

## Article

# The Role of Climatic and Non-Climatic Factors in Smallholder Farmers' Adaptation Responses: Insights from Rural Ethiopia

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**Abstract:** This paper discusses how climatic and non-climatic factors, either separately or together, shape the adaptation responses of smallholder farmers in the Raya Azebo district of Ethiopia. Their adaptation responses included adjusting planting periods, crop diversification, changing crop types, adopting improved seeds, using irrigation, conducting migration, participation in wage employment, selling local food and drinks, and owning small shops. These adaptation responses were motivated by various climatic (e.g., drought and rainfall variability) as well as non-climatic factors (e.g., market conditions, yield-related factors, land scarcity, labor shortages, soil fertility issues, crop diseases, and limited local employment options). We therefore argue (i) that successful adaptation requires a broader understanding not just of climatic factors but also of the various social-ecological factors that shape smallholder farmers' adaptations; and (ii) that the successful design and implementation of locally appropriate planned adaptation interventions require the inclusion of both climatic and non-climatic factors.

**Keywords:** smallholder farmers; adaptation decision-making; climatic and non-climatic factors; Ethiopia; Africa



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## 1. Introduction

Climate change is an increasing concern for Africa. A report by the Intergovernmental Panel on Climate Change (IPCC) indicates that over the past 50 to 100 years, temperatures in most parts of Africa have increased by 0.5 °C or more [1]. Rainfall is projected to decline in some regions of the continent with serious consequences for agriculture and food security [1,2]. In Sub-Saharan Africa, for instance, smallholder farmers will be affected by the impact of climate change because of their dependence on rain-fed farming and low adaptive capacities [3–5].

In Ethiopia, climate change has become one of the biggest threats to smallholder farming systems in recent decades [6–8]. Increasing temperatures, erratic rains, severe drought, and flooding events have become common occurrences across the country [9–11]. The Tigray region, where the site for this study was located, is highly affected by climate-linked risks [12,13].

Particularly, the region experiences high spatio-temporal variabilities in temperature and rainfall parameters. Analysis of historical temperature data (1954–2008) shows that both average annual minimum and maximum temperatures in the region have increased by about 0.72 and 0.36 °C every ten years, respectively [14]. Over most parts of the region, an

increase in mean annual maximum and minimum temperatures by a range of 0.8–5 °C and 0.8–5.6 °C is expected for the period of 2030–2050, respectively [15].

Between 1980–2009, both increasing and decreasing trends in annual precipitation totals have been observed in different parts of the Tigray region, but these trends are not statistically significant [16]. Over the period of 2030–2050, the *Kiremt* (long-season) rainfall totals are projected to increase in most areas of the Tigray region, while the *Belg* (short season) rainfall amounts are expected to decrease significantly across the region [15]. Beyond rainfall totals, the region experiences erratic and unreliable rainfall patterns, which are characterized by late or early cessation of rainfall during crop planting seasons [17,18]. Historically, the region also suffers from severe and recurrent droughts [13,19].

In Tigray, the adverse impact of climate change on smallholder farmers' livelihoods as well as on natural resources including freshwater availability and land and forest resources is significant [20,21]. Adaptation is therefore fundamental for minimising the present and future risks of climate change and building the adaptive capacities of local communities [22–24].

Over recent decades, the concept of adaptation has gained increasing attention within the field of climate change. In the scholarly literature, numerous definitions of adaptation exist. However, there is a lack of consensus on how adaptation on the ground should be framed to build the adaptive capacity of climate-vulnerable groups such as smallholder farmers [25,26]. Some scholars relate adaptation to specific climate change impacts, while others relate it to conventional development objectives [27,28]. The IPCC defines adaptation as “the process of adjustment to actual or expected climate and its effects” [29] (p. 5). Other scholars define adaptation more broadly such as “changes in social-ecological systems in response to actual and expected impacts of climate change in the context of interacting non-climatic changes” [30] (p. 22026). This paper follows the latter definition. Some scholars suggest merging adaptation with development, thereby highlighting efforts towards reducing general vulnerability and increasing resilience to climatic and non-climatic stressors [25]. In this sense, adaptation has the potential to improve development outcomes by strengthening the livelihoods and capacities of vulnerable people.

Adaptation actions are classified into two forms: autonomous and planned adaptation [31]. While the former denotes adaptation measures that are taken proactively by households or communities without external support, the latter refers to measures taken by governments and development organizations to reduce the impact of climate change [32,33]. As autonomous adaptation is insufficient to address risks associated with climate change, planned adaptation has become a major policy response [34].

Most empirical studies have explored the different adaptation measures taken by Africa's smallholder farmers to reduce the current and future impacts of climate change [35–38]. While these studies are important, some researchers have highlighted that rural households' vulnerability to climate change impacts does not occur in isolation from other socio-economic, institutional, and political drivers of vulnerability [39–41]. Consequently, their adaptation decisions are shaped by both climatic and non-climatic factors [42–44].

In a broader sense, decision-making is a process of choosing options to deal with a particular situation. Smallholder farmers can be considered as utility maximizers [45,46], who make decisions to maximize benefits by reducing risks and by taking advantages from new opportunities. For example, farmers adjust farming practices to reduce risks that are associated with drought, erratic rains, pest infestations, land degradation, and labour shortages [47–49]. They also adjust their farming strategies in response to emerging markets, new technologies, improved infrastructure, and institutional support [44,50,51]. One could view farmers as rational actors with full information about their available choices that make deliberate decisions to maximize their benefits, relying on the information they obtain to meet that goal [52].

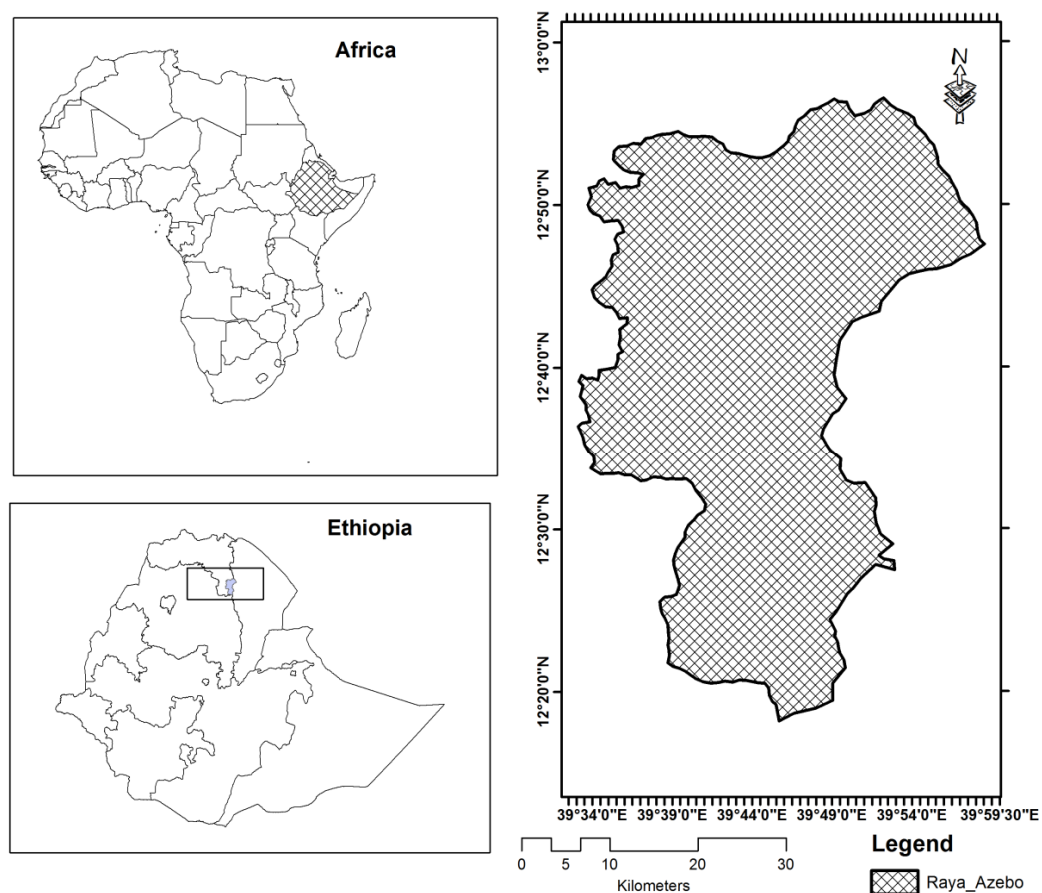
Under conditions of uncertainty, however, individuals regularly make decisions with heuristic shortcuts (i.e., based on instinct, emotions, and experiential learning) instead of using rational decision-making methods [52,53]. Smallholder farmers in developing countries

often operate in a complex and uncertain environment where climate change and other broader development challenges are characterized by these uncertainties [49,54,55]. Hence, it is expected that they utilize heuristic decision-making approaches in this context [52].

As other researchers have argued, climate change adaptation decision-making should be explored with a recognition and deep awareness of the socio-economic, cultural, institutional, and political factors that also shape adaptation actions simultaneously [56–60]. This is because, adaptation research that solely focuses on climatic factors will not adequately inform planned adaptation measures that are aimed at enhancing smallholder farmers' adaptive capacities. In this paper, we explore farmers' adaptation responses to climate change within the context of non-climatic influences in the Raya Azebo district of the Tigray region. We use adaptation as the core conceptual frame driving our investigation. We seek to understand the non-climatic factors that affect implementation of effective adaptation: how these dynamics affect adaptation in situ. This focus on adaptation clearly delineates this study from rural development and livelihood studies, although our findings will have implications for both. By doing so, this study provides valuable knowledge that can be used to inform the development of effective planned adaptation interventions, strategies, and policies that benefit smallholder farmers in Ethiopia and other developing countries with similar socio-economic contexts.

## 2. Methods

The study was carried out in the Raya Azebo district, which is part of the Tigray region of Ethiopia (Figure 1). It was chosen purposely as it is one of the rural districts most vulnerable to climate change, as well as to other socio-economic challenges, in Ethiopia [13]. The district has a total area of 1343 km<sup>2</sup> and encompasses lowland (47%), midland (50%), and highland (3%) [61]. According to the last population census conducted in Ethiopia, Raya Azebo is home to 135,870 households who are primarily engaged in mixed crop-livestock farming [62]. The rainfall pattern of the study area is bimodal, with mean annual rainfall ranging between 400–700 mm and mean annual temperature varying between 15 °C and 30 °C [63]. Out of 20 *Kebeles* (lower administrative units) in the Raya Azebo district, one Kebele called Hade Alega was selected randomly using a lottery method. We chose a random sampling technique to select one specific *Kebele* based on the information we received from the district's administrative officials. Smallholder farmers residing across the 20 *Kebeles* experience more-or-less similar socio-economic and environmental challenges regardless of their location. Similar to all the other *Kebeles*, the agricultural production system in Hade Alega is mixed-crop-livestock farming system. Despite their exposure to climatic and non-climatic risks, smallholder farmers residing in these *Kebeles* have received little support from governmental and non-governmental institutions. It is common to observe poor rural infrastructure (including bad roads and a lack of electricity, pipe water, and communication facilities) throughout the *Kebeles*.



**Figure 1.** Location Map of Raya Azebo district. Source: [64].

The study, which was conducted between December 2016–February 2017, used a mixed-method case study approach to enable in-depth and multifaceted [65,66] exploration of smallholder farmers' adaptation responses. Both qualitative and quantitative methods, in the form of focus group discussions (FGDs) and household surveys, were employed. The data collection started with an FGD with smallholder farmers. The focus group participants (four women and seven men) were chosen purposively as they were considered knowledgeable of the local conditions and the issues under investigation. The aim of this focus group was twofold: (a) to identify locally relevant farm- and non-farm-related livelihood strategies that are commonly practised by farmers in the study area; and (b) to elicit information about the key motivating factors that induce the locally identified farm, off-farm, and non-farm livelihood strategies, without reference to climate-related factors to avoid bias in the responses. The focus group was conducted in a public place where farmers would gather for a meeting. Two research assistants helped the first author in facilitating the discussions and taking notes. The FGD lasted for 3 h.

The surveys were administered to household heads, which constituted the unity of analysis for this study. We interviewed household heads due to their primary role in important livelihood decisions within the household. Using the table on confidence ranges for variability attributable to sampling [67] (p. 41), this research estimated four hundred (400) respondents at 95% confidence level. The respondents were selected using a systematic random sampling technique [68,69]. This technique was employed by selecting every 10th house until the sample size of 400 was obtained. To administer the household survey, a structured questionnaire was developed based on an extensive literature review on the common adaptation strategies practised by smallholder farmers in Africa and the possible motivating factors for adopting those strategies [70–72] and revised based on the results from the initial FGD. A pre-test of the questionnaire was carried out to check the reliability and validity. In this regard, the Cronbach alpha test was used to check for the

reliability while exploratory and confirmatory factor analysis was used to check convergent and discriminatory validity.

The modified questionnaire was structured in three parts: (i) household socio-demographic characteristics; (ii) types of farm, non-farm and off-farm related strategies conducted by smallholder farmers over the last five years; and (iii) farmers' motivations behind conducting those strategies in the past five years. Following [73], we consider farm strategies to be if the household earned income from its own farmland; off-farm strategies if income was derived from participation in wage employment or exchange of labour on other farms; and non-farm strategies if income sources came from non-agricultural activities (e.g., migration, businesses, etc.).

Most of the questions in the questionnaire had close-ended response categories and respondents were given the option to choose multiple responses from the available list. The use of close-ended questions in the questionnaire enabled higher response rates, facilitating the coding process and the statistical analysis of the data. Open-ended questions were also included to allow respondents to provide answers which may not have been included in the fixed list of response options (i.e., adaptation responses) and to capture detailed motivations behind their adaptation responses. The open-ended questions corroborated the quantitative findings and provided a more nuanced story of the data.

The focus group discussion was digitally recorded, translated into English from the Tigrinya language, and thematically analysed. The questionnaire data were coded and entered into the Statistical Package for Social Sciences (SPSS) version 22 (IBM, Armonk, NY, USA). The survey achieved a high response rate of 100% and there were no missing data. To analyze the quantitative survey data (including farm households' socio-demographic characteristics, adaptation response, and motivations), descriptive statistical techniques were employed which made use of frequencies and percentages. Inferential statistical technique (Chi-square test) was also used to formulate and check the association between key socio-demographic variables and farmers' adaptation responses and motivations. Moreover, quotes from the open-ended survey questions were extracted to illustrate the themes that emerged from the analysis.

### 3. Results

The results are presented in three sections. First, the socio-economic characteristics of the survey respondents are outlined. Second, the type of farm-related adaptation strategies implemented by smallholder farmers and the role of climatic and non-climatic factors in motivating those actions are discussed. Finally, the non-farm and off-farm adaptation strategies used by smallholder farmers and the driving forces behind farmers' decisions to adopt those strategies are reported.

#### 3.1. Socio-Demographics of Smallholder Farmers in Raya Azebo, Ethiopia

The majority of the surveyed smallholders (69.8%) were males and the remaining 30.2% were females (Table 1). In terms of age structure, most of the respondents (41%) were between ages of 36 and 45. Relatively few respondents belonged to the younger age (18–25) and older age (65+) groups. Of the total 400 survey respondents, almost two-thirds of the respondents were married, 22.3% were widowed, 12.3% were divorced and the remaining 1.8% were single. It is important to note that most female-headed households in rural Ethiopia are either widowed or divorced. Indeed, the survey results show that, out of the 122 female respondents, 63 were widowed and 42 were divorced. Table 1 indicates that the majority (46%) of the survey respondents had a large family size (between 5 to 8 children).

Concerning religion, the majority (83.5%) were Orthodox Christians, while a small minority (16.5%) were Muslims. As can be seen in Table 1, the status of education was very low. A large number of the survey respondents (85.6%) were uneducated. Few respondents (10.5%) could read or write via attending some formal education (Grades 1–4). The remaining respondents had attended formal education up to the primary (2.3%), secondary (1%),



and tertiary level (0.5%). There was substantial income inequality among the surveyed households, which ranged from 500 ETB to 40,000 ETB (USD 10–USD 804.55).

**Table 1.** Socio-demographics of surveyed smallholder farmers.

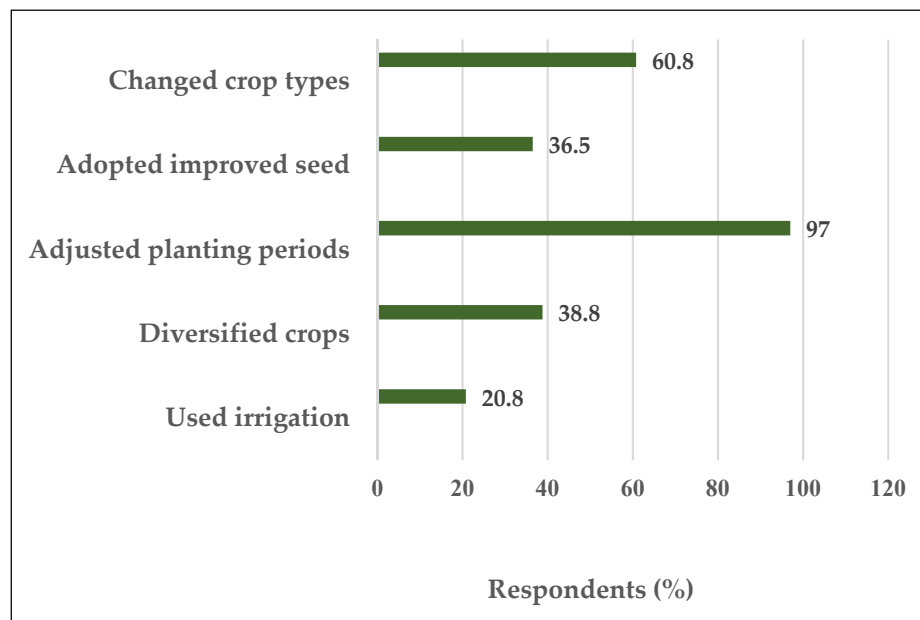
Socio-Demographic Variables	Description	Total Number (Frequency)	Percent (%)
Gender	Female	121	30.3
	Male	279	69.5
Age	18–25	21	5
	26–35	86	22
	36–45	163	41
	46–55	76	19
	56–65	36	9
	65+	18	4.5
Marital status	Married	254	63.8
	Widowed	89	22.3
	Divorced	49	12.3
	Single	8	1.8
Number of children	No children	30	7.5
	1–2	58	14.5
	3–4	119	29.8
	5–8	184	46
	8+	9	2.3
Religion	Orthodox Christian	334	83.5
	Muslim	66	16.5
Education	Do not read and write	343	85.7
	Read and write	42	10.5
	Primary education	9	2.3
	Secondary education	4	1.0
	Higher education	2	0.5
Annual income (ETB)	500–5000	86	21.5
	6000–10,000	139	34.8
	11,000–25,000	86	21.5
	26,000–40,000	52	13
	40,000+	37	9.2

### 3.2. Types of On-Farm Adaptation Strategies

Figure 2 shows that farmers had adopted five different types of on-farm adaptation strategies. The most common adaptation strategy was changes made to crop planting dates (periods), which was practised by almost all the farm-households (97%). The results indicated a significant association between adjusting planting dates and level of income ( $\chi^2 = 10.671$ ,  $df = 4$ ,  $p = 0.05$ ). In particular, all households (100%) whose incomes were between 26,000–40,000 (ETB) adjusted crop planting dates, compared with households (89%) who belonged to a higher income category (40,000+) (ETB) (Table S1).

Changes in crop types and crop diversification were also part of on-farm adaptation responses, which were reported by 60.8% and 38.8% of survey respondents, respectively. Of those who diversified crops, more male-headed households (42%) were found to be using this strategy compared with female-headed households (29%) (statistically significant association at:  $\chi^2 = 6.386$ ,  $df = 1$ ,  $p = 0.01$ ) (Table S2). In addition, a higher proportion of households (40%) who were aged between 36–45 employed a crop diversification strategy, compared with households (30%) who belonged to the 26–35 age group (a statistically significant association at:  $\chi^2 = 11.669$ ,  $df = 5$ ,  $p = 0.04$ ) (Table S3). The results also indicated a significant association between level of education and crop diversification ( $\chi^2 = 10.04$ ,  $df = 4$ ,  $p = 0.04$ ) (Table S4). More specifically, households who did not read and write (39%) diversified more compared to those who could read and write (26%). Except for crop

diversification, the survey results showed no significant association between educational level and other on-farm adaptation responses. Moreover, a higher proportion of households (43.5%) with a large family size (5–11) were likely to diversify than households (40%) who had a family size of 3–4 (43.5%) (significant at:  $\chi^2 = 15.8$ ,  $df = 4$ ,  $p = 0.003$ ) (Table S5).



**Figure 2.** Smallholder farmers' on-farm adaptation strategies.

The results further showed that 36.5% of the surveyed households adopted improved seed varieties as an adaptation strategy (Figure 2). There was a significant association between adopting improved seed varieties and the type of farm-household headship ( $\chi^2 = 5.282$ ,  $df = 1$ ,  $p = 0.02$ ), with more male-headed households (40%) adopting the strategy compared to female-headed households (29%) (Table S2). Irrigation was the least-utilised on-farm adaptation measure, employed by only 21% of surveyed households. Compared with female-headed households (14%), male-headed households (24%) adopted irrigation to a greater extent (a statistically significant association at:  $\chi^2 = 4.736$ ,  $df = 1$ ,  $p = 0.03$ ) (Table S2).

### 3.3. The Role of Climatic and Non-Climatic Factors in Motivating On-Farm Adaptation Strategies

The driving forces that motivated smallholder farmers to undertake on-farm adaptation measures were diverse. As shown in Table 2 below, the climatic factors mainly consisted of droughts and erratic rains, while the non-climatic factors included market conditions, yield consideration, land scarcity, labour constraints, limited local employment options, soil fertility issues, and crop diseases. The survey results revealed that farmers considered either one or multiple factors simultaneously when applying each on-farm adaptation strategy. The section below presents the role of climatic and non-climatic factors in inducing each on-farm adaptation response.

**Table 2.** The role of climatic and non-climatic factors in motivating on-farm adaptation measures.

On Farm Adaptation Strategies	Motivation for Taking On-Farm Adaptation Measures	Respondents (Frequency)	Respondents (%)
Adjusted planting dates	Climate-related factors	335	88%
	To take market opportunities	216	56%
	Other	23	6%
Changed crop types	Climate-related factors	203	84%
	Poor soils	166	68%
	The low market price of some crops	161	66%
	Labour constraint	144	50%
	Some crops do not provide better yield	103	42%
	Pest and disease	88	36%
	Small land	69	28%
	Other	44	18%
Diversified crops	To minimize market risks	117	77%
	Climate related factor	108	71%
	To control pests and diseases and improve soil fertility	77	50%
	To balance food demand	73	48%
	Other	15	10%
Adopted improved seeds	Seeking better yield	121	82%
	Climatic factor	111	76%
	High market demand	80	55%
	Improved seeds resist disease	48	33%
	Other	16	11%
Adopted irrigation	Climatic factor (erratic rains)	72	87%
	The desire for more income	53	64%
	Government support	50	60%

Note: Multiple responses were possible.

### 3.3.1. Adjusting Crop Planting Dates as an On-Farm Adaptation Measure

As can be seen in Figure 2, adjustment of crop planting dates was one of the most practised adaptation strategies in the study area. Of those farmers who used this strategy, the majority (88%) mentioned climate change as one of the triggering factors (Table 2). Participants during the focus group discussion mentioned that they changed crop-planting dates following seasonal weather conditions (i.e., the onset of seasonal rains). Depending on the onset of the first few rainy days, farmers of the study area shifted crop planting dates in the short (*Belg*) and long rainy seasons (*Meher*). One of the surveyed farmers explained this as follows:

Normally February is the month I plant teff [*Eragrostis tef*] during Belg (the short rainy season). But these days the weather is so unpredictable. If the rain comes earlier than February, I plant teff immediately. If it does not come on time, then I wait until it rains either in March or April. Some years the Belg rain does not come at all. In this case, I would wait for the onset of Meher season rainfall. (Respondent # 35, Household Survey).

As can be seen in Table 2, over half of the respondents (56%) adjusted plant growing periods to take advantage of market opportunities. This is particularly the case among vegetable producers, who adjusted plant-growing periods by planting vegetable seeds



at different times in a sequential manner rather than planting them all at once (i.e., plant staggering). This strategy was an income-smoothing mechanism in the face of market uncertainties. As vegetable growers illustrated:

The problem in our area is that most farmers plant vegetables at the same time. As a result, there will be excess supply in the market and the price of vegetables goes down. I used to plant vegetables during wet seasons, but now I have shifted the growing period to dry season using irrigation. The profit is good when you grow and harvest vegetables in the dry season. (Respondent # 57, Household Survey).

I have started planting tomatoes in three rounds. If the market price for tomatoes become cheap in the first-round harvest, it might go up in the second or third round. (Respondent # 225, Household survey).

### 3.3.2. Changing Crop Types as an On-Farm Adaptation Strategy

Farmers' motivation for changing crop types was diverse. Of those farmers who practised the strategy, 84% stated climate related factors (Table 2). For example, one of the survey respondents reported that he switched from Zama maize variety to Melkasa 1-6 (SADVIB#) as the latter one is drought tolerant. He explained:

I do not plant Zama anymore. Because when there is water shortage [drought] the plant quickly dies. Melkasa is better as it can survive even when drought is severe. (Respondent # 22, Household Survey).

As shown in Table 2, 68% of farmers reported soil fertility issues as one of the driving forces for making the change. Throughout the survey period, some farmers indicated that they had switched from sorghum to teff (*Eragrostis tef*) because sorghum required more reguid (fertile soil) than teff. On the other hand, 66% of farmers decided to change the crop type they use because the price of some crops in the local market was very low or there was no market demand. Interviewed farmers during the survey commonly reported that they had switched from a sorghum variety known as america to other sorghum varieties (e.g., kodem, aba ora, and keye mashela), as the price of america was lower in local markets. For example, at the time of the study, kodem Sorghum used to be sold at 18 ETB/Kg, compared with the america variety which sold only for 13 Birr/Kg. As such, both climate factors as well as non-climate drivers coalesced to impact farmers' livelihoods and drive adaptation practice in a way that reflected their adjustments based on both dynamics.

Of those farmers who changed crop types, 50% stated that labour constraints were one of the motivating factors for making changes. During focus group discussion, it was mentioned that some farmers switched from using cereal crops to pulses when they lacked labour-power. This technique was particularly practised by older farmers and female-headed households. For example, one old farmer during the survey stated:

Growing teff requires high labour-power. I must plough the land five to six times before I plant the seeds. It also requires high labour input for weeding. As I am very old now, I do not have the energy to grow teff anymore. I have switched to pulses because they require less labour. (Respondent # 70, Household survey).

Yield-related factors further motivated 42% of smallholder farmers to change crop types (Table 2). During the focus group discussion, it was noted that farmers in the study area were abandoning the Zama maize variety and planting melkasa (SADVIB#) as it provided better yield. This was also raised during focus group discussion. For example, one of the participants estimated that up to 40 quintals/ha could be harvested from melkasa (SADVIB#) compared to the 25 quintals/ha which were gained from Zama. Some farmers (36%) mentioned making changes to crop varieties to control the spread of pests and diseases. During focus group discussion, it was reported that farmers were switching from a local maize variety to barley due to an outbreak of kurtim (crop disease). On the other hand, 28% of those who changed crops reported using the strategy because of land shortage (Table 2).

### 3.3.3. Crop Diversification as an On-Farm Adaptation Strategy

In the study area, crop diversification was a common adaptation strategy, particularly practised by farmers who owned a relatively large holding (>1 ha of land). These farmers diversified into two or more different crop types, depending on the size of their farmland. Of those farmers who reported using a crop diversification strategy, 77% indicated using it to minimize market risks and thereby stabilize farm income (Table 2). A higher proportion of households who did not read and write (30%) tended to diversify crops to minimize market risks compared with those who could read and write (24%) ( $\chi^2 = 9.330$ ,  $df = 4$ ,  $p = 0.05$ ) (Table S6).

In the words of a farmer who diversified crops for a market reason:

I always grow three different types of crops in three different plots; if the market price of one crop type goes down, I might still get a better profit from other crops. (Respondent # 44, Household survey).

As shown in Table 2, climate-linked factors were vital motivation for a large number of smallholder farmers (71%) to diversify into more crops. Focus group participants explained that farmers minimized the risk of complete crop failure by choosing to grow different crop types. As one FGD participant explained:

I grow four different crops [sorghum, teff, barely, maize] each season. If drought occurs, Sorghum and teff tolerate the stress better than barley and maize. So, I may not lose all the planted crops. If I am lucky and there is no drought in that season, I get a good harvest from all the crops. (Participant #3, FGD).

As also seen in Table 2, 50% of the households used crop diversification to control crop pests and diseases. Farmers who used this practice stated that they grew legumes (particularly peas and beans) and cereal crops in the form of intercropping. Those who did not read and write (20%) were more likely to diversify crops to control pests and diseases than those who could read and write (12%) ( $\chi^2 = 12.2$ ,  $df = 4$ ,  $p = 0.01$ ) (Table S6). Less than half of the surveyed farmers (48%) stated that one of their reasons to diversify into more crops was to balance their food demand. For example, teff was primarily used to make flatbread called Tayita, pulses were used to make stews, and sorghum was mainly used to brew the local drink.

Climatic and non-climatic factors combined to influence farmers' on-farm adaptation options. For example, focus group participants noted how the occurrence of drought in 2015 interacted with non-climatic factors (low soil fertility and high prevalence of crop diseases) to force local farmers to shift from a crop diversification strategy to other non-farm adaptation options.

### 3.3.4. Adoption of Improved Seed Varieties as an On-Farm Adaptation Measure

As shown in Table 2, of those households who adopted improved seeds, 82% indicated they used the strategy to obtain better yield while another 76% mentioned climate-related reasons. Focus group discussion participants noted that plant-growing seasons were becoming shorter and shorter as the rains in the local area were coming late and ending early. In response, some farmers were using fast-maturing improved varieties. Of the survey respondents who adopted new improved seeds, the often-cited improved seed was *melkam* (a sorghum variety, WSV 387), favoured for its drought-tolerant and fast-maturing nature. As one sorghum grower explained:

The reason why I chose to plant melkam [improved sorghum variety] is that it is drought resistant as compared to local sorghum varieties. It is also fast maturing. It can be harvested quickly within three months without requiring more rainwater. (Respondent # 66, Household survey).

Moreover, 55% of the household reported using improved seeds to take advantage of market opportunities. In the focus group discussion, it was revealed that some farmers adopted an improved teff variety known as *dukem* (DZ-01-974), as the crop gave better yield

and demand was high in the local market. Table 2 further shows that some households chose to adopt improved seed varieties to reduce the spread of pests and diseases in planted crops. According to one of the surveyed farmers who adopted improved seeds, *melkam* (WSV 387) better resisted *hetela tekely* (smut disease) compared with *degalit*, which was a local improved seed variety.

In most cases, climatic and non-climatic factors interplayed to shape the adaptation responses of smallholder farmers. During focus group discussion, some participants recalled how the 2015 drought event interacted with a non-climatic factor (the intensification of crop diseases in the same year) and influenced them to adopt more improved seed varieties (e.g., a sorghum variety, WSV 387) that were both drought tolerant and simultaneously disease resistant.

### 3.3.5. Using Irrigation Farming as an On-Farm Adaptation Measure

Among farming households who used irrigation, the majority (87%) adopted the strategy in response to erratic rains. For example, one farmer who was then using irrigation said:

I cannot depend on rain-fed agriculture completely. Irrigation farming is not without risk, but at least I do not worry about crop failure in case the rain does not come. (Respondent # 114, Household survey).

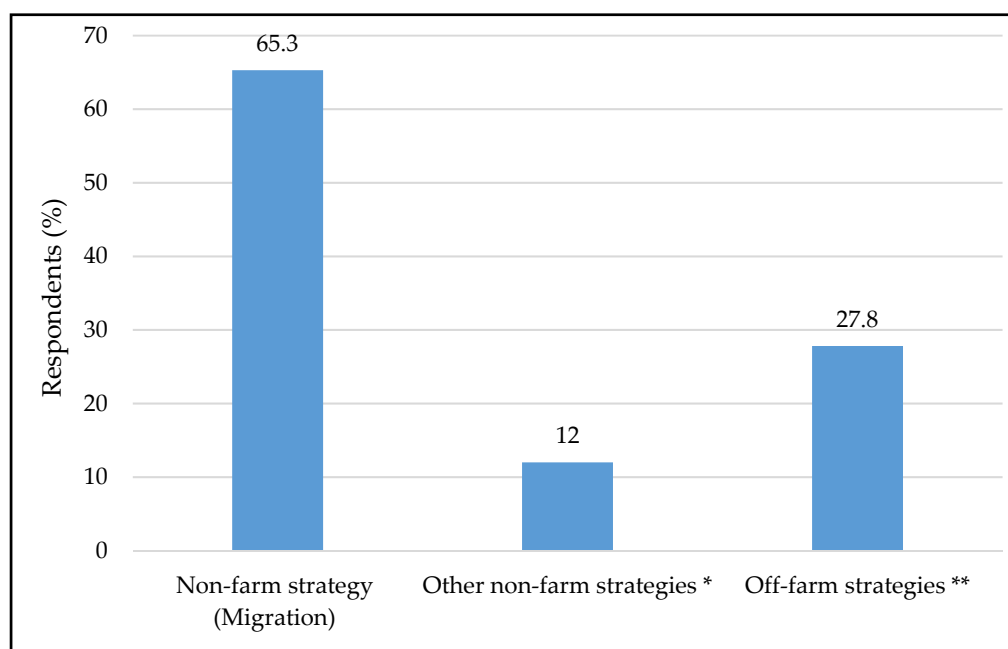
In addition, over half of the respondents (64%) further indicated that their decision to use irrigation facilities was motivated by a desire to increase agricultural incomes. During focus group discussion it was noted that relatively better-off farmers could invest the required capital to adopt irrigation as an adaptation strategy. For example, one wealthy farmer stated:

I can only harvest once or twice a year if I depend on rainfed agriculture. That is why I rented farmland that has irrigation access. I can harvest and sell high-value crops three times a year and earn more money. (Respondent # 25, Household survey).

Government support was another impetus for using irrigation-farming for smallholder farmers (60% of the respondents). Irrigation schemes were a poverty reduction intervention implemented by the Tigray regional government [74]. At the time of the study, there were eight small-scale irrigation sites in Hade Alega. However, not all farmers were beneficiaries of the scheme due to the limited number of irrigation water points. Overall, the findings of the focus group discussion suggested that in most cases farmers considered both climatic and non-climatic reasons concurrently to make a final decision on whether to use irrigation facilities as an on-farm adaptation measure.

### 3.4. Types of Non-Farm and Off-Farm Adaptation Strategies

As shown in Figure 3, temporary migration was the most common non-farm adaptation strategy and was conducted by over half of farm households (65.3%). In addition, 27.8% of survey respondents had participated in off-farm adaptation strategies, which mainly involved working on other agricultural farms and collecting and selling firewood. Further, 12% of the households had been involved in at least one of the following non-farm adaptation strategies: owning small shops, selling local food and traditional alcohol drinks, and wage employment (Figure 3). The survey results showed no significant association between the key socio-demographic variables (i.e., gender, age, education, and income) and the farmers' non-farm and off-farm adaptation responses (Supplementary Materials File S1).



**Figure 3.** Smallholder farmers' non-farm and off-farm adaptation strategies. Note: \* includes owning small shops, selling local food or traditional alcohol drinks, or wage employment. \*\* involves working on other agricultural farms and collecting and selling firewood.

### 3.5. The Role of Climatic and Non-Climatic Factors in Motivating Non-Farm and Off-Farm Adaptation Measures

Similar to the on-farm adaptation measures, the driving forces that motivated non-farm and off-farm adaptation measures were multiple. In Table 3 below, climatic and non-climatic factors (landlessness, desire to earn more income, family reasons, agriculture market instability, and lack of alternative employment options) triggered farmers' non-farm and off-farm strategies. The sub-sections below describes the role of these different factors in motivating each measure.

**Table 3.** The role of climatic and non-climatic factors in motivating non-farm and off-farm adaptation measures.

Type of Strategy	Reasons for Conducting the Strategy	Respondents (Frequency)	Respondents (%)
Temporary migration	Land scarcity/landlessness	221	85%
	Unfavorable climate condition	192	75%
	Lack of employment opportunity	178	68%
	To repay fertilizer debt	157	60%
	Family reason	125	48%
	To pursue education	102	39%
	Other	25	9.6%
Other non-farm/off-farm strategies	In response to unfavorable climate conditions	130	82%
	Poor agricultural markets (low profit from agriculture)	126	76%
	Desire to earn more income	106	67%
	Lack of access to agricultural land or land shortage	81	51%
	Other	9	6%

### 3.5.1. Temporary Migration as a Non-Farm Adaptation Strategy

Survey respondents who used temporary migration as a non-farm adaptation strategy were asked to indicate reasons for their migration decision. In Table 3, the majority of the households (85%) cited land scarcity/landlessness as their motivation for their migration decision. For example, one survey respondent explained why his two sons migrated to Addis Ababa as follows:

My grandfather used to own sufficient land [3 ha]. My father inherited one hectare of land from my grandfather, and I got 0.5 hectares of land from my father. I gave my son 0.25 hectares of land when he got married. Now I am left with 0.25 ha of land. I cannot divide this land anymore. This is the reason why my two sons migrated to Addis Ababa. (Respondent # 330, Household survey).

As Table 3 shows, the majority of smallholder farmers (75%) also indicated climate-related factors as justification for using migration as an adaptation strategy. During focus group discussions, participants explained that during extreme drought periods, temporary migration was a common strategy employed by household members to support livelihoods. For example, of the surveyed respondents who answered 'unfavourable climate conditions' as a reason for migration, the 2015/2016 drought was mainly reported as a driving force for their migration decisions. One household head during the questionnaire survey explained the reason for his migration decision as follows:

The 2015 short rainy season was very disappointing which caused poor harvest. So, I decided to migrate to Mekelle city to do some temporary jobs and send money to my family. I returned to my village after the situation improved. It was an important decision. Otherwise, it would have been difficult for us [the family] to cope with the drought event. (Respondent # 56, Household Survey).

Apart from climate-related factors, 68% of the households also mentioned a lack of local employment opportunities as a triggering factor for migration decisions, and another 60% migrated to repay debts associated with fertilizer loans. Further, 48% and 39% of those who had conducted migration as an adaptation strategy cited family-related reasons and education, respectively.

### 3.5.2. Other Non-Farm and Off-Farm Adaptation Strategies

Those respondents who conducted other non-farm or off-farm adaptation strategies were asked to state their reason for engaging in those activities. As shown in Table 3 below, 82% cited climate-related factors as a reason for their involvement in non-farm/off-farm strategies. For example, some farmers who diversified into non-farm activities did so with the intention that when drought occurred in a particular year, non-farm activities would provide alternative income sources to the household and help them overcome some of the impacts caused by drought (e.g., food insecurity). For example, one of the survey respondents stated his reason as follows:

My wife and I are currently doing both [farming and non-farm]. It is hard to depend only on rain-fed agriculture these days. As you see, we sell food and local drinks in this small restaurant. When it is a drought year and farming is not promising, we can still feed our children and send them to school from the money we make from this business. (Respondent # 120, Household survey).

As seen in Table 3, 76% reported a poor agricultural market as a reason for their engagement in either non-farm or off-farm adaptation measures. One farmer who ran a small grocery store in Hade Alega explained his reason as follows:

Farming is a difficult task. I put a lot of effort to produce crops. But after all the hard work, the profit is minimum, and it is also hard to predict the market situation. I get a steady income from this grocery store, and it helps me to overcome my financial difficulties when I lose money from agriculture. (Respondent # 15, Household survey).

Table 3 indicates that 67% of the households had engaged in other non-farm/off-farm work to earn more income. On the other hand, slightly over half (51%) of the respondents indicated a lack of access to agricultural land (land shortage) as a reason for their engagement in other non-farm/off-farm activities. The focus group results suggested that farmers with a shortage of farmland worked for domestic and international investors engaged in agricultural business and/or for local farmers who were unable to farm for various reasons. One survey respondent who worked for farmers in a local area stated:

My land is small . . . it does not provide a good harvest. In rainy seasons, I work on my farm as well as for those who are incapable of farming [e.g., for older people]. This way, the landlord pays me in the form of money or sharecropping. (Respondent # 54, Household Survey).

During focus group discussion, some of the participants highlighted how climatic factors (the 2015 drought) compounded by non-climatic factors (low profit from agricultural products) affected farm income and pushed farm households to look for off-farm adaptation strategies (i.e., collecting and selling firwoods). According to FGD participants, the 2015 drought was severe and thus crop production was poor both in quality and quantity. As a result, the market prices of agricultural products were very low compared to the previous years. Farmers during that particular year therefore engaged more in off-farm adaptation measure to compensate the loss of income associated with the climatic risk.

#### 4. Discussion

Our study corroborates other studies which show that both climatic and non-climatic factors operate independently or in association with one another to shape the adaptation responses of smallholders [60,72,75]. In addition to climatic factors, non-climatic factors (such as market-related forces, issues pertaining to land, declining soil fertility, labour shortages, and biotic factors) have been important drivers of smallholder adaptations. It was identified that the adoption of non-farm adaptation strategies was largely motivated by non-climatic factors (landlessness, desire to earn more income, family reasons, agriculture market instability, lack of alternative livelihoods, etc.), while on-farm methods were adopted largely because of climate-related factors. Notwithstanding this, there were instances where farmers tended to engage in adaptation (be it on-farm, non-farm, or off-farm) in response to the outcomes of the interplay between climatic and non-climatic factors. For example, some respondents alluded to the fact that they were using temporary migration because of unfavorable climatic conditions that made farming unviable. In search of alternative jobs, they migrate to perceived areas of greener pastures. Consequently, for the sake of sustainable adaptation, it becomes imperative that researchers and practitioners answer holistically the question of “adaptation to what?” [76] (p. 229), as smallholder farmers are not adapting to only climatic factors.

The findings indicated that smallholder farmers were responding not only to climatic and non-climatic challenges but also to opportunities. Interestingly, it was found that the unviability of farming due to droughts presented some households the opportunity to send at least one member to cities to pursue education. Moreover, as this study demonstrated, farmers experimented and adopted different seed varieties, relying on their extensive farming experience and considering various opportunities (e.g., market profitability, better yields, irrigation facilities, etc). This suggests that farmers rationally and actively respond to opportunities, and they are not simply passive victims of the challenges posed by climatic and non-climatic conditions. This finding has important implications for adaptation policies and interventions. It suggests that the focus of adaptation policies and interventions should not be limited to addressing climate change-related risks and challenges. Instead, equal focus should be given to exploiting farmers’ ingenuity and indigenous farming knowledge and enhancing their existing local opportunities.

Beyond farm-related adaptation measures, the findings indicate that smallholder farmers’ decisions rely on available non-farm and off-farm adaptation options. These options (e.g., owning small businesses) contribute to farmers’ adaptive capacities in the face of



climate-linked risks. However, climate-related policies in Ethiopia lend a substantially heavier emphasis to agricultural-related adaptation measures than non-farm and off-farm strategies [77,78]. We argue that equal emphasis should be given to non-farm and off-farm strategies to support farmers in diversifying into alternative income generation activities, particularly during agricultural off-seasons. Compared with agricultural adaptation measures, non-farm adaptation strategies are less sensitive to climate change impacts, and thus they have the potential to effectively support smallholder adaptation [79,80].

These findings largely highlight the positive outcomes related to the adaptation measures of smallholder farmers. However, some of the adaptation strategies could be beneficial or effective in the short-term, but maladaptive in the long run. Selling firewood, for instance, is one of the short-term strategies that bring quick cash and thereby support the farmers in managing climatic and non-climatic stresses. However, in the long-term, this strategy could lead to maladaptive outcomes as it may result in the loss of forest ecosystem services. For this reason, policy efforts that are aimed at facilitating smallholder adaptations need to recognize the risks of maladaptation and work towards avoiding them [81,82].

It is imperative to mention that some socio-demographic characteristics of farmers were found to be significantly associated with some adaptation decisions. These included education level, age, family size, gender, and income level. Results of this study suggest that the probability of crop diversification is greater for those who are uneducated compared with those who have some level of education. In contrast, most studies indicate a positive association between education level and adaptation decisions [83–85]. It is argued in other studies that educated farmers are more perceptive, better informed, and have the ability to understand and react quickly to socio-ecological changes than less-educated farmers, and thus adapt more [86,87]. In this study, it is possible that uneducated farmers had limited opportunities compared to those who had some level of education, and thus they relied on their existing resources (e.g., land) to diversify into more crops to sustain their livelihoods. The finding that uneducated farmers diversified to minimize market risks and control pests and diseases more than those who had some level of education suggests a tendency of avoiding risks at all costs due to their limited options beyond farming practices. The findings also show that, compared to younger farmers, a higher proportion of relatively older farmers used crop diversification strategies. In line with other studies [88,89], this is expected because older farmers have more experience in farming and accumulated skills in adaptation practices. The significant association between household family size and one of the adaptation choices (crop diversification) was also expected given the link between family size and labour endowment, which enables farm households to engage in various agricultural tasks [83,90]. The findings indicate that male-headed households are more likely to employ crop diversification strategies and adopt improved seeds and irrigation than female-headed households. Female-headed households in Ethiopia experience various economic, socio-cultural, and institutional challenges [91], and therefore they may not adapt as readily to climatic and non-climatic factors compared to their male counterparts. Finally, the results suggest that those households with less income tend to adjust crop planting dates compared to those who belong to a higher income group. Studies indicate that households with higher incomes are more likely to use their financial resources to adopt various adaptation practices [70,90]. However, in this study, the adjustment of crop planting dates did not require financial investment. Hence, it is not a surprise that households that belonged to the less-income category were using the strategy to a greater extent.

Overall, our findings imply that adaptation policies and interventions need to embrace holistic decision-making processes that acknowledge that climatic and non-climatic factors are inter-related and require integrated policy responses. Such integration will have positive implications for rural development and smallholder livelihoods as well as providing benchmarks for inter-connected adaptation policy in countries such as Ethiopia. Particularly, adaptation policies in Ethiopia should focus on integrating climate-specific interventions (e.g., climate information service provisions) with non-climatic interventions (e.g., market information services, the installation of irrigation facilities, and the facilita-

tion of rural land access) to enhance smallholder farmers' adaptive capacity to climate change and reduce their overall vulnerabilities. For example, the crucial role of climate information in adaptation decision-making has been recognized in both scholarly literature and adaptation policy [92]. However, climate information services are largely missing for Ethiopian smallholder farmers [36,93]. Planned adaptation interventions therefore need to place adequate emphasis on the dissemination of essential climate services at the local level. Parallel to climate information services, the provision of market information services to smallholder farmers would be very useful. Most smallholder farmers in Ethiopia walk long distances to access market information. This is largely attributed to poor rural infrastructural development across the country (e.g., poor roads and a lack of transport or mobile networks) [94]. Adaptation policies and interventions should therefore focus on improving smallholder farmers' access to market information through private and public investment in the mobile industry and the establishment of mobile market information services. This will assist smallholder farmers in receiving general market information as well as specific climate-related information that will invariably have direct implications on climate change adaptation. In addition, the development of irrigation infrastructure would certainly facilitate smallholder adaptations. However, it requires higher financial investment [95]. Without external support, the majority of resource-constrained Ethiopia's smallholder farmers are unlikely to adopt irrigation on their own. Thus, adaptation policy-makers and practitioners should mobilize domestic and international climate finance to support irrigation development and meet the needs of resource-poor households. Finally, to address the issue of land shortage/landlessness, it is important that adaptation policy-makers give particular attention to improving land access in rural Ethiopia. In the Tigray region, for example, communal lands are not fully utilized [96]. This necessitates the need to distribute these types of lands to enable the adoption of on-farm adaptation strategies (particularly crop diversification) among land-constrained farmers and thereby increase their resilience against climate-linked risks.

## 5. Conclusions

Adaptation policies, particularly in developing countries such as Ethiopia, often consider the risk of climate change in isolation, when in reality, farmers, as was shown in this paper, are responding to risks and opportunities from multiple sources (transcending non-climatic and climatic spheres). The paper highlighted how various climatic and non-climatic factors operate either in isolation or in concert to shape smallholder farmers' on-farm, non-farm, and off-farm adaptation responses. We found these adaptation measures to be driven by climatic (e.g., drought and erratic rains) and non-climatic factors (e.g., limited local employment options, market conditions, land shortage, soil fertility issues, and crop diseases). Adaptation policies, therefore, need to recognize the multidimensional factors that engender smallholder farmers' responses in the design and implementation of locally appropriate planned adaptation interventions.

**Supplementary Materials:** The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/su14095715/s1>, File S1: Links between socio-demographic variables and adaptation responses, File S2: Household Survey.

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## References

- Niang, I.; Ruppel, O.C.; Abdrabo, M.A.; Essel, A.; Lennard, C.; Padgham, J.; Urquhart, P. Africa. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Climate Change 2014: Impacts, Adaptation and Vulnerability—Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014. Available online: [https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap22\\_FINAL.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/WGIIAR5-Chap22_FINAL.pdf) (accessed on 15 March 2017).
- Serdeczny, O.; Adams, S.; Baarsch, F.; Coumou, D.; Robinson, A.; Hare, W.; Schaeffer, M.; Mahé Perrette, M.; Reinhardt, J. Climate change impacts in Sub-Saharan Africa: From physical changes to their social repercussions. *Reg. Environ. Chang.* **2017**, *17*, 1585–1600. [[CrossRef](#)]
- Harvey, C.A.; Rakotobe, Z.L.; Rao, N.S.; Dave, R.; Razafimahatratra, H.; Rabarijohn, R.H.; Rajaofara, H.; MacKinnon, J.L. Extreme vulnerability of smallholder farmers to agricultural risks and climate change in Madagascar. *Philos. Trans. R. Soc. B Biol. Sci.* **2014**, *369*, 20130089. [[CrossRef](#)] [[PubMed](#)]
- Cacho, O.J.; Moss, J.; Thornton, P.K.; Herrero, M.; Henderson, B.; BDIRSKY, B.L.; Humpenöder, F.; Popp, A.; Lipper, L. The value of climate-resilient seeds for smallholder adaptation in sub-Saharan Africa. *Clim. Chang.* **2020**, *162*, 1213–1229. [[CrossRef](#)]
- Bedeke, S.B. Climate change vulnerability and adaptation of crop producers in sub-Saharan Africa: A review on concepts, approaches and methods. *Environ. Dev. Sustain.* **2022**. [[CrossRef](#)]
- Habtemariam, L.T.; Kassa, G.A.; Gandorfer, M. Impact of climate change on farms in smallholder farming systems: Yield impacts, economic implications and distributional effects. *Agric. Syst.* **2017**, *152*, 58–66. [[CrossRef](#)]
- The World Bank Group. Climate Risk Profile: Ethiopia. 2020. Available online: [https://climateknowledgeportal.worldbank.org/sites/default/files/2020-06/15463-WB\\_Ethiopia%20Country%20Profile-WEB\\_v2.pdf](https://climateknowledgeportal.worldbank.org/sites/default/files/2020-06/15463-WB_Ethiopia%20Country%20Profile-WEB_v2.pdf) (accessed on 15 June 2021).
- Shukla, R.; Gleixner, S.; Yalaw, A.W.; Schauburger, B.; Sietz, D.; Gornott, C. Dynamic vulnerability of smallholder agricultural systems in the face of climate change for Ethiopia. *Environ. Res. Lett.* **2021**, *16*, 044007. [[CrossRef](#)]
- Suryabhadgavan, K.V. GIS-based climate variability and drought characterization in Ethiopia over three decades. *Weather Clim. Extrem.* **2017**, *15*, 11–23. [[CrossRef](#)]
- Gummadi, S.; Rao, K.P.C.; Seid, J.; Legesse, G.; Kadiyala, M.D.M.; Takele, R.; Amede, T.; Whitbread, A. Spatio-temporal variability and trends of precipitation and extreme rainfall events in Ethiopia in 1980–2010. *Arch. Meteorol. Geophys. Bioclimatol. Ser. B* **2018**, *134*, 1315–1328. [[CrossRef](#)]
- Gebrechorkos, S.H.; Hülsmann, S.; Bernhofer, C. Changes in temperature and precipitation extremes in Ethiopia, Kenya, and Tanzania. *Int. J. Clim.* **2019**, *39*, 18–30. [[CrossRef](#)]
- Araya, A.; Stroosnijder, L. Assessing drought risk and irrigation need in northern Ethiopia. *Agric. For. Meteorol.* **2011**, *151*, 425–436. [[CrossRef](#)]
- Gebrehiwot, T.; van der Veen, A.; Maathuis, B. Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. *Int. J. Appl. Earth Obs. Geoinf.* **2011**, *13*, 309–321. [[CrossRef](#)]
- Gebrehiwot, T.; van der Veen, A. Assessing the evidence of climate variability in the northern part of Ethiopia. *J. Dev. Agric. Econ.* **2013**, *5*, 104–119. [[CrossRef](#)]
- Hadgu, G.; Tesfaye, K.; Mamo, G. Analysis of climate change in Northern Ethiopia: Implications for agricultural production. *Arch. Meteorol. Geophys. Bioclimatol. Ser. B* **2015**, *121*, 733–747. [[CrossRef](#)]
- Gebre, H.; Kindie, T.; Girma, M.; Belay, K. Trend and variability of rainfall in Tigray, northern Ethiopia: Analysis of meteorological data and farmers' perception. *Acad. J. Agric. Res.* **2013**, *1*, 88–100.
- Jacob, M.; Frankl, A.; Haile, M.; Zwertvaegher, A.; Nyssen, J. Assessing spatio-temporal rainfall variability in a tropical mountain area (Ethiopia) using NOAA's rainfall estimates. *Int. J. Remote Sens.* **2013**, *34*, 8319–8335. [[CrossRef](#)]
- Berhane, A.; Hadgu, G.; Worku, W.; Abrha, B. Trends in extreme temperature and rainfall indices in the semi-arid areas of Western Tigray, Ethiopia. *Environ. Syst. Res.* **2020**, *9*, 3. [[CrossRef](#)]
- Gidey, E.; Dikinya, O.; Sebege, R.; Segosebe, E.; Zenebe, A. Modeling the Spatio-Temporal Meteorological Drought Characteristics Using the Standardized Precipitation Index (SPI) in Raya and Its Environs, Northern Ethiopia. *Earth Syst. Environ.* **2018**, *2*, 281–292. [[CrossRef](#)]
- Gebrehiwot, T.; van der Veen, A. Climate change vulnerability in Ethiopia: Disaggregation of Tigray Region. *J. East. Afr. Stud.* **2013**, *7*, 607–629. [[CrossRef](#)]
- Hishe, H.; Giday, K.; Van Orshoven, J.; Muys, B.; Taheri, F.; Azadi, H.; Feng, L.; Zamani, O.; Mirzaei, M.; Witlox, F. Analysis of Land Use Land Cover Dynamics and Driving Factors in Desa'a Forest in Northern Ethiopia. *Land Use Policy* **2021**, *101*, 105039. [[CrossRef](#)]

22. Eriksen, S.H.; O'Brien, K. Vulnerability, poverty and the need for sustainable adaptation measures. *Clim. Policy* **2007**, *7*, 337–352. [[CrossRef](#)]
23. Ford, J.D.; Berrang-Ford, L.; Bunce, A.; McKay, C.; Irwin, M.; Pearce, T. The status of climate change adaptation in Africa and Asia. *Reg. Environ. Change* **2015**, *15*, 801–814. [[CrossRef](#)]
24. Islam, M.T.; Nursey-Bray, M. Adaptation to climate change in agriculture in Bangladesh: The role of formal institutions. *J. Environ. Manag.* **2017**, *200*, 347–358. [[CrossRef](#)] [[PubMed](#)]
25. Sherman, M.; Berrang-Ford, L.; Lwasa, S.; Ford, J.; Namanya, D.B.; Llanos-Cuentas, A.; Maillet, M.; Harper, S.; IHACC Research Team. Drawing the line between adaptation and development: A systematic literature review of planned adaptation in developing countries. *Wiley Interdiscip. Rev. Clim. Change* **2016**, *7*, 707–726. [[CrossRef](#)]
26. Masud-All-Kamal, M.; Nursey-Bray, M. Socially just community-based climate change adaptation? Insights from Bangladesh. *Local Environ.* **2021**, *26*, 1092–1108. [[CrossRef](#)]
27. McGray, H.; Hammill, A.; Bradley, R.; Schipper, L.; Parry, J.E. *Weathering the Storm: Options for Framing Adaptation and Development*; World Resources Institute: Washington, DC, USA, 2007; Volume 57.
28. Ayers, J.; Dodman, D. Climate change adaptation and development I: The state of the debate. *Prog. Dev. Stud.* **2010**, *10*, 161–168. [[CrossRef](#)]
29. IPCC. Summary for Policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., et al., Eds.; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; pp. 1–32. Available online: [https://www.ipcc.ch/site/assets/uploads/2018/02/ar5\\_wgII\\_spm\\_en.pdf](https://www.ipcc.ch/site/assets/uploads/2018/02/ar5_wgII_spm_en.pdf) (accessed on 17 June 2021).
30. Moser, S.C.; Ekstrom, J.A. A framework to diagnose barriers to climate change adaptation. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 22026–22031. [[CrossRef](#)]
31. Smit, B.; Pilifosova, O. Adaptation to climate change in the context of sustainable development and equity. In *Climate Change 2001: Impacts, Adaptation and Vulnerability IPCC Working Group II*; Mc-White, J.J., Ed.; Cambridge University Press: Cambridge, UK, 2001; pp. 877–912.
32. Klein, R.J. Adaptation to climate variability and change: What is optimal and appropriate. In *Climate Change in the Mediterranean: Socio-Economic Perspectives of Impacts, Vulnerability and Adaptation*; Edward Elgar: Cheltenham, UK, 2003; pp. 32–52.
33. Preston, B.L.; Stafford-Smith, M. *Framing Vulnerability and Adaptive Capacity Assessment*; Working Paper No. 2; Climate Adaptation National Research Flagship; CSIRO: Canberra, Australia, 2009. Available online: [https://research.csiro.au/climate/wp-content/uploads/sites/54/2016/03/2\\_Working-Paper2\\_CAF\\_PDF-Standard.pdf](https://research.csiro.au/climate/wp-content/uploads/sites/54/2016/03/2_Working-Paper2_CAF_PDF-Standard.pdf) (accessed on 18 February 2018).
34. IPCC. *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*; Pörtner, H.-O., Roberts, D.C., Tignor, M., Poloczanska, E.S., Mintenbeck, K., Alegría, A., Craig, M., Langsdorf, S., Lösschke, S., Möller, V., et al., Eds.; Cambridge University Press: Cambridge, UK, 2022.
35. Kichamu, E.A.; Ziro, J.S.; Palaniappan, G.; Ross, H. Climate change perceptions and adaptations of smallholder farmers in Eastern Kenya. *Environ. Dev. Sustain.* **2017**, *20*, 2663–2680. [[CrossRef](#)]
36. Kidane, R.; Prowse, M.; De Neergaard, A. Bespoke Adaptation in Rural Africa? An Asset-Based Approach from Southern Ethiopia. *Eur. J. Dev. Res.* **2018**, *31*, 413–432. [[CrossRef](#)]
37. Atampugre, G.; Nursey-Bray, M.; Rudd, D. Micro-level Dynamics of Climate Risks Adaptation in a Semi-arid Agroecology. In *Handbook of Climate Change Management*; Leal Filho, W., Luetz, J., Ayal, D., Eds.; Springer: Cham, Switzerland, 2021; pp. 1–28.
38. Rahut, D.B.; Aryal, J.P.; Marennya, P. Understanding climate-risk coping strategies among farm households: Evidence from five countries in Eastern and Southern Africa. *Sci. Total Environ.* **2021**, *769*, 145236. [[CrossRef](#)]
39. Westerhoff, L.; Smit, B. The rains are disappointing us: Dynamic vulnerability and adaptation to multiple stressors in the Afram Plains, Ghana. *Mitig. Adapt. Strat. Glob. Chang.* **2009**, *14*, 317–337. [[CrossRef](#)]
40. Owusu, M.; Nursey-Bray, M. Socio-economic and institutional drivers of vulnerability to climate change in urban slums: The case of Accra, Ghana. *Clim. Dev.* **2019**, *11*, 687–698. [[CrossRef](#)]
41. Kidane, R.; Wanner, T.; Nursey-Bray, M. Understanding the Climatic and Non-climatic Drivers of Livelihood Vulnerability in the Tigray Region of Ethiopia. In *Climate Vulnerability and Resilience in the Global South*; Alam, G.M.M., Erdiaw-Kwasie, M.O., Nagy, G.J., Leal Filho, W., Eds.; Climate Change Management; Springer: Cham, Switzerland, 2021; pp. 279–296.
42. Mertz, O.; Mbow, C.; Maiga, A.; Diallo, D.; Reenberg, A.; Diouf, A.; Barbier, B.; Zorom, M.; Ouattara, I.; Dabi, D.; et al. Climate Factors Play a Limited Role for Past Adaptation Strategies in West Africa. *Ecol. Soc.* **2010**, *15*, 25. [[CrossRef](#)]
43. Eakin, H.; Tucker, C.M.; Castellanos, E.; Diaz-Porrás, R.; Barrera, J.F.; Morales, H. Adaptation in a multi-stressor environment: Perceptions and responses to climatic and economic risks by coffee growers in Mesoamerica. *Environ. Dev. Sustain.* **2014**, *16*, 123–139. [[CrossRef](#)]
44. Burnham, M.; Ma, Z. Multi-Scalar Pathways to Smallholder Adaptation. *World Dev.* **2018**, *108*, 249–262. [[CrossRef](#)]
45. Duflo, E. Poor but Rational? In *Understanding Poverty*; Banerjee, A.V., Bénabou, R., Mookherjee, D., Eds.; Oxford University Press: New York, NY, USA, 2006; Volume 24, pp. 367–379.
46. Sanga, U.; Park, H.; Wagner, C.H.; Shah, S.H.; Ligmann-Zielinska, A. How do farmers adapt to agricultural risks in northern India? An agent-based exploration of alternate theories of decision-making. *J. Environ. Manag.* **2021**, *298*, 113353. [[CrossRef](#)]



47. Forsyth, T.; Evans, N. What is Autonomous Adaption? Resource Scarcity and Smallholder Agency in Thailand. *World Dev.* **2013**, *43*, 56–66. [[CrossRef](#)]
48. Bhatta, G.D.; Aggarwal, P.K.; Kristjanson, P.; Shrivastava, A.K. Climatic and non-climatic factors influencing changing agricultural practices across different rainfall regimes in South Asia. *Curr. Sci.* **2016**, *110*, 1272–1281.
49. Waldman, K.B.; Attari, S.Z.; Gower, D.B.; Giroux, S.A.; Caylor, K.K.; Evans, T.P. The salience of climate change in farmer decision-making within smallholder semi-arid agroecosystems. *Clim. Chang.* **2019**, *156*, 527–543. [[CrossRef](#)]
50. Nielsen, J.; Reenberg, A. Temporality and the problem with singling out climate as a current driver of change in a small West African village. *J. Arid Environ.* **2010**, *74*, 464–474. [[CrossRef](#)]
51. Tessema, Y.A.; Joerin, J.; Patt, A. Climate change as a motivating factor for farm-adjustments: Rethinking the link. *Clim. Risk Manag.* **2019**, *23*, 136–145. [[CrossRef](#)]
52. Waldman, K.B.; Guido, Z.; Todd, P.M.; Evans, T.P.; Carrico, A.; Attari, S.Z. Reorienting climate decision making research for smallholder farming systems through decision science. *Curr. Opin. Environ. Sustain.* **2021**, *52*, 92–99. [[CrossRef](#)]
53. Orlove, B.; Shwom, R.; Markowitz, E.; Cheong, S.M. Climate decision-making. *Annu. Rev. Environ. Resour.* **2020**, *45*, 271–303. [[CrossRef](#)]
54. Singh, C.; Dorward, P.; Osbahr, H. Developing a holistic approach to the analysis of farmer decision-making: Implications for adaptation policy and practice in developing countries. *Land Use Policy* **2016**, *59*, 329–343. [[CrossRef](#)]
55. Sarku, R.; Dewulf, A.; van Slobbe, E.; Termeer, K.; Kranjac-Berisavljevic, G. Adaptive decision-making under conditions of uncertainty: The case of farming in the Volta delta, Ghana. *J. Integr. Environ. Sci.* **2020**, *17*, 1–33. [[CrossRef](#)]
56. Berrang-Ford, L.; Ford, J.D.; Paterson, J. Are we adapting to climate change? *Glob. Environ. Change* **2011**, *21*, 25–33. [[CrossRef](#)]
57. Adger, W.N.; Arnell, N.W.; Tompkins, E.L. Successful adaptation to climate change across scales. *Glob. Environ. Chang.* **2005**, *15*, 77–86. [[CrossRef](#)]
58. Eriksen, S.H.; Nightingale, A.J.; Eakin, H. Reframing adaptation: The political nature of climate change adaptation. *Glob. Environ. Chang.* **2015**, *35*, 523–533. [[CrossRef](#)]
59. Burnham, M.; Ma, Z. Linking smallholder farmer climate change adaptation decisions to development. *Clim. Dev.* **2016**, *8*, 289–311. [[CrossRef](#)]
60. Singh, C.; Tebboth, M.; Spear, D.; Ansah, P.; Mensah, A. Exploring methodological approaches to assess climate change vulnerability and adaptation: Reflections from using life history approaches. *Reg. Environ. Chang.* **2019**, *19*, 2667–2682. [[CrossRef](#)]
61. NMA (Ethiopian National Meteorological Agency). Guide to the Use of Weather and Climate Information (WCI) for Agricultural Practices over Selected Districts of SNNP and Tigray National Regional States. Ethiopia. Addis Ababa, Ethiopia. 2017. Available online: <http://www.wmo.int/pages/prog/dra/raf/documents/Climate%20Guide%20for%20Tigray%20and%20SNNPR.pdf> (accessed on 10 November 2021).
62. CSA (Central Statistical Agency). The 2007 Population and Housing Census of Ethiopia: Statistical Report for Tigray Region. 2007. Available online: <http://phe-ethiopia.org/pdf/tigray.pdf> (accessed on 10 November 2021).
63. Bewket, W.; Radeny, M.; Mungai, C. *Agricultural Adaptation and Institutional Responses to Climate Change Vulnerability in Ethiopia*; CCAFS Working Paper No. 106; Climate Change, Agriculture and Food Security (CCAFS): Copenhagen, Denmark, 2015.
64. TBFED (Tigray Bureau of Finance and Economic Development). *GIS Layers, Administrative Boundaries of Tigray*; GIS Section; TBFED: Mekelle, Ethiopia, 2018.
65. Baxter, J. Case studies in qualitative research. In *Qualitative Research Methods in Human Geography*, 4th ed.; Hay, L., Ed.; Oxford University Press: North York, ON, Canada, 2016; pp. 130–146.
66. Yin, R.K. *Case Study Research: Design and Methods*, 4th ed.; Sage Publications: Thousand Oaks, CA, USA, 2009.
67. Fowler, F.J., Jr. *Survey Research Method: Applied Social Research Method Series*, 4th ed.; Sage: Thousand Oaks, CA, USA, 2009.
68. Bryman, A. *Social Research Methods*, 5th ed.; Oxford University Press: Oxford, UK, 2016.
69. Rea, L.M.; Parker, R.A. *Designing and Conducting Survey Research: A Comprehensive Guide*, 3rd ed.; Jossey-Bass: San Francisco, CA, USA, 2005.
70. Bryan, E.; Deressa, T.T.; Gbetibouo, G.A.; Ringler, C. Adaptation to climate change in Ethiopia and South Africa: Options and constraints. *Environ. Sci. Policy* **2009**, *12*, 413–426. [[CrossRef](#)]
71. Epule, T.E.; Ford, J.D.; Lwasa, S.; Lepage, L. Climate change adaptation in the Sahel. *Environ. Sci. Policy* **2017**, *75*, 121–137. [[CrossRef](#)]
72. Ahmed, A.; Lawson, E.T.; Mensah, A.; Gordon, C.; Padgham, J. Adaptation to climate change or non-climatic stressors in semi-arid regions? Evidence of gender differentiation in three agrarian districts of Ghana. *Environ. Dev.* **2016**, *20*, 45–58. [[CrossRef](#)]
73. Ellis, F. *Rural Livelihoods and Diversity in Developing Countries*; Oxford University Press: New York, NY, USA, 2000.
74. Gebregziabher, G.; Namara, R.E.; Holden, S. Poverty reduction with irrigation investment: An empirical case study from Tigray, Ethiopia. *Agric. Water Manag.* **2009**, *96*, 1837–1843. [[CrossRef](#)]
75. Karki, S.; Burton, P.; Mackey, B. Climate change adaptation by subsistence and smallholder farmers: Insights from three agro-ecological regions of Nepal. *Cogent Soc. Sci.* **2020**, *6*, 1720555. [[CrossRef](#)]
76. Smit, B.; Burton, I.; Klein, R.J.; Wandel, J. An anatomy of adaptation to climate change and variability. In *Societal Adaptation to Climate Variability and Change*; Kane, S.M., Yohe, G.W., Eds.; Springer: Dordrecht, The Netherlands, 2000; pp. 223–251.

77. NMA (Ethiopian National Meteorological Agency). Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia. Addis Ababa, Ethiopia. 2007. Available online: <https://unfccc.int/resource/docs/napa/eth01.pdf> (accessed on 11 February 2022).
78. FDRE (Federal Democratic Republic of Ethiopia). Ethiopia's Climate-Resilient Green Economy Green Economy Strategy. 2011. Available online: <https://www.undp.org/content/dam/ethiopia/docs/Ethiopia%20CRGE.pdf> (accessed on 30 March 2021).
79. Imai, K.S.; Gaiha, R.; Thapa, G. Does non-farm sector employment reduce rural poverty and vulnerability? Evidence from Vietnam and India. *J. Asian Econ.* **2015**, *36*, 47–61. [[CrossRef](#)]
80. Danso-Abbeam, G.; Ojo, T.O.; Baiyegunhi, L.J.; Ogundeji, A.A. Climate change adaptation strategies by smallholder farmers in Nigeria: Does non-farm employment play any role? *Heliyon* **2021**, *7*, e07162. [[CrossRef](#)]
81. Magnan, A.K.; Schipper, E.; Burkett, M.; Bharwani, S.; Burton, I.; Eriksen, S.; Gemenne, F.; Schaar, J.; Ziervogel, G. Addressing the risk of maladaptation to climate change. *WIREs Clim. Chang.* **2016**, *7*, 646–665. [[CrossRef](#)]
82. Asare-Nuamah, P.; Dick-Sago, C.; Ayivor, R. Farmers' maladaptation: Eroding sustainable development, rebounding and shifting vulnerability in smallholder agriculture system. *Environ. Dev.* **2021**, *40*, 100680. [[CrossRef](#)]
83. Deressa, T.T.; Hassan, R.M.; Ringler, C.; Alemu, T.; Yesuf, M. Determinants of farmers' choice of adaptation methods to climate change in the Nile Basin of Ethiopia. *Glob. Environ. Chang.* **2009**, *19*, 248–255. [[CrossRef](#)]
84. Amir, S.; Saqib, Z.; Khan, M.I.; Ali, A.; Bokhari, S.A.; Haq, Z.U. Determinants of farmers' adaptation to climate change in rain-fed agriculture of Pakistan. *Arab. J. Geosci.* **2020**, *13*, 1025. [[CrossRef](#)]
85. Sertse, S.F.; Khan, N.A.; Shah, A.A.; Liu, Y.; Naqvi, S.A.A. Farm households' perceptions and adaptation strategies to climate change risks and their determinants: Evidence from Raya Azebo district, Ethiopia. *Int. J. Disaster Risk Reduct.* **2021**, *60*, 102255. [[CrossRef](#)]
86. Abid, M.; Schneider, U.A.; Scheffran, J. Adaptation to climate change and its impacts on food productivity and crop income: Perspectives of farmers in rural Pakistan. *J. Rural Stud.* **2016**, *47*, 254–266. [[CrossRef](#)]
87. Uddin, M.N.; Bokelmann, W.; Entsminger, J.S. Factors Affecting Farmers' Adaptation Strategies to Environmental Degradation and Climate Change Effects: A Farm Level Study in Bangladesh. *Climate* **2014**, *2*, 223–241. [[CrossRef](#)]
88. Khanal, U.; Wilson, C.; Lee, B.L.; Hoang, V.-N. Climate change adaptation strategies and food productivity in Nepal: A counterfactual analysis. *Clim. Chang.* **2018**, *148*, 575–590. [[CrossRef](#)]
89. Marie, M.; Yirga, F.; Haile, M.; Tqubo, F. Farmers' choices and factors affecting adoption of climate change adaptation strategies: Evidence from northwestern Ethiopia. *Heliyon* **2020**, *6*, e03867. [[CrossRef](#)] [[PubMed](#)]
90. Tessema, Y.A.; Aweke, C.S.; Endris, G.S. Understanding the process of adaptation to climate change by small-holder farmers: The case of east Hararghe Zone, Ethiopia. *Agric. Food Econ.* **2013**, *1*, 13. [[CrossRef](#)]
91. Mersha, A.A.; Van Laerhoven, F. A gender approach to understanding the differentiated impact of barriers to adaptation: Responses to climate change in rural Ethiopia. *Reg. Environ. Chang.* **2016**, *16*, 1701–1713. [[CrossRef](#)]
92. Singh, C.; Daron, J.; Bazaz, A.; Ziervogel, G.; Spear, D.; Krishnaswamy, J.; Zaroug, M.; Kituyi, E. The utility of weather and climate information for adaptation decision-making: Current uses and future prospects in Africa and India. *Clim. Dev.* **2018**, *10*, 389–405. [[CrossRef](#)]
93. Asfaw, A.; Simane, B.; Bantider, A.; Hassen, A. Determinants in the adoption of climate change adaptation strategies: Evidence from rainfed-dependent smallholder farmers in north-central Ethiopia (Woleka sub-basin). *Environ. Dev. Sustain.* **2019**, *21*, 2535–2565. [[CrossRef](#)]
94. Wudad, A.; Naser, S.; Lameso, L. The impact of improved road networks on marketing of vegetables and households' income in Dedo district, Oromia regional state, Ethiopia. *Heliyon* **2021**, *7*, e08173. [[CrossRef](#)]
95. Awulachew, S.B. Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. *Gates Open Res.* **2019**, *3*, 22.
96. Oniki, S.; Negusse, G. Communal Land Utilization in the Highlands of Northern Ethiopia: Evidence of Transaction Costs. *Jpn. J. Rural Econ.* **2015**, *17*, 40–45. [[CrossRef](#)]