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Climate change mitigation and livelihood components under smallholder coffee farming: a bibliographic and systematic review

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Abstract
Coffee ranks high in terms of growth, trade, and consumption across the world. Although there has been an increasing trend in its consumption as a beverage across the globe, its on-farm production and productivity are threatened by climate change in the dominant coffee-growing regions. Smallholder farmers produce about 80% of the world's coffee and are constrained in adopting climate-smart improved technologies. Climate change and livelihoods are interconnected, and understanding and strengthening their linkages is crucial in generating sustainable coffee supplies. This paper analyzed climate change and mitigation components in the context of livelihoods under smallholder coffee farming systems. An online search of globally published journal articles was done in the Web of Science and Google Scholar databases. Bibliographic and metadata analysis was done using VOSviewer software, while the publication trend of the included articles was analyzed using Mann–Kendall. Overall, this review reveals that livelihood assets owned by the coffee farmer have a strong bearing on the adaptation and mitigation of climate change, while Fairtrade certification has mixed effects on farmers' income and well-being. Agroforestry is a major climate change adaptation strategy under coffee farming and is linked to the livelihood status of the farmer, gender, and certification. This review echoes the strong linkage between agroforestry, livelihood components, and Fairtrade certification under smallholder farmers based on the empirical researched information available.

Keywords Climate change, Mitigation, Agroforestry, Livelihoods, Fairtrade certification

Introduction

For the period 2013–2023, there has been a positive, though not significant trend in the productivity of coffees on the global scale (Fig. 1). However, in the same period, the global area under coffee production is estimated to have significantly increased from 10.4 to 12.21 million hectares, indicating a 1.81 million hectare increase in the land allocated to coffee production. In addition, in the same period, production rose from 147 million (60 kg-bag of Fair Average Quality (FAQ) coffee) to 176 million bags, indicating a 29 million increase in output [1]. Relatedly, statistics indicate that productivity per hectare on the global scale fluctuated between 14.14 and 14.39 (-60 kg bags of FAQ), per hectare over the same period. This is below the potential and expected yield per hectare

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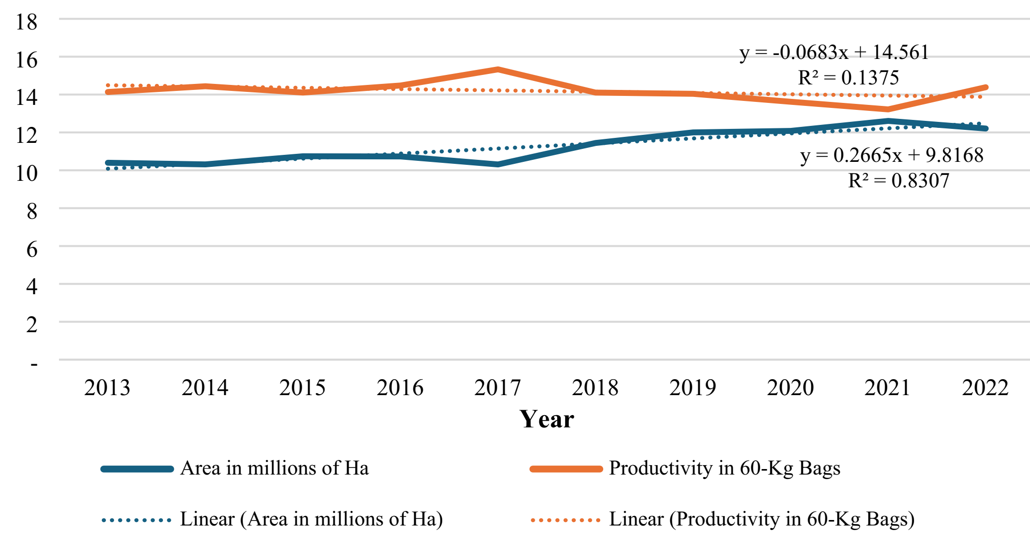

Fig. 1 Trend in area under coffee and coffee productivity (2013–2023). *Source* [1]

relative to 26.12–60 bags FAQ, as the yield that Brazil obtains on average per hectare [2].

Inadequate coffee volumes notwithstanding, the global effective demand for coffee beverages and their blends reveals a significant positive trend that has hovered above the global coffee supply (Fig. 2) [3]. The positive trend in consumption is associated with the progressive increase in the Gross Domestic Product plus the Human Development Index which has been registered in the major coffee-consuming areas in Europe, Brazil, and Ethiopia among other countries [4]. This is also influenced by the numerous benefits obtained from routine coffee consumption that include the preferred levels of caffeine, and aroma in the coffee products associated blend. This trend is reflected in the 2.2% growth in the worldwide coffee trade in the years 2022–2023 [3].

However, climate change presents a potentially existential threat to sustainable coffee production, whose primary actors are smallholder coffee farmers, who farm in developing tropical countries. Climate change manifests in adverse weather conditions, namely, continuous temperature rise, erratic annual precipitation, hailstorms, heavy winds, floods, hurricanes, among others, which impact coffee yield in the predominantly coffee-growing regions in the Americas, Asia, and Africa [5]. The main effects manifest through adverse weather conditions, increased incidences of pests and diseases, reducing the suitability levels of the current coffee growing areas,

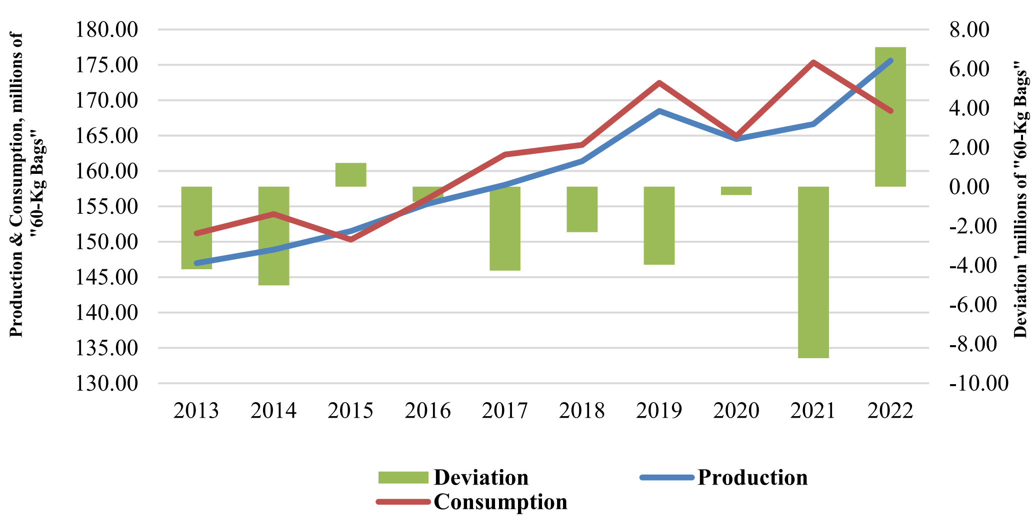

Fig. 2 Summary of the world coffee market (millions of "60-kg bags"). *Source* [1]

and lowering the quality and quantity of coffee cherries [5, 6]. All these and others may have a significant subsequent effect on the incomes and livelihoods of the farming households, and other value chain actors involved in the coffee value chain at local, regional, and global scales. This is seen in the 2022–2023 production year, where Asia witnessed an increase in production and productivity, while South America and Africa experienced declines of 4.7 and 7.2%, respectively [3].

This review study is underpinned by five main concepts, the Sustainable Livelihoods Framework (SLF), highlights the importance of farmers' level of assets endowment in adapting and mitigating climate change and the associated impacts [7]. Climate-Smart Agriculture (CSA) that involves the adoption of on-farm sustainable agricultural practices such as agroforestry, provision of shade, intercropping, and soil fertility management to increase the resilience of the farming systems and reduce greenhouse gas emissions [8]. Furthermore, the Agroecological Framework (AF), which mainly focuses on biodiversity and ecosystem-based services to support sustainable farming systems [9]. In addition, the Development Economics Theory (DET), which explores the diverse effects of Fairtrade certification on farmer's incomes and well-being [10]; and finally, limate change Adaptation And Vulnerability Theories (CCAVT), highlight how socio-economic and the farmers' demographic factors influence their capacity to cope with climate change and associated risks [11]. In general, these five theoretical frameworks lay a foundation for explaining how smallholder coffee farmers can sustainably adapt to climate change and its impacts across coffee-growing regions.

As such several researchers and farmers have continuously embarked on developing technologies and adopting mitigation measures such as, agroforestry, improved and resistant coffee varieties, and other on-farm climate-smart agricultural practices [12, 13]. These mitigation strategies require appropriate and targeted resource allocation right from production through the entire supply chain for the uptake of climate-smart technologies to be realized, which is also dependent on the farmer's level of endowments [14]. The effectiveness and sustainability of the mitigation measures vary with the location of the coffee farm and the variety of coffee under consideration among other factors [15, 16]. It is important that extending the application of the SLF concept can help identify farming practices that can merge on-farm and off-farm best practices with the smallholder coffee farmers' incomes and thus guarantee the sustainability of interventions [17]. However, due to climate change, and because coffee is predominantly produced by smallholder farmers in developing countries with other production and market-related risks, there is an increase in existential threat, so that volumes of coffee produced and traded may drop significantly in most of the coffee-producing areas [18]. Notwithstanding these challenges, smallholder coffee farmers and other value chain actors are innovating to counteract the impacts of climate change and, therefore, increase resilience. Some of the measures that have been adopted in most coffee-producing regions include forming viable producer–farmer organizations, such as coffee cooperatives and unions, utilization of family labor to reduce the cost of production, and implementing some of the climate-smart agricultural practices, such as agroforestry [19, 20].

Furthermore, sustainable development goals (12) and (13) emphasize the importance of ensuring both sustainable production and consumption, while strengthening the resilience and adaptive capacities through appropriate policy framework and building the knowledge and skill base [21]. Empirical studies postulate that climate change will shrink the areas that were originally suitable for coffee production, by curtailing growth and impacting average yields obtained [22]. The COP28 Agriculture, Food, and Climate national action toolkit highlights poverty as a major barrier to adopting climate-smart technologies among smallholder farmers [23]. Some of the key strategies for mitigating, adapting, and coping with climate change effects include agroforestry and the reduction of emission of greenhouse gases, such as carbon dioxide [24]. A comprehensive online search of the available database for empirical information reveals scattered linkages among climate change adaptation components of agroforestry, Fairtrade certification, and livelihoods. Understanding and establishing these links is fundamental for effective mitigation and adaptation to climate change and sustainable coffee yield under smallholder coffee farming systems. This review aims to fill this knowledge gap by analyzing online journal articles to synthesize findings from various scholars, identifying coherent linkages, gaps, and grey areas that can further inform research and other coffee value chain actors. This study aims to disclose the strong linkages between climate change, livelihoods, and adaptation strategies in smallholder coffee farming through a bibliographic review of published articles from coffee-growing regions worldwide to meet the two main objectives.

(i) To analyze the development trend of recent research on climate change and the livelihoods of smallholder coffee farming systems.
(ii) To examine climate change on-farm mitigation measures and associated impetuses to sustainable livelihoods of smallholder coffee farmers.

Methodology

Identification of database, search strategy, and article screening

Complete search three databases, Web of Science, Google Scholar, and Scopus were first searched as they are the main databases containing great quality peer-reviewed articles from impactful indexed journals, using the keywords chosen for the study, it was found that Web of Science and Google scholar gave more resources based on the search queries and most of the outputs in the Scopus were mainly covering post-production areas of the coffee value chain, and therefore, for the scope of this study, decision was made to use both Web of Science and Google Scholar databases. We considered the most recent publications made between 2013 and 2023, and the search was carried out on 10th December 2023. The aim was to assess the most recent focus in terms of research, innovations, interest, and experience with the prevailing effects of climate change on smallholder coffee farmers across the globe and how they are coping with using well-adapted methods [25]. The search terms used are "climate change" and "coffee" and "adaptations" or "mitigation" and "smallholder farmers" and "Livelihoods". The search was restricted to articles only in the English language. The online search yielded 1820 journal articles, which were later subjected to manual meta-extraction and analysis.

The procedure was set to guide the inclusion and exclusion of certain articles based on the title, keywords, and abstract screening.

(i) Was the study done on coffee?
(ii) Was the study covering climate change aspects?

Based on the queries, only those articles that had "Yes" for both questions were considered to have met the inclusion criteria (Fig. 3). This review adopted and utilized only 17 items in the PRISMA checklist that we found were more suitable for this systematic and bibliographic literature review. The items that were deemed not so suitable for this review were (12, 14, 15, 18, 19, 20, 21, 22, 24 and 25).

Meta-data extraction and its analysis

From the two databases, a total of 2387 journal articles were obtained, (18) were removed as they were duplicated, and were screened based on document titles, and abstracts, A three-categorical level of ranking was created in an additional column in Excel spread where; "0 = "Exclude", 1 = "Include" 2 = "Not Sure". It was those articles that fell in the category "2" that were subjected

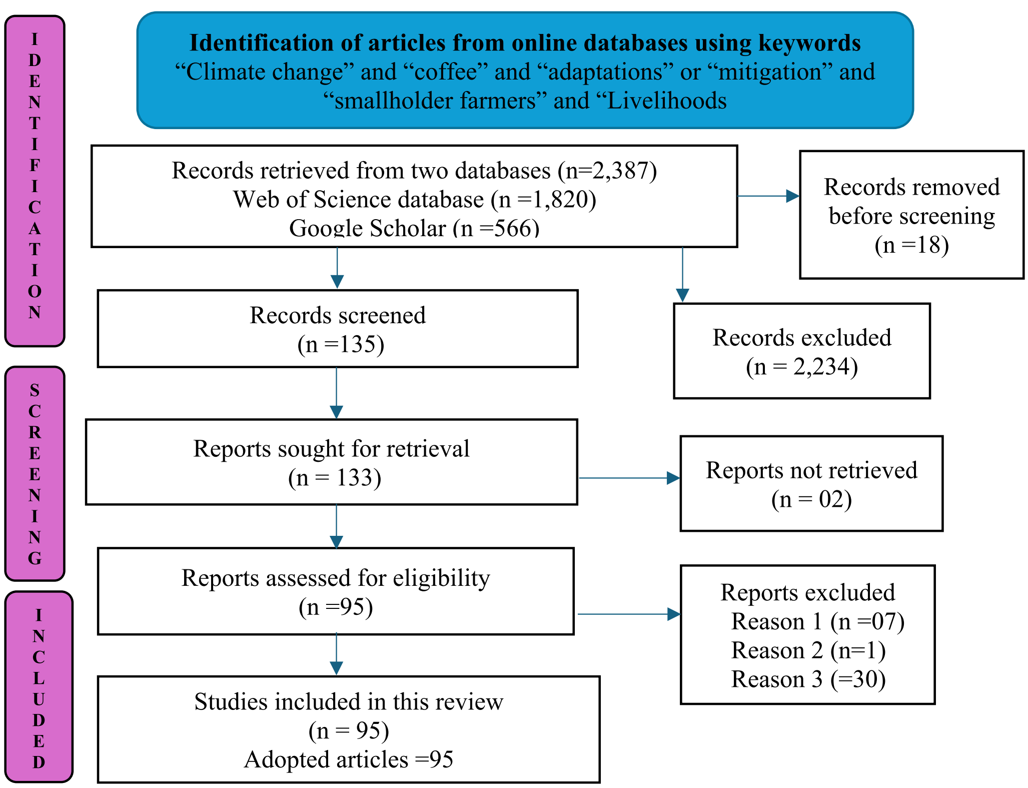

Fig. 3 Flow diagram showing the process of searching, and screening of databases used. Adopted from [26]

to full-text screening. At first articles that did not cover “coffee” in either the title, abstract or keywords and others that were reports and not journal articles excluded (2234). In addition, (02) articles could not be retrieved and were dropped, and thereafter, a deeper analysis of the abstract of all the articles was done and other (38) journal articles were excluded as the studies were not done on coffee farming (30), seven (07) articles did not have DOI (digital object identifier), and one (01) had not been published in the English language. This screening process was done by the two members of the review team and was done iteratively, especially by reading the articles in their entirety.

These processes yielded 95 (ninety-five) articles, that were converted (where necessary) from ‘.csv’ into a Microsoft Excel workbook and subsequent analysis including establishing a two-dimensional representation of the published research articles per year within the time scope of this study, and then establish the mostly cited articles within the same period using the Mann–Kendall test, and finally a network analysis was done by use EVIEWS software. VOSviewer bibliometric tool was used to perform bibliometric visualization of the co-occurrence of author keywords and their associated links. For objective (ii) all the included articles were reviewed in detail covering key findings, recommendations, and areas recommended for further research, and all these were synthesized qualitatively under the four thematic areas of climate change, agroforestry practices, sustainable livelihoods, and Fairtrade certifications in smallholder coffee farming.

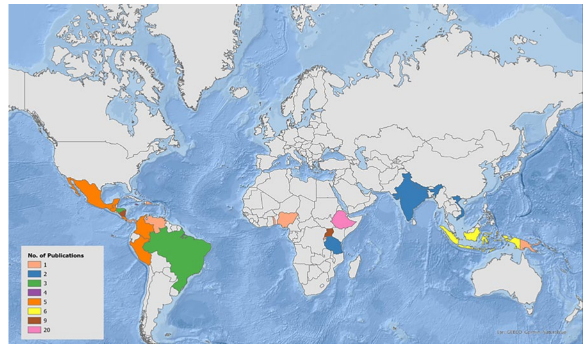

Fig. 5 Distribution of articles used based on the literature scope of the study for the years 2013–2023

Results and discussion

The trend of recent research on climate change and livelihood components under smallholder coffee production systems for the period 2013–2023

After the screening process, 95 articles were adopted for further analysis. The preliminary analysis indicates an increasing publication trend for the period 2013–2023 (Fig. 4) with model fit $R = 0.46$. However, using the Mann–Kendall analysis, the trend was not significant at $p = 0.1$. The highest number of articles published were registered in the year 2022 (23%) and the least publications in the year 2016 (1%). Published Scientific findings play a key role in solving the empirical knowledge gap, and this is critical in addressing societal problems in the case of applied research. For coffee and its value chain and being one of the most consumed and traded agricultural commodities at the global scale, such publications indicate the level of importance and the significance of the challenges.

Based on the scope of this study, 24 coffee-growing countries are represented in the 95 articles used in the

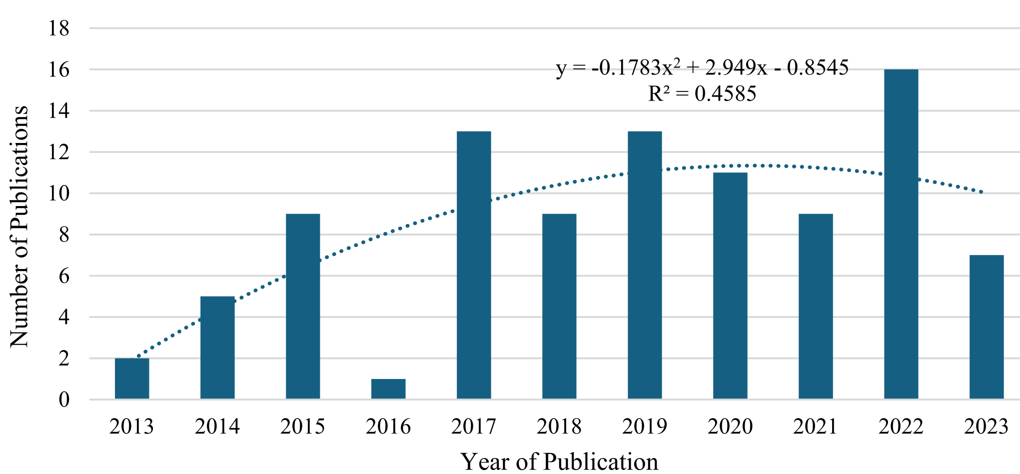

Fig. 4 Publication trend on climate change, adaptation, and mitigation under coffee farming

study (Fig. 5). Each of these 14 countries had at least one to three articles and these represented 29% of the sample used in the study, seven countries had four to six articles each, and all the articles from these represented 31% of the sample and the remaining 40% came from Ethiopia (20 articles), Uganda and Nicaragua each with nine articles. Most of these countries lie near the equator (tropics), which has offered a suitable climate for coffee growing for several decades. The number of articles for a given country could have a bearing on extreme climatic conditions experienced over the last one or more decades; for instance, Ethiopia had experienced several recurrent droughts, causing streams to dry up and subsequent food shortages [27] and significant changes in the livelihoods of smallholder farmers, and again it doubles as Africa's largest coffee producer. It is indicated that Arabica coffee originated in Ethiopia followed by Uganda, before it spread to all the Arabica coffee-producing and consuming regions [28] . However, with the change in the database, the results can change as numerous studies on coffee farming covering slightly different areas have been published in other databases.

According to the bibliometric network's co-occurrence of keywords from the abstract section of the articles and based on the occurrence of each of the words, it can be established that the words with several links were mapped to a higher link strength (Fig. 6; Table 1). With all the articles in the app, the VOSviewer map generated 55 items, these were arranged in ten clusters, and the top five keywords with the highest total link strengths were coffee (52), climate change (37), Agroforestry (19), Smallholders (16) and, Vulnerability (16) . These form the center of most of the sampled articles in this study. One key factor to note is that Ethiopia appeared in many publications, mainly because it ranks number one in terms of coffee production in Africa, and because it is among the countries that have suffered the challenges of climate change through droughts [27]. The dominance of coffee, climate change, adaptation, and smallholders, is because they were the keywords in the search query. The other key area that the authors have given significant attention to is food security as smallholder farmers are subsistent and depend on their farms for both food security, nutrition, and income and they are highly vulnerable mainly, because of the low asset endowment, and because of the nature of agriculture that they do. Agroforestry and cooperatives are some of the key risk adaptation strategies in

Table 1 Keyword link strength and occurrences of significant-top 11 author keywords

S. no.	Keyword(s)	Cluster	Occurrences/links	Total link strength
1	Coffee	9	27	52
2	Climate change	1	23	37
3	Agroforestry	5	15	19
4	Smallholders	9	11	16
5	Vulnerability	1	13	16
6	Agriculture	1	13	15
7	Adaptation	8	10	13
8	Food security	8	9	13
9	*Hemileia vastatrix*	8	10	12
10	Diversification	2	11	12
11	Cooperatives	6	8	11
12	*Coffea arabica*	8	9	11

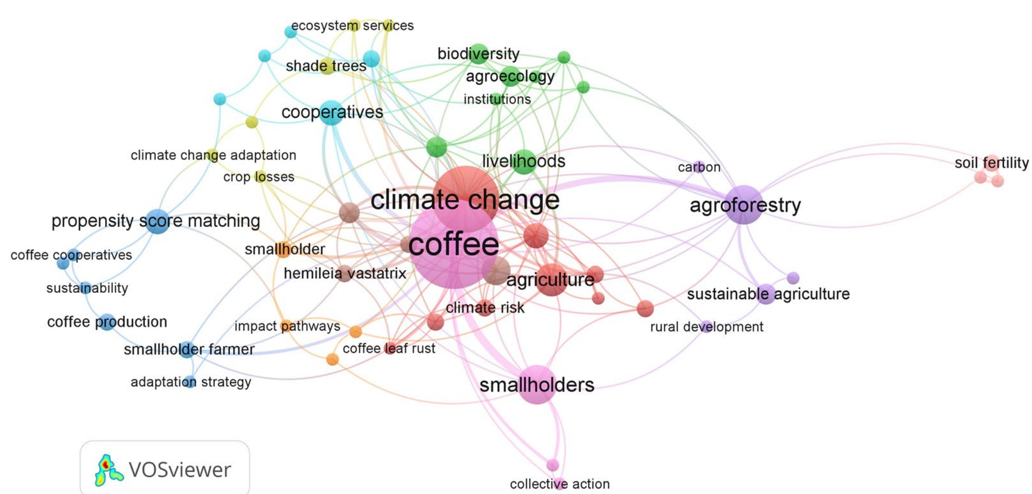

Fig. 6 Network co-occurrence of all author keywords on climate change, adaptation, under coffee farming from scholarly articles between 2013 and 2023

coffee farming across the globe, while *Himileia vastatrix* is the common multicellular fungus that causes coffee leaf rust that has devastated coffee fields in the last three decades mainly in America's [29, 30].

The top cited articles conveyed by the author were majorly those that were published in 2015 and 2017 (Table 2) and distributed across three publishers with Elsevier taking the lead followed by Springer, which are the dominant publishers of scientific articles on climate change in the English language. It is clearer that there is a relationship between the age of the article and the number of times it is cited. The average citation per year reveals the sustained impact of a given article on either the existing challenges or forms a firm foundation for theory for current and future research. The top six articles with over one hundred citations covered broader areas of climate change of production coffee, coffee diseases mainly the coffee leaf Rust and its effects in the Americas, food standards, certification, and poverty among coffee farmers, how Fairtrade farmer organizations aim at sustainable farming systems through incorporating climate change adaptation strategies in temporal and spatial coffee production, with emphasis on practices, such as agroforestry to balance agro-ecosystem services.

Climate change on-farm mitigation measures and associated impetuses to sustainable livelihoods of smallholder coffee farmers

Overview of climate change impact on smallholder coffee production

Of the two major global coffee types (Arabica and Robusta coffee), Arabica also known as highland coffee thrives well under cool temperatures which are mostly found in mid to high-altitude regions, while Robusta coffee cultivation is favored by relatively warmer temperatures, a common characteristic of lower altitudes [28]. However, available information indicates that there has been constantly rising temperature, across the coffee production areas in the tropical regions and the trend is expected to continue for many years to come, and this will negatively affect the suitability of coffee farming through yield reduction, that will translate into commodity price fluctuations and lower incomes and livelihoods [31, 32]. This significant rise in temperature and erratic precipitation is projected to cause a drastic decrease in the total area favorable for coffee production by the year 2050 by more than 50% [22], and this will also be accompanied by a decrease in bee richness which is important for pollination purposes [33]. There is a possible disappearance of mainly Arabica coffee in the areas that were originally suited for it, resulting in the displacement of the crop to higher latitudes that are projected to be cooler and more suitable [34].

In addition, most of the coffee farming systems will experience temperature increases that will predispose the coffee farms to Coffee Leaf Rust, Coffee Berry Disease, and Black Coffee Twig Borer which are some of the main coffee pests and diseases that are causing significant reductions in the yield and eventual death of the coffee trees [35]. Coffee Twig Borer is an important coffee pest reported in most coffee-growing regions, though with varying levels of incidence [36], this may exacerbate the already existing challenges of poor soil fertility and erratic rainfall distributions across the predominant coffee-growing regions. Smallholder coffee farmers whose farms are situated at lower elevations may no longer be

Table 2 Top 15 cited articles analyzed by denoted authors for the years 2013–2023

S. no.	Author names	Times cited	Average citation per year	Publisher
1	Bunn et al. (2015) [16]	278	34.75	Springer
2	Avelino et al. (2015) [35]	338	42.25	Springer
3	Chiputwa et al. (2015) [86]	154	19.25	Elsevier
4	Läderach et al. (2017) [15]	128	21.33	Springer
5	Bacon et al. (2014) [98]	123	13.67	Elsevier
6	Ango et al. (2014) [49]	113	12.56	Resilience Alliance
7	Cerda et al. (2017) [57]	86	14.33	Elsevier
8	Wang et al. (2015) [36]	79	9.88	Elsevier
9	Vellema et al. (2015) [91]	71	8.88	Elsevier
10	Rahn et al. (2014) [50]	65	7.22	Springer
11	Imbach et al. (2017) [33]	61	10.17	NATL ACAD Sciences
12	Tschora et al. (2020) [51]	55	18.33	Elsevier
13	Mitiku et al. (2017) [87]	54	9.00	MDPI
14	Jezeer et al. (2018) [64]	54	10.80	Elsevier
15	Bouroncle et al. (2017) [37]	50	8.33	Springer

able to maintain high quantity and quality coffee unless certain mitigation measures are put in place, as climate change will induce a reduction in coffee production and productivity at low altitudes [15]. The change in the suitability of coffee intercrops will occur across different regions, for example, beans and bananas, which are major coffee intercrops are likely to become unsuitable [37, 38]. However, if the projected decline in suitability in the current major coffee-producing regions is not adequately compensated, the likely implications are, reduced supplies that may trigger market disequilibrium that will eventually cause increased price volatility, disruption to supply chain operations and livelihoods in case of the smallholder farmers whose main source of income is through coffee farming [39].

Shifting coffee farming to areas of higher elevations that are expected to be cooler, as one of the forced adaptation mechanisms, may result in the loss of forests thus further deepening the impacts of climate change [34]. Other frequently reported climate change challenges include falling coffee trees and branches, due to heavy winds and hailstorms, pests, and diseases [27, 35, 40, 41]. These negative impacts of climate change on smallholder coffee farmers are exacerbated by the prevailing production challenges that include limited access to credit and other sources of inputs to purchase improved technologies to mitigate and increase coping mechanisms for climate change [39]. If appropriate adaptation measures are not put in place, climate change impact will result in food insecurity and loss of livelihoods in general for most of the coffee value chain actors [42].

Nonetheless, other scholars postulate that some coffee trees may maintain yield at higher temperatures than previously predicted; however, this may occur in very limited geographical regions [43]. It is paramount that area-specific climate change mitigation practices be put in place to improve the resilience of the crop and farming households rather than ignoring the negative potential impacts that the present and future climate may have on coffee [15]. However, some scholars indicate that spatial coffee production decline in one region could partly be replaced if the same acreages are opened in other areas, thus allowing the countries to maintain current production [22, 34, 44]. Available climate change projection information indicates that Ethiopia, the largest Arabica coffee producer in Africa is likely to experience an increase in coffee and Teff yields at high altitudes by the year 2060 [45].

Agroforestry as a principal climate change mitigation strategy under smallholder coffee production

There has been a reported substantial decline in the forest cover at a rate of more than 1% per year in the last three decades across the coffee-growing areas [46]. With this, the European Union recently passed legislation that will bar the importation of coffee and other crops from regions where coffee replaced natural forests [47]. Several smallholder coffee farmers have moved to semi-forest and semi-plantation coffee covers to adapt to climate change effects [34, 48]. This is not good for the quality of coffee produced plus the environment where coffee is grown and for global climate change adaptation. On the other hand, as the demand for coffee continues to grow, amidst climate change impasse reducing the coffee suitability areas, it will trigger land-use land-cover change to satisfy the growing demand for quality coffee at the global market [46], this shift will consistently drive forest conversion. Also important to note is that coffee grown under tree shade produces high-quality cherries with a great aroma. Furthermore, under coffee–agroforestry farming systems, coffee plants benefit from temperature regulation under the tree canopy and improved soil physical, chemical, and biological properties which also offer an ecosystem that is biodiverse with higher levels of carbon storage within these farms [49–52]. Afforestation and reafforestation practices offer good and sustainable synergies, especially in ameliorating temperature in coffee gardens while also offering other agro-ecosystem-based services [50, 53].

With the projected rise in greenhouse gas concentrations and emissions, across the globe, the corresponding increase in shade tree levels can alleviate the warming conditions in coffee gardens and offer an opportunity for income diversity especially if the tree selection is done carefully [54]. It is postulated that when afforestation is properly done around water sources, it protects them and is good for combating climate change [55]. However, higher shade densities can lower coffee yields due to competition for growth parameters like light for photosynthetic and soil macro and micronutrients [54]. Available research findings recommend certain agroforestry trees that may be well suited to plant in coffee gardens. For example, Macauba is good for modifying the microclimate through the reduction of the maximum temperature, intensity, and availability of photosynthetically active radiation in some regions when compared with the unshaded coffee [56]. To ensure a balanced ecosystem, a mixture of tree species on the same farm will guarantee adequate carbon storage, increased coffee yield, and soil nutrient replenishment while also enhancing climate change mitigation [54, 57]. Available information indicates that the agroforest trees of the Inga species have higher abilities to sequester carbon as they are known to be dense trees, and therefore, when incorporated into the coffee farming systems produce a higher contribution to the reduction in the carbon dioxide gas thereby reducing the greenhouse effects [58]. An empirical study in Xalapa-Coatepec reveals that these tree species were able to sequester 2.4 mg of carbon across about 3000 ha [58].

In addition, there is a significant positive relationship between the wood density of the agroforest trees and the local values, implying that for sustainable agroforestry and conservation planning, one needs to integrate trees ideal to specific areas [59]. It is noted that anthropogenic activities aimed at satisfying human needs result in the artificial selection of trees through continuous tree felling, expansion of agricultural farms replacing growth of trees in higher concentrations and at a closer spacing with those of reduced-thickness and quick maturing tree species in most coffee–agroforestry farming systems [59]. However, it should be emphasized that high-density tree species though slow-growing, offer numerous uses as compared to fast-growing but low-density tree species [59]. Furthermore, to adequately sustain high quantity and quality coffee production, while mitigating climate change, tree characteristics such as biomass should be taken into consideration. It is postulated that the amount of carbon sequestered is a function of tree age, species, density, composition, site on which the tree in question is grown, and the farmer's management aspects [24].

Also, when agroforestry is rightly done, for example, with the inclusion of leguminous trees, such as Calliandra, the soil properties (biological, physical, and chemical) important for coffee regeneration are addressed, compared to the farming systems where the coffee trees are fertilized with inorganic fertilizers but grow under direct solar radiation with no shading [60, 61]. In addition, there are no tradeoffs from services under the tree canopy as it will guarantee the provision of numerous ecosystem services. Furthermore, shaded coffee farming systems have significantly higher levels of pH, and this is important in increasing the availability of Phosphorous and Potassium within the soil, thus ensuring resilience to pests and diseases, and aiding efficient water uptake in comparison to coffee farms grown under open sun [60]. As smallholder coffee farmers have limited acreages, the majority plant the agroforest trees in the coffee plots, around their homes, and others in the boundaries of their plots. This is important in increasing tree coverage around the farm thus harnessing the albedo services provided by increasing tree coverage [49], this may guarantee the preservation of trees in semi-managed forest coffee [49, 62]. For medium to large-scale farmers not constrained by land, the establishment of woodlots with exotic trees in restructuring the forest–agriculture mosaic is a recommended practice as it improves native tree conservation [49, 63]. This is important in increasing revenue streams through timber harvests, sales, and associated business opportunities for coffee farmers through diversification [64].

Adopting agro-forestry coffee farming systems lays a foundation for increased coffee production, productivity, and profitability as compared to other farming models that entail growing coffee under pure stand [65]. Empirical research also indicates that coffee-tree intercrop is a predominant practice at lower elevations and such systems are associated with higher carbon storage and biomass than at higher elevations [62, 63, 66]. In addition, at mid-shade levels the microclimate under the intercrop reduces the direct heating of the coffee leaves by direct solar radiation, thus reducing the rate at which the leaves wither, age, and fall. This is important in reducing fruit abortion and, therefore, ensuring obtaining higher yields [43]. Over the years, the tree density in the coffee-tree intercrop may reduce, this depends on factors, such as tree species and richness, for example in stable coffee–agroforestry farming systems, epiphytic plants may grow and rise in number with an increase in the number of years of the coffee plot [67].

When applying coffee–agroforestry systems, farmers use less of inorganic agrochemicals, this is important in ensuring a climate resilience natural ecosystem [30]. Some of the agrochemicals such as nitrous-containing fertilizers are associated with greenhouse gas emissions to the atmosphere, and if used for extended periods and on an expansive area, may contribute to global warming. This is a hopeful nature-conserving strategy that supports farmers' and environmental autonomy, thus making coffee agroforestry systems perform equally or better than conventional coffee farming systems [64]. Usually, coffee farmers select trees that are fast growing with multiple features, such as wide crowns, provision of fruits especially for the children for proper nutrition income, poles, firewood, and timber [54, 68, 69].To ensure a sustainable plant functional density under the coffee–agroforestry farming systems, there is a need to have a good mix of trees that may include palms, fruit trees, wooden trees, food crops, such as bananas [51, 70]. One important consideration is that the overall performance of this ecosystem depends on the elevation of the area and management aspects of the farmer [57]. This is to ensure proper access to growth factors like light and nutrients through maintenance of adequate spacing and pests and disease management among other factors.

Furthermore, altitudes play a key role in the densities of the intercrops in the coffee–agroforestry farming systems, as some intercrops are well adapted for certain elevations and not for others. A case in point is the banana–coffee farming systems, the banana densities tend to increase with the increase in the altitude of the farm [70, 71]. However, at a closer spacing with coffee, the banana plants may be outcompeted as the coffee trees establish, due to their rigorous interwoven rooting system, and in most cases, shade trees increase with decreasing household's farm size. In addition, to sustain coffee–agroforestry farming systems, there is a need for smallholder farmers to diversify their livelihood sources and avoid overreliance on coffee as their main income source [48].

Important to note, is that in most of the coffee farming communities, the gender component has a significant impact on certain climate change mitigation practices. For example, tree establishment is normally seen as a male territory, as compared to the production of food crops like vegetables. These are some of the main intercrops used in the coffee farming systems among the smallholder farmers who are land-constrained. Agroforest trees intercropped with coffee in the coffee farming systems are often seen as a male responsibility [72].

Social networks and demographics as driving impetuses to climate change mitigation under smallholder coffee production Social networks

Information access on new and improved technologies about climate change is important for the smallholder coffee farmers as this drives their decisions on which livelihood source is well adapted in each area, at a certain time and, therefore, adoption and sustenance. Commodity-based farmer organizations such as the coffee cooperatives offer platforms for access and information sharing, facilitating the dissemination of climate change information on carbon credit and how it links with livelihoods, market information, and other climate-smart agricultural technologies for sustainable coffee production [50, 73]. Empirical studies have postulated that social networks influence and motivate coffee farmers to adapt to risks from external factors, some of these may include farmer-to-farmer sharing of pedagogies. However, risk perception and experience are not sufficient to motivate farmers to adopt certain practices [74–77].

Farmer-to-farmer sharing of information guided by the community facilitators ensures quick uptake of improved technologies [76–78]. In addition, smallholder farmers' membership in a farmer organization such as a coffee cooperative (also recognized as social capital under the livelihood framework) is an important aspect of the adoption of climate change practices through information sharing, and other production resources. In addition, adopting mixed farming techniques, such as rearing animals alongside crop farming, can increase resilience to climatic shocks [27, 76].

Access to weather information, in addition to having diverse income streams, is critical in preparing adequate and resilience coffee-farming systems [78]. With the increased occurrence of droughts and erratic rainfall, the adoption of soil and water conservation practices can buffer coffee farming systems while ensuring a sustainable environmental system [79–81]. Importantly, to improve efficiency, access to services concerning good agronomic practices and proven modern farming technologies plus up-to-date information about climate variation can influence perception and household decisions on climate change mitigation [42, 82].

Farmer demographics

Furthermore, perception and understanding of climate change expressed in terms of temperature and monsoon variations are linked to the farmer's demographics and household characteristics, such as family size, education, and farm size [53, 83], and understanding these perceptions helps in shaping synergies and strategies for adaptation [62]. Most smallholder coffee farming households depend on family labor as an important human resource for building climate change mitigation and adaptation practices. However, big household sizes require high maintenance costs, this relationship is reversed for the farming households with larger farming areas, as these can generate additional harvests and incomes to cater for more members [83]. The smallholder farmer's level of endowment of both physical assets in addition to human assets has a strong bearing on the capacity to adopt certain climate change mitigation measures, this implies that those with higher asset bases are more resilient and can easily cope with negative impacts of climate change as compared to those that are less endowed.

Migration and profit sharing are also considered measures adopted to increase the resilience of smallholder farming households. As disasters hit, some livelihood assets and sources may vanish resulting in households slipping into destitute and poverty, if this happens, for extended periods [20, 29]. However, with increased population, land scarcity, reduced food consumption, and migration of households and farms to other areas, are some of the coping mechanisms used in some regions such as, the Americas, are deemed unsustainable; nonetheless, profit sharing is workable [25]. Securing non-farm formal employment either at the local or regional level can be a viable alternative in reducing over-dependence on coffee farming. Expanding non-farm income sources such as engagement in business can also buffer against the negative effects of climate change. This can be realized if the smallholder farmers invest in education to tap into formal employment opportunities [84]. In addition, because women are usually disadvantaged by the limited access to education in many coffee-farming communities, their level of resilience is impeded, and, thus, end up adopting fewer and sometimes less effective adaptation strategies [25, 85].

Fairtrade sustainability components under smallholder coffee production As part of the coffee industry and company-led coffee trade in the international market, standards aimed at ensuring equity and environmentally sustainable production are a governing principle for sourcing coffee cherries. One of its aims is to impact the livelihoods of vulnerable smallholder coffee farmers through improvement in the standards of living and poverty reduction [86, 87]. Most smallholder coffee farmers under Fairtrade certification agreements and organic coffee production, reveal that this farming system is less profitable as compared to the conventional coffee farming system [88]. The main reason behind this is that it is associated with substantially lower yields and thus lower incomes, a case in point is certified organic coffee farmers in Ethiopia [89].

Some smallholder coffee farmers achieve much lower benefits when Voluntary Sustainable Standards (VSS) are combined with Fairtrade, and this happens on the account of lower coffee yields obtained, resulting changes in farm production practices [90]. However, not all Fairtrade certification schemes result in lower yields, as some schemes like Utz-Rainforest Alliance increase the productivity of some of the most limiting inputs, such as land and labor, which yields higher harvests and incomes, thereby causing a reduction in poverty among the certified smallholder coffee growing households [19]. This implies that the outcomes of the certification scheme in combination with VSS vary spatially and are thus not cast in stone, and available information indicates that, on-farm agricultural income-generating activities have a resounding relationship with certification performance [91]. Gender plays a central role in the adoption of some of the certification practices in coffee production, with most women more attracted to adopting climate change environmentally friendly adaptation measures [92]. Although some certification methods like Double Fairtrade-Organic certification offer higher prices for coffee cherries, they do not stimulate increased land and labor productivity. This gives a low net effect on the income of the certified smallholder coffee farmers consequentially leading to no reduction in poverty [87].

As the Fairtrade-led companies purchase certified coffee from farmers, they offer premiums to the farmer organizations like unions or cooperatives based on the prior sale and buying agreements. These premiums have often been used by some organizations to create the necessary infrastructure that is important in sourcing and creating traceable product supply chains and training their membership. This is important in creating a robust institutional framework that guarantees quality coffee supplies [87]. It is important to note that smallholder coffee farmers producing certified coffee for the specialty coffee markets are motivated to adopt on-farm climate change adaptation strategies. This is aimed at maintaining a high-quality yield for the regional and international certified buyers, whose standards cause a significant improvement in their livelihoods without excluding the less privileged while empowering their farmer institutions [90, 93]. On the other hand, trade certification at the farmer organization or cooperative level does not usually translate into higher returns to the certified coffee farming households [94].

With increased interest in product traceability, effective coffee certification schemes result in higher and stable prices for the coffee cherries, more especially when dealing with wet-processed coffee. However, smallholder farmers with few coffee harvests and thus very low incomes may be demotivated to join these marketing arrangements [92, 95]. Certified producers engage in land conservation and tree planting, which increases their resilience to climate change impacts in the long run and as such in some regions, Fairtrade farmers experience yield gains, while organic farmers have a price advantage [95, 96]. As a result of the producer agreements between the certification companies and with the smallholder coffee farmers through their producer organizations, farmers can appreciate and be mindful of the nitty–gritty involved in sustaining the specialty markets through a conscious adoption of good coffee agronomic practices [95, 97]. Consequently, trade certification at the farmer organization or cooperative level does not usually translate into higher returns to the certified coffee farming households [94].

Under the Fairtrade arrangement, some farmers and farmer organizations have customized environmental and local food production and access systems that improve sustainable land use management [98]. Empirical evidence of country-level and regional-level successes have also been documented in India, where Fairtrade cooperative members have realized good yield and price returns when compared to non-certified farmers, leading to high livelihoods for certified farmers [89].Country-level differences are pronounced on the effect of certification under smallholder coffee farming systems, whereby countries such as Nicaragua and Uganda obtained better output prices for the coffee cherries than the minimum agreed upon. However, the premiums offered by the certification companies are not usually significant [87, 94]. Besides, the good pricing regimes received in some countries may not be permanently guaranteed as they depend on what happens in the upstream supply chain.

It is noted that under coffee certification systems, smallholder farming households invest more production resources, especially labor to coffee and its related activities. This significantly reduces labor and land allocation to the production of other agricultural products and other livelihood sources such as engaging in off-farm employment which shrinks the diversity of livelihoods and their associated incomes [91]. All in all, harnessing the importance of certifications sustainably with substantial economic growth requires addressing both the market and production constraints that smallholder farmers face [94]. Furthermore, the decline in yield under the organically certified smallholder farmers is due to a lack of organic inputs such as fertilizers and herbicides that are organic and accepted under the Fairtrade arrangement, and premiums offered by the coffee purchasing companies usually do not compensate for the drop in the out prices [90, 96]. These render the ultimate effect of most of the Fairtrade schemes on coffee farming households' livelihoods and incomes so insignificant.

To increase uptake of sustainable climate change good agricultural practices, resilience, and coping strategies of smallholder farmers, empirical evidence of the role of government policy in the creation and operationalization of reliable early warning systems is crucial [35] in perpetuating the status quo is paramount. A robust multi-stakeholder platform including researchers is critical. For example, those involved in the development of resistant coffee cultivars and other climate-smart agricultural technologies, coffee purchasing and processing companies, and other local community stakeholders [99].

Areas for further research based on the findings

Fairtrade certification schemes are premised on a foundation that provides an environment that guarantees community development, sustainable coffee production and associated working conditions, environmental sustainability, improved income, and livelihoods of smallholder farmers. It is paramount to analyze the practical ways in which Fairtrade certification systems can be structured to offer sustainable benefits to smallholder coffee farmers. This should be cognizant of the notion that smallholders are land-constrained, and they mainly depend on family labor for most of the farming operations. This means that a new technology that does not increase both land and labor productivity is likely not to yield a substantial impact on their livelihoods.

Some certification schemes are opposed to the use of any inorganic agrochemicals on the entire farm, such as insecticides, herbicides, and synthetic fertilizers, yet with climate change, most farmers find it difficult to get alternative remedies to the prevalent pests and diseases (such as Black Coffee Twig Borer, Coffee Berry Disease and Coffee Leaf Rust) and increasing levels of soil infertility. Therefore, assessing alternative viable methods that can be used to replenish soil fertility and control pests and diseases without overreliance on inorganic agricultural chemicals offers an area of applied future research. In addition, one of the major highlights of why Fairtrade certification fails to cause a significant positive change in the incomes of smallholder coffee farmers is that it is associated with a decline in coffee yields. Certification schemes, such as Organic Fairtrade, are against the use of synthetic agrochemicals which is good for the environment, but the available alternatives to restore the lost soil nutrients are not sufficient and thus make the production systems unsustainable in the long run.

One of the five critical pillars of the Sustainable Livelihood Framework in rural agricultural production is social capital. This entails establishing viable social networks, involving among others, forming, and activating farmer organizations, such as cooperatives. These offer numerous benefits including bulking of farm produce and negotiating better markets, access to farm inputs and information. With climate change and other production and marketing risks becoming prevalent, it is important to determine how cooperatives and farmer organizations can be utilized to influence the adoption of coffee–agroforestry farming systems as a main climate-smart agricultural practice. It is, therefore, important, that as a recognized sustainable livelihood social asset, these organizations are empowered and streamlined to increase their potential for making climate change mitigation impacts through promoting agroforestry.

Conclusion

This literature review study was done to scientifically establish the deep linkages from already published articles covering climate change, livelihoods, and adaptation under smallholder coffee farming from coffee-growing regions across the globe. There was a non-significant positive rise in the tendency of the number of published research articles based on the content and time scope of this study. The highest number of online published research articles was obtained in the year 2022, while the lowest number was visible in the year 2016. The increasing positive trend of the number of scholarly published articles over the last decade, covering the content scope of this review, directly suggests a level of significance to addressing coffee production and value chain climate change-influenced bottlenecks through research to ensure a sustainable supply chain.

Adoption of agroforestry as a universal climate change mitigation measure under coffee farming is generally influenced by farmer characteristics and their endowments, such as farm size, household size, experience, gender, altitude of the farm, and the type of tree species. In addition, the livelihood pentagon of assets has a strong bearing on the adoption and sustainability of the climate change mitigation measures, the extent and level of contribution of each of the assets varies from farmer to farmer, from one organization to another, and from region to region. Several Fairtrade certification company-led standards exist across the coffee growing regions and have a diversity of impacts on the farming communities depending on the structure of their operations.

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