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Climate-Informed Decision-Making in Data-Poor Environments: Managing Climate Risk Through Citizen Science Networks

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Climate change impacts have become a verifiable reality in most communities in Africa and have already shown its ruthlessness in derailing modest gains made toward sustainable development. While evidence of climate change impacts abounds, especially in key climate-sensitive sectors, not many people living in affected communities have the requisite knowledge, understanding and capacity to respond to emerging impacts. Most communities in Ghana and Africa, broadly, lack the requisite climate change knowledge resources to inform adaptation choices. Adaptation decision-making, in most cases, is reactive, speculative, and based on flawed assumptions and understandings of the climate change phenomenon. This is essentially because most countries lack the capacity to make climate-informed decisions which is also a function of the pervasive lack of efficient climate information services regime across Africa. The paucity of climate change knowledge and associated climate information services is undoubtedly an issue of institutional capacity; however, it is also a function of an enduring culture—a poor attitude toward data collection and application—in decision-making processes. Data-poor environment, or data-poverty, as implied in this work, therefore, broadly describes the absence of a data management culture in decision-making processes; however, specifically to climate change, it describes the lack of functional climate information services regime in local communities in Africa and how such omissions impede the ability of countries to make climate-informed decisions to support adaptation and resilience building. Focusing on Ghana, the paper problematizes the lack of climate information in local communities. The paper argues that Africa's climate crisis is as much a knowledge and learning challenge which requires new and innovative learning approaches to build capacities to facilitate the making of data-driven and climate-informed adaptation decisions in local communities. The paper, therefore, foregrounds citizen-science networks as avenues for community-focused and community-based climate knowledge co-producing mechanisms.

Keywords: climate risk, climate services, adaptation, knowledge, citizen science-production

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INTRODUCTION

Impacts of climate change have become pervasive and verifiably evident in many local communities across Africa (Hjerpe et al., 2014; Nyamekye et al., 2018). The diversity of impacts and the intensity of manifestations in key climate-sensitive sectors have signaled an ominous future prospects with devastating potential to derail Africa's sustainable development aspirations (Koubi, 2019; Steiner, 2019). The situation is particularly dire in sub-Saharan Africa (SSA) where existing vulnerabilities, weak institutions and low adaptive capacities converge with the brutal force of emerging climate change impacts to create more complex challenges (Mondal et al., 2018).

As impacts evolve to become more complex and destructive, countries such as Ghana have come to recognize the devastating potential of the threats posed by current and future climate change risks and have in the last few years intensified policy and practice efforts to manage such risks (Würtenberger et al., 2011; MESTI, 2013; Antwi-Agyei et al., 2018; Sam et al., 2021). While these efforts are underway in many countries across SSA, results have been slow or none in some instances (Luterbacher and Sprinz, 2018). Reasons are varied; however, it is a fact that most countries across SSA lack the requisite knowledge resources as well as institutional and technical capacity to implement effective and responsive adaptation measures (Lamb and Minx, 2020).

Of particular concern is the lack of functional climate information services (CIS) regimes to provide well-distilled, timely, relevant, accessible, and usable climate data to inform decision-making in key climate-sensitive sectors and at different levels of governance (Clements et al., 2013; Lugen, 2020).The lack of climate data to support adaptation-decision making is unfortunately widespread and remains a major barrier to current climate adaptation and sustainable development efforts in Africa (Laddey, 2011; Jones et al., 2015; Williams et al., 2021). Development decisions, for the most part, are made devoid of critical data to serve as evidence for well-informed interventions (Orlove et al., 2020).

This remains an enduring challenge in SSA's development efforts and can be linked to the generally poor attitude toward data collection and application in development decision-making. This attitude is what we describe here as "*data-poverty*"—a situation where state institutions consistently demonstrate no sense of value and urgency to data collection and application. The consequence is the creation of a situation that presents, perhaps, the most formidable obstacle to the effective management of climate-induced risks in SSA's sustainable development efforts (Vincent et al., 2017).

In this paper, we problematize the lack of climate-informed decision making in SSA's sustainable development aspirations. We argue that such situations exists primarily because many countries in SSA lack functional CIS regimes to provide the requisite climate data to inform decision making on current and future climate change impacts. We argue further that the paucity of climate information and other climate knowledge resources are part of an enduring culture and a debilitating practice which has incapacitated many African governments in their quest to effectively manage climate change risk for sustainable development. It is our contention, therefore, that data-poverty, as it implies a lack of data and as it relates to CIS, is negatively impacting proactive climate risk management (CRM) for effective adaptation planning in SSA.

Thus, while we speak generally about the lack of CIS or climate data in most SSA countries, we use Ghana as a reference to highlight a widespread institutional capacity problem which continues to infringe on the abilities of governments to initiate and sustain proactive climate adaptation programs to build adaptive capacity and resilience. Our desire is to make bold proposals as a contribution to current efforts to support climate risk management across sectors. More importantly, we call for the introduction of citizen science networks (CSN) as an innovative avenue for community-focused climate knowledge co-production and adaptation learning as an innovative approach to address both climate knowledge and adaptation learning deficits in local communities (Manteaw, 2020).

In doing so, we adopt a user perspective by employing the phrase "climate-informed decision-making" to imply decisions that integrate climate information as data and analysis products, forecasts, and climate change predictions. Climate risk is sometimes used interchangeably with climate impacts to imply the likelihood of any of the following: injury, damage, or loss caused by factors such as severe or extreme weather events; unusual seasonal variation such as heat waves or droughts; and excessive moisture or long-term changes in climate or climate variability (Seneviratne et al., 2012; Eckstein et al., 2021). CRM, as a recurring reference describes an approach to decision-making in climate sensitive activities with a view to maximizing the positives while minimizing the negative influence of weather or climate. In CRM, therefore, we make implicit inferences to adaptation as the "adjustment in natural or human systems to a new or changing environment" (Roka, 2019, p. 1).

MANAGING CLIMATE RISK IN DATA-POOR ENVIRONMENTS

CRM and adaptation strategies can minimize loss of life and damage to assets, infrastructure, and crop production from natural climate variability and extreme climate event. The effective management of climate risks therefore hinges on the effective use of climate information in adaptation planning and decision-making (Bowyer et al., 2014). It is about information, knowledge and learning which therefore makes the availability, accessibility, and usability of well-distilled climate science critical for proactive CRM for adaptation planning (Street et al., 2019).

It is from such a perspective that CRM has since emerged as a distinct area of activity within the wider field of climatology (McGregor, 2015). Its' focus is on the integration of climate and non-climate information to enhance decision-making processes in a wide range of climate-sensitive sectors of society (Räsänen et al., 2017). An effective CIS regime is therefore fundamental to CRM as well as for the pursuit of the goals of sustainable development (Steynor and Pasquini, 2019).

As climate impacts become more pronounced in local communities across SSA, and as efforts are intensified to address the combined challenges of climate change impacts and sustainable development, it has also become clear that the lack of relevant knowledge in the forms of timely, relevant, accessible, and usable climate information is impeding many countries in SSA from effectively managing current and future climate change risks (Laddey, 2011; Popoola et al., 2020; Williams et al., 2021).

Ghana, as a climate vulnerable country, is no exception and like many others in SSA, has come under the brutish impacts of climate change (USAID, 2017; World Bank, 2017; Nyamekye et al., 2018). Managing these climate-induced socio-ecological and economic risks imply knowing and understanding the complexities of the climate change phenomenon and having the knowledge and resource capacity to respond to observed and anticipated risks. As a matter of policy, therefore, and as part of the Government of Ghana's efforts to build adaptive capacity to manage both current and future climate change risks, various measures have since been put in place in different sectors and at different levels of governance (e.g., MESTI, 2013; National Development Planning Commission, 2017; Antwi-Agyei et al., 2018; World Economic Forum, 2021).

Results, however, have not been as expected; they have been slow or none in some instances (Würtenberger et al., 2011; Atampugre et al., 2021). There are some critical climate-sensitive sectors such as health, water resources, agriculture, energy, biodiversity, and many others who continue to suffer from the unrelenting impacts of climate change even under current adaptive decision-making efforts. This, though, is not indicative of ineffective adaptation efforts but an affirmation of the fact that adaptation in its varied forms take time, are context-specific and knowledge-driven.

Thus, while slow results many not necessarily be a basis to evaluate current efforts in Ghana, or elsewhere in SSA, there is ample reason to believe that the state of climate change knowledge and in particular the difficulties involved in integrating climate data in climate adaptation decision is a major impediment to effective adaptation. It is fair, therefore, from such a perspective, to conclude that the lack of adequate climate knowledge resources and the lack of understanding of the climate change phenomenon and impact manifestation obstructs proactive and effective climate-informed decision-making. Adaptation decision-making in key climate-sensitive sectors across SSA remain reactive, speculative and are premised largely on flawed assumptions and understandings of the climate change phenomenon which, in the long run, leads to wrong decisions and maladaptation (Yaro et al., 2015; Schipper, 2020).

Maladaptation as a result of poor decision-making is fundamentally a function of a lack of knowledge and in this regard, the lack of the requisite climate information and other knowledge resources to inform decision-making. These situations typify what we describe as data-poor environments and are characterized by generally poor attitudes toward data collection and application in decision-making processes for sustainable development. Such attitudes are regrettably widespread across Africa, especially in SSA and represent an institutional flaw and an enduring culture where governments, organizations, and communities either lack quality data, or fail to appreciate the value of the integration of well-researched data in decision-making processes (Bédécarrats et al., 2016; Shaffer et al., 2018).

While poor data collection and application in development decision-making remain counterproductive to Africa's sustainable development efforts (Antwi-Agyei et al., 2012; Niang et al., 2014), it is the extension of such attitudes and practices into CRM that has emerged as a worrying concern in an era of changing climatic conditions with consequential impacts. It is even more worrying considering the fact that that climate change and CRM are highly complex processes. This, ultimately, makes the effective management of climate change risk a learning issue and one which require conscious and intentional efforts of knowledge development and learning at different scales and levels.

CLIMATE INFORMATION SERVICES AS ADAPTATION LEARNING

The emergence of climate science as an unavoidable prerequisite for the effective management of climate change risks has highlighted the imperative for climate knowledge development and adaptation learning as critical components of any effort to effectively management climate risks (Steynor and Pasquini, 2019). This has become even more important as advances continue to be made in seasonal climate forecasts, decadal climate predictions and multi-decadal climate change predications (Suckling, 2018).

Advancements in CIS, especially in more advanced countries, continue to prove that when individuals, communities, and institutions get easy access to timely, predictive, reliable, and usable climate information, they become better equipped and capable to engage in proactive management of climate change risks for effective adaptation (Martínez et al., 2012; Guido et al., 2019). CIS, also referred to as climate services (Lugen, 2020), have since evolved to become an unavoidable prerequisite in CRM for adaptation decision-making (Hellmuth et al., 2011; Popoola et al., 2020).

In its different forms and interpretations, CIS functions primarily as a decision-support tool while focusing on the transformation of climate and weather-related data into tailored information and knowledge that enable users to make climate-informed decisions across different sectors and in diverse contexts (Steynor and Pasquini, 2019; Vogel et al., 2019). Its essence is to produce and provide customized, relevant, and usable climate knowledge for policymakers and vulnerable communities based on available climate information (Tall et al., 2018). And, it does so by integrating access to information, knowledge brokerage, and learning networks to facilitate climate knowledge distillation and uptake for proactive CRM (Dessai et al., 2009; Martínez et al., 2012; Brasseur and Gallardo, 2016).

Broadly, CIS is seen as an avenue for the development and provision of climate data through participatory and co-production processes (Hewitt et al., 2012; Capela Lourenço et al., 2015). While many definitions, as shown in **Table 1** above, have

TABLE 1 | Definitions of climate information services/climate services in literature.

Definition	References
Climate services seek to improve decision-making in a variety of climate-sensitive sectors, including health, food security, agriculture, water management, and disaster risk management, through targeted support, and provision of climate information.	Hellmuth et al. (2011)
Climate services encompass a range of activities that deal with generating and providing information based on past, present, and future climate and on its impacts on natural and human systems.	World Meteorological Organization (2011)
The transformation of climate-related data-together with other relevant information-into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counseling on best practices, development, and evaluation of solutions and any other service in relation to climate that may be of use for society at large.	European Commission (2015)
The provision of data and information on both weather conditions over the short term and climate events over the longer-term is referred to as climate information services	Serra and McKune (2016)
Climate information services provide weather and climate forecasts to local communities who can then use this information to proactively adapt their activities.	Gbetibouo et al. (2017)
Climate information services may be defined as services that provide climate information in a way that assists decision-making by individuals and organizations.	Machingura et al. (2018)
Climate services constitute the provision of information for climate-related (e.g., seasonal forecasts to multi-decadal projections) decision-making.	Street et al. (2019)
Climate information services require information gathered over longer periods of time (from years to decades) to inform longer-term decisions, such as a water utility company making investment decisions to ensure the viability of the business over the next decade.	Climate Investment Funds (2020)
Climate services, or climate information services, can be simply understood as the production and delivery of climate information to assist decision-making.	Lugen (2020)
Climate services provide climate information to help individuals and organizations make climate-smart decisions.	Dupar et al. (2021)

since emerged, one of the most instructive definitions has been that given by the European Commission in 2015 (European Commission, 2015), which defines CIS as:

> The transformation of climate-related data–together with other relevant information–into customized products such as projections, forecasts, information, trends, economic analysis, assessments (including technology assessment), counseling on best practices, development and evaluation of solutions and any other service in relation to climate that may be of use for society at large (p. 3).

A distinctive attribute of this and many other definitions has been the inherent imperative to customize climate services to suit the unique needs of a particular audience or end users (Tall and Njinga, 2013). This imperative is premised on the fact that CIS is context-specific and must be developed and deployed based on a certain familiarity, knowledge and understanding of the unique conditions and specific needs of a defined contest. Such familiarity enhances understanding and knowledge development, as well as facilitates customization of information to suit the unique needs of a particular locale. An efficient CIS is therefore place-based and place-responsive; it is predicated on usable knowledge and the fact that climate information is most valuable and usable when created with an understanding of the end-users' or decision-makers' local, social, and environmental context (Lemos et al., 2012).

"Knowing your context" has thus emerged as an organizing principle in CIS and requires scientists, and all involved in the development of climate data be guided by a desire to learn and a disposition to value local realities, differences, and particularities (Brugger et al., 2015). CIS is thus inherently a capacity building mechanism (Martínez et al., 2012); it is about knowledge development and learning to respond directly to CRM and adaptation learning requirements in local communities (Lugen, 2020).

The World Meteorological Organization has been at the forefront of the development and deployment of CIS around the world and has contributed to the development of specific attributes that have helped to define its usefulness (World Meteorological Organization, 2011). Among these attributes are, availability, timeliness, dependability, usability, credibility, authenticity, flexibility, and responsiveness to local particularities or needs (Vaughan and Dessai, 2014). These attributes have been particularly influential in the growing levels of interests and investment toward its continued development and deployment.

The World Bank remains a major advocate of CIS and continues to invest heavily in its development around the world and (World Bank, 2016, 2020). The Bank's interest is to support its development and deployment particularly in some of the most vulnerable regions of the world.

Despite increasing acceptance of CIS as a critical climate decision support tool around the world, there is concern about the difficulties some developing countries face in institutionalizing a functional and efficient CIS regime (Martínez et al., 2012; Clements et al., 2013; Lugen, 2020).

Ghana is no exception, and like most other SSA countries, have struggled to develop an efficient CIS regime to support current CRM efforts. This, as discussed earlier, is essentially because most countries in Africa and especially in SSA either lack the institutional capacity or the data management and deployment architecture that supports CIS at different levels

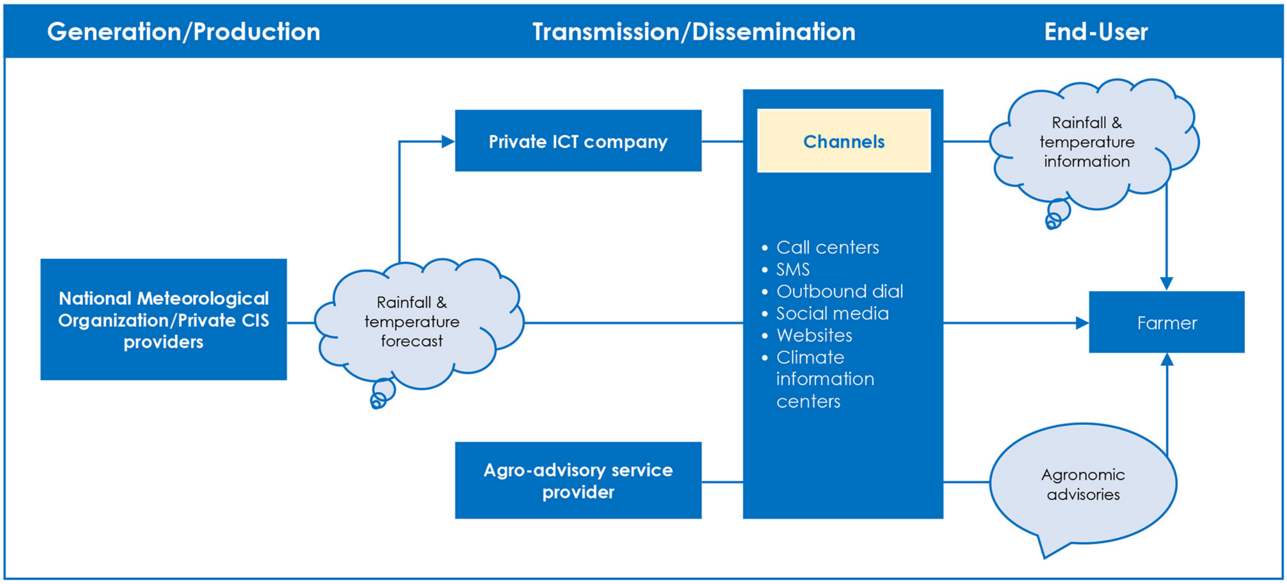

FIGURE 1 | Existing linear model of CIS production in Ghana produced by authors.

and scales (Niang et al., 2014; OECD, 2021). These are existing operational challenges and even though countries such as Ghana can boast of established national metrological agencies, whose mandate is to provide the requisite scientific, operational and organizational leadership in the development and deployment functional CIS, many of such agencies are limited in their capacities and as a result are unable to be efficient and effective in the provision of the required climate services.

CLIMATE INFORMATION SERVICES IN GHANA

Again, Ghana, like most other SSA countries, is highly vulnerable to both climate variability and climate change (Pachauri et al., 2014; USAID, 2017). This inherent vulnerability has attracted a new sense of urgency for the creation of the requisite institutional environment and capacity to support climate risk management for informed adaptation decision-making (Capela Lourenço et al., 2015).

Central to the effective management of climate change risks is the availability, deployment, and uptake of usable CIS to serve the unique needs of end users in specific places and contexts (Lemos et al., 2012; Tall et al., 2013). This responsibility lies within the remit of the government of Ghana and through its meteorological agency, the Ghana Meteorological Agency (GMet), which serves as the only recognized specialized entity mandated to collect, manage, and provide credible climate change information services to the entire country (Anaman et al., 2017).

Although the organization can boast of recent modernizations which have seen increases in investments to boost the development of regional weather stations and other technologies, the agency continues to face different institutional, structural, and operational challenges which, in many ways, have impacted its ability to deliver to its fullest potential (Shilenje and Ogwang, 2015; Anaman et al., 2017). What this means is that many climate-sensitive sectors such as agriculture, forestry, health, energy, transportation, disaster management, and many others are not well-served and so go about their activities and operations without the assured reliance on the services of the meteorological agency.

The consequence, as has become common in most of these sectors, is the lack of integration of climate information in sector-based decision-making. Decisions are driven largely by speculative information, historical trends, flawed assumptions, and wrong understanding of climate change impacts phenomenon. While this can be explained as a lack of technical and operational capacity, it is also a function of the enduring and endemic data-poverty culture which, as we have discussed, has created situations where people, communities and institutions are unable to access reliable data as knowledge to support adaptation planning and decision-making (Pane, 2013; Simon and Leck, 2015).

Challenging the Status Quo

As climate change impacts become more pronounced, and as the urgency for purposeful climate actions rise on the political agenda, the need for actionable climate knowledge to inform policy and practice, particularly at the local level, has emerged as a priority concern for national governments (Vogel et al., 2019). While Ghana undoubtedly face significant challenges in the development and deployment of reliable, usable, and context-relevant CIS to support decision-making, there have, however, been some modest efforts which all aim to rectify current weakness and gaps in CIS delivery. A number of these new efforts are either led by international development agencies, or driven by private sector entities who all go into some form of partnership arrangements with the national metrological agency to improve CIS delivery in Ghana.

This model represents the status quo which is generally linear. The National Meteorological Agency is the primary technical authority that produces climate information which is later disseminated through other agencies such as private ICT companies who act as intermediaries to transfer information through platforms or channels such as mobile phones, radio stations and climate information centers. Such processes are linear because it follows one predictable pattern which originated from the source of production to the eventual users.

Figure 2 as shown above represents what we see as the disruption of the status quo. It is an iterative and participatory process which even though maintains the technical authority of the Meteorological Agency, also allows for the inclusion of other participants in the validation of such knowledge. Most importantly, this proposed model emphasizes place-specificity and the critical importance of participatory scenario planning in local places. Climate data or information is therefore aimed at the unique needs of specific locations while it encourages the full participation of local non-scientists in the generation, validation of new knowledge.

The CARE Adaptation Learning Programme (ALP) is one such innovation that was aimed at addressing existing imbalances in access to climate data in Ghana. The program served as a multi-country learning program aimed at empowering local communities to make climate-informed decisions (Nottawasaga Institute, 2012). It used a participatory approach to ensure selected communities were fully involved from the bottom up as a way to change the power and ownership dynamics in a program like this.

As a way of deepening the programs's participatory nature, a three-component approach was adopted and managed largely by local people. The components were: Participatory Scenario Planning (PSP), Regional Impact Assessments, and the creation of Climate Information Centers in selected local communities. They were distinct, but integrated in their different functions to provide coherent platforms for multi-level and multi-sector stakeholder engagement process that engaged participants from local communities with different backgrounds, knowledge, experiences and expertise.

Participants in these components collaborated with expert climate scientists from the Ghana Metrological Agency (GMet) and climate adaptation policy experts to interpret short-term climate forecasts with a view to developing potential seasonal scenarios and advisories. Primarily, the program aimed primarily at addressing the climate information access and usability gap by directly targeting and involving local communities in the co-production and uptake of climate services (Hewitt et al., 2012).

The ALP and others of its kind that focused on climate-knowledge co-production were novel in Ghana and they introduced a new culture of climate adaptation social learning which increased awareness about climate change, as well as facilitated the development of simplified historical climate data that allowed local communities, and especially farmers, to appreciate the nature and extent climate variability and change in their communities. It also helped to build the capacity of local framers to work together with expert scientists to analyze local climate data to create plausible future scenarios.

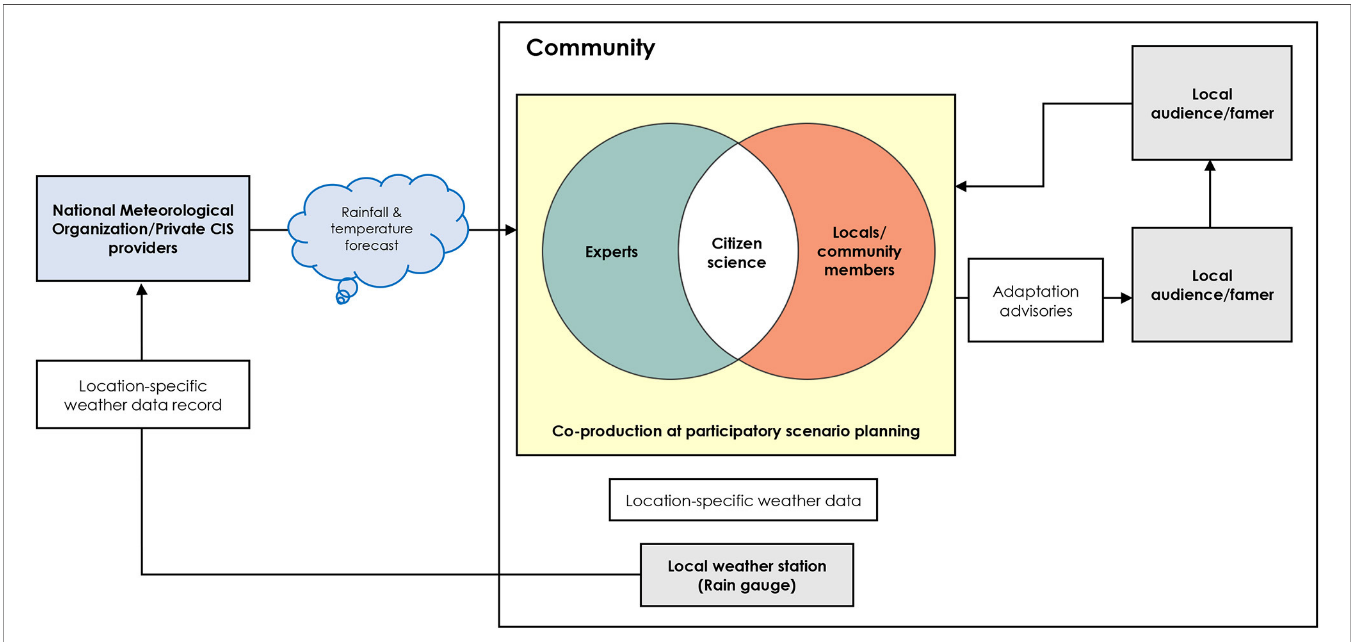

FIGURE 2 | A new climate information co-production and deployment model produced by authors to differentiate the status quo as in **Figure 1** from what is proposed.

Even more impressive, perhaps, was efforts to link generated climate information directly to mobile phones of rural farmers. As one of the many innovations that emerged out of the program, the transmission of climate information through mobile phones has since proved particularly instrumental in empowering farmers to integrate new knowledge and climate information in in their decisions. With such knowledge, farmers were also able to engage confidently in live radio call-in programs on climate change impacts and adaptation measures in their immediate communities. These were significant learnings that underscored the essence of social learning and climate knowledge co-production in the communities they worked.

Much as the programs were participatory and successful in bringing experts and lay people together for the co-production and deployment of climate information, the processes were top-down, largely, and expert-dominated. It failed to challenge existing linear models in any significant way. Limitations, notwithstanding, the CARE program was somehow successful in its ability to create awareness about climate change and in the mobilization of local participation in what could be described as climate change social learning.

Farmers, in particular, acquired the ability and confidence to participate in community-based scenarios planning and seasonal forecasting exercises to boost their understanding of the climate change phenomenon. While we hesitate to describe the model as a silver bullet, we acknowledge its ability to introduce novel learning opportunities in the quest to improve climate services delivery in Ghana and in particular how they empowered marginalized groups in making climate-informed decisions at the local community level (Assan et al., 2018; Adzawla et al., 2019).

CITIZEN SCIENCE AS CLIMATE KNOWLEDGE CO-PRODUCTION

Citizen Science

The last few years have seen significant increases in the adoption and application of Citizen Science approaches in diverse development sectors around the world (Dickinson et al., 2012; Cooper et al., 2014; Hecker et al., 2018; Land-Zandstra et al., 2021). Its essence is to equalize knowledge development processes by blurring the boundary lines between trained and untrained scientist. CS, therefore, begins from the premise that everyone is endowed with unique knowledge and capabilities which if appreciated and carefully harnessed may contribute significantly to knowledge development. Even though CS as knowledge co-production approach is relatively new, there have been different variants across time and history and with an equally diverse focus on topics ranging from public health, water management, disaster risk management (Simon and Leck, 2015), agriculture extension, forest management and many more (Wiggins and Crowston, 2011; Bonney et al., 2014; Franzoni and Sauermann, 2014; Eitzel et al., 2017).

As an emergent avenue for community-focused participatory social learning, CS can be described as a process in which communities and individuals are involved in designing a research question, performing scientific experiments, and engaging in issue exploration with minimum involvement of professional scientists (Eitzel et al., 2017). It is essentially a collaborative learning and action process where trained experts and non-experts, also known as community-based organic intellectuals (Thalla, 2018), come together as equal partners with mutual respect to engage in "scientific" explorations of specific issues of common concern (Mourad et al., 2020). By its very nature, CS offers what many now describe as an open software and hardware approach through its rare ability to create opportunities for engagement and equal participation in knowledge creation (Kythreotis et al., 2019; Land-Zandstra et al., 2021).

Scholars and practitioners from different fields of studies continue to give increased attention to CS for its ability to "democratize" science and scientific learning (Dickinson et al., 2012; Hecker et al., 2018). This idea to democratize science, according to Bonney et al. (2014), originates from the 2002 publication of Alan Irwin's book: *Citizen Science: A Study of People, Expertise, and Sustainable Development* (Irwin, 2002) in which Irwin described the primary goal of citizens science as the creation of more active "scientific citizenship" in decision-making processes.

While some see CS primarily to increase the productivity of traditional scientific research, others see it as an opportunity to open science up to non-traditional institutions and by doing so provide opportunities for amateur or non-scientists to take advantage of the unfettered scientific citizenship, created to influence change and development in different ways (Irwin, 2002; Nielsen, 2020). Various exciting trends in CS have been recorded worldwide and all have been relatively successful in bringing several lay participants from within and beyond different backgrounds and countries to engage in citizen science (Tauginiene et al., 2020). The motivation for its application in science and for the refinement of knowledge for use in different communities and contexts have been varied, but convincing enough to challenge the exclusivity myth that has surrounded science for a while now.

Climate Knowledge Co-production

The use of CS to study climate change impacts has emerged to strengthen current calls and efforts toward community-focused knowledge co-production processes that build capacity for climate action at the local community level (Spellman et al., 2018; Kythreotis et al., 2019; Bremer et al., 2019a; Semjanová, 2020). Most of current knowledge co-production works have focused mainly on building scientific understanding of climatic change through collaborative and participatory studies of climate-induced impacts in local ecosystems (Dickinson et al., 2012; Cooper et al., 2014). The underlying essence of co-production efforts is to equalize knowledge development through the creation of equal learning partnerships between scientists and community-based practitioners (Turrini et al., 2018).

It is from such a perspective that knowledge co-production in CS has emerged as a promising procedural theory that enhances understanding of the science-society interface and how local people could work closely with scientists to co-produce context and purpose-responsive knowledge (Bremer et al., 2019b). Co-production mechanisms serve as knowledge exchange mechanisms that challenge the dichotomized notion of climate knowledge producers and "end users". "End user", from a CIS perspective, has assumed a localized interpretation which ascribes an unequal relationship between knowledge producers and users (Lemos et al., 2012; Harvey et al., 2019).

The popular use of the phrase "end user" assumes homogeneity of context by paying little or no attention to the underlying requirement of customization and contextuality in CIS delivery. The "end user" mentality is not only counterproductive to the ideals of participatory knowledge co-design and co-production as represented in the philosophy of CS, but it is also inherently patronizing while failing to realize that:

> Living creatively with climate change will require re-linking larger scales of scientific representation with smaller scales of social meaning. How, at the levels of community, polity, space, and time, will scientists' impersonal knowledge of the climate be synchronized with the mundane rhythms of lived lives and the specificities of human experience? (Jasanoff, 2010, p. 238).

Responses such as Jasnoff's are suggestive of a growing acknowledgment of flaws in the current linear model of climate knowledge production and dissemination and particularly as they pertain in places such as Ghana. Such flaws, as pointed out in the CARE Adaptation learning Program, affirm the underlying need for a new models of climate knowledge creation and one that acknowledges end-users as equal partners and valuable bearers of critical knowledge of the places they live. A major concern with the linear model of climate knowledge production is its' condescending assumption that the "end-user" lacks "climate knowledge" and that all that is required is to "fill up" what is perceived as a deficit knowledge gap with ready-made information, or to bridge the knowledge divide with some token engagements (Vogel and O'Brien, 2004; Tall and Njinga, 2013).

Token engagements, as has become known in such exercises, have been on the ascendency, somewhat, as the need to include users in the knowledge production processes intensify (Bremer and Meisch, 2017). If nothing else, the new rush to engage "end users" in climate knowledge production further exposes existing flaws in dominant linear models. That said, some of these engagements remain intrinsically superficial and top-down as they are manipulated by some experts scientists to publicly demonstrate their acknowledgment of non-experts as "partners". These are problematic and they undermine CIS's guiding mantra of "knowing your context" by prioritizing the serving of a finished products by experts. Such models remain fundamentally problematic and therefore, require new knowledge production partnerships that are based on equality and mutual respect.

TOWARDS CLIMATE-INFORMED DECISION-MAKING IN AFRICA

While the climate crisis worsens, efforts to build adaptive capacity and resilience have, unfortunately, been reactive and slow in most instances both in Ghana and across SSA. This is happening also at a time when climate risks have become more pronounced and widespread in many local communities. Indeed, some of these slow or non-actions are attributable to a diversity of integrated reasons which, invariably, impede proactive CRM. Prominent among them is the lack of knowledge resources and the capacity for local people to collect timely, relevant, and actionable climate data to inform decision-making in different sectors and at different levels.

Such situations, as we have discussed, are enduring and have overtime amplified the problem of data-poverty as a formidable impediment to climate knowledge development and effective adaptation planning. As climate change impacts become more inhibitive in local communities in some of the developing regions of the world, it has also become an urgent imperative for countries such as Ghana to explore new ways of empowering people to take control and lead adaptation processes in their communities. This remains a challenge and one which most governments have committed to addressing, but with little or no results so far. Meeting this challenge will require radical new approaches to expand opportunities for knowledge co-production and learning in local communities. It also requires that CRM as an adaptation effort, is premised on the principle of social learning to reaffirm climate adaptation is a learned process.

It is against this background that we propose the creation of Citizen Science Networks (CSN) in local communities in Ghana, and across Africa, to serve as a new social learning mechanism for climate knowledge co-production and exchange. By "networks" we highlight the place-based and territorial attributes of climate change impacts; we acknowledge the fact that climate change impacts are place and context-specific and require cross-territorial learnings and knowledge exchanges to facilitate a full appreciation of the diversity of adaptation choices.

CSN, as we suggest, therefore, will function as communities of practice in different locales to serve the purpose of democratizing climate knowledge production through partnership learning and actions. Operating, therefore, on the philosophy of "knowing your context", CSN will aim to bridge the gap between experts and so-perceived "end-users" in local communities by creating an open and equal platform where the right blend of experts and non-experts will work in collaboration to ask the right questions, define problems and act together to explore the right climate information to support adaptation choices.

It is our firm conviction that the idea of CSN, if embraced, as an avenue for climate change risk management will create a social architecture that facilitates cross-sector and cross-territoral learning and knowledge co-production process. Such an architecture, we envisage, will democratize climate knowledge development processes to build the requisite capacity for local communities and institutions to integrate climate information in adaptation decision-making at the local community level. Ultimately, it is our expectation that CSNs in local communities will challenge existing linear climate information models through participatory approaches that bring both experts and non-experts into equal learning partnerships.

AUTHOR CONTRIBUTIONS

BM conceptualized the paper, defined the outline and led in the authorship, and including reviewing and streamlining the final manuscript. A-BA provided experiences on climate information services in Ghana, worked in and engaged stakeholders the sector for decades, and led in authoring the section on Climate Information Services In Ghana. BA contributed on helping to design the figures used in the paper as well as contributing to authoring the section on 'Citizen Science As Knowledge Co-Production'. KE contributed on reviewing literature on the state-of-the-art on climate information services and citizen science and authored the concluding section of the paper 'Towards Climate-Informed Decision-Making in Africa'. All authors contributed to the article and approved the submitted version.

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