contrast, the roofing material and neighborhood layout were rated as "highly influential" and "influential," respectively, by the *LUSPA_Res.*[3]

The level of awareness of urban form effects on rooftop solar PV was higher among real estate developers and SHS companies than households. This higher level of awareness can be attributed to the direct involvement of real estate developers and SHS companies in designing and building houses and installing rooftop PV systems, respectively. However, when asked to elaborate on the reasons for their ratings in Fig. 3, most respondents from the real estate companies skipped this question. In contrast, respondents from the SHS companies provided some explanations in Table 1. In line with the results in Table 1, stakeholders' reactions to urban form effects on rooftop PV in Fig. 3 indicate that the position of trees, the shape of the roof, the roofing material, and the height of neighboring buildings are the most influential factors. The roofing material and position of trees were also rated as "highly influential" by the *LUSPA_Res*.

However, building density and neighborhood layout were not regarded as highly influential by all the stakeholders, even though previous studies have shown that building density is one of the most significant factors in the BIPV (Kanters & Wall, 2014; Mohajeri et al., 2016). Households demonstrated the lowest perception, as observed in Fig. 3. This lower perception could create resistance to any regulations that seek to make solar energy considerations an integral part of the urban planning and building development process. In the ensuing section, we examine the association between their awareness of urban form effects on BIPV and their socio-demographic characteristics to understand the households' dynamics better. This analysis hinges on Merleau-Ponty's assertion that a comprehensive view of people's awareness requires understanding their characteristics (Merleau-Ponty, 2013).

Household's thoughts about integrating solar considerations into the building plan

The low level of households' awareness of urban form effects on rooftop solar PV is also manifested in their views on whether it is important to incorporate solar PV considerations when preparing a building plan. The majority (62.5 %) of households thought it was unimportant to include solar considerations in the preparation of the building plan. The chi-square test was used to ascertain whether there is a statistically significant association between the socio-demographic characteristics of the respondents and their response to this question. The results are presented in Table 2.

Apart from gender, the socio-demographic attributes of households are statistically significantly associated with their view on whether it is important to include solar considerations in a building plan. Most households in the gated estate (89 %) think including solar energy considerations in a building plan is unimportant. Most homeowners in gated communities and estates often purchase readymade houses (Ehwi et al., 2019) and are not directly involved in a building plan; hence, they are more unlikely to see the need for including solar integration in preparation for a building plan. Secondly, some property developers include backup electricity systems (e.g., diesel generators, diesel plants, or SHSs). Thus, homeowners in such houses may not know about PV system installation and the importance of including them in a building plan. Based on the survey of the real estate developers, 73.3 % of the estate developers indicated that they install backup electricity systems when building houses. Most of those who add backup systems to their properties (63.6 %) use diesel generators or plants. Affordability was the dominant reason for choosing diesel generators or plants. This high usage of backup generators partly explains why dwellers in the gated neighborhood do not think it is important to include solar PV considerations in the building plan. Fig. 4 shows the distribution of households' views on integrating solar energy considerations into the building plan by socio-economic factors.

Contrary to the view of households in the gated estate, most households in the non-gated neighborhood (60 %) agree that including solar considerations in a building plan is essential. Homeowners typically acquire land in these neighborhoods and contract architects to prepare a building plan based on their preferences (Arku, 2006; Owusu-Ansah & Asante, 2022). The choice of a backup electricity source also rests with the homeowners. Therefore, they are more likely to consider incorporating solar energy into a building plan. A statistically significant association was found between age and peoples' thoughts on whether SHS should be included in a building plan. As age increases, the proportion of people who agree with having solar considerations in a building plan also increases (Fig. 4). The same pattern is observed for homeownership, where most homeowners saw the need to integrate solar considerations into the building plan while most short-term and long-term renters did not.

Discussion

An integrated approach to solar energy and urban planning is necessary to ensure optimum outcomes by building integrated solar PV systems such as rooftop solar PV in cities. Yet, the sectoral divide

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[3] No figure was created because there was only one respondent (key informant interview) at the LUSPA.

Fig. 3. Stakeholders' ratings of urban form effects on BIPV.

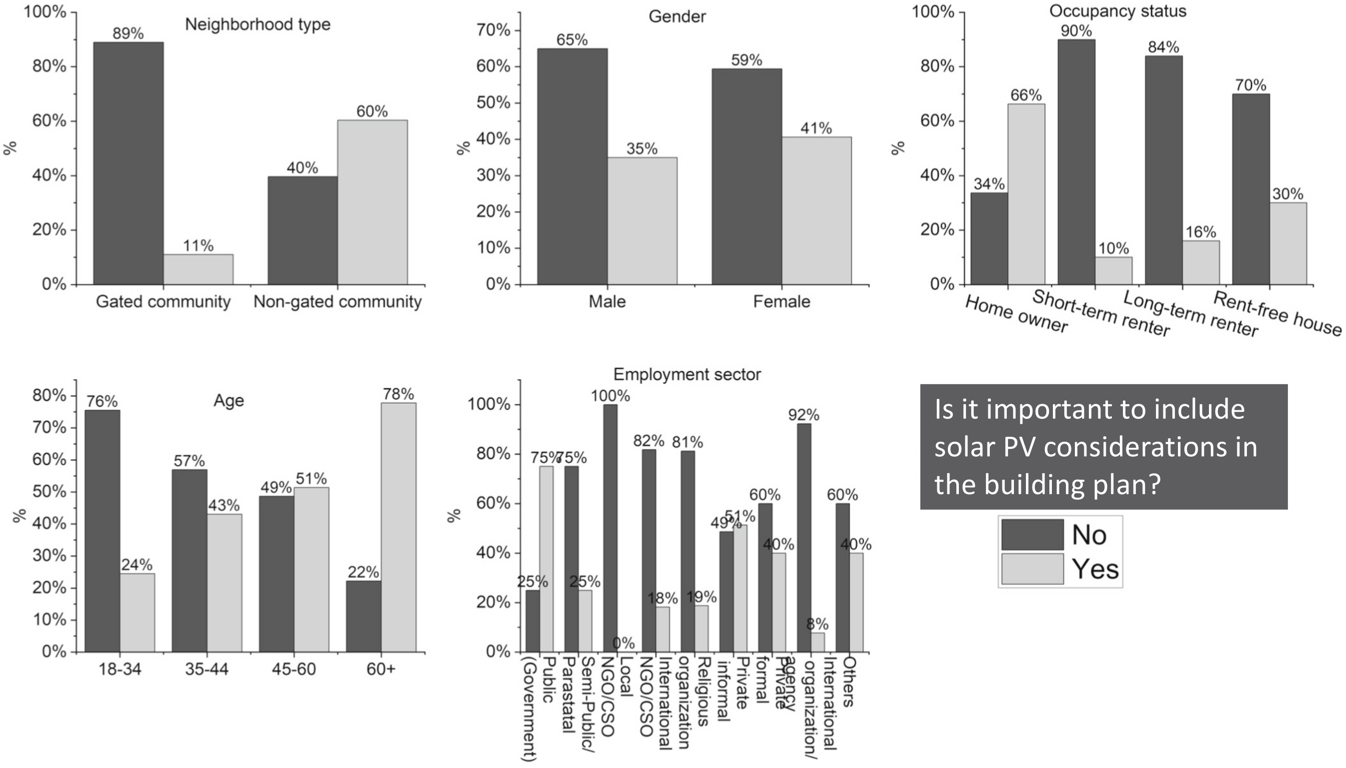

Fig. 4. Households' view on integrating solar PV considerations into the building plan.

between energy and urban planning has traditionally constrained this process (Akrofi & Okitasari, 2022). Past studies show that while an integrated approach to solar energy and urban planning is ideal for building low-carbon cities, such an approach requires either the modification of existing planning regulations or the enactment of new ones (Kanters & Wall, 2018; Lobaccaro, Lindkvist, et al., 2017). SHS installers affirmed the effects of urban form attributes on rooftop solar PV installation and performance in Accra. While these urban form

Table 2
Results of the chi-square test.

Pearson Chi-Square Tests		
Variables		Is it important to include solar considerations in the building plan?
Type of neighborhood	Chi-square	61.371
	df	1
	Sig.	0.000*
Gender	Chi-square	0.72
	df	1
	Sig.	0.396
Occupancy status	Chi-square	54.119
	df	3
	Sig.	0.000*
Age	Chi-square	17.284
	df	3
	Sig.	0.001*
Educational attainment	Chi-square	22.578
	df	3
	Sig.	0.000*
Sector of employment	Chi-square	29.588
	df	5
	Sig.	0.000*
Income	Chi-square	44.012
	df	4
	Sig.	0.000*

* The Chi-square statistic is significant at the 0.05 level.

constraints are better resolved through urban planning/design, which is the primary function of the Land Use and Spatial Planning Authority (LUSPA), our interviews with the LUSPA in Accra revealed that currently, there are no legislations that require the integration of solar energy considerations into urban planning or building plans. As a result, such considerations are not made in preparing urban development plans. The *LUSPA_Res* at the unit recounted, "*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. No regulations specify the incorporation of renewable energy in the preparation of spatial plans.*" This response affirms that even though the Ghana Buildings Code defines guidelines and standards for integrating solar PV systems into buildings (Ghana Standards Authority, 2018), no legislation requires considering such systems in building or spatial plans.

Adopting an integrated approach will, thus, require enacting new urban/spatial planning regulations to this effect. While the LUSPA and the Energy Commission regulate urban planning and renewable energy, respectively, the ultimate recipients of these regulations are the households. However, households' awareness of urban form effects on rooftop PV and, consequently, the need to integrate solar considerations into urban planning and building plans was low. The high level of awareness from the institutional stakeholders suggests that they are more likely to support a change toward integrating solar considerations into the existing urban planning regulations. Some real estate developers have demonstrated a positive drive toward rooftop solar PV systems. Their interest in such systems stimulates them to integrate solar considerations into their building designs. A *SHS_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.*" Another pointed out, "*Our roofing is flat and friendly to any homeowner who has [an] interest in using solar systems on their roof.*"

The responses above, coupled with the high level of awareness of urban effects on rooftop solar PV demonstrated by the institutional stakeholders, imply that greater support can be obtained from them in initiating an integrated approach to solar energy and urban planning in Ghana. Both private and public sector institutions are instrumental in the success of this process, as shown in previous studies (Lobaccaro et al., 2019; Lobaccaro, Lindkvist, et al., 2017; Lundgren & Dahlberg, 2018). On the other hand, households may not comply with any regulations that seek to formalize such requirements without an adequate understanding of the need to include solar energy considerations in preparing urban and building plans. Not only could there be non-compliance, but potential conflicts could also arise between neighbors regarding installing solar panels, a situation popularly known as NIMBYism. NIMBY is an acronym for "not in my backyard" and has been used in renewable energy research to describe opposition to the installation of renewable energy technologies either from a community (typical for wind farms or large-scale solar plants) or individual homeowners regarding residential solar PV systems (Burningham, 2012; Johnson, 2012; Petrova, 2016). Identifying and dealing with such opposition is fundamental to the success of solar urban planning initiatives. Public consultations, workshops, and information campaigns effectively dealt with resistance and gained stakeholder support for solar urban planning initiatives (Lobaccaro et al., 2019; Lobaccaro, Lindkvist, et al., 2017; Lundgren & Dahlberg, 2018).

Conclusion

A substantial body of recent literature suggests that residential solar PV systems are becoming increasingly less expensive, but their wide-scale adoption depends on how much they can be integrated into the built environment (Akrofi & Okitasari, 2022; Lobaccaro et al., 2019; Lobaccaro, Lindkvist, et al., 2017;Lundgren & Dahlberg, 2018; Wall et al., 2017). Consequently, an integrated approach to solar energy and urban planning (termed solar urban planning), where solar PV technologies are treated as an urban design parameter, has recently gained increased attention (Lundgren & Dahlberg, 2018; Wall et al., 2017). This study is the first attempt to gauge stakeholders' awareness of the interrelationships between urban form and residential rooftop solar PV in Ghana. Doing so draws attention to bridging the sectoral dichotomy between solar energy and urban planning.

Existing urban planning regulations in Accra do not necessitate considering solar PV systems in preparing urban or spatial plans. Our findings indicate an interest of institutional stakeholders in promoting residential solar PV systems and affirm that urban form attributes affect the installation and performance of such systems. The findings from SHS companies and real estate developers affirm that urban form elements such as buildings' roof shape, type of roofing material, the position of landscape elements such as trees, and the height of neighboring buildings affect the feasibility and performance of SHS. Moving forward, it is important to check these factors during the preparation of urban plans and building plans. Our results also imply that households demonstrated low awareness of urban form effects on rooftop solar PV systems. Awareness is needed through public consultations and stakeholder engagement, which local LUSPA units can carry out.

Integrating solar energy considerations into Ghana's urban planning system requires strong institutional coordination and collaboration between the LUSPA, the energy commission, and real estate developers. Generally, there is little adherence to building regulations and planning standards in Ghana's residential space, especially in non-gated estates. However, gated estates on the rise in the country's cities are exceptionally planned and built to high standards by building regulations. This feature of estates makes them an ideal space for trialing integrated solar energy and urban planning.

One possible caveat of our study is the relatively small sample size, resulting in the limitation of generalizing our findings outside the Ghanaian context. However, our primary focus is not to generalize these findings but to provide some initial insights and stimulate further interest in solar urban planning in the Ghanaian context and, hopefully, in African cities. It is noteworthy that the Ghanaian context regarding urban planning processes, urban form, and SHS diffusion is not so different from African countries, as evidenced by similar studies (e.g., Barau et al., 2020; Bensehla et al., 2021; Haine & Blumberga, 2016; Iwaro & Mwasha, 2010; Silva, 2015). Thus, this study potentially provides useful insights to policymakers and is a good basis for similar studies in other African cities. Future research focusing on cross-country comparisons with larger sample sizes will contribute significantly to a broader understanding of this subject in the African context. Moreover, this study shows the potential for an integrated approach to solar energy and urban planning in Ghana, especially from institutional actors. Identifying appropriate strategies to achieve such integration and ensuring buy-in and compliance from homeowners are essential issues that future research may address.

CRediT authorship contribution statement

Mark Akrofi: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing- Original draft preparation. **Mahesti Okitasari:** Conceptualization, Supervision, Writing- Reviewing and Editing. **Upalat Korwatanasakul:** Supervision, Writing- Reviewing and Editing.

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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. A summary of studies on urban form effects on BIPV

Authors	Study objective(s)	Urban form parameters	Methods	Findings
(Bensehla et al., 2021)	To examine how different urban forms affect solar PV potential on buildings' rooftops.	Building shapes, type of house, urban density, and building material.	3D simulations using CitySim software	Urban form features significantly influence the rooftop solar PV potential of buildings.
(Zhang et al., 2019)	To examine the relationship between solar energy potential, urban block typology, and energy efficiency in buildings.	Urban block types	Parametric 3D modeling using Rhinoceros3D software.	Designing appropriate urban block typologies could yield 200 % more rooftop solar PV potential.
(Lobaccaro & Frontini, 2014)	To investigate how urban densification affects solar energy potential on buildings' rooftops and facades.	Height and size of buildings, the distance between blocks, building envelopes.	3D modeling using Rhinoceros3D software.	Available solar potential varies due to overshadowing effects, which vary by buildings' height, location, and exposure direction on the site/area
(Mohajeri et al., 2016)	To examine the relationship between urban compactness and solar potential for BIPV across different neighborhoods	Building density, nearest neighbor ratio, site coverage, and volume-area ratio.	Simulation and modeling using CitySim and GIS software	Solar potential decreases as urban compactness increases. However, compactness affects the solar potential on rooftops less than on facades.
(Boccalatte et al., 2022)	To undertake a city-wide assessment of the impact of urban morphology on rooftop solar PV radiation.	Building heights, density, shapes, footprint area, and floor area ratio.	GIS-based analysis using LiDar data and 3D solar cadastres	Building heights, shading, density, and building shapes significantly affect the solar irradiance received on their rooftops.
(Kanters & Wall, 2014)	To examine the effects of urban design decisions on the solar energy potential of net zero buildings.	Building blocks, the orientation, roof type, and density.	3D modeling and simulation using *DIVA-for-Rhino* software	Urban density is the most influential parameter on the solar potential of building blocks.
(Mahaya et al., 2022)	To investigate the relationship between urban morphology and solar availability	Building types, height, density, volume-area ratio, site coverage, urban block type, orientation, and volume-area ratio.	3D modeling using Rhino3D/Grasshopper software	Neighborhoods with consistent building height, low volume-to-area ratio, low site coverage, low density, and detached configuration have higher rooftop solar potential
(Sarralde et al., 2015)	To explore the relationship between aggregated urban form parameters and solar energy potential on buildings' roofs and facades	Building types, density, building geometry, and land-use patterns.	Simulations using GIS Pythonthon scripting	Optimizing urban form parameters could increase solar irradiation of roofs and facades by 9 % and 45 %, respectively.
(Morganti et al., 2017)	To identify urban form parameters that affect solar energy potential on facades	Gross space index, floor space index, façade-to-site ratio, building height, volume-area ratio, and aspect ratio.	Parametric modeling using *Heliodon2* software and regression analysis	Gross space index, façade-to-site ratio, and sky factor correlate positively with solar energy potential on facades
(Lobaccaro, Carlucci, et al., 2017)	To assess the indirect mutual solar reflections created by the urban surroundings on solar PV potential on row houses and high-rise apartments	Building orientation, building materials, and ground soil.	solar analyses and simulation using *DIVA-for-Rhino* software	Solar potential can be increased by 25 % when buildings' orientation, height, and distance between buildings are optimized in the early design stages.

Appendix B. Demographic characteristics of households

Socio-demographic variables	Type of Neighborhood		
	Gated	Non-gated	Total

(continued on next page)

(*continued*)

Socio-demographic variables		Type of Neighborhood					
		Gated		Non-gated		Total	
		Count	Row N %	Count	Row N %	Count	Row N %
		Count	Row N %	Count	Row N %	Count	Row N %
Gender	Male	58	48 %	62	52 %	120	100 %
	Female	42	44 %	54	56 %	96	100 %
Age	18–34	52	53 %	46	47 %	98	100 %
	35–44	34	47 %	38	53 %	72	100 %
	45–60	12	32 %	25	68 %	37	100 %
	Above 60 years	2	22 %	7	78 %	9	100 %
Educational attainment	Basic school (up to Junior High School)	0	0 %	7	100 %	7	100 %
	Secondary School (Senior High School and Vocational /Technical school)	7	13 %	48	87 %	55	100 %
	Tertiary (Bachelors, HND, Specialized Training)	29	43 %	39	57 %	68	100 %
	Post Tertiary (Masters and Doctoral)	55	90 %	6	10 %	61	100 %
	None	9	36 %	16	64 %	25	100 %
Sector of employment	Public (Government)	5	31 %	11	69 %	16	100 %
	Semi-Public/Parastatal	5	63 %	3	38 %	8	100 %
	Private formal	17	49 %	18	51 %	35	100 %
	Private informal	18	24 %	56	76 %	74	100 %
	Local NGO/CSO	8	80 %	2	20 %	10	100 %
	International NGO/CSO	10	91 %	1	9 %	11	100 %
	Religious organization	9	56 %	7	44 %	16	100 %
	International organization/agency	26	100 %	0	0 %	26	100 %
	Other (please specify)	2	10 %	18	90 %	20	100 %
Monthly[a] income	less than GHS2000	5	9 %	51	91 %	56	100 %
	GHS2000-3000	8	12 %	59	88 %	67	100 %
	GHS3001-4000	34	85 %	6	15 %	40	100 %
	GHS4001-5000	16	100 %	0	0 %	16	100 %
	Above GHS5000	37	100 %	0	0 %	37	100 %
Occupancy status.	Homeowner	32	37 %	54	63 %	86	100 %
	Short-term renter (two years or less)	21	53 %	19	48 %	40	100 %
	Long-term renter (more than two years)	32	64 %	18	36 %	50	100 %
	Rent-free house (e.g., family house)	15	38 %	25	63 %	40	100 %

[a] GHS 1 = USD 0.08 in October 2022 (https://www.bog.gov.gh/economic-data/exchange-rate/).

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