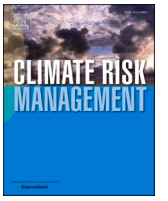
Climate Risk Management 51 (2026) 100780

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm



Assessing perceptions of various stakeholders on climate change mitigation and adaptation in rural areas in Cameroon: The use of ICTs

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ARTICLE INFO

Keywords:
Climate change
Informatics
Communication technologies
Adaptation
Agricultural production

ABSTRACT

The threat of climate change is a global issue that requires international attention. These impacts affect agricultural production, with smallholder farmers recording lower yields as rainfall patterns change and the temperatures increase. This study aims to provide a comprehensive understanding of the potential contributions of information and communication technologies (ICTs) to climate change adaptation and, where applicable, mitigation efforts in rural areas, with a specific emphasis on agricultural adaptation. This qualitative case study was based on three focus group discussions with 30 smallholder farmers in the Koung-Khi department of Western Cameroon. Participants were selected purposively, and the data were analysed thematically using NVivo software. The results indicate that the absence of modern technologies limits rural communities' ability to adapt to climate change. Additionally, many rural communities require more financial resources to invest in modern technologies to help them adapt to climate change-related impacts. To address the high risks of climate change to agriculture and food security in rural settings, national policies and institutions should develop ICT-based national programs for smallholder farmers and producers. People have gained a deeper understanding of how modern technologies can adapt to climate change, enabling them to diversify and produce crops under various circumstances. Governments and development agencies should promote and support rural adaptation and mitigation by investing in modern technology.

1. Introduction

Globally, agriculture is experiencing the impact of climate change, primarily in rural areas (Appiah and Guodaar, 2022). According to Clarke et al. (2022), changes in precipitation, temperature increases, and extreme weather are indicators of climate change. These changes affect crop and livestock production and, thus, farmers' livelihoods (Clarke et al., 2022). The Intergovernmental Panel on Climate Change 2022 states that climate change could reduce global crop production by 2050. In sub-Saharan Africa, climate change is already affecting agricultural production, with farmers recording lower yields owing to changing rainfall and increased pests and diseases (Nkem et al., 2011).

Therefore, rural farmers require adaptation strategies to deal with the effects of climate change. According to Edger et al. (2009),

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https://doi.org/10.1016/j.crm.2025.100780
Received 21 April 2025; Received in revised form 18 November 2025; Accepted 8 December 2025
Available online 11 December 2025

adaptation involves changing circumstances that alter attitudes, practices, or agricultural technologies. Modern science and technology are crucial for adapting to and mitigating climate change (Matos et al., 2022). IPCC (2023) argued that technological advances can reduce greenhouse gas emissions and enable robust agricultural systems to respond to climate change. Farmers in areas vulnerable to climate change use various adaptation strategies, such as alternate planting days, drought-tolerant crops, and conservation agriculture (Nkem et al., 2011). Within the framework of addressing climate change through adaptation and mitigation, science and technology are integral components that play a pivotal role in these efforts.

Adaptation to climate change in Africa, especially in the sub-Saharan region of Cameroon, has become a pressing concern that requires prompt action (Tenzing and Conway, 2022). The dependence on natural resources in this region highlights the significance of efficient communication in the local management of these resources. Information and communication technologies (ICTs) have significantly improved local livelihoods, particularly through initiatives such as Internet radio, social networks for indigenous forest management, local organic markets, and training programs focused on environmental issues (Kausar et al., 2023). The substantial reliance on natural resources in this region's economies is crucial for vulnerable communities' ability to adjust to the adverse effects of climate change.

Since the early 2000s, Africa has undergone a notable transition toward adaptation strategies and governance processes that foster innovation and stakeholder inclusion in climate change (Tenzing and Conway, 2022).

This evolution highlights the growing importance of ICTs in mitigation efforts, adaptation strategies, and management of other climate-related challenges in developing regions.

This study examines the West Cameroon region in this context. This study established the socioeconomic and demographic profiles of participants to enhance understanding of how ICTs can facilitate adaptation to climate change. While ICTs can support both climate change mitigation (e.g. reducing emissions) and adaptation (e.g. improving resilience), this study focuses primarily on adaptation strategies relevant to smallholder agricultural communities.

This study critically examines the challenges of using modern technologies and scientific advancements in agriculture in the context of climate change. The incorporation of ICTs into adaptation strategies is crucial for empowering local communities. ICTs improve decision-making processes in natural resource management and agricultural practices by facilitating access to information and resources (Choruma et al. 2024). Additionally, ICTs can enhance community engagement and collaboration among stakeholders, thereby reinforcing resilience to climate-related shocks (Khan et al., 2024). However, various obstacles impede the efficient application of ICTs in climate change adaptation efforts. These factors include restricted access to technology, insufficient infrastructure, and a deficiency in digital literacy among older demographics (Omweri, 2024). Addressing these barriers requires targeted interventions to improve education and training programs tailored to local contexts.

1.1. *Theoretical framework*

This study is grounded in the Diffusion of Innovations Theory (Rogers, 2003), which explains how new technologies, such as ICTs, spread within a social system. This theory provides a useful lens for analysing how rural farmers adopt, use, or reject technological tools for climate change adaptation. Factors such as perceived usefulness, complexity, trialability, and compatibility influence adoption decisions. Additionally, the Sustainable Livelihoods Framework informs the analysis by considering how ICTs can strengthen farmers' access to livelihood assets (human, social, natural, physical, and financial capital), thereby enhancing their resilience to climate shocks. These theoretical lenses support both the methodological design (focus groups) and the interpretation of farmers' experiences and adoption behaviour. The combination of the Diffusion of Innovations Theory and the Sustainable Livelihoods Framework provide a way to examine the role of ICTs in rural climate adaptation in a more organised manner. These frameworks facilitate the examination of smallholder farmers' perceptions, adoption, and utilisation of technical breakthroughs, especially in relation to climate-induced difficulties.

Following these theoretical underpinnings, the subsequent literature review utilises global and regional research to contextualise the function of ICTs in climate change adaptation and mitigation in developing countries. It emphasises how contemporary science and digital technologies have been used to bolster agricultural resilience, while also pinpointing current deficiencies that this research aims to rectify in the Cameroonian setting.

1.2. *Literature review*

In many parts of the world, several examples of science and technology facilitate climate adaptation and mitigation (Abbass et al., 2022). For example, weather forecasting technology helps farmers make informed planting and harvesting decisions (Kumari and Muthulakshmi, 2024; Getahun et al., 2024). Similarly, crop improvement and conservation agriculture help farmers cope with the effects of climate change (Kodaparthi et al. 2024). The Sixth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (2023) suggests that modern science and technology, such as precision agriculture, climate-sensitive agriculture, agroecology, and climate information management, can help adapt to and mitigate the effects of climate change. Precision agriculture is an emerging technology that uses satellite imagery, drones, and sensors to provide farmers with real-time information on weather, soil moisture, and crop health (Surendran et al., 2024; Sangeetha et al., 2024; Usama, 2024). These technologies enable smallholder farmers to make informed decisions regarding irrigation, crops, and pest control, increase crop yields, and reduce water and fertiliser use (Shaikh et al., 2022). Climate-sensitive agriculture combines three objectives: improved productivity, adaptation to climate change and reduced greenhouse gas emissions (Katel et al., 2022).

This approach uses sustainable land management practices, such as conservation agriculture and agroforestry, to increase soil

carbon sequestration and reduce greenhouse gas emissions (Kamyab et al., 2024; Mali et al., 23023; Kumar et al., 2023).

Agroecology is a scientific approach to agriculture that emphasises the integration of biological principles into agricultural systems (Gliessmann et al., 2022). This method uses different cropping systems, such as intercropping and crop rotation, to increase soil fertility and reduce the use of fertilisers and pesticides (Gliessmann et al., 2022). Agroecological practices promote biodiversity conservation and climate change adaptation by enhancing ecosystem services, such as pollination and natural pest management (Ewert et al., 2023). In addition, weather data processing provides farmers with more accurate and timely weather forecasts and information (Muema et al., 2018; Georgeson et al., 2017).

These technologies enable farmers to plant and harvest crops, manage water resources, and adapt to climate change impacts, such as droughts and floods (Muema et al., 2018). Similarly, Wang et al. (2024) asserted that numerous advanced satellite communication systems enable agricultural activities. Singh et al. (2022) also agreed that satellite communication technology is crucial for monitoring agricultural products.

By leveraging satellite communication systems, farmers and agricultural professionals can access a range of data and information to make more informed decisions regarding their operations (Wang et al., 2024).

Advances in the accuracy of satellite images have also allowed increasingly detailed analyses of natural phenomena and human activities, including land use for agricultural purposes (Getahun et al., 2024). Interest in the use of satellite data in agriculture has grown with the emergence of the Sustainable Development Goals, particularly environmental protection and food security (Ziesche et al., 2023). Sensors and connected objects (mobile phones, computers, and connected watches) allow real-time information analysis, machine automation, remote precision irrigation, rapid identification, and appropriate treatment of plant and animal diseases (Ziesche et al., 2023).

Africa's future hinges on its agriculture's ability to provide food security for its expanding population while addressing the additional risks posed by global warming (Bedasa & Deksisa, 2024). However, adapting rural societies to climate risks is key to meeting this new challenge (Magwegwe et al., 2024). Considering the close links between vulnerability in the face of climate change and achieving sustainable development targets in developing nations, the contribution of ICTs to empower the process of adapting rural populations to climate change will be a significant challenge (Eisenmenger et al., 2020).

In agriculture, droughts, floods, and reduced yields resulting from climate change can cause food shortages, malnutrition, and various challenges in rural areas (Onyeaka et al., 2024). In this context, ICTs can support agricultural training services by expanding employment in rural and marginalised areas in developing countries (Choruma et al., 2024). In this regard, Benyam et al. (2021) argue that information technology plays a significant role in food security beyond the production and display of information on food logistics, storage, distribution, and consumption.

It can strengthen rural local knowledge, crop diversity, and productivity under varying climatic conditions (Choruma et al., 2024). According to Adeola et al. (2023), ICTs can also strengthen the capacity of institutions at the national level to facilitate effective local adaptation practices.

Social information technology, through geographic information and positioning (GIS) software and applications such as modelling, can assist the physical environment of social systems in adapting to climate change (Mohanty et al., 2020). These activities can help develop protection strategies and identify optimal locations to ensure that self-sustainable agricultural systems are robust and safe (Mohanty et al., 2020). From an economic perspective, information technology can support institutions that must strengthen climate-resilient systems, support social networks, and facilitate agricultural communication (Aithal and Aithal, 2024). They can improve communication in social networks, increase self-connections, and strengthen mutual trust, shared norms, and values.

They can facilitate access to more comprehensive assets and support the ability of livelihood systems to recover from climate-related events (Mohanty et al., 2020). Information technology can increase the available resources by combining remote and local processing (Okundamiiya 2021). By examining the perspectives of various authors and analysing case studies, this study provides a comprehensive understanding of the contributions of modern science and technology to climate change adaptation and mitigation efforts in rural areas. Therefore, this study aims to explore and describe the multifaceted contribution of information and communication technologies (ICTs) to climate change adaptation and mitigation strategies in rural areas. It examines how mobile devices, televisions, radios, and weather forecasting systems augment rural exchanges to adapt to climate change.

Cameroon serves as an intriguing case study for this research because of its extreme vulnerability to climate change. The significant role of agriculture in the economy compounds this vulnerability. The diverse agricultural and agro-ecological sectors of the country present unique challenges and opportunities. This context is suitable for examining the potential role of ICT in climate change mitigation and adaptation. Cameroon can serve as a centre for the integration of technological advancements into environmental practices.

Thus, examining this dynamic can yield significant insights into Cameroon and beyond. This applies to other developing countries that face similar challenges.

Investigating climate change in rural Cameroon through the lens of ICT adoption presents a promising approach to enhancing agricultural resilience in rural Cameroon. This approach can enhance flexibility and mitigate the risks associated with climate change effects.

The importance of this study lies in its ability to inform decision-makers and stakeholders about effective strategies for integrating modern technologies to adapt to a changing climate.

In this context, this study aims to provide a comprehensive understanding of the potential contributions of information and communication technologies (ICTs) to climate change adaptation and, where applicable, mitigation efforts in rural areas, with a specific emphasis on agricultural adaptation.

This study explored the role of Information and Communication Technologies (ICTs) in addressing climate change in rural Cameroon. Specifically, this study seeks to achieve the following objectives:

1. Assess smallholder farmers' perceptions of the contribution of ICTs to climate change adaptation and mitigation.
2. Identify the types of ICT tools most used in rural areas of Cameroon for climate resilience purposes.
3. Analyse the socio-demographic factors influencing the use and adoption of ICTs in climate change responses.
4. Examine the challenges and barriers to ICT implementation in rural areas for climate adaptation.
5. Policy and practice recommendations are proposed to improve ICT integration in rural climate-action strategies.

This investigation was directed by the following research questions: 1. What are the perceptions of smallholder farmers in rural Cameroon regarding the role of ICTs in climate change adaptation and, where relevant, mitigation? 2. Which ICT tools are most frequently employed in rural settings to facilitate climate-resilient agricultural practices? 3. How do socio-demographic variables, including age, gender, educational attainment, and farming experience, affect the adoption of ICTs for climate change responses? 4. What obstacles and impediments hinder the effective utilisation of ICTs in climate adaptation initiatives within rural Cameroon? 5. What policy and practical avenues exist to improve the integration of ICTs into rural climate-action strategies?

This study explored the contributions of ICTs to climate adaptation strategies in rural Cameroon, focusing on smallholder farming communities. Despite existing research on ICTs in African agriculture, little attention has been paid to how demographic and gender-based differences affect local-level ICT adoption for climate change adaptation.

This study addresses this gap by focusing on Koung-Khi, a region with distinct agroecological characteristics, high rural ICT ownership, and limited digital literacy (DL). This context provides a unique perspective for assessing the real-world applications of ICT. This study advances practice by offering policy-relevant insights into integrating ICT tools into rural adaptation strategies and contributes theoretically by contextualising ICT use within the socio-cultural barriers in sub-Saharan Africa. This study draws on the Diffusion of Innovations Theory (Rogers, 2003) as a theoretical framework to understand how smallholder farmers in Cameroon adopt ICT tools for climate adaptation.

The theory helps explain the adoption process, including awareness, persuasion, decision, and implementation, which aligns with the observed variations in ICT use based on age, gender, and education. The structure of this paper provides a comprehensive understanding of this topic.

The introduction explains the context of ICTs and their importance in climate change adaptation and mitigation in rural areas. Following the introduction, the literature review critically examines existing research and studies on the contribution of ICTs. The paper then presents the research methodology used for data collection and analyses. The results and discussion section synthesises and contextualises the main findings. This paper concludes with a summary of the key insights, implications for policy and practice, and future research opportunities. This structure ensures the flow of meaningful information, facilitating a comprehensive understanding of the complex interactions between ICTs and climate action in rural contexts..

2. Methodology

A literature review was conducted to inform the study design and contextualise the findings. It was not used as a data source for the empirical analysis. Therefore, the review strategy and empirical data collection are presented separately in this section. This study was conducted in Cameroon, a country in Central Africa, mainly in the Gulf of Guinea, with a population of 28,6 million. This study was conducted in the western agroecological zone of Cameroon, specifically in the Koung-Khi department (Fig. 1). This research focuses on the various terrains and wildlife that make this region unique and fascinating. This region covers an area of 353 km^2 and houses approximately 70,600 inhabitants (National Institute of Statistics, 2019). Agriculture plays a vital role in the department of Koung-Khi, which encompasses the three districts: Poumougne, Bayangam, and Demdeng (Fig. 1). This region is predominantly rural, with approximately 98 percent of households relying on agriculture for subsistence.

The authors used the following electronic databases for literature searches: Web of Science, PubMed, ScienceDirect, and Scopus. The authors accessed electronic databases through the University of the West of Scotland Library System and Hamburg University of Applied Sciences. Furthermore, the authors manually searched the grey literature using Google Scholar as an additional supporting database. This literature review was narrative rather than systematic. The aim was to provide a contextual background for the research and support the design of the focus group discussion themes. No formal systematic review methodology (e.g. PRISMA) was used in this study, and the related Medical Subject Heading (MESH) keywords were informatics, communication, modern science, technology, climate change, adaptation, mitigation, and rural areas. For this study, only published journal articles on related topics in English were used. The searched items were from published journals on the subject with no year limit. These published sources were further filtered based on relevance, so that only the most appropriate were selected and used for the study.

Accordingly, the authors focused on re-evaluating existing claims and reports, instead of gathering and analysing newly collected field data.

A case study with a qualitative approach was applied through focus group discussions to generate qualitative information from smallholder farmers about the contribution of informatics and communication technologies to the adaptation and mitigation of climate change in rural areas. In summary, 30 smallholder farmers, comprising 15 males and 15 females, participated in three focus group discussions. Prior to the group discussion, the participants completed a short demographic survey to collect individual information such as age, education level, and farm size. The descriptive statistics are presented in Table 1. No individual interviews were conducted, and all qualitative data were generated through structured focus group discussions. A survey was conducted to select the smallholder farmers who participated in discussions. The equal representation of male and female participants (15 each) was a

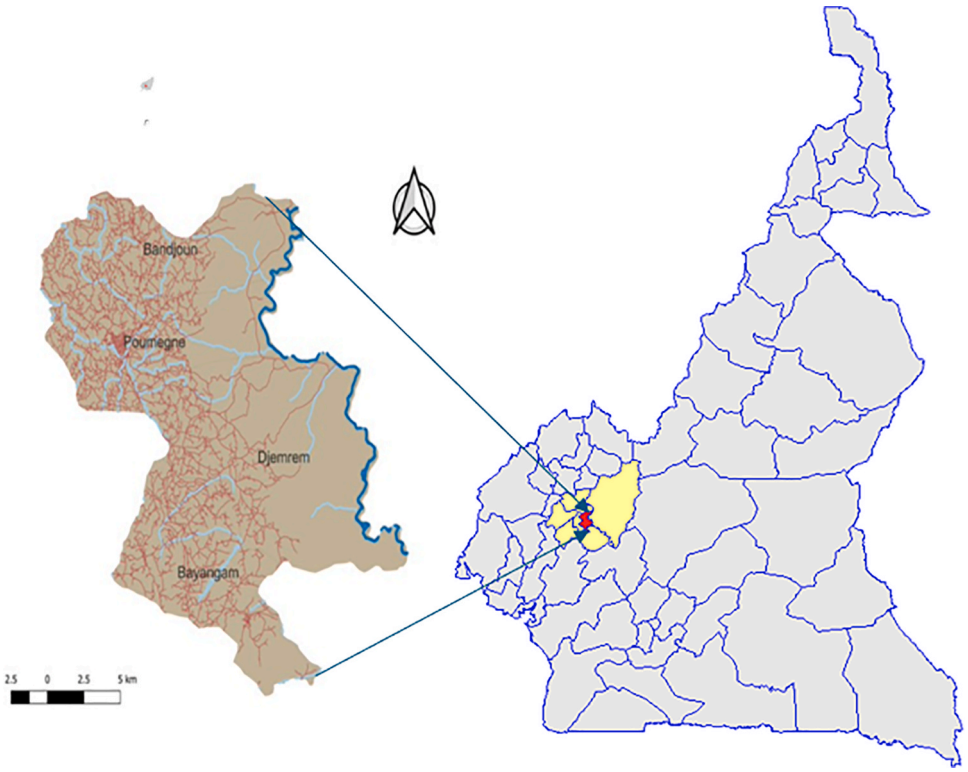


Fig. 1. Location of the case study in the western region of Cameroon.

deliberate strategy to ensure inclusive and balanced perspectives across gender. Although not statistically representative, the survey used a purposive sampling technique targeting farmers who were familiar with ICTs in farming contexts and willing to participate. This non-probability sampling was based on the participants' experience in agriculture and their ability to engage in group discussions on ICT-related issues. They were selected based on their knowledge of the topic and ability to use information and communication technology tools efficiently, including the Internet, mobile phones (smartphones), radio, and television. The focus group discussions were conducted in the districts of Poumougne, Bayangam, and Demdeng in the western region of Cameroon. Each discussion lasted for 40–60 min. Several questions framed the discussion, covering (1) the contribution of modern science and technology to climate change adaptation and mitigation in rural areas, (2) the digitalisation of agriculture in rural areas, and (3) the challenges and solutions to these issues. The data from the focus group discussions were analysed thematically to better understand the contribution of informatics and communication technologies in mitigating and adapting to climate change.

With the participants' consent, the discussion was recorded on an audiotape and transcribed from French to English with the aid of proficient local language transcription experts. The translation process involved two bilingual experts to ensure the accuracy and consistency of the translation. One expert translated the content, while the second reviewed the translation for fidelity to the original meaning and accuracy. Discrepancies were resolved through discussion and consensus.

We imported transcriptions and field notes into QSR NVivo 14 software to streamline the coding process for the thematic analysis. The coding reliability was strengthened through double coding by two researchers. Discrepancies were discussed until consensus was reached. After the coding process, the analysis was conducted in three phases. The initial phase consisted of importing the transferred transcripts into the QSR NVivo 14 software and establishing nodes to contain relevant text from the transcripts.

Several emerging issues were noted and coded based on their connotations. The authors categorised the codes into themes during the second phase and constructed a thematic chart. The research report considered all perspectives by examining the patterns, similarities, and differences between these codes and themes. Similar meaning codes were grouped, and phrases representing the standard messages were assigned. Descriptions of the themes were created by combining words from the different code groups. To determine their level of under- or over-representation, the second author verified the accuracy of these descriptions. The third step involved providing context to the original codes and text to address the study aim. To enhance the analytical rigor and validity of our thematic analysis, a second coder independently reviewed the transcripts and validated the initial codes and themes of the study. Discrepancies in coding were discussed and resolved through consensus, establishing inter-coder reliability, and ensuring analytical consistency.

This process increased the number of abstract analytical themes. To convey the meaning of the text to the reader, descriptive quotes were used to encapsulate the analytical themes.

3. Results and discussion

3.1. Demographic and socio-economic characteristics of participants

According to the Table 1 bellow, the investigation found that 43 % of the participants were between 50 and 59 years of age. Fifty percent of the participants were male and female. This equal representation allowed each gender an equal chance to share their viewpoints on the topics discussed. Of the participants, 83 % were married and had 1–5 persons in their household. Regarding education, 63 % attended secondary school, 30 % attended primary school, 3 % had a diploma, and 3 % had no educational qualifications. This factor is significant to the study's objective, as a thorough understanding of ICTs devices necessitates a foundational understanding of information technology. Concerning farm size, 60 % had 1–5 ha, and 43 % had farming experience between 25 and 30 years. All the participants were owners of an ICT device (Table 1).

The socio-economic and demographic profiles of those involved in this study serve as an important measure of the level of availability and adoption of information and communication technologies (ICTs). These findings are based on stakeholder perceptions shared during focus group discussions and do not reflect measured behavioural changes or quantified impact.

This analysis exposes paradoxical readings of the efficacy of ICTs in actualising adaptation strategies to climate change, particularly for small-scale farmers in West Cameroon. ICTs tools are widely adopted, although their use and benefits differ depending on the demographic group.

One remarkable finding from this study is that 43 % of respondents fall within the age group 50–59 years, making it the most represented age group (Table 1). This demographic insight is significant because older populations in Africa and West Cameroon generally exhibit a greater reluctance to adopt new technologies than their younger counterparts. Generational differences in attitudes toward technology play a critical role in influencing acceptance. This is because many older adults in rural African communities are less acclimated to digital tools, hindering their capacity to leverage ICTs for adaptation to climate variability (Raihan, 2024).

The hesitancy of older people stems from multiple factors. For instance, most of their surroundings have not kept pace with technological advancements, making it challenging for them to adapt to a rapidly changing world. Third, the practice of most societies places digital literacy as something important for young people who are not only born into a digital world but also receive exposure to technology through learning systems (Imjai et al., 2024). This generational difference brings older individuals into a situation where they have the ICT tools but do not have the knowledge to use them to enhance agricultural adaptations to climate change.

Table 1
Demographic and socio-economic characteristics of participants.

Variables	Categories	Frequencies (n = 30)	Percentage (n = 100 %)
Age	30–39	3	10 %
	40–49	8	27 %
	50–59	13	43 %
	60–69	5	17 %
	70 and above	1	3 %
Gender	Female	15	50 %
	Male	15	50 %
	Others/ Divers	0	0 %
Marital Status	Married	25	83 %
	Single	0	0 %
	Divorced	1	3 %
	Widowed	4	13 %
Education	No education	1	3 %
	Primary school	9	30 %
	Secondary school	19	63 %
	Diploma	1	3 %
	Postgraduate	0	0 %
Household size (Person)	1–5	25	83 %
	6–10	5	17 %
	10 and above	0	0 %
Farm size (Hectare)	1–5	18	60 %
	5–10	9	30 %
	10–15	3	10 %
	15–20	0	0 %
	20 and above	0	0 %
Farming experience (Year)	1–5	0	0
	5–10	0	0
	10–15	0	0
	15–20	2	7 %
	20–25	8	27 %
	25–30	13	43 %
	30 and above	7	23 %
Owner of ICT devices	Yes	30	100 %
	No	0	

Source: Fieldwork 03.2023.

Moreover, older individuals who have been using traditional farming methods for a long time and have proven their productivity may be hesitant to incorporate ICTs into their routines.

The study found that older farmers usually have experience as a priority over innovation, making the adoption process much slower for more effective practices supported by digital applications Tikita and Lee (2024). In practice, while the possession of ICT tools may be comparable across age groups, there is a significant difference in their actual use among the groups.

Another important dimension is the link between education and ICTs use. The results showed that 66 % of the respondents had up to secondary-level education. The higher the level of education, the more likely a person is to adopt and use ICTs effectively.

According to Sharma et al. (2023), people with higher educational levels are more adept at using technological tools and

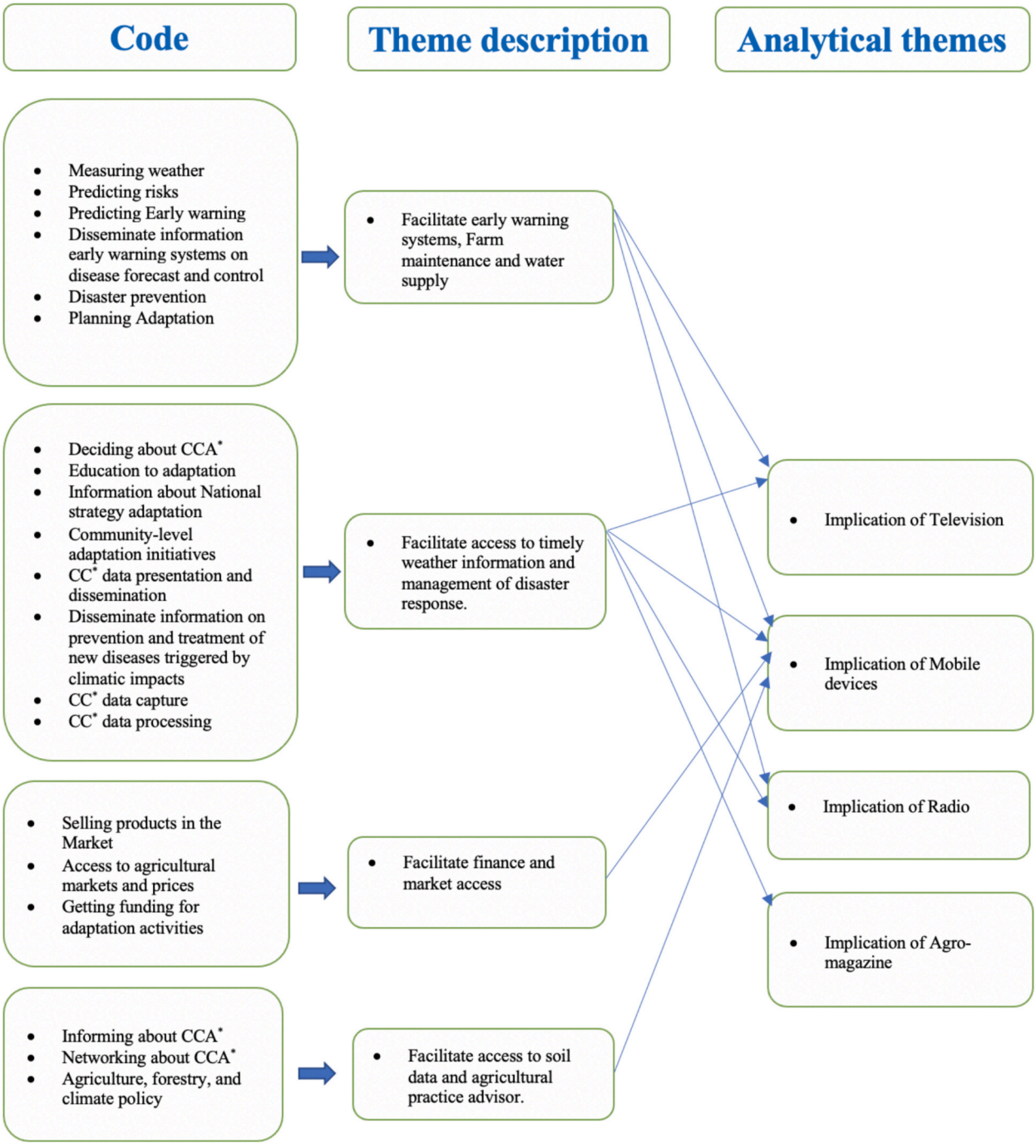


Fig. 2. Thematic analysis from codes to analytical themes. Sources: Fieldwork 03.2023. CCA*= Climate Change Adaptation. CC*= Climate Change.

information systems. Education not only enhances access to cognitive skills through ICT diffusion but also broadens knowledge of climate issues and potential solutions.

Cameroonian educational institutions are progressively acknowledging the significance of incorporating ICTs into the curriculum (Alemnge and Oben, 2024). This aims to equip the youth to interact proficiently with technology. Programs aimed at enhancing digital literacy among adolescents might enable them to use ICTs for weather tracking (Alemnge and Oben, 2024).

However, this difference raises serious concerns about the continuing learning of older generations.

Agricultural extension services and community training programs focused on the use of ICTs in agriculture are important for fostering an environment where older farmers can develop their skills and become more involved with digital technology (Mapiye et al., 2024). To ensure optimal effectiveness, training programs must consider the varied learning styles and specific contexts of older farmers. Prioritising ownership and utilisation of ICT-targeted interventions tailored to various demographic groups is essential. Encouraging intergenerational dialogue, in which younger farmers mentor older farmers, may mitigate disparities in technology access.

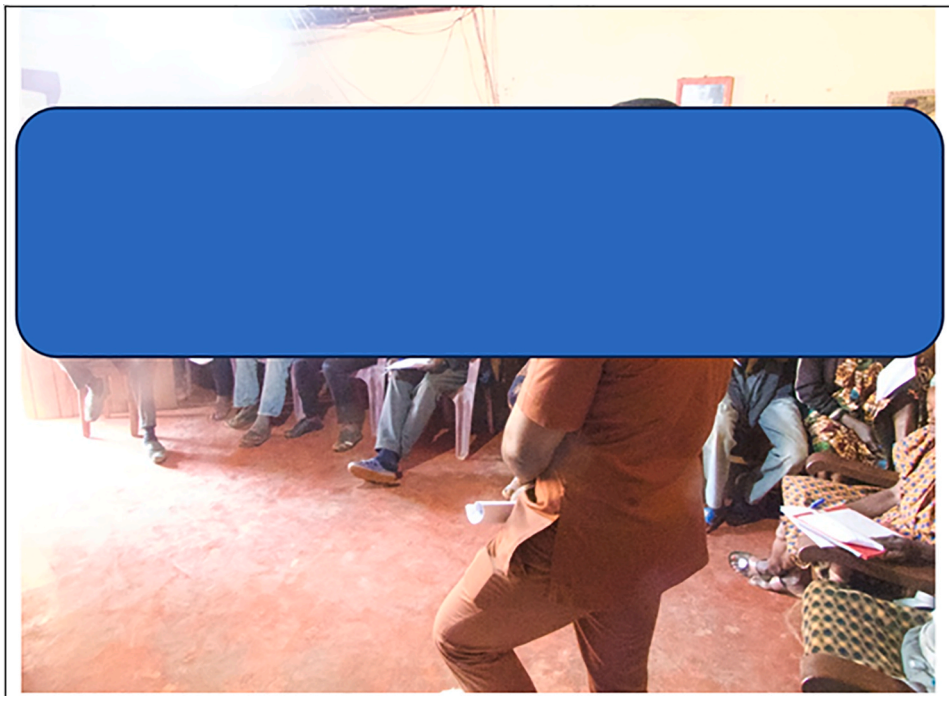
This cooperation facilitates knowledge transfer and enhances a shared understanding of the application of ICTs in agricultural practices. To enhance strategies for adapting to climate change, local governments and NGOs can significantly contribute by investing in community-based training programs aimed at youth and seniors to ensure access to ICTs tools. The socio-economic and demographic analysis of this study highlights the complexities regarding the use of using ICTs adapted to climate change among the population in Western Cameroon. Although ownership of ICTs tools prevails, the effectiveness of deploying them varies significantly across age groups and educational levels. The technology of the aging population addresses the reluctance to confess, which is crucial.

This multifaceted approach can lead to more effective climate-change adaptation practices. This approach can enhance the resilience of rural farming communities.

This Fig. 2 depicts a framework that outlines the conceptual and theoretical underpinnings of integrating ICTs into climate change adaptation strategies, with a specific focus on the agricultural sector in developing countries. In a rapidly expanding field of study, this figure 2 offers a comprehensive overview of research, combining three tools (television, radio, and mobile devices) and presenting an innovative approach to the theoretical research. As new scientific and empirical evidence regarding climate change impacts emerges and advanced technologies continue to evolve, the significance and potential of ICTs in climate change mitigation strategies will evolve. ICTs may contribute to enhanced resilience, particularly in a rapidly changing rural environment, if enabling conditions such as infrastructure, digital literacy, and affordability are satisfied.

3.2. Implication of mobile devices

The data breakdown generated four analytical themes: television, radio, mobile devices, and agro-magazines. We recognise the engagement of farmers in rural areas to adapt to changing weather events. They realise their huge responsibility in providing food for



Picture 1. Focus Group Discussion 01. 2023.
Source: Fieldwork 03

families and communities worldwide. Proper adaptation comes from effective practice and the application of adaptation strategies. The most concerned parties should then receive information on adaptation activities at the appropriate time. Information and communication technologies are relevant channels for disseminating adaptation information in rural areas. During the group discussion, smallholder farmers identified mobile devices or smartphones as the most used ICTs tool in their village's adaptation process (Picture 1).

All participant images were anonymised using a blurring filter to protect their identities in accordance with ethical research standards.

"Regarding our various climate adaptation activities, we use the telephone more often to communicate and exchange necessary information with our community.

It supports establishing connections across various levels, such as interactions involving community members and urban-based scientists, diagnosticians, researchers, or government officials, and executing capacity-building initiatives for local farmers. People often use it to access timely weather information, communicate with agricultural practice advisors, and, more specifically, to access markets. (FGD, 03.2023).

For instance, we can now communicate about meetings thanks to the availability of mobile phones. If the invitation had been sent through television or a journal, it would not have reached many of us. (FGD, 03.2023).

Farmers mentioned that in the absence of mobile phones, the exchange of information necessitated the involvement of agents, who were often concerned about inefficiency. Furthermore, based on adaptable information, farmers asserted that mobile phones significantly enhance the exchange of supply and demand information by providing first-hand and accurate data for action. Another benefit of mobile phones is their ability to coordinate the market supply chain. Market farmers who grow tomatoes said they sometimes must call buyers into the field to inspect the products and decide whether to buy them.

Additionally, the buyer's visit to the farm enables them to schedule the harvest day, as there are specific times for harvesting tomatoes. While some farmers suggest sending photos to the buyer through specific mobile applications, most buyers opt to visit the farm to inspect the animals.

Most farmers agree that mobile phones help them communicate among themselves; for example, when someone has essential or valuable information, they forward it via mobile phone. The information can be on weather, agricultural practices, and market access. Eichmann et al. (2022) argue that access to information can foster flexibility by identifying possible choices and providing information on different revenue opportunities, including demand and prices in foreign markets. Addaney et al. (2024) made similar observations while investigating the climate change adaptation strategies of cocoa farmers in Ghana. Likewise, between 2011 and 2013, a local NGO, the Cameroon Youth Initiative for Rural Development (CAMYIRD), experimented with mobile phones to support rural producers in Cameroon. CAMYIRD had five advisers trained in various areas of intervention. The project directly involved 120 farmers, using mobile phones to raise awareness among producers about ecological and conservation techniques and attitudes through SMS messages, which were then translated into voice SMS.

The Centre de Documentation et de Développement Rural (CDDR) of the Service d'Appui aux Initiatives Locales (SAILD) has been experimenting for the last ten years with an agricultural information call centre under the slogan Allo Ingénieur. This free call centre provides farmers with remote advice via mobile phones. This NGO has no short-term plans to develop interactive tools or up-to-date information platforms on the web. Regarding the economic aspect, some smallholder farmers expressed that they use smartphones because they are affordable in the market. Despite their low quality, these smartphones enable farmers to communicate and exchange valuable information about farming and adaptation.

Studies on ICTs and agricultural activity in developing countries focus more on access to farming information. Cameroonian policies increasingly advocate the green revolution or second-generation agriculture (Mbongsi & Bachange, 2019).

Although the state has disengaged from its mission to empower farmers over time, the development of agriculture through ICTs is becoming inevitable (Akpan-Obong, 2023).

From a different perspective, Ahamed (2024) asserted that rich countries have highly developed ICTs in agriculture, such as tractors equipped with computers and Internet consultations for specific weather services. According to the 2013 Euro-African ICTs Conference in Addis Ababa, radio and mobile phone systems are viable and sustainable solutions that can help improve agricultural production in Africa if appropriately managed on a large scale. Similarly, Mapiye et al. (2023) agreed that the use of appropriate ICTs applications in agricultural activities can contribute to an increase in food production.

Furthermore, the participants actively discussed gender issues and presented diverse opinions. All female participants (13 out of 15) enthusiastically embraced the use of ICTs in adaptation actions. In contrast, 12 of the 15 male participants expressed opposition to their wives' use of smartphones, owing to concerns about potential misuse or threats to marital stability. These findings align with those of Addaney et al. (2024), who observed similar benefits of mobile phones for market access in Cameroon. However, the strong gender divide noted here contradicts the assumption of uniform benefits across household members, as suggested by Choruma et al. (2024).

> ***"I will never accept that my wife uses a smartphone because it may help her do something else that can bring problems in our marriage or separate us. (Male participant, FGD, 03 2023)"***

This was because certain relatives witnessed the device serving their wives for other uses, causing trouble in entering. Other male farmers believe that they should provide their wives with useful information rather than giving them smartphones for other purposes. These findings highlight a gendered digital divide rooted in social norms and information-access control. Restricted access to ICTs undermines women's capacity to make independent farming decisions and weakens the household's climate resilience.

Addressing these disparities requires culturally sensitive interventions that promote gender equality in technology use, including

targeted training for women and sensitisation campaigns for men to understand the benefits of shared access to ICT tools. These remarks highlight the issue of gender access to adaptive information in rural settings for older adults.

The results of the discussion show that smallholder farmers in the Koung-Khi department need to better understand the contribution of modern science and technology to climate change adaptation. These findings are based on stakeholder perceptions shared during focus group discussions and do not reflect measured behavioural changes or quantified impacts. Smallholder farmers must integrate the effective use of information and communication technology to adapt to climate change. In addition to general communication, participants provided specific instances of how using their phones directly affected their adaptation. Farmers, for example, said they changed their planting plans when they received SMS-based weather warnings from local advisory organisations. Some tomato producers used WhatsApp groups run by extension staff to communicate real-time rainfall projections and plan irrigation schedules. Others called to get advice on disease outbreaks, which led to the quick adoption of the right remedies that kept crops from dying. A group of maize farmers spoke about how selling their crops in bulk using mobile platforms helped them get higher prices, which increased their income and allowed them to buy climate-resilient seeds again. These examples show that talking on mobile devices is more than just sharing information; it also helps people make smart and timely choices that make farming more resilient to climatic shocks.

In conclusion, the focus group talks revealed that mobile devices are the most widely available and often used ICT tools for supporting rural Cameroon's resilience to climate change. Farmers said they used their phones to communicate with agricultural consultants, coordinate markets, share information and obtain weather reports. These instruments have improved the timeliness of decision-making and increased the connectedness of agricultural communities. However, obstacles such as low digital literacy, particularly among older adults, gender-based access inequalities, and infrastructure problems such as patchy energy and poor network coverage, still prevent mobile technology from reaching its full potential in rural adaptation plans. To successfully use mobile devices to assist resilient agricultural practices, these obstacles must be removed.

3.3. Implication of agro-magazines

During the focus group discussion, smallholder farmers mentioned that reading is not a big problem, as the agro-magazines are written in English or French (Picture 2).

We do not read agro-magazines because they are unavailable in the village. To obtain one, we must travel to a distant part of the city. Moreover, each time we visit the city to enquire, they consistently inform us that the item is sold out. They consistently informed us that the city was experiencing a shortage and was not printing in large quantities. So, it does not help us here in the village, not because we cannot read, but because of availability, she said. (FGD, 03.2023)".

However, the farmers noted that the Internet's contribution to adapting to climate change is low. Some participants reported that certain blogs, such as Agri-bloggers, offer farmers a variety of agricultural information. Social networks link most blogs to facilitate information dissemination. Some of the most popular blogs mentioned by farmers were:

Picture 2. Focus Group Discussion 02. 2023.
Source: Fieldwork 03

- **La plume de l'information** aims to facilitate access to information for young producers wishing to start farming. The rural world widely reads and visits these blogs.
- **Agriculture Info:** aims to provide information on opportunities in the agricultural sector and short-distance learning courses.
- The data are available in French and English.
- **Afrique sans faim:** helps reduce food insecurity in Cameroon by offering tips on adapting to climate change, promoting the potential of Cameroonian agriculture, and facilitating the sharing of opportunities among producers.
- **Agricultural tech: aims** to share technological innovations in the agricultural sector, focusing on resilience in the face of climate change and the promotion of agroecology. The blog also provides information on capacity-building opportunities in the Agro-pastoral sector. Most farmers expressed that, despite the existence of these blogs, they are unable to access them because of the high cost and poor quality of Internet connections in rural areas. Accessing adaptation and mitigation information via blogs in rural areas is a massive challenge.

3.4. Implication of radio and television (TV)

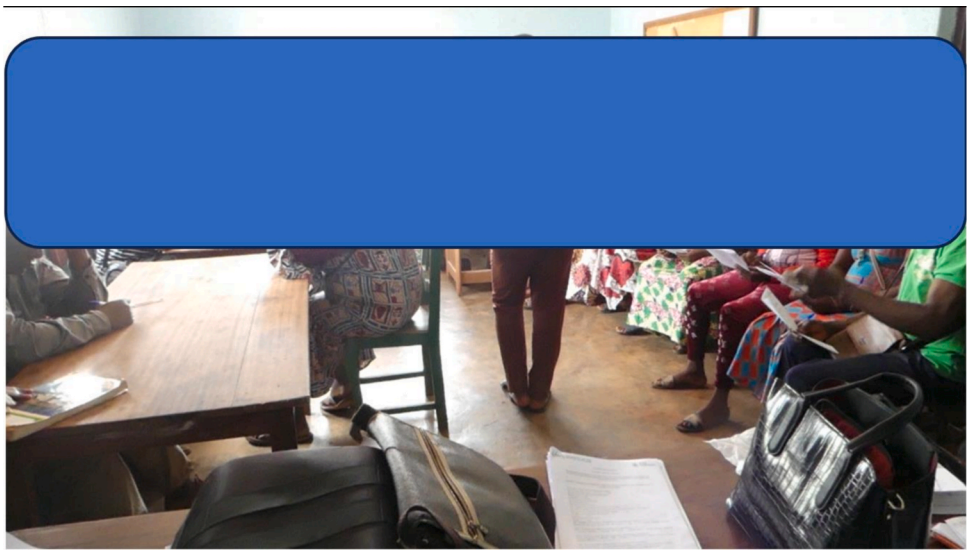
Farmers also heavily relied on radio and television to obtain adaptation information (Picture 3). Listening to the news on the radio or watching TV at home made farmers more likely to engage in this behaviour. Rural producers increasingly use community and local radio stations to disseminate information and provide forums.

> "We use radio and television to get information about the climate. Most often, after the 8:00p.m. news, television announces the weather information for the next day. After obtaining the weather information, we planned the field activities for the next day. This information also serves as a useful guide when visiting the market to sell.
> We receive a greater amount of this information from television than we do from the Ministry of Agriculture.
> Television serves us every day when we are at home in the evening after work. Occasionally, we carry small radios that provide daytime weather updates. This is particularly useful when working on farms that are far from home. (FGD, 03.2023)".

In rural areas, where access to information is often limited, radio and television remain powerful sources of information (Mansour, 2024). Radio and television are the most important media for disseminating information on climate change and adaptation strategies (Onuegbu et al., 2024). According to Khan et al. (2023), radio and television specials on climate education raise awareness of rural communities and help them understand the changes and actions they can take. Current weather information can reduce risks by assisting residents in preparing for and responding to disasters.

With its visual effects, television is instrumental in awareness campaigns to adapt to climate change threats. Special weather broadcasts on radio or television can serve as early warnings for rural communities (Shukla, 2023). Calls for adaptation on social media, radio, and television platforms encourage community participation and collaboration (Chookah & Moussa, 2023). This promotes solidarity in the rehabilitation process by facilitating the sharing of local knowledge, experiences, and reform strategies (Ngake, 2023). Radio and television platforms allow the incorporation of regional content and local knowledge into law enforcement communication (Borah et al., 2024). As technology advances, harnessing the potential of today's media can contribute to the empowerment and sustainable development of rural areas. (Alotaibi et al., 2024).

Concerning funding for adaptation activities in rural areas, Odiambo (2023) noted that ICTs enable rapid access to and mobilisation



Picture 3. Focus Group Discussion 03. 2023.
Source: Fieldwork 03

of financial assets, mainly through mobile banking and financial services. By providing quick access to capital and financial transactions, ICTs strengthen local livelihoods and enable local communities to work more efficiently and effectively to cope with and adapt to the risks and phenomena associated with climate change (Ndimbo et al. 2024). The telecommunications sector can play a crucial role in climate change adaptation by providing technical and financial assistance and forming multisectoral alliances to implement ICTs solutions (Mayoyo et al., 2024).

3.5. Challenges in using ICT for adaptation to agriculture and climate change

The results of a case study in the western region of Cameroon also indicate challenges in the Koung-Khi department regarding the use of ICTs for climate change adaptation. Some of these challenges include the high prices and tariffs associated with telecommunications services and Internet access in Cameroon.

> ***"Most of the time, there is no electricity in rural areas, which compromises the use of ICTs". We cannot charge our phones or use other tools like televisions and radios (FGD, 032023)."***

Almost all participants agreed that digitising agriculture in rural areas is impossible because of the many challenges it presents. Among the challenges mentioned were limited Internet access and the need for qualified personnel to maintain the devices and equipment. Smallholder farmers noted that farming practices are still indigenous because they have been doing them for a long time and because most of the land is in hills and valleys. Using machinery is also challenging because of the inappropriate geography.

Farmers also reported a low adoption rate of ICT devices in remote rural areas due to inadequate investment in telecommunication infrastructure by both the private and public sectors.

> "As rural farmers, we confront limits and have been speaking out for a long time, but no one listens. Success is not possible alone. We require government or private funding. We produce enough food for the nation and more than our neighbours. If we remain isolated, agricultural yields will drop, causing food insecurity for the nation and its neighbours. In Cameroon, rural areas feed urban areas. If rural areas experience food shortages, what about cities? Worsening conditions will raise food costs and cause famine among the urban poor.
>
> Reaching zero hunger by 2030 is a huge challenge for the SDG. Overall, rural farmers require contemporary information and communication technology to ensure productivity and adapt to climate change. These technologies will be difficult to operate, but possessing them will motivate us to utilise them well, as they are vital to our existence" (FGD, 03.2023)".

Additional challenges raised by the smallholder farmers were a low level of web and mobile application development adapted to rural producers' situations and a low level of awareness of the value of ICT tools for agricultural entrepreneurship. Rural areas require ICT infrastructure due to the scarcity of well-supplied and infrequently updated agricultural information.

For example, the website of the Institute of Agricultural Research for Development (IRAD) has a list of technical fact sheets, but the documents are not available online.

Additionally, financial constraints present a significant challenge to the use of advanced science and technology for weather change adaptation and mitigation in rural areas (Saikanth et al., 2013). Despite these challenges, reasonable solutions can help overcome barriers to using advanced science and technology for climate change adaptation and mitigation in rural areas. A significant solution is to raise awareness of and understanding of climate change in rural communities. We should evaluate the effectiveness of awareness campaigns among producers to use or integrate ICTs into their daily habits. Agricultural producers should recognise and capitalise on the enormous potential of modern science and technology while maintaining an open-minded approach to promoting innovation. Education and awareness campaigns that provide information on climate change impacts and available adaptation and mitigation measures can accomplish this (Ngcamu, 2013). Governments and development agencies can also financially support rural communities to invest in modern technologies to help them adapt to climate change (Raihan et al., 2024). Furthermore, endorsing sustainable agricultural practices can help mitigate climate change in rural areas.

To date, the analysis has indicated positive and essential links between ICTs and the resilience of climate-vulnerable systems (Osumba et al., 2021). However, an analysis of the role of ICTs must also recognise that they can harm livelihood systems, which may reduce their resilience and adaptability to climate-related risks, trends, and variations (Ajwang & Nambiro, 2022). The most obvious danger of ICTs is that they can absorb the internal resources of a system, including a community (Shah et al., 2022). ICTs are expensive and often consume resources for other uses (Baumüller et al., 2023). Less obviously, Shah et al. (2022) added that ICTs could require time and motivation, potentially compromising adaptive capacity and actions. Using ICTs for adaptive measures that fail to integrate or recognise these factors could lead to poor overall adaptation. Devoting exclusive attention and resources to a single endeavour, such as a catastrophe early warning system, diverts these assets from other initiatives.

3.6. Strengths of the study

This study had several notable strengths that contributed to its value and relevance. First, its qualitative design offers deep, context-specific insights into the perceptions of rural smallholder farmers, capturing nuances that quantitative methods might overlook. Second, the study's geographical focus on the Koung-Khi department of West Cameroon provides rare empirical data from a region that is highly vulnerable to climate change but is underrepresented in the academic literature. Third, balanced gender participation (50 % men, 50 % women) adds richness and inclusivity to the findings, allowing for the exploration of gendered dynamics in ICT adoption. Finally, this study advances the literature by linking ICT adoption directly to local adaptation strategies in rural Cameroon, offering

practical insights that can inform both policy and future research.

4. Conclusions

This study shows that there are various obstacles to climate change information in Cameroon. Access to climate change adaptation information is important for enhancing effective climate adaptation strategies. Concepts such as climate-smart, digital, and sustainable agriculture and agroecology are essential for addressing climate change challenges, particularly in Cameroon and potentially in other Sahelian and Western African countries. Efficient gathering and application of information through ICT devices require a comprehensive understanding of the technologies.

This study seeks to provide insights for both academics and practitioners concerning suitable ICT tools that facilitate adaptation initiatives in rural settings. This study examined the level of knowledge and understanding rural farmers possess regarding the use of ICTs tools for effective adaptation. The findings suggest that the Koung-Khi department's use of ICTs for climate change adaptation is limited. Based on stakeholder perceptions rather than empirical measurements, the findings suggest that ICTs assist rural farmers in comprehending current and future climatic patterns, thereby enabling informed decision-making that enhances climate resilience.

This study anticipates that the integration of modern science and technology into climate change adaptation and mitigation strategies in rural areas will yield innovative ideas. Despite current challenges, mobile phones, radio, media, and the Internet may contribute to enhanced resilience, particularly in a rapidly changing rural environment, if enabling conditions such as infrastructure, digital literacy, and affordability are met. Emerging technologies are increasingly essential for climate adaptation and mitigation strategies in rural Cameroon and comparable areas. Environmental sustainability remains a significant issue for Cameroon and similar sub-Saharan African countries, with overarching strategies primarily focused on mitigation, monitoring, and adaptation. These elements highlight the significance of this issue, as demonstrated in the conceptual model. This emphasis corresponds with the increasing acknowledgement of the significant effects of climate change in developing nations, highlighting the varied priorities in this area. Studies assessing the role and potential of ICTs, increasingly linked to analyses of the vulnerabilities and resource limitations characteristic of developing nations, reflect this recognition.

The Cameroonian government must prioritise the role of ICTs in formulating public policies on climate change. Highlighting the capacity of ICTs to develop an agricultural calendar that corresponds with current climatic conditions is essential for facilitating informed decision-making by producers and enhancing agricultural yield. The current literature recognises that ICTs can yield positive outcomes, including enhanced transportation efficiency and reduced travel needs; however, they may also lead to heightened energy consumption and increased electronic waste generation. Digital technologies can facilitate the dematerialisation of specific products and decrease travel requirements; however, prevailing consumption patterns may increase travel and the demand for low-cost products, potentially undermining the initial ecological advantages.

The identified risks highlight the need for additional investigations into the potential effects of ICTs on climate change, emphasising both the specific results of technological applications and the lifecycle of ICT products, as well as the behavioural or systemic consequences associated with new production and consumption processes.

Adopting a systems approach is essential for understanding the role of ICTs in climate change while recognising the complex interconnections among mitigation, monitoring, adaptation actions, and strategies, especially in regions such as Cameroon and similar contexts in Western Africa.

4.1. Policy implications

The effectiveness of ICT-based services in rural areas often depends on existing national policies, governance structures and institutional capacities. Policymakers should also consider implementing targeted subsidies for ICT tools and services to reduce cost barriers for rural farmers. Additionally, national governments and NGOs should prioritise adult digital literacy programmes, particularly targeting older demographics and women. These interventions can empower broader segments of the rural population to engage effectively with ICT platforms for agricultural and climate-related decision making. Therefore, this study recommends research on policies and strategies for integrating ICTs into climate change initiatives. Over time, with the recognition of the potential of ICTs, policies should support the development of robust ICTs systems in remote areas. Policymakers are encouraged to collaborate with industrial actors and communities to develop solutions tailored to rural lifestyles and unique economic and environmental circumstances. In addition, policies should prioritise capacity building in rural areas to harness the full potential of ICTs. This includes training programs, awareness campaigns, and educational materials to promote digital literacy and technology.

Finally, policymakers should encourage research and development in emerging technologies and foster innovation that is consistent with sustainable rural development goals.

Although this study provides a better understanding of the role of information and communication technologies (ICTs) in climate change adaptation in rural areas, it is essential to acknowledge several limitations.

1. Limited sample size and generalisability: The qualitative focus group discussions involved only 30 smallholder farmers from the Koung-Khi department in Cameroon's western region. While the findings provide valuable insights, the small sample size limits generalisability to other rural areas or regions with different socioeconomic or agroecological conditions. As a case study based on a limited number of focus group participants, the findings cannot be generalised to all rural areas of Cameroon. However, they offer transferable insights relevant to similar agroecological and socioeconomic settings.

2. Geographic scope: This study focused solely on one agroecological zone in Tanzania. Therefore, the results may not reflect the diversity of experiences and ICT adoption levels across other regions in Cameroon and sub-Saharan Africa.
3. Translation and transcription challenges: Focus group discussions were conducted in French and later translated into English by the authors. Despite quality assurance measures, including bilingual transcription and independent review, nuances may have been lost or changed during translation.
4. Self-reported data: Data were based on participants' recollections and subjective experiences, which may be prone to biases or inaccuracies.
5. Lack of longitudinal perspective: The study was conducted at a single point in time. It does not capture seasonal variations or long-term shifts in ICT adoption or climate-adaptation practices.
6. Limited socioeconomic impact analysis: Although some sociodemographic factors were considered, a deeper statistical analysis of how variables such as income, gender, or social status affect ICT usage was beyond the scope of this qualitative study.

Future research should address these limitations by expanding the sample size, including multiple regions, and integrating mixed methods to allow for both qualitative and quantitative insights into the subject.

This study contributes to the theoretical grounding of the interplay between ICTs and climate change action in rural areas. By combining the existing literature and research findings, this study comprehensively describes the theoretical framework underpinning the use of ICTs in climate change adaptation and mitigation. This research reinforces divergent theoretical perspectives and identifies gaps and nuances in understanding how these technologies work in rural contexts. By enriching the theoretical foundation, this study provides scholars and researchers with a concrete framework for further exploration and development. In addition to its theoretical contributions, this study provides valuable insights for practitioners and programs involved in grassroots climate change policy. Through a thorough analysis of case studies and empirical evidence, this study extracts practical lessons from the use of specific ICT tools and platforms in rural areas to adapt to and mitigate climate change. This practical lens highlights success stories, potential challenges, and pitfalls in implementing IT-based strategies. While this study provides a nuanced understanding of real-world information technology applications, it offers actionable insights for practitioners to design and implement climate-resilience strategies more effectively in rural areas.

CRediT authorship contribution statement

Hubert Fudjumdjum: . **Walter Leal Filho:** Writing – review & editing, Validation, Supervision, Project administration.

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.

Acknowledgements

This paper contributes to the initiative "100 papers to accelerate the implementation of the UN Sustainable Development Goals"
Ethical authorisation and permission for participation: not applicable.
Accessibility of data and resources: The data is readily accessible from the first author to any interested parties

Data availability

Data will be made available on request.

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