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Exploring the state of solar photovoltaic decentralization in Ghana: trends and success factors

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Abstract. This research explores the trends of photovoltaic (PV) decentralization in Ghana and provides an updated illuminating insight into the sector. A literature review was carried out to understand and map out the trends, risks, and success factors. Additionally, time-series analysis was used to explore the installation trends from 2013 to 2019. A one-sample t-test was used to test the significance of each of the underlying indicators. The study identifies 2015 and 2018 as the years with the highest PV installations. On regional distribution, the research identified Central (63.25%), Greater Accra (26.44%), and Upper East (3.99%) as areas with the highest cumulative rate of a PV installation, respectively. This research raises awareness on the emerging perspectives on PV investment risk decisions and success criteria in Ghana. Considerations for potential investment opportunities and the stage of PV installations are expounded. It brings to light the geographical spread of installation that will aid critical policy decisions. Findings would be invaluable in making profound changes in the state's policy formulation around PV. The study provides a sound basis for further research, to be directed towards complementing this work by focusing on the social impacts and further engagement of end-users with solar PV.

1. Introduction

There is an abundant of renewable energy (RE) in Ghana which include Hydro Solar PV, Biomass, and Wind [1]. The renewable energy master plan for the country has recently been revised. It has an objective to increase the portion of renewable from 42.5 MW in 2015 to 1363.63 MW by 2030 with grid connections amounting to 1094.63 MW within the same period. The plan intends to provide about 1000 off-grid communities with decentralized electricity[2].

According to [3][4], Ghana's power sector is faced with a myriad of challenges. Chief among all is the lack of proper investment resulting in dilapidated infrastructure, stemming from bad managerial decisions and political influence. As a result, the sector has not attracted adequate substantial capital investment for several decades. Electricity access has increased extensively in Ghana, given the cheap power price that is supplied from Akosombo Dam and the hydroelectric facilities (1.6 US Cents per kWh). This, in turn, resulted in low electricity tariff rates until the 1990s [5]. And demand outstripped supply, because of the country has move to a middle-income status as pointed out by [3], hence the introduction of thermal plants that run on fossil fuels.

Furthermore, additional energy will be crucial as the country attempts to end poverty; eradicate hunger; improve human health, and achieve the Sustainable Development Goals (SDGs). However, major challenges lie in finding sustainable ways to meet these energy demands with clean energy [6]. Amidst all these challenges and uncertainties, solar energy generation through PV appears to be the game-changer, with tariffs being more economical – compared to conventional generation methods [4][7]. Besides, PV has numerous benefits in terms of reducing carbon emissions [8].

According to the report by [9], solar PV technology has advanced rapidly globally in the last decade. The authors of paper [10] reported a global PV installed capacity of 94 Gigawatts (GW) in 2018. The paper [11] explored the need for changing the power matrix into a more solid, secure, proficient, and clean system. With these in mind, building integrated PV(BIV) are becoming ubiquitous[2], [7]. PV technology has become the preferred choice to provide cheaper electricity for isolated communities [12][13]. Within the off-grid communities, PV application is vital for health delivery, education, ICT, clean water etc [14]. This has created a stream of research allocated to the topic. Authors of paper [15] explored the possible economic viability of PV power in Ghana. [16] confirmed the findings of [15] that Governments' subsidies will boost investments in the industry with their study on historic trends to a sustainable economy. Similarly, authors of paper [17] investigated the state of reliability and degradation of almost two-decade old Polycrystalline modules in Ghana. In the works of [18], they fleshed out the latent factors that impede PV investment in Ghana and confirmed the findings by [19] and [16] that, subsidies and tax exemptions will boost PV investment in Ghana.

Despite the contribution of these research studies, none has explored the current PV installation trends, and therefore a current picture of the installation state of play remains elusive in Ghana. This research aims to complete the research gab. The intention is to critically explore the state of solar photovoltaic decentralization in Ghana. To this end, the following objectives are formulated. i)Analyze various PV system designs, ii) Ascertain the regional distribution of PV installations; iii) Examine the trend of solar PV installations from 2013 to 2019; iv) Explore the historical perspective of PV installations in Ghana.

This paragraph summarizes the structure of the this paper. A review of energy consumption through the lens of climate change is covered in the introduction. The historical perspective of PV dissemination in Ghana is outlined in section 2. Experimentation analysis are discussed in section 3. Section 4 examines results. Results discussions are done in section 5. In section 6, conclusions were done.

2. Materials and methods

2.1 Historical PV Perspectives in Ghana

According to [20] PV development has seen an exponential growth since its introduction from the 1950s in Ghana, and is still being pursued in the 1970s, after the oil crisis [21]. [22] confirm that religious missions have initiated many solar energy projects in Ghana since the 1980s. Initially, solar energy facilities were intended for elementary lighting in isolated villages, through several government initiatives with development partners. [21][23] confirm many of these installations are executed through donor support in a private-public partnership (PPP). They provided the learning curve as Ghanaians became innovative with solar systems [2].

In a research study by [24], the Government of Ghana adopted PV into the rural electrification plan, because it was almost impossible to provide electricity to island communities beyond the volta lake in the 1990s. However, the development of national policies on renewables can be traced back to 1983. At the end of 1991, an estimated total of 335 solar PV installations were done in Ghana amounting to about 160 kilowatts. [22] show an increasing trend in PV from 150 kW to 1000 kW from 1991 to 2003. In 2013, the largest solar PV power plant of 2 MW was commissioned in Ghana [19] By 2015, over 10 MWp PV installations can be counted in Ghana.

There have been several government PV projects. Notable among them include the Weichau project initiated in 1997 under a fee-for-service supported arrangement for the Isofoton and Respro projects. Some government initiatives like the National Electrification Scheme (NES), The Ministry of Mines and Energy led the off-gird electrification project that enable individuals and communities to finance PV [22]. Finally, the ARB Apex Bank Project, which involved the private sector in providing maintenance and system supply [2]. The Spanish/Ghana governments and UNDP/GEF RE service project in 1998 and 1999 respectively were some of the earliest major PV donor project. The sum of the budget for these two major projects accounted for around US$4.5 million[25].

Furthermore, significant progress has been made in diverse areas regarding solar PV applications, including the addition of radio and TV operations to basic lighting solar projects, led by the Dutch government in 2007. This was extended to vaccine refrigeration, PV water pumping for irrigation, street lighting etc.

According to [15], in their study of the potential and economic viability of PV power in Ghana, the government's intention to provide subsidies for the power sector will boost investment in the industry. [17] investigated the state of reliability and degradation of certain PV modules in Ghana to provide useful information to project developers and manufactures.[18] unraveled the latent factors impeding PV investment in Ghana and confirmed the findings by [19] and [16] that, subsidies and tax exemptions will boost PV investment in Ghana.

Together with the encouragement of off-grid schemes, numerous grid-connected schemes have also been developed. The 44 kW systems at Kwame Nkrumah University of Science and Technology (KNUST) are some of the leading projects in this regard [26]. Several public institutions and private industries have also adopted the technology and installed solar PV of different capacities, mainly to reduce their reliance on the national grid. Figure 1 shows a steady rise in this trend, as a result of the government policy, backed by a massive drive by Ghana's Energy Commission.

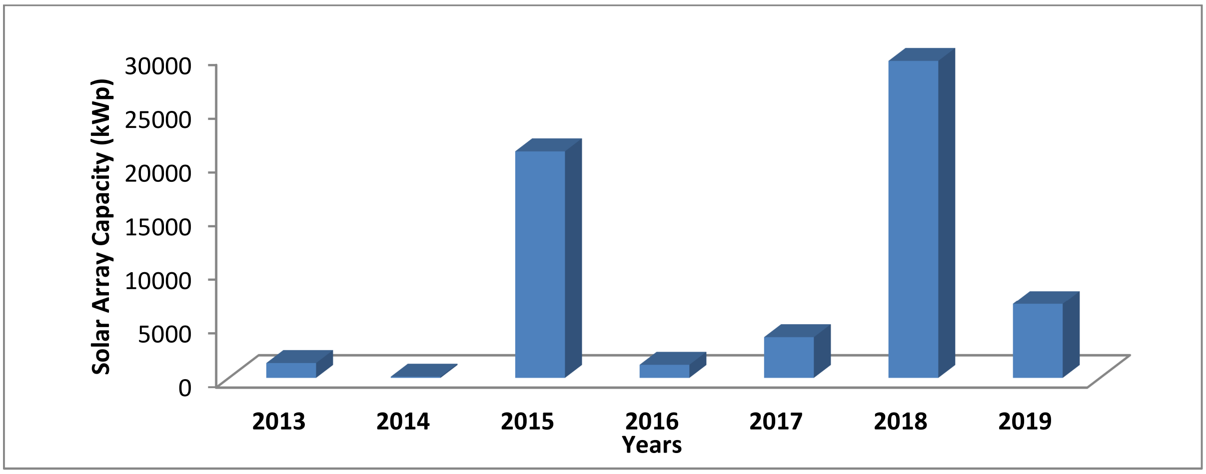

Figure 1. Yearly installation trend from 2013-2019-Capacity (kWp). **Source:** Author

2.2 Exploring the PV investment risk factors in Ghana

The PV infrastructure can be developed within 6-12 months, reasonably faster than alternative types of power plants that require over 4–5 years [27]. PVs nonetheless are becoming more attractive to utility providers, given that the costs associated with PV continue to fall [28]. Photovoltaic has revolved into the novel energy assets for the planet [11] and should be integrated into the grid to resolve the congestion on both distribution and transmission systems.

For any PV project to effectively take off, a preliminary conceptual outline ought to be created that assists to estimate capacity or megawatts (MW), desires, rough venture necessities, vitality yield, expected tax, and related income. Along these lines, business model evaluation can be made, including the degree of return on investment (ROI). An initial budget is normally created [29]

The dangers related to PV ventures are identified with the energy asset venture siting and allowing, solar-based innovation (generally new), potential debasement of PV modules. In Ghana, certain financing instruments such as venture capital, equity finance, debt financing, and crowd financing and many others are not fully developed [30][31]. In a research by [32], the weak Ghanaian cedi against many international trading currencies, predominantly the US Dollar (US$) and the rate of depreciation contributed to a rise in consumer price inflation [33]. Another risk metric that can be used to quantify the risks associated with an investment in solar PV plants is the Cash Flow at Risk (CFaR) [34].

In the works of [31], countless market-related risks such as immature supply chain, insignificant market size, and lack of fruitful PV project progress in Ghana. Market outlook and biases for example fossil fuel subsidies have rendered PV investment unappealing. Nonetheless, the development of renewable energy projects has seen significant improvement in recent times, possibly because of the presence of renewable energy legislation and policies in Ghana.

2.3 Experimentation Analysis

A deductive methodological approach was adopted for this paper. survey questionnaire was used to gather primary data. The survey help improves the consistency of interpretations and enhances replication. The research also depended on secondary data on PV installations in Ghana. The secondary source was from the Energy Commission of Ghana.

Undoubtedly, it may not be likely to find the precise population hence a theoretical sample was adopted. The sampling technique adopted in relation to its design, make inference is the purposive sampling. When a researcher wants to reach out to a targeted sample easily a purposive sampling is the most suitable[35]. Purposive sampling was adopted to reach the sample size of solar installation companies, government agencies, consultancy firms, and financial institution.

The two-page questionnaire was administered to eighty (80) respondents. Forty-seven (47) responses were received as in Table 1 below. The questionnaire was titled ‘Survey on exploring solar photovoltaic investment risk in Ghana.’ The questionnaire comprised two sections: A and B. Section A contains the demographic profile of the respondents that captured; the highest level of education, years of work experience with PV, and professional category. Section B comprised items to be rated on the level of their impact. The respondents were asked to rank PV investment risk based on a five-point Likert scale using the following Likert scale [1= Not a risk; 2= Somewhat of a risk; 3= Moderate risk; 4= Extreme risk; 5= Very Extreme risk] and tick (√) in the spaces provided.

The finalized set of questionnaires was distributed to respondents mainly from the public and private sectors who are experts with PV in Ghana. The questionnaire was distributed to respondents via Google form. The questionnaire was initially piloted with four prospective respondents before administering it. This was to minimize uncertainty, receive feedback, and finalize the questionnaire. [36], theorise the targeted respondent and, their ease of reading the survey instrument should be critically considered when drafting and organizing the survey instrument.

2.4 Respondents' profile

The respondents' highest level of education was found to be a Doctorate degree; having obtained a significant level of work experience mostly above 5 years. Their experience with solar photovoltaic will go a long way to enhance the quality of statistics to achieve the study objectives. The survey sourced information from technical groups (Utility Company e.g. VRA, ECG, Installation Company, Energy Commission). There were also investors (individual home users, financial institutions example banks, pension funds, insurance companies Ministry of Finance). Moreover, the last professional groups were policy institutions (NGOs, International Development Agencies like USAID, IFC Energy Commission). These respondents were chosen because [31] concluded they play diverse and consistent roles from policy design and implementation from local to national level which are crucial.

Table 1. Questionnaire response rate

Respondent job title	No.	%	Level of Education	No	%	Period of work (years)	No.	%
Technical Experts	24	51.1	Diploma	2	4.3	Below 5	2	4.3
			Master's degree	3	6.4	Below 5	2	4.3
						11 – 15	1	2.1
			Undergraduate Degree	19	40.4	Below 5	16	34.0
						6 – 10	3	6.4
Individual Investors	17	36.2	Master's degree	5	10.6	Below 5	4	8.5
						6 – 10	1	2.1
			Undergraduate Degree	9	19.1	Below 5	9	19.1
			Diploma	3	6.4	6 – 10	3	6.4
Policy Institutions (NGOs)	6	12.8	Doctorate degree	1	2.1	6 – 10	1	2.1
			Master's degree	3	6.4	6 – 10	1	2.1
						Below 5	2	4.3
			Undergraduate Degree	2	4.3	Below 5	2	4.3
Total	**47**	**100**		**47**	**100**		**47**	**100**

While the sample size is relatively small, it provides adequate coverage of technical experts based on the central limit theorem [37] and given that participants with extensive experience on the topic – 5 to 15 years – were involved. As argued by [38] and [31], assessing respondents' profile, particularly their extended professional practice are crucial features in establishing the authority of respondents in research studies.

Secondary data of time series on the solar array capacity (kWp) were used to analyze the installation trend from 2013-2019. These years mark the beginning of the renewable energy Act, licensing regime, and framework on government policies to utilize solar PV to provide electricity to off-grid communities and industries efforts to adopt the technology to meet their energy needs. The study incorporates trend analysis to investigate the situation of solar PV installation and distribution in Ghana. Descriptive statistics (mean score and standard deviation) were used and the results were graphically displayed using, frequency table, pie chart, bar chart, and line graph. Descriptive statistics enable the comprehension of massive amounts of data.

Given the increasing dispersed data on PV installation in Ghana, the analyses carefully focus on high-quality data provided by the Ghana Energy Commission (EC). The EC is the only institution in Ghana mandated by law to regulate, grant license, and supervise all providers of energy in the country. Data on 1920 installations across all the ten (10) regions in Ghana from 2013-2019 were analyzed. All retrieved data were pre-processed, and cleaned, to remove duplication and irrelevant information. The following fields were created in the data for the purposes of this study to aid the analysis: installation date, name of client/company, town, region, solar array capacity (kWp), system type, and type of mounting. The processed data were then aggregated into various categories and analyzed using spreadsheets and International Business Machines Statistical Package for Social Sciences version 26 (IBM SPSS). The SPSS tool was used to estimate the central tendency (sum) and descriptive analysis (a frequency with percent) and a sum of variables (a type of mount, capacity, and system type). Results including trends in frequency and percentage of each installation over time, the predominance of installation by region, and cumulative installed capacity (kWp) were graphically displayed using an excel spreadsheet. A similar analysis was performed according to the system type (grid-tied, grid-tied (non-net metered), grid-independent, home system, solar power street light, solar water pump system, standalone), and type of mount (carport, ground mount rooftop, etc).

3. Results and discussion

3.1 Reliability test

The research adopted several pointers to quantity the latent variables (constructs) – risk to solar PV investment factors. The reliability level of the pointers to the constructs was explored. Findings revealed that there is high internal consistency among measurement indicators since the Cronbach's Alpha value (0.861) was bigger than the cut-off point of 0.70. This indicates that the indicators measured their corresponding constructs, signifying a high level of reliability.

3.2 Connected installed PV according to different systems types.

The study analyzed the data based on the classification of installations in Ghana according to various categories of systems. From the data in Table 2, standalone systems have the largest number of installations amounting to 44834.57 kWp – this represents 75% of the total. Grid-tied (non-net metered) system is the second-largest, with an installed capacity of 11695.17 kWp, representing 13.9%.

Table 2. Connected PVs in Ghana by system type

System design	Frequency	Percent	Capacity
Grid Connected	128	6.7	5386.26
Grid tied (Non-Net Metered)	241	12.6	10129.91
Solar power street light	4	0.2	1364
Solar water pump system	14	0.7	47.30
Standalone	1450	75.6	2336.25
Utility-Scale	3	0.2	42500
Unknown system type	79	4.1	2088.91
Total	**1919**	**100.0**	**63852.63**

Regarding regional distribution, the cumulative installed capacity in Table 3 shows that the Central region has the highest share of installation with a total installed capacity of 40419.97 kWp, representing 63.25%. This is because the region hosts the biggest solar plant in currently the country with an installed capacity of 20kWp. Greater Accra region is the next region with a higher share of 16898.54 kWp – representing 26.44%. The next region with a high volume of installation is the Upper East region with a total installed capacity of 2553.38 kWp, which represents 3.99%. Volta region has the least installed capacity with a total installed capacity of 12.11 kWp representing 0.30%.

3.3 Classification of PV according to mounted design

Figure 2 presents various types of solar PV installations, segmented into ground-mounted, rooftop, carport, and some design categories. The study used descriptive statistics to present the total installations, followed by a percentage of installation and total installed capacity (kWp) for each category. As inferred from the pie chart in Figure 2, the ground mounting design has the largest share of PV installed, an installed capacity of 43176.62 kWp representing 68%. The rest are rooftop (20%), carport (11%), and unknown (1%).

Table 3. Combine regional PV installation by various system type

Region	System Type						Total install Capacity
	Grid Connected	**Grid tied (Non-Net Metered)**	**Utility-scale**	**Solar power street light**	**Solar water pump system**	**Standalone**	
Ashanti	15(16.5)	8(8.8)	-	-	-	68(74.7)	544.07
Brong Ahafo	-	-	-	-	1(11.1)	8(88.9)	48.2
Central	4(10.0)	14(35.0)	2(5.0)	1(2.5)	-	19(47.5)	40419.97
Eastern	1(1.8)	26(45.6)	-	0	-	30(52.6)	917
Greater Accra	106(6.8)	179(11.5)	-	1(0.10)	-	1266(81.6)	16885.8
Nationwide	-	-	-	2(100.0)	-	-	1320
Northern	1(12.5)	2(25.0)	-	-	1(12.5)	4(50.0)	631.7
Upper East	-	1(5.6)	1(5.6)	-	12(66.7)	4(22.2)	2553.38
Volta	-	8(21.6)	-	-	-	29(78.4)	12.11
Western	1(3.8)	3(11.5)	-	-	-	22(84.6)	154.94
Total	128(7.0)	241(13.1)	3(0.20)	4(0.2)	14(0.8)	1450(78.8)	365.45

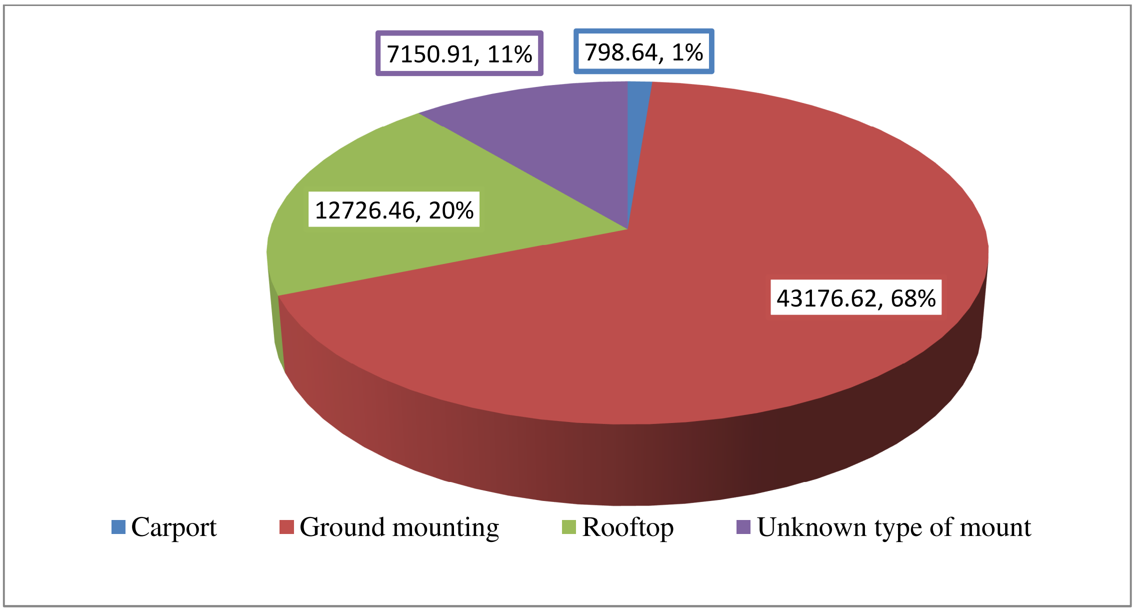

Figure 2. Connected PV in Ghana by type of mount

3.4 Regional installed PV distribution by capacity

In Figure 3, the regional distribution of PV installations is demonstrated, according to an installed capacity that exceeds 1000kWp from 2013 to 2019. This is important to differentiate between industrial and non-industrial users. Greater Accra, as the capital city, has a steady rise in installations from 2013 to 2019. The central region follows next. It has an intermittent installation that rose sharply in 2015 and slowed down in 2016. In 2017, installation began to rise gradually and peaked in 2018. The trend eventually deep in 2019. The upper east region is the third, having have its installation started between 2016 and 2017. The trend increased and picked in 2018 when it started to drop in 2019.

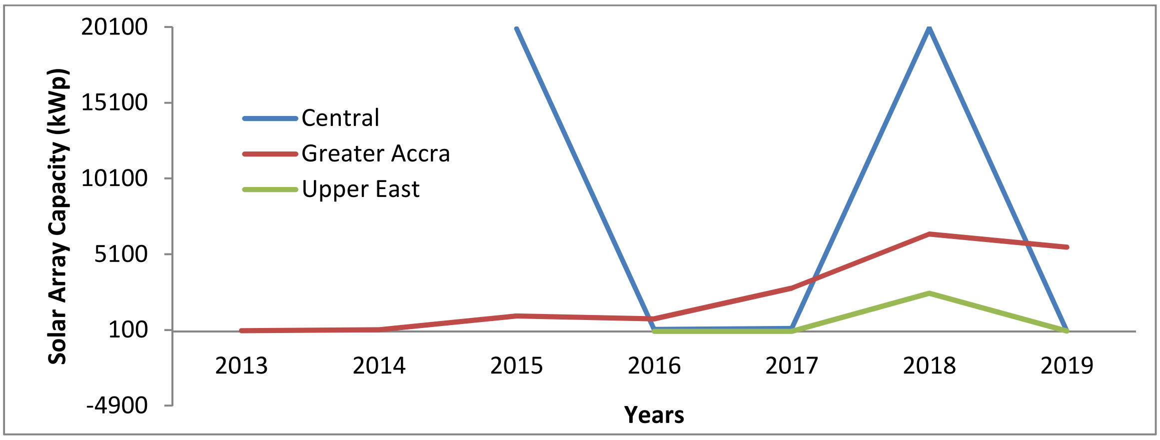

Figure 3. Regional PV distribution with capacity exceeding 1000kWp from 2013-2019

According to Figure 4, a regional distribution having installations less than 1000 kWp shows that there has been a gradual improvement of installation in eight (8) regions. The Ashanti region had a steady rise in installations from 2015 up until 2019. Followed by the Eastern region also has its fair share of the installations that started in 2015 and kept rising until 2019. The remaining regions had significant installed capacity, yet at intermittent levels.

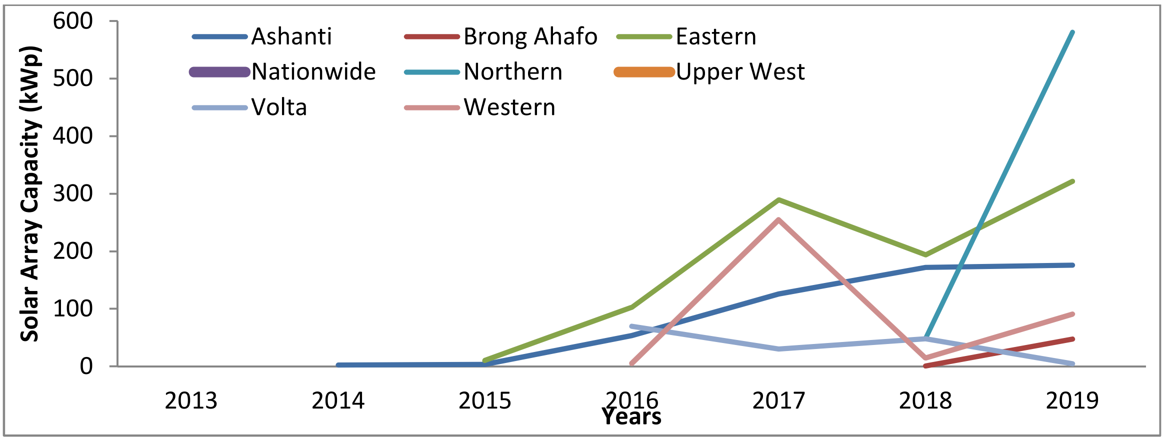

Figure 4. Regional PV distribution with a capacity below 1000 kWp from 2013-2019

4. Conclusion

This article explored the state of solar photovoltaic decentralization in Ghana from 2013 -2019. In doing so, the paper extended the work of [15] from 2013 to 2019 and shed light on human energy consumption through the lens of recent environmental changes on climate and public policy. Various historical perspectives of PV dissemination were also examined. Findings bring to light that in order to meet Ghana's industrialization objectives, reduce energy poverty and meet the SDGs [39], the exploitation of PV is vital, especially in the provision of electricity for deprived and island communities. This will help alleviate the perennial energy challenge in the country. Hitherto, a clear policy framework and effective implementation roadmap have remained missing in Ghana's RE vision [21]. That said, the Government of Ghana has recently shown clear policy commitment by the enactment of the country's renewable energy Act 835 backed by various interventions This includes the renewable energy technology transfer project, scraping of import duties on certain PV accessories,

creating a conducive environment for the technology transfer, implementation of capital subsidy for rooftop solar PV programme, and Sustainable Energy for All (SE4ALL) initiative just to name a few. This has resulted in a massive public and private investment within the PV industry in recent times.
PV installations and market penetration originate from conducive environment, for example the feed-in-tariffs (FiT), decent financing prospects, presence of skilled PV labour, and public acceptance of the technology[25]. Admittedly, this research identifies the major investment risk factors to be financing strategy, currency fluctuations, market obstructions, and regulatory framework and support mechanisms. This supports the argument by [40][31] [17][41]. The paper argued that addressing these factors would accelerate the decentralization of the technology and help to meet the governments RE policy agenda for 2030.

As other contributions of the study, six categories of PV installations designs, and four mounting types were identified. Findings also show that three regions have the highest number of installations. Policy analysis, business modeling, and geographically spread of the technology are the key implications of this research. The trend analysis of the installations shed light on some valuable understandings of the geographical spread of the PV technology at the regional levels. That is, the research identified the urban centers led by the Central region having the biggest installed capacity of PV installations. Energy poverty is predominant in rural villages and with this trend, it will be difficult to achieve universal energy access to meet the SDGs. The recommendations below are

- The government must encourage PV dissemination into deprived communities. This will enable the government to provide universal electricity access to its citizens.
- Governments support to financial institutions to enable them provide flexible long term financial backing to individuals and industries to be able to afford the technology. This will help meet our energy demands, prevent perennial energy crises, and cut down on the country's CO2 emission to improve the quality of life.

The study revealed a steady rise in both on-grid and off-grid installation year-on-year. On regional dissemination, the Central region has the largest share of PV installation followed by Greater Accra and Upper East respectively. With these findings, the research contributes to enhancing the awareness of global investors, entrepreneurs and financial institutions of PV project, conditions and investment that stimulate the growth and dissemination of PV in Ghana. From a practical perspective, this research provides a guide to private investors and the government to develop policies on stimulating RE investment.

This article has combined time-series data and literature to contribute to filling the theory gap on the state of solar PV dissemination, and its contribution to power generation in Ghana. In doing so, it has shed light on the financing obstacles in the sector. The findings demonstrate that there has been a massive increase in the rate of public and private PV investment in recent times compared to the early 2000s. Evidence from this paper has proved that the market is fully developed for commercial usage of solar PV. The paper proves a quantum leap of PV adoption in both individual homes, industries, and public institutions. It further suggests that, if this trend should continue at this rate, government will meet its RE target of 1094.63 MW by 2030.

This study is constrained to the PV industry in Ghana. Future research design to analyse the impact of PV adoption by private businesses, individuals, and on the national grid will significantly add to this knowledge gap.

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