Essays on Climate Smart Agriculture and Land Reform

Thesis submitted for the degree of Doctor of Philosophy

School of Agriculture, Policy and Development

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Declaration of original authorship

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Abstract

In an era of global warming, addressing key agricultural development challenges, including reducing food insecurity and feeding a growing population, while building resilience to the adverse effects of climate change and minimising further environmental degradation induced by the agricultural sector requires a transformation of agricultural systems. Climate Smart Agriculture (CSA) is a sustainable agriculture approach that can help guide such a transformation by orienting agricultural system actions towards the realisation of a triple-objective – sustainably increasing agricultural productivity, adapting to climate change, and contributing to lower the concentration of greenhouse gases in the atmosphere. Yet, high levels of inequality in the distribution of land, a key natural resource for agricultural production, and land tenure insecurity may limit opportunities for widespread farmer adoption of CSA. Policy interventions, such as land reforms, that can broaden landless and land-poor farmers' access to land as well as to markets, infrastructure and advisory services, and that can enhance farmers' tenure security, may not only help improve equity and efficiency but also contribute to build an enabling environment for CSA, thereby enhancing environmental sustainability. This thesis comprises three papers investigating associations between CSA and land reform, with a particular emphasis on lower-income country settings. The first paper (Chapter 2) introduces and describes a conceptual framework, the Climate Smart Land Reform (CSLR) framework, which builds on theoretical and empirical literature on CSA and land reform and uncovers associations between the two concepts. It describes a CSLR as comprising of four pillars, land redistribution, land tenure reform, markets and infrastructure, and Rural Advisory Services (RAS). These four pillars are considered, within the framework, to have the potential to foster CSA adoption and to generate positive effects on a range of social, political, economic and environmental objectives that land reformers may entertain, including the three CSA objectives. The CSLR framework represents an innovative way to conceptualise how land reforms can contribute not only to socio-economic and political improvements, but also to environmental sustainability. The second paper (Chapter 3) explores the linkage presented in the CSLR framework between the land tenure reform pillar of the framework and the three CSA objectives by examining the land registration and certification programme undertaken at the end of the 1990s in Tigray (Ethiopia). The use of a difference-in-differences approach applied to an original panel dataset constructed from Earth Observation data reveals that the reform has led to progress on the three CSA objectives. This suggests that land tenure reforms can contribute to the achievement of rural development objectives, including objectives associated with climate change. The third paper (Chapter 4) is dedicated to the study of the South African land reform. It includes a historical summary of the causes and of the process that led to its launch, as well as a critical analysis comparing land reformers' initial intentions with the actual implementation of the land reform. This analysis exposes key issues that have hampered the realisation of land reformers' original intentions, including the implementation of inadequate measures for the transfer of land and for the provision of support services to land reform participants. Building on these findings, secondary data from a farm-household level survey are used to analyse empirically the association between the land redistribution and RAS pillars of the CSLR framework and CSA adoption. Results from the estimation of binary response models show that land redistribution participation was associated with a higher likelihood of adopting CSA, but only in the absence of RAS, thus providing evidence of the inadequacy of RAS in fostering CSA in the South African land reform context and confirming the need to enhance efforts for the establishment of a well-coordinated, multi-stakeholder and participatory RAS system.

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An adapted version of Chapter 3 of the thesis, *Examining land reform through satellite lenses – a study of the effects of the Ethiopian tenure reform on the Climate Smart Agriculture objectives*, co-authored with Dr Stefania Lovo, has been submitted for publication in an academic journal and is currently under review.

An abridged version of Chapter 4 of the thesis, *Land reform in South Africa – laudable intentions, implementation challenges, and opportunities for Climate Smart Agriculture*, has been submitted for publication in an academic journal and is currently under review.

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Chapter 1. Introduction

This chapter introduces the thesis by providing, first, a background that describes the rationale underpinning this research (Section 1.1). The aims, objectives and key research questions of the thesis are then presented in Section 1.2, and finally the last section of the chapter (Section 1.3) provides a detailed outline of the thesis.

1.1. Background

Four key facts help illustrate the need for a transformation in agricultural systems. The agricultural sector:

i. is a significant contributor to climate change;
ii. is strongly affected by climate change;
iii. is facing increased pressures due to a growing population (and a consequent increase in food demand), and
iv. to rising food insecurity.

This background section begins with a detailed description of these four facts providing the rationale for conducting research on Climate Smart Agriculture (CSA) – a sustainable agriculture approach that has been promoted for its potential to guide the required transformation in agricultural systems (FAO, 2017a). The principal characteristics of CSA are then discussed, along with some of the main criticisms that have targeted CSA. Building on these criticisms a research gap is uncovered. This research gap relates to the insufficient consideration, within the CSA literature, of policy actions that can tackle questions of rights, social injustice, unequal power relations and inequality, and thus help to create the enabling environment necessary for widespread and effective CSA adoption. The section concludes by indicating that research on the association between CSA and land reform can contribute to fill this gap.

i. The climate is changing and agriculture is contributing to this change – insights from the sixth Assessment Report of the Intergovernmental Panel on Climate Change

There is unequivocal evidence that anthropogenic forces are driving increases in global mean temperatures both at the level of the land and of the ocean (IPCC, 2021). The latest data gathered in the sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) indicated that global surface temperature was approximately 1.1°C higher in 2011-2020 compared to 1850-1900 (IPCC, 2021:5).[1] Considering only land areas,

[1] "The period 1850-1900 represents the earliest period of sufficiently globally complete observations to estimate global surface temperature and […] is used as an approximation for pre-industrial conditions." (IPCC, 2021:5)

the increase in temperature was larger, with close to 1.6°C higher temperatures in 2011-2020 than in 1850-1900 (IPCC, 2021:5). Anthropogenic greenhouse gas emissions have been the dominant driver of the witnessed increases in greenhouse gas (GHG) concentrations in the atmosphere, which have reached unprecedented levels in at least 800,000 years (Arias *et al.*, 2021:67), and have thus been the dominant force behind the observed changes in climate (IPCC, 2021:7).

Without a transition to net-zero carbon dioxide (CO_2) emissions and deep, rapid and sustained reductions in emissions of other GHGs, the commitment that 193 Parties made in the Paris Agreement of maintaining the increase in the global average temperature to well below 2°C above pre-industrial levels (and preferably below 1.5°C above pre-industrial levels) is severely threatened (Riahi *et al.*, 2022; United Nations, 2015).[2]

Such a transition will require transformations across various economic sectors, including agriculture. Recent estimates indicate that the agricultural sector is directly responsible for approximately 11% of total anthropogenic GHG emissions (Dhakal *et al.*, 2022). Including emissions from Land Use, Land Use Change and Forestry (LULUCF), which are predominantly caused by deforestation induced by agricultural expansion (Feng *et al.*, 2022; Gibbs *et al.*, 2010; Hong *et al.*, 2021; Hosonuma *et al.*, 2012), the contribution of the Agriculture, Forestry and Other Land Use (AFOLU) sector to global anthropogenic GHG emissions amounts to approximately 22% (Dhakal *et al.*, 2022). When considering the contribution of food systems (i.e. when including processing, distribution, consumption of food and management of food system residues) to global anthropogenic greenhouse gas emissions, the share rises to approximately 31% (Babiker *et al.*, 2022).[3] Regionally, Latin America and the Caribbean, South-East Asia and Africa dominate global AFOLU emissions with a combined share of close to 70% of global AFOLU emissions (Dhakal *et al.*, 2022; Nabuurs *et al.*, 2022). And although in these regions CO_2 emissions make up the largest source of AFOLU GHG emissions, methane (CH_4) and nitrous oxide (N_2O) emissions have been growing significantly in the last decades; Africa, for instance, experienced a 44% increase in AFOLU CH_4 emissions between 1990 and 2019 (Nabuurs *et al.*, 2022).

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[2] The 193 Parties that have joined the Paris Agreement (as of July 2022) include 192 governments and the European Union.

[3] The presence of uncertainties in the estimates of GHG emissions (and in particular large uncertainties in the estimates of CO_2 emissions from LULUCF), imply that figures for the share of AFOLU GHG emissions (and consequently of food systems GHG emissions) should be read with due consideration of these uncertainties (Dhakal *et al.*, 2022; Friedlingstein *et al.*, 2022; IPCC, 2022b:Figure SPM.1; Nabuurs *et al.*, 2022).

Interventions that contribute to the reduction of AFOLU GHG emissions are therefore crucial for climate change mitigation. According to the IPCC's AR6, all illustrative pathways that are consistent with a warming of below 2°C in the 21st Century compared to pre-industrial levels will require reducing AFOLU GHG emissions (Riahi *et al.*, 2022). The mitigation options with the largest potential are related to the protection, improved management and restoration of forests and other ecosystems, with reduced deforestation featuring among the measures with the highest potential, particularly in Latin America and the Caribbean, Africa and Middle East, and Asia and Developing Pacific regions (Nabuurs *et al.*, 2022; Roe *et al.*, 2021). Yet, mitigation options directly related to the agricultural sector, such as carbon sequestration through agroforestry, biochar, and soil carbon management in croplands and grasslands, as well as measures that reduce CH_4 and N_2O (e.g. improved management of livestock and manure, of crop nutrients and of rice cultivation) are also considered to have substantial mitigation potential (Nabuurs *et al.*, 2022).

ii. The agricultural sector is strongly affected by GHG emissions and climate change

The available scientific evidence indicates that climate change has an impact on all agricultural and fishery sub-sectors, via both direct and indirect effects (Bezner Kerr *et al.*, 2022). Direct effects include the influence of temperature increases and heat stress on plant growth and crop yields (Adams *et al.*, 1998; Hatfield and Prueger, 2015; Scheelbeek *et al.*, 2018; Zhao *et al.*, 2017) and on livestock growth, production and welfare, as well as on the quality of animal products (Godde *et al.*, 2021). Heat stress can indirectly result in adverse effects on crop and livestock production via reduced agricultural labour productivity, particularly in warmer geographical areas such as the tropics (de Lima *et al.*, 2021; Godde *et al.*, 2021). Further indirect effects on agricultural crops occur via possible increases in biotic stress due to changes in the rates of reproduction and distribution of weeds, pests, pathogens and diseases, as well as in possible reductions in the effectiveness of pollinator agents and in changes in soil and water quality (Bezner Kerr *et al.*, 2022). In turn, the direct and indirect effects on plant production affect livestock feed and thus substantially impact livestock production. Climate change also affects fisheries and aquaculture, including via oxygen loss and a reduction in upper ocean stratification (Bindoff *et al.*, 2019).

At the same time, increases in human-induced global warming enhance the frequency and intensity of extreme climate and weather events, including hot extremes and heavy precipitation, and raise the likelihood and severity of pluvial floods and of droughts (Seneviratne *et al.*, 2021). Such extreme climate and weather events can have dramatic repercussions on agricultural systems and on the livelihoods of rural populations (FAO *et al.*, 2018; FSIN and Global Network Against Food Crises, 2021; Hasegawa *et al.*, 2021).[4]

Overall, anthropogenic climate change has already caused significant adverse effects on the agricultural sector, with a cumulative negative impact on global agricultural total factor productivity (TFP) growth estimated at close to 21% between 1961 and 2020, which corresponded to a loss of seven years of productivity growth (Ortiz-Bobea *et al.*, 2021:301). Ortiz-Bobea *et al.* (2021) highlighted the presence of marked regional disparities, with warmer regions such as Africa, the Near East and North Africa, and Latin America and the Caribbean experiencing the highest losses, amounting to 34%, 30% and 26%, respectively, and cooler higher-latitude regions such as North America (-12.5%) and Europe and Central Asia (-7.1%) suffering relatively lower impacts of anthropogenic climate change on TFP growth (Ortiz-Bobea *et al.*, 2021:310). Future impacts are also expected to be characterised by a similar geographic heterogeneity, with negative yield changes projected to be most prevalent in low latitude regions and areas with higher current average temperatures (Bezner Kerr *et al.*, 2022; Hasegawa *et al.*, 2022; Jägermeyr *et al.*, 2021; Mbow *et al.*, 2019; Willett *et al.*, 2019).

In combination, these first two facts show the strong interconnection between agriculture and climate change and signal the need for actions that can help mitigate climate change - through both the reduction of GHG emissions and the capture of GHGs - and build resilience to the adverse effects of climate change. In this optic, one of the key messages reported in the IPCC’s second working group contribution to the AR6 can be deemed particularly relevant to the agricultural sector and to the populations that depend upon it:

> The cumulative scientific evidence is unequivocal: Climate change is a threat to human well-being and planetary health. Any further delay in concerted anticipatory global action on adaptation and mitigation will miss a brief and rapidly closing window of opportunity to secure a liveable and sustainable future for all. (IPCC, 2022a:33)

iii. Global population is rising…

The third key fact relates to population growth. Projections from the United Nations’ World Population Prospects indicated that global population will reach 8.5 billion by 2030 (United Nations, 2022a), the year that the global community has set to try to achieve the 17

[4] Further effects of anthropogenic GHG emissions on agricultural production, which are not effects of a changing climate *per se* but rather of changes in atmospheric composition, include the ozone effect due to increased emissions of GHGs such as methane, considered to have a negative effect on plant productivity (Ainsworth *et al.*, 2020; Shindell *et al.*, 2019), as well as effects due to elevated CO_2 concentrations, such as the ‘fertilisation effect’ and the increase in water use efficiency, which are considered to have generally positive effects on plant growth (Toreti *et al.*, 2020), but also potentially negative effects on the nutritional content of crops (Myers *et al.*, 2014; Zhu *et al.*, 2018), and negative effects on marine ecosystems due to ocean acidification (Doney *et al.*, 2020).

Sustainable Development Goals (SDGs) (United Nations General Assembly, 2015), and close to 10 billion by 2050 (United Nations, 2022a).[5] The increases in global population are projected to be largely driven by population growth in Africa and Asia, with over half of the projected global increase in population between 2022 and 2050 originating from just eight countries, five in Africa and three in Asia (United Nations, 2022c:5).[6] Africa, in particular, has already become the main source of global population growth, overtaking Asia in 2020, and is projected to continue to witness the highest population growth rate in future decades, with an average annual rate of population change of 2% between 2022 and 2050 (United Nations, 2022a).[7] By 2050, over 25% of the global population will thus be concentrated in Africa (United Nations, 2022a).

With an increase in population the demand for food will also rise and therefore agricultural production must increase.[8] The Food and Agriculture Organization of the United Nations (FAO) estimates that by 2050 (from a 2012 baseline) global agricultural output will need to increase by close to 50%, and in Sub-Saharan Africa (SSA) and South Asia it will need to more than double, to meet increased demand (FAO, 2017b:46).[9] Considering past achievements, such increases are in principle feasible. Global agricultural production, for instance, increased by more than 125% in the equivalent pre-2012 timeframe (i.e. between 1974 and 2011) (FAO, n.d.). Yet, past agricultural output growth, which was driven by both land conversion (particularly in tropical areas), and agricultural intensification, has occurred to the detriment of numerous ecosystems, with resulting land and water degradation, biodiversity loss, and substantial GHG emissions (FAO, 2017b; Foley *et al.*, 2011; Tilman *et al.*, 2011; Willett *et al.*, 2019). Therefore, the current challenge consists in achieving the necessary increases in agricultural production without persisting on such an unsustainable pathway (Godfray *et al.*, 2010).

According to FAO estimates, some scope for agricultural expansion in currently unprotected and non-forested areas remains (FAO, 2018b). Yet, the future agricultural land

[5] These projections correspond to the "medium variant" (see United Nations (2022b) for a description of the methodology used to produce the projection variants).

[6] The eight countries are the Democratic Republic of the Congo, Egypt, Ethiopia, India, Nigeria, Pakistan, the Philippines and the United Republic of Tanzania (United Nations, 2022c:5).

[7] In comparison, the annual growth rate at the global level is projected at 0.71%, and other regions' rates are projected to range from -0.2% for Europe to 0.9% for Oceania (with Asia, Latin America and the Caribbean, and Northern America all projected to grow below the global rate, with rates of 0.42%, 0.46% and 0.4%, respectively).

[8] Beyond population growth, projections of income growth, of per capita food consumption, and of changes in diets are also considered in most studies projecting food demand (Alexandratos and Bruinsma, 2012).

[9] Other studies have estimated even higher demand and consequent future agricultural output requirements. Tilman *et al.* (2011), for instance, forecasted an increase of 100-110% in global crop demand between 2005 and 2050. Pardey *et al.* (2014) estimated that global agricultural consumption would increase by 69% between 2010 and 2050.

requirements necessary to cover projected food demand will likely exceed such a reserve of suitable land (Lambin and Meyfroidt, 2011; FAO, 2018b; Searchinger *et al.*, 2019).

Land degradation is one of the major causes that reduce the availability of suitable land for agricultural production (FAO, 2018b; Lambin and Meyfroidt, 2011). Land degradation consists in the “reduction or loss of biological and economic productivity of land and its constituents: soil, water, and biodiversity” (UNCCD, 2022:xv). A recent report of the UN Secretary-General on progress towards the SDGs indicates that 20% of the World’s land area (approximately 2.4 billion hectares) is already degraded (United Nations Economic and Social Council, 2022); and according to Lambin and Meyfroidt (2011) a further 1 to 2.9 million hectares per year of land is projected to be lost to land degradation. In value terms, the Economics of Land Degradation initiative estimates that the ecosystem service values losses from land degradation amount to USD 6.3-10.6 trillion per year (ELD Initiative, 2015).

Natural factors, such as geomorphic and topographic conditions, can be considered to contribute to land degradation processes (Kiage, 2013). Yet, anthropogenic drivers, and in particular agricultural systems related practices, such as deforestation, improper management of annual and permanent crops, cultivation of marginal lands as well as overgrazing and improper livestock management, improper soil management and disturbance of the water cycle are key determinants of land degradation (Olsson *et al.*, 2019; UNCCD, 2018). Transforming agricultural systems is therefore paramount to reduce and avoid further land degradation, and potentially reverse land degradation (UNCCD, 2022:5).

In addition, exploiting the reserve of “suitable land” would imply maintaining current areas of protected land instead of augmenting these (as argued e.g. by the World Wildlife Fund for Nature (WWF, 2020) and as recently agreed at the fifteenth meeting of the Conference of the Parties to the Convention on Biological Diversity (UNEP, 2022)), and would also lead to further environmental costs since these areas, albeit considered suitable for agriculture, are still rich in biodiversity (Lambin and Meyfroidt, 2011). Most of the required increases in food production will thus need to be generated through agricultural intensification and a reduction in yield gaps. Yield gaps are generally estimated by the difference, at a given location and moment in time, between potential output per unit of land (i.e. potential yields) and current farmers’ average yields (Lobell *et al.*, 2009). Recent studies have reported the presence of large yield gaps, particularly in SSA, as well as in areas of Latin America and the Caribbean, of India and of Eastern Europe and Central Asia (FAO, 2022; Lobell *et al.*, 2009; Mueller *et al.*, 2012), suggesting the existence of ample opportunities to enhance agricultural production via increases in productivity. However, to avoid further environmental degradation, pathways for sustainable agricultural intensification that enable the achievement of higher levels of agricultural productivity while reducing inefficient natural resource (e.g. water, land) and other input (e.g. nutrients, chemicals) use are required (Cordell and White, 2014; Foley *et al.*, 2011; Gadanakis *et al.*, 2015; Mueller *et al.*, 2012; Tilman *et al.*, 2011; Willett *et al.*, 2019). In other words, sustainable increases in agricultural productivity are critically needed to respond to the projected increases in food demand without further impairing ecosystems.

iv. …and so is Food Insecurity

Sustainable increases in agricultural productivity are also needed to help agri-food systems reduce the already exceedingly high number of food insecure people in the world.[10] FAO projections reveal that there were between 702 million and 828 million - with a mid-range projection of 768 million - chronically undernourished people in the world in 2021 (FAO *et al.*, 2022).[11] This represented an increase of 26-63 million compared to 2020 and of 84-210 million compared to 2019. Whilst such a large rise has mainly been attributed to the effects of the Covid-19 pandemic, FAO data show that global hunger was already on an upward trajectory prior to the pandemic, with an increasing trend in both the number of undernourished and the Prevalence of Undernourishment (PoU) since 2017 (FAO *et al.*, 2022). The second indicator of food access used to track progress towards the realisation of SDG target 2.1,[12] provides a grimmer picture still. The estimated prevalence of moderate

[10] Although a multipronged strategy across and beyond agri-food systems is indeed required to address the main drivers of food insecurity (FAO *et al.*, 2021; Searchinger *et al.*, 2019; Springmann *et al.*, 2018), sustainable increases in agricultural productivity can have a positive impact on the four dimensions of food security and help reduce food insecurity. Food availability can be enhanced as increased productivity corresponds, *ceteris paribus*, to increased output. Food access can be improved for food producers whose higher yields and output directly results in additional food (and hence consumption) at the household level and indirectly through the increased earnings from the sale of their produce. Food access can also improve for rural and urban non-agricultural producers via the reduction in food prices associated with increased food supply. In terms of food utilisation, the paradigm shift from conventional agricultural intensification towards sustainable increases in agricultural productivity entails, among other elements, a transition from a trend of "genetic erosion" (FAO, 2017a) to one of genetic diversity that includes indigenous crops and livestock species alongside modern varieties (including biofortified varieties) (FAO, 2021a; Garnett *et al.*, 2013; Godfray and Garnett, 2014). Such a shift would enhance the nutritional content, diversity and quality of foods and contribute to improvements in food utilisation. Further improvements in food utilisation indicators could occur as a consequence of enhanced food availability and food access. Finally, if the increases in agricultural productivity are indeed sustainable (i.e. current increases in productivity do not economically, socially and environmentally jeopardise future agricultural productivity), then such increases can also positively contribute to food stability by lowering yield variability and helping to stabilise food supplies and food prices.

[11] The corresponding projections for the prevalence of undernourishment in 2021 were 8.9-10.5% (with a mid-range of 9.8%) (FAO *et al.*, 2022).

[12] "By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round" (United Nations General Assembly, 2015: Goal 2 Target 2.1).

or severe food insecurity in the population, based on the Food Insecurity Experience Scale (FIES), was 29.3% in 2021. In other words, in 2021 there were an estimated 2.3 billion people in the world without access to adequate food (FAO *et al.*, 2022:24-26). Whilst the prevalence and the number of moderately or severely food insecure people were relatively stable between 2020 and 2021, the prevalence and the number of severely food insecure continued to rise in 2021 for the sixth year running. The global prevalence of severe food insecurity reached close to 12% in 2021, up from 10.9% in 2020 and up from 7.5% in 2015, the year when the 2030 Agenda for Sustainable Development was adopted by the UN General Assembly. The corresponding estimate of the number of severely food insecure people in the world was 924 million in 2021, representing an increase of 74 million individuals compared to 2020 and of close to 370 million compared to 2015 (FAO, n.d.; FAO *et al.*, 2022).

Few data related to nutrition indicators at the global level have been generated after the start of the Covid-19 pandemic. The most recent available information shows that improvements were occurring in terms of the number of infants with low birthweight, and the number of stunted children under five years of age, as well as in the rate of exclusive breastfeeding in the first six months of life (FAO *et al.*, 2022). Yet, indicators related to other global nutrition targets, such as the prevalence of anaemia among women of reproductive age, the prevalence of overweight children under-five and of adult obesity, were all on the upside. The latest estimate of the prevalence of wasting among children under-five was almost 7%, over 2.2 times the target of less than 3% set for 2030 (FAO *et al.*, 2022:43).

In terms of the food security outlook for 2030, and despite improvements in a few indicators, current estimates show that the world is off-track to achieve all global nutrition targets and thus SDG target 2.2 (FAO *et al.*, 2022:44).[13] Similarly, current FAO projections indicate that close to 670 million people will be undernourished in 2030, representing 8% of the population, and thus precluding the achievement of SDG target 2.1. Coincidentally, 8% is also the estimated global PoU for the year 2015 (FAO *et al.*, 2022:22). Given current projections, global PoU would be at the same level in 2030 (i.e. the year that the SDGs are intended to be achieved) as it was in 2015 (i.e. the year that the SDGs were adopted by the UN General Assembly within the 2030 Agenda for Sustainable Development).

[13] "By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons" (United Nations General Assembly, 2015: Goal 2 Target 2.2).

In summary, with clear evidence of a changing climate that is both affecting and in part caused by the agricultural sector, an already exceedingly high proportion of food insecure people in the world, and an increase in future food demand due to population growth, a transformation of agricultural systems is urgently needed. Such a transformation will require embedding actions that can contribute to climate change mitigation, climate change adaptation, and sustainable increases in agricultural productivity.

Climate Smart Agriculture

Climate Smart Agriculture (CSA) is a sustainable agriculture approach aimed at achieving precisely these three objectives – sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation. CSA is in fact defined by the FAO as:

> [A]n approach for developing actions needed to transform and reorient agricultural systems to effectively support development and ensure food security under climate change. CSA aims to tackle three main objectives: sustainably increasing agricultural productivity and incomes; adapting and building resilience to climate change; and reducing and/or removing greenhouse gas emissions, where possible. (FAO, 2017a)

The CSA concept first emerged in 2009 (FAO, 2009), it was subsequently formalised in 2010 (FAO, 2010), and detailed in the 2013 CSA sourcebook (FAO, 2013), of which a second digital platform edition was released in 2017 (FAO, 2017a).

Climate Smart Agriculture includes farm-level interventions that are aimed at improving crop, livestock, land, soil, and water management, within crop, livestock and integrated production systems (FAO, 2017a: modules B1, B2, B5, B6, B7). The CSA approach can also extend beyond the farm-gate, through landscape-level actions (FAO, 2017a: module A3; Harvey *et al.*, 2014; Scherr *et al.*, 2012), as well as through interventions at the wider food system level (FAO, 2017a: module B10). Furthermore, CSA can encompass interventions linked to the fisheries and aquaculture sectors (FAO, 2017a: module B4) and to the forestry sector (FAO, 2017a: module B3). Critically, the CSA approach also entails building an enabling environment that is coherently oriented towards the maximisation of synergies and the reduction of trade-offs among CSA's three objectives (FAO, 2017a: modules C3, C10).

CSA must therefore be understood as a holistic and inclusive approach, that does not exclude *a priori* specific sets of policies, strategies, technologies and practices, insofar as these contribute positively (or at least non-negatively) to the attainment of the three CSA objectives. This orientation towards a triple-objective, which explicitly features climate change, is what makes CSA particularly distinctive and innovative compared to other concepts related to sustainable agriculture, such as sustainable intensification (Pretty, 1997), agroecology (Wezel *et al.*, 2009), regenerative agriculture (Lal, 2020), among others

(Bell *et al.*, 2018; Campbell *et al.*, 2014). The outcome-oriented nature of CSA and the explicit reference to climate change among its objectives represents a key opportunity for decision-makers to integrate climate change adaptation and mitigation when designing sustainable agricultural strategies (Lipper *et al.*, 2014:1068), and opens-up windows for policymakers to access climate finance to support the implementation of such strategies (Lipper *et al.*, 2014).

The risks for agricultural systems posed by climate-related hazards and the relative contribution of the AFOLU sector to global GHG emissions vary between global regions (see, for instance, Nabuurs *et al.* (2022) and Roman-Cuesta *et al.* (2016) for details on the geographic distribution of AFOLU GHG emissions and IPCC (2022a:Annex I) for global maps showing observed and projected impacts and risks of climate change on agricultural systems). This implies that global hotspots of climate change adaptation and mitigation may not always coincide, and that trade-offs may exist between these two climate-related objectives of CSA. Hence, at the regional (or national/local) level one of the CSA climate-related objectives may be prioritised vis-à-vis the other. For instance, in areas with very high vulnerability and exposure to the adverse effects of climate change, such as in small-island states or mega-deltas, where rural populations are particularly vulnerable and exposed to sea-level rise, flooding, storm surge and salinisation (IPCC, 2022a; Jarvis *et al.*, 2021), but where relatively low potential for climate change mitigation exists due to the relatively low amount of AFOLU GHG emissions, then climate change adaptation would tend to be prioritised. Conversely, in areas where rural populations are currently facing less risks associated with climate-related hazards, and where AFOLU mitigation actions can have a large impact in reducing the concentration of GHGs in the atmosphere, interventions primarily aimed at climate change mitigation may generally be prioritised.

Be that as it may, CSA remains relevant also in such contexts. The literature shows that initiatives that primarily target one of the CSA climate-related objectives can generate co-benefits onto the other climate-related objective (e.g. Dubash *et al.*, 2022; Locatelli *et al.*, 2015). For instance, restoring mangroves to reduce flood and storm surge risk in coastal areas represents a climate change adaptation strategy (IPCC, 2022a; Menéndez *et al.*, 2020). Yet, mangroves are one of the most carbon rich forests (Alongi, 2014; Donato *et al.*, 2011) and restoring mangroves can therefore generate substantial mitigation services (Duarte *et al.*, 2013; Dubash *et al.*, 2022; Nabuurs *et al.*, 2022). Similarly, a range of actions primarily focused on climate change mitigation can have positive spillovers on climate change adaptation. Agroforestry, for instance, constitutes a strategy that is often featured in National Determined Contributions as a means to reduce GHG concentrations in the atmosphere (Duguma *et al.*, 2017; Rosenstock *et al.*, 2019). Yet, beyond its mitigation benefits, agroforestry can also build resilience of agricultural systems to the adverse effects of climate change, as it can lead to enhanced soil fertility and moisture, reduced runoff, and potentially yield additional high-value produce (e.g. fruits, nuts) that complements farmers' incomes and provides a buffer against climate change induced losses (Duguma *et al.*, 2017; IPCC, 2019; 2022a; Mbow *et al.*, 2014; Verchot *et al.*, 2007).

Thus, prioritising one of the CSA climate-related objectives does not preclude the implementation of actions that can generate combined benefits on both climate-related CSA objectives. Strategies that can deliver synergies are available and should therefore be chosen over alternative options that may instead lead to negative spillovers.

Although the CSA approach is relevant for both "advanced economies" and lower-income countries,[14] most initiatives and literature related to CSA focus on lower-income countries.[15] This may be due to multiple factors, but, centrally, lower-income countries tend to suffer disproportionately more from the key facts introduced above. Since its inception, the CSA approach has thus been championed on the global stage by institutions such as the FAO (FAO, 2010; 2017a; 2018a; 2021a; 2021b), the World Bank (World Bank, 2015; 2016; 2018; 2021), the Consultative Group on International Agricultural Research (CGIAR) (Aggarwal *et al.*, 2018; CCAFS, n.d.; Loboguerrero *et al.*, 2017; Loboguerrero *et al.*, 2019; Nyasimi *et al.*, 2014), among others (IFAD, 2011; 2021; WFP, 2021; World Bank *et al.*, 2011).

Multi-stakeholder alliances, platforms and networks that stimulate the development of partnerships and the sharing of information, knowledge and experience on CSA have also been established both at the global (Global Alliance for CSA – GACSA) and continental/regional levels (e.g. African CSA Alliance – ACSAA; West Africa CSA Alliance – WACSAA; Southern Africa CSA Alliance – SACSAA; Association of Southeast Asian Nations Climate Resilience Network – ASEAN-CRN; North America

[14] Throughout this PhD thesis, the concept "lower-income countries" is employed loosely to distinguish countries that do not belong to the category of "advanced economies", as classified for instance by the International Monetary Fund (IMF) (IMF, 2021). The IMF classifies non-advanced economies as "Emerging Market and Developing Economies" (IMF, 2021: Statistical Appendix). The broader and relative term "lower-income" can instead be used to avoid referring to particular groups of countries as "developing" countries, a term that can be viewed as misleading as it implies that so-called advanced (or "developed") economies are no longer developing. Whilst indeed other country classifications exist, such as the World Bank's income-based classification, or the pre-2022 UN country classification distinguishing between "developing" and "developed" regions, these conventional classifications are often seen as carrying a value judgement, and the UN has in fact since the end of 2021 removed the concept of "developed regions" and "developing regions" from the standard country or area codes for statistical use (known as M49 standard), which is now based on geographical regions (United Nations, n.d.).

[15] Notable exceptions include Long *et al.* (2016) and CSA initiatives launched by the European Commission (EC, 2021) as well as the United States Department of Agriculture (USDA, 2021a; 2021b).

CSA Alliance – NACSAA). And at continental, regional and national scales, various CSA strategies and plans have emerged (e.g. CAC and SICA, 2017; FAO and MADR, 2019; Government of Lesotho and World Bank, 2019; Government of the Republic of Kenya, 2017; 2018; Hashemite Kingdom of Jordan and World Bank, 2021; MOAI *et al.*, 2015; NEPAD, 2014).

Interest in CSA has also been growing within the wider scientific community, as witnessed by the increasing volume of peer-reviewed literature featuring CSA and its mention in key global reports (HLPE, 2019; IPCC, 2019; 2022a; 2022c; Loboguerrero *et al.*, 2018; Searchinger *et al.*, 2019; UNFSS, 2021).

The flexible and broad character of CSA, however, has generated misunderstandings and criticisms. Various civil society organisations have strongly criticised CSA (ActionAid, 2014; Civil Society Organisations, 2015; La Via Campesina, 2014). These criticisms mainly reflect fears that specific agricultural approaches, such as agroecology, be outcasted in favour of corporate and industrial food systems that harm the environment and further exacerbate smallholder farmers' vulnerability to poverty and food insecurity. Whilst it is important not to overlook these criticisms, it is also key to understand that there is not necessarily a conflict between agroecology and CSA; rather, in many contexts, the application of agroecological principles can have beneficial effects on the three CSA objectives (Altieri *et al.*, 2015; Altieri and Nicholls, 2017) and can thus be considered as CSA. Indeed, the CSA approach embodies several characteristics of agroecology, such as the recognition of the value of local indigenous and traditional knowledge for the planning and implementation of interventions as well as the critical importance of ensuring genetic diversity (FAO, 2017a: modules A1, A3, B3, B7, B8, C1, C2, C5). Likewise, both agroecology and CSA are approaches that are highly context and capacity specific. In terms of CSA, this implies that particular options may be considered as climate-smart and applicable in a given location at a given moment in time, but not in others, depending on factors such as agroecological, socioeconomic as well as cultural and institutional conditions (Abegunde *et al.*, 2019; FAO, 2017a; Loboguerrero *et al.*, 2019; Simelton *et al.*, 2017).

Peer-reviewed literature also contains articles that criticise elements of the CSA approach. Amongst the most prominent ones, Taylor (2018) reports:

> [CSA does not incorporate] the questions of power and inequality that animate agrarian political economy traditions. […] CSA is steadfastly concerned with how food is produced, not who has access to land, water, labour and other inputs to produce it […]. In focusing so intently on field-level technologies and practices, CSA isolates food production within an apolitical realm of managed fixes to technical problems […T]he thorny terrain that marks the political economy of development with its focus on local inequities of access to resources

> such as land, water and credit [is neatly sidestepped]. A paradigm shift in agriculture [is being proposed] without acknowledging the vast inequalities of access to land, inputs, water and food that stratify contemporary patterns of food production, distribution and consumption. (pp.95,96,103)

These criticisms are echoed by Hellin and Fisher (2019), who argue that prevalent CSA discourses and interventions do not sufficiently consider the socioeconomic and political factors that shape the high levels of poverty and inequality faced by farmers in lower-income countries. In turn, poverty and inequality - including in access to land - may affect farmer capacity to uptake CSA. The authors thus warn that omitting these factors can lead to trade-offs between SDG 13 (climate action), and SDG 1 (no poverty), SDG 5 (gender equality) and SDG 10 (reduced inequalities); trade-offs that, in the authors' view, risk becoming CSA's "Achilles' heel" (Hellin and Fisher, 2019:494).

In a similar vein, Chandra *et al.* (2017) highlight that "the emerging CSA discourse can better embed social and political factors for scaling-up practices in smallholder farming communities" (Chandra *et al.*, 2017:834). The authors argue that CSA should incorporate political ecology perspectives, as these can help understand, and subsequently address, the underlying causes of inequality and injustice that generate farmer marginalisation and vulnerability to climate change, food insecurity and poverty, which in turn may lead to the exclusion of such farmers from CSA initiatives (Chandra *et al.*, 2017-826). In the authors' words:

> [V]ulnerabilities among the most marginalized at local and global levels will amplify if 'climate-smart' policies sidestep issues related to smallholder farmer rights, equitable distribution of agricultural resources and hegemonic power relations. CSA interventions need to move beyond the farm level and target inequality, unequal power relations and injustice beyond the farm to address socio-political processes influencing livelihoods, food production, and vulnerability. (Chandra *et al.*, 2017:836)

Such criticisms have been relayed by authors of chapter five of the Contribution of Working Group II to the IPCC's AR6, who indicate that:

> CSA programs have tended to overlook questions of inequity […] Addressing questions of rights, social injustice, unequal power relations and inequality would help make CSA-related policy responses more effective in addressing vulnerability. (Bezner Kerr *et al.*, 2022:5-145)

Questions of rights, social injustice, and inequality, particularly with respect to scarce natural resources for agricultural production such as land, remain indeed topical due to the extent and severity of inequality in land distribution, on the one hand, and of insecure land rights, on the other hand. Recent data show increasing trends and alarming levels of land inequality (Anseeuw and Baldinelli, 2020), as well as a high prevalence of tenure insecurity at global and regional scales (Feyertag *et al.*, 2020).

Global land inequality, measured using the traditional methodology which derives the Gini coefficient from census data, has been increasing since the 1980s, reaching levels that in the last 100 years had only been attained in the 1920s and in the 1960s-early 1970s (Anseeuw and Baldinelli, 2020:36-37). The use of survey data has enabled researchers to start developing more refined methodologies for the estimation of land inequality. Bauluz *et al.* (2020)'s methodology, for instance, overcomes several of the shortcomings from traditional census-based measures of land inequality, as it accounts for differences in land quality (by incorporating land values), it considers multiple ownership of plots and, notably, it includes the landless population involved in agriculture (Bauluz *et al.*, 2020). Using such a methodology, land inequality has been shown to be even larger compared to findings that utilise the traditional census-based measure. For instance, land inequality for an unweighted average of 11 countries for which data were available across Asia, Latin America and Africa, has been estimated to be 41% higher compared to estimates based on the traditional method that employs census data (Anseeuw and Baldinelli, 2020).

In terms of tenure insecurity, a report from a global initiative launched by the Overseas Development Institute and the Global Land Alliance stated that 16% of the global rural adult population perceived their land tenure as insecure (Feyertag *et al.*, 2020:17).[16] The regions with the highest prevalence of rural tenure insecurity were found to be Sub-Saharan Africa and Middle East and North Africa (both regions with 22% of the rural adult population perceiving their tenure as insecure), followed by Latin America and the Caribbean (21%), and South Asia (18%) (Feyertag *et al.*, 2020). At the regional level, only Europe and Central Asia, North America, and East Asia and Pacific had a proportion of the rural adult population with perceived tenure insecurity below that of the global (weighted) average of 16%.

These reports provide an up-to-date assessment of the state of land inequality and tenure insecurity, and signal the need for interventions that can equalise the distribution of land, including by enhancing landless and land-poor farmers' access to land, and ensure more secure land tenure rights (Anseeuw and Baldinelli, 2020; Guereña and Wegerif, 2019; ILC *et al.*, 2021).

To summarise, the CSA approach, by aiming to achieve sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation, can contribute to addressing the challenges associated with the four key facts described above and thus help to guide the required transformation in agricultural systems. In addition, CSA

[16] The report is based on data collected from "more than 140 countries, representing 96% of the world's adult (18+) population" (Feyertag *et al.*, 2020:8).

should not be seen as being in conflict or opposition with other sustainable agriculture approaches, such as agroecology. Rather, such approaches should be viewed, in most cases, as powerful allies for the realisation of the required transformation of agricultural systems. Other criticisms targeting CSA, however, warrant the need for CSA to consider policy actions directed at tackling questions of rights, social injustice, unequal power relations and inequality in order to create the enabling environment necessary for widespread and effective CSA adoption.

It is in this sphere that this thesis is positioned. This thesis seeks to fill an existing gap in the CSA literature by presenting three original papers that explore the association between particular policy interventions - land reforms - and CSA.

Land reforms consist of “modifications in the legal and institutional framework governing land policy” (Ciparisse, 2003:69), and can help to address most of the aforementioned criticisms related to CSA by tackling questions of rights and in particular land rights, notably of women, indigenous peoples, and marginalised landless or land-poor farmers (Binswanger-Mkhize *et al.*, 2009; Cotula *et al.*, 2006; Deere, 2017; Deininger, 2003; Prosterman *et al.*, 2009; United Nations, 2018), unequal power relations (Barraclough, 1999), social injustice (Cotula *et al.*, 2006; El-Ghonemy, 1990; Quan, 2006), poverty and inequality (Lipton, 2009).

Land reforms can also help build rural populations’ resilience to a range of shocks that extend beyond the climate resilience sought by CSA. Land reforms, through the redistribution of land and/or the enhancement of land tenure security, contribute to the provision of a secure asset to landless, land-poor and tenure insecure farmers. Such an asset can act as a crucial safety net for rural households in the event of an adverse shock (Meinzen-Dick *et al.*, 2009). Indeed, the combination of increased (secure) assets via land reform and the adoption of CSA can reduce rural populations’ vulnerability to adverse shocks and thus generate positive resilience building effects for these populations.

1.2. Aims, objectives and key research questions

The overarching aim of this thesis is to advance research on the association between CSA and land reforms, and thereby improve knowledge and understanding upon the contribution that land reforms can have in generating an enabling environment for CSA, particularly in contexts experiencing high levels of land inequality and/or tenure insecurity.

The thesis investigates, first conceptually and then empirically, key channels associating CSA and land reforms. It does so by introducing a conceptual framework that uncovers such channels and by presenting two case studies of land reforms undertaken in Sub-Saharan Africa which provide empirical evidence on specific channels of the conceptual framework.

Two specific objectives underlie the elaboration of this thesis:

Objective 1. Introduce a conceptual framework that describes potential associations between Climate Smart Agriculture (CSA) and land reform.

Objective 2. Provide empirical evidence upon specific channels of the conceptual framework in different land reform contexts.

To achieve the objectives, the following four key research questions are addressed in the thesis. These can be grouped under two umbrella questions; the first relates to the research questions that underpin the elaboration of the conceptual framework, and the second includes the research questions linked to the empirical analysis of specific channels of the framework in the land reform contexts studied.

I. How can the Climate Smart Agriculture (CSA) approach be associated with land reforms?
   - i. Can land reforms be considered a conducive environment to foster CSA adoption?
   - ii. What are the main channels through which land reforms can be associated with CSA adoption and with the realisation of the CSA objectives (as well as other objectives of land reformers)?

II. What empirical evidence on the channels associating land reform and CSA can be drawn from specific land reform experiences?
   - iii. Has the land tenure reform implemented in the Tigray region of Ethiopia in the late 1990s contributed to progress on the three CSA objectives?
   - iv. Was there any association between land reform and the likelihood of CSA adoption among farm-households in the Limpopo river-basin of South Africa?

1.3. Outline of the thesis

The four key research questions are addressed consecutively in the thesis.

Following on from this introduction, the second chapter of the thesis tackles the first two research questions. The chapter introduces and describes a conceptual framework, the Climate Smart Land Reform (CSLR) framework, which builds on theoretical and empirical literature on CSA and land reform and uncovers the channels through which these two concepts can be associated. It describes a climate-smart land reform as comprising of four pillars, namely land redistribution, land tenure reform, markets and infrastructure, and Rural Advisory Services (RAS). In turn, the framework illustrates key channels through which the four pillars can relate to CSA adoption and to the range of intermediate and ultimate objectives that land reformers may entertain. These include, as proximate objectives, social, economic and political objectives such as the reduction of poverty, inequality, conflicts (the more ‘traditional’ objectives of land reformers), as well as the three CSA objectives – sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation. Achieving progress on these proximate objectives would contribute to improvements in agroecological and socioeconomic conditions of rural areas and populations, improvements that are considered as the ultimate objectives of land reformers within the CSLR framework. The CSLR framework introduced in this chapter of the thesis represents an innovative way to conceptualise how land reforms, through redistributive and/or tenure types of reforms - potentially integrated with the provision of support services to land reform participants - can generate beneficial effects on the attainment of the more ‘traditional’ objectives of land reformers (be they social, economic, political) and at the same time represent a conducive environment to foster CSA adoption and thus contribute to improvements on the three CSA objectives. In this optic, land reforms can be seen as policy interventions that have the potential to enhance equity and efficiency but also environmental sustainability.

The CSLR framework is employed as the conceptual basis for the following two empirical chapters of the thesis.

Chapter three of the thesis addresses the third research question. In particular, the chapter examines whether the Land Registration and Certification Programme (LRCP) undertaken in 1998 in the Tigray region of Ethiopia contributed to progress towards the three CSA objectives. Earth observation data are used to construct an original panel dataset containing a rich set of climate and weather indicators, as well as the Normalised Difference Vegetation Index (NDVI), an indicator of plant ‘greenness’ widely used in the literature as a proxy of agricultural productivity and carbon uptake. The dataset includes, as cross-sectional units, 1,008 pixels equally sub-divided between the Tigray region, where the LRCP was first implemented (the 'treated' area), and the North of the neighbouring Amhara region (the 'control' area). The timeframe of the study ranges from 1991, the year when the socialist *Derg* regime was overthrown paving the way to democratisation in Ethiopia, to 2004, when the Amhara region began its own large-scale implementation of the LRCP. A difference-in-differences design is employed comparing pixels in the 'treated' area with pixels in the 'control' area before and after the reform to uncover its causal effects. Results from the baseline specification, as well as from various robustness checks, show the presence of a positive and significant effect of the LRCP on NDVI over the landscapes of Tigray. Positive correlations between NDVI and agricultural yield data from the Ethiopian 2001 Agricultural Census validate the use of NDVI as a proxy for agricultural productivity in the context of this study. Similarly, positive correlations between NDVI and Net Primary Productivity (NPP) - an indicator of carbon uptake by vegetation - confirm NDVI's potential to serve as a measure of carbon uptake and thus of climate change mitigation over Tigray and Amhara. The positive effects of the LRCP on NDVI can therefore be interpreted as suggestive evidence of a positive effect of the programme on agricultural productivity and climate change mitigation. Furthermore, by examining years where adverse climate and weather events occurred, the study reveals that the programme contributed to build resilience to the adverse effects of climate change over the landscapes of Tigray. In combination, these results suggest that the reform has led to progress on the three CSA objectives. The results are indeed consistent with the reform enhancing farmers' tenure security and inducing an increase in CSA adoption. The findings from this study imply that land tenure reforms - which can be undertaken swiftly at a large scale and at a low cost - can help attain rural development objectives, including objectives associated with climate change.

Chapter four of the thesis turns the attention to the case of the South African land reform, launched at the dawn of post-apartheid democratisation. The first part of the chapter examines the process that led to the land reform programme in the country, and includes a summary of the history of land dispossession and of administrative control that Africans suffered under the colonial and apartheid era, as well as a critical analysis comparing the initial intentions of land reformers with the actual implementation of the land reform. This first part highlights the historical complexity of land dispossession in South Africa, as well as key issues linked to the actual implementation of the land reform that have hampered the realisation of land reformers' initial intentions, including inadequate measures for the redistribution of land and for the provision of support services to land reform participants. The second part of the chapter builds on these latter findings to tackle more directly the fourth research question and shed light on possible associations between land reform and CSA adoption. Secondary data from a farm-household level survey undertaken in the Limpopo river-basin of South Africa are used to analyse empirically the association between the land redistribution and RAS pillars of the CSLR framework and the likelihood of CSA adoption. Results from the estimation of binary response models reveal that, among the studied farm-households, land redistribution participants had a higher likelihood of adopting CSA compared to non-participants, but only in the absence of RAS. These results provide suggestive evidence of land reforms' potential in fostering CSA adoption, but they also confirm the inadequacy of RAS in stimulating CSA in the South African land reform context. Increased efforts in the establishment of a well-coordinated multi-stakeholder and participatory RAS system therefore seem to be required to improve RAS in South Africa, particularly for land reform participants, and provide further thrust to the land reform in enhancing CSA adoption.

The thesis, which gathers three original 'stand-alone' essays that are nonetheless conceptually linked by the two common themes of CSA and land reform - and more specifically bound by the CSLR framework - concludes by presenting a summary of the key findings, main contributions, and avenues for future research.

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Chapter 2. Land reform in the era of global warming – can land reforms help agriculture be climate-smart?[1]

Abstract

In an era of global warming, long-standing challenges for rural populations, including land inequality, poverty and food insecurity, risk being exacerbated by the effects of climate change. Innovative and effective approaches, such as Climate Smart Agriculture (CSA), are required to alleviate these environmental pressures without hampering efficiency. In countries with unequal distribution of land, where issues of access to and use of land rank high on the policy agenda, policymakers are confronted with the challenge of implementing interventions such as land reforms, whilst endeavouring to ensure that sustainable agriculture approaches be adopted by farm-households. The aim of this study is to investigate how land reforms can provide an opportunity for policymakers, particularly in lower-income countries, to enhance not only equity and efficiency but also environmental sustainability. In particular, this study builds on an extensive review of the theoretical and empirical literature and employs a conceptual framework analysis method to develop and describe a framework that explores how land reforms can be associated with the CSA approach. The resultant "Climate Smart Land Reform" (CSLR) framework contains four driving pillars, namely land redistribution, tenure reform, rural advisory services and markets and infrastructure. The framework disentangles relevant channels through which land reform, via its four pillars, can foster CSA adoption and thus contribute to the attainment of sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation. The framework also includes relevant channels through which more 'traditional' objectives of land reformers, including economic, social and political objectives, can be achieved. In turn, the (partial) attainment of such objectives would lead to improvements in agroecological and socioeconomic conditions of rural areas and populations. These improvements are considered within the framework as the 'ultimate' objective of land reformers. The CSLR framework represents an innovative way of conceptualising how land reforms can generate beneficial effects not only in terms of equity and efficiency but also of environmental sustainability.

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2.1. Introduction

Enhancing food security in the context of an increasing population and global warming requires the implementation of innovative and effective approaches across food systems. Climate Smart Agriculture (CSA) is a sustainable agriculture approach that includes climate change in two of its three objectives – sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation (FAO, 2017; IPCC, 2019). Institutions that have pioneered CSA include the Food and Agriculture Organization of the United Nations (FAO), who first introduced the CSA concept in a 2009 report and then more formally in 2010 (FAO, 2009; 2010), the Consultative Group for International Agricultural Research (Aggarwal *et al.*, 2018; Sova *et al.*, 2018) and the World Bank Group (World Bank, 2016; 2019a; 2019b) – all members of the Global Alliance for Climate Smart Agriculture (GACSA). CSA should not be prescribed as a specific set of agricultural practices and technologies universally adoptable. Rather, it should be understood as a holistic approach that can include both traditional and modern agricultural practices and technologies, insofar as these contribute positively (or at least non-negatively) to the attainment of the three CSA objectives (FAO, 2017).

The existence of a wide range of agricultural practices with "climate-smart" potential and the rising popularity of the approach have led to a growing literature on CSA and numerous studies have analysed drivers and barriers to CSA adoption (see, for instance, Abegunde *et al.*, 2019; Asfaw *et al.*, 2016; Kpadonou *et al.*, 2017; McCarthy *et al.*, 2011). Unsurprisingly, these studies reveal that there exists a wide range of factors determining or limiting CSA adoption by farmers. This is due to the existence of a large heterogeneity between the different contexts studied, but also between the specific CSA practices analysed within each study.

In order to implement successful CSA strategies, stakeholders at both the farm level and the wider economic and political environment need to make decisions on the allocation and use of resources, including finite natural resources such as land (Dunnett *et al.*, 2018). At the policy level, this can translate into interventions such as land reforms that have the potential to advance, on the one hand, a socially efficient allocation of land and, on the other hand, an enabling environment for scaling CSA adoption. However, there is no existing framework that can be utilised to explore the specific linkages between land reforms and CSA adoption. This study intends to fill this gap by investigating the potential channels connecting land reforms to CSA and does so via the construction of a conceptual framework. The overarching aim of this study is to investigate how land reforms can provide an opportunity for policymakers, particularly in lower-income countries, to enhance not only equity and efficiency but also environmental sustainability. The general research questions that this paper addresses are as follows:

(1) Can land reforms be considered a conducive environment to foster CSA adoption?
(2) What are the main channels through which land reforms may affect CSA adoption and the realisation of land reformers' objectives?

Two premises are important at this stage. The first concerns the definition of land reform and the second narrows down the scope of the definition within this paper. Multiple definitions of land reform have been employed in the literature. These range from narrower definitions, which focus mostly on land redistribution (Banerjee, 1999; Binswanger-Mkhize *et al.*, 2009; Griffin *et al.*, 2002; Lipton, 2009), to definitions which broaden the scope of land reforms to include complementary measures in support of land reform beneficiaries (African Union *et al.*, 2010; Cohen, 1978; Raup, 1963; United Nations, 1962). In the context of this paper, a relatively broad definition of land reform is used: "Land reform is the generic term for modifications in the legal and institutional framework governing land policy" (Ciparisse, 2003:69).[2] Moreover, the focus is placed on agricultural land reforms, omitting reforms directly affecting urban tenures and urban land use.

Because of the specificity of each country context, modern land reforms have been developed and implemented in a variety of forms and for a variety of reasons.[3] Land reforms include interventions related to two broad categories. The first category considers changes in the tenure structure and includes both land redistribution (i.e., the reallocation of land, therefore affecting directly land concentration) and land tenure reforms (i.e., "changes to the rules of tenure" (FAO, 2002:47)). These represent the first two 'pillars' that drive the conceptual framework introduced in this paper. Both land redistribution and tenure reforms can be undertaken in a variety of forms and indeed there are circumstances where they coexist. Land redistribution programmes can be State-led, market-led or hybrids of the two (Ciamarra, 2003). In addition, land redistributions can have a multitude of different specific characteristics and triggering factors. Tenure reforms can range from tenancy reduction or rebalancing laws, to tenancy registration, legal recognition of customary tenure rights, patrialisation, collectivisation, etc. (see, for instance, Albertus, 2015; Lipton, 2009). In some circumstances land redistribution programmes have been complemented with tenure reforms aimed at enhancing tenure security (e.g., in South

[2] Land policy refers to "the set of intentions embodied in various policy instruments that are adopted by the state to organise land tenure and land use" (Ciparisse, 2003:69).
[3] In addition to country contexts, evolutions in external pressure trends have also played a role in influencing the types or forms of land reforms in different countries. Examples of these pressures are the Alliance for Progress (AfP) set by the United States (US) Government in 1961 or the World Bank's influential role in prioritising land titling programmes in numerous developing countries in the last decades of the twentieth century and in supporting market-led land reforms.

Africa), in other circumstances tenure reforms have been employed as a means to transfer land (e.g., the 'land to the tiller' reforms of East Asia; the patrialisation schemes occurring after decolonisation). The second broad category relates to interventions affecting the support services available to rural populations, and in particular to land reform beneficiaries. These include interventions linked to Markets and Infrastructure (MaI) and to Rural Advisory Services (RAS). Although such services "may or may not be extended or improved with or without land reform" (Tuma, 1965:12), there is ample recognition in the literature of the crucial importance of these support services for the attainment of the objectives of land reformers (Adams, 2000; Albertus, 2015; Deininger, 2003; FAO, 2006a; Stiglitz, 1998). MaI and RAS are thus included in the framework as the third and fourth 'pillars' driving the framework. The objectives of land reformers represent the second main component of the framework. In general terms, the 'traditional' objectives of land reformers are rooted in economic, social and political grounds (Dixon-Gough and Bloch, 2006; Kay, 1998; King, 2019; Tuma, 1965). These include objectives such as the reduction of inequality and poverty, enhancing agricultural productivity and output growth, economic growth, avoiding conflicts, increased employment, gender equality, freedom and stability (both economic and political). Occasionally, references can include environmental considerations and environmental sustainability as an additional objective of land reformers (Boyce *et al.*, 2005; Colchester and Lohmann, 1993; Dorner, 1992; Jacobs, 2013). In the conceptual framework advanced in this study, both 'traditional' objectives and environmental objectives are included. The environmental objectives are represented by the three CSA objectives – sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation. In the remainder of the paper, we therefore refer to it as the "Climate Smart Land Reform (CSLR)" framework.

The CSLR framework introduced and analysed in this paper represents an innovative way for policymakers to integrate the CSA objectives in the (re)design phase of land reform, alongside the more 'traditional' objectives, and to consider appropriate channels through which these objectives can be attained. Moreover, it presumes that the (partial) attainment of these objectives generates positive effects on what is considered to be the 'ultimate' objective of land reformers within the framework: improved agroecological and socioeconomic conditions of rural areas and populations.

This paper is structured as follows. Section 2.2 provides a brief background on the four pillars driving the CSLR framework. Section 2.3 focuses on the first two pillars of the framework, namely land redistribution and tenure reform, and explores the main channels through which these can affect CSA adoption and the attainment of 'intermediate' and 'ultimate' objectives of land reformers. Section 2.4 describes such channels for the latter two pillars of the framework, MaI and RAS (i.e., the support services available to land reform beneficiaries). Section 2.5 concludes, providing a brief discussion on the potential uses of the framework.

2.2. Overview of the four pillars driving the CSLR framework

The CSLR framework introduced in this paper is illustrated in Figure 2.1. The framework has been elaborated by following the various phases of the conceptual framework analysis (Jabareen, 2009), a qualitative research method employed widely across a multitude of research fields (see, for instance, applications of the method by Dlouhá *et al.*, 2019; Eizenberg and Jabareen, 2017; Kostoska and Kocarev, 2019; Nikolakis *et al.*, 2018; Zhu *et al.*, 2015). The analysis involved undertaking an extensive multidisciplinary review of the theoretical and empirical literature surrounding the subjects of land reform and CSA. This enabled us to identify, name and categorise the various key concepts, and subsequently to integrate and synthesise these concepts within a framework. The procedure was further enriched by the feedback received during the validation phase of the analysis.[4] This iterative process resulted in the CSLR conceptual framework depicted in Figure 2.1, which is driven by the four pillars of land redistribution, tenure reform, Markets and Infrastructure (MaI) and Rural Advisory Services (RAS). Although the framework suggests that land reforms which combine interventions on the four pillars can enhance the likelihood of CSA adoption and generate exponential benefits on the livelihoods of rural populations, it also recognises that in specific country contexts it might not be feasible (or in particular cases necessary) to act on all four pillars simultaneously. This may be due to a multitude of factors, including pre-reform tenure arrangements, status of markets and infrastructure, demands and expectations of potential land reform beneficiaries, budgetary constraints, among others. In contexts where, for instance, farm operation is already undertaken by peasant-like farmers (via fixed rent or sharecropping types of tenancy arrangements), there may be less or no need for direct land redistribution: 'land to the tiller' types of tenure reforms may be more appropriate.[5] Instead, where tenure types imply that farm operation is undertaken by wealthier farmers (via the hiring of labour) then redistributive types of land reform may be more relevant (Binswanger and Deininger, 1993). In other instances where rural infrastructure may already be deemed to be satisfactory, financial efforts to improve these may not be an immediate priority and could be sequenced out appropriately.

[4] For a detailed explanation of the conceptual framework analysis, including a description of the different phases composing the methodology see Jabareen (2009:53-54).

[5] Such reforms consist essentially in transforming farm operation in farm ownership. Typical examples of successful 'land to the tiller' types of reform are those that occurred after the end of the Second World War in Eastern Asia (Japan, Taiwan, South Korea).

This implies that the framework does not prescribe the 'don't do anything till you can do everything doctrine'.[6] Rather, it considers that land reform which combines actions related to the four pillars can enhance the likelihood of CSA adoption and generate exponential benefits for the livelihoods of rural populations, but that interventions on individual pillars can nonetheless be advisable. Moreover, different demands from land reform beneficiaries will emerge with respect to the individual pillars, based on a multitude of factors including the pre-reform tenure arrangements. The framework acknowledges that a partial land reform is better than no land reform and that the specific pre-land reform context is crucially important in determining the relevant set(s) of intervention(s) to be undertaken on each pillar.

It is also important to note that the four pillars upon which the framework is built are strongly interconnected with the overall land management activities present at the country level. These include the underlying broader institutional arrangements governing land policy, the land information infrastructure developed within a country and the land administration systems (Williamson *et al.*, 2010). Although not described in this paper, these play a crucial role in the efficacy of a land reform.

[6] This doctrine, which argues that only comprehensive interventions can be effective and that little, if any, benefit can be obtained without concurrent action on all facets, may put at risk the realisation of any land reform actions (Adams, 2000; Lipton, 2009).

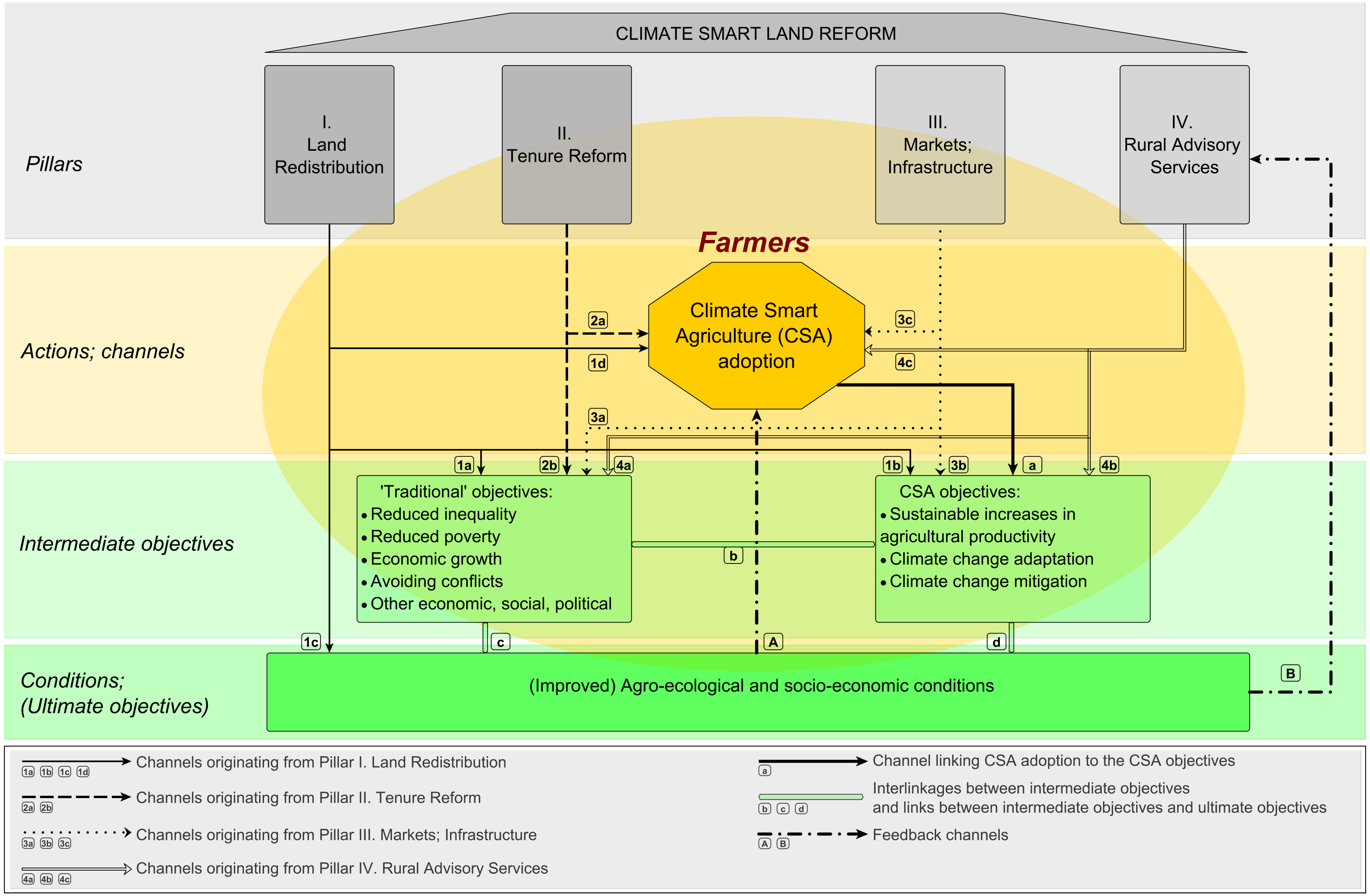

Figure 2.1. Climate Smart Land Reform framework

Source: Authors

2.3. Changes in the tenure structure: land redistribution and tenure reform

2.3.1. Pillar I. Land redistribution

The first of the four pillars shown in Figure 2.1 is land redistribution and involves the passage of an asset (the land) from individuals or groups of individuals (the "land losers") to other individuals (the "land gainers"). Traditionally, land redistribution programmes are undertaken by the State as main actor (so-called State-led redistributions), who either centrally or via devolved administration (e.g., regional, provincial, communal governments) sets, in a more or less participatory manner, the grounding rules for the redistribution (e.g., ceiling on the amount of land that an individual can possess; whether a compensation shall be paid to the land losers, by whom, when and in what amount; which geographic areas are to be prioritised, etc.). The State also sets the procedures for the implementation of the programme (e.g., the requirements and processes for individuals to be included among the land gainers; the processes for, and the timing of, the possession of the land from the land losers and the subsequent distribution to the land gainers) (Lipton, 2009). These State-led programmes characterised most of the land redistributions that occurred before the 1990s (e.g., Mexico, Cuba, Chile, Peru, Iraq, Iran, Egypt, China, Vietnam, etc.). More recently, alternative forms of land redistribution emerged, which altered the role of the State to that of market facilitator (so-called market-led or market assisted redistributions). This occurred, particularly since the 1990s, in countries such as Colombia, Brazil, South Africa and Malawi (Borras, 2003; Deininger, 1999; Pereira and Fajardo, 2015). There also exists a hybrid "joint state/market land redistributive policy" (Ciamarra, 2003:31), whereby the redistribution can occur both via willing-seller and willing-buyer market processes and via expropriation and redistribution from the State (e.g., in the Philippines). Land redistributions can also be characterised by their main triggering factor(s). Social revolutions have, for instance, played a role in creating the basis for land reform in numerous countries (e.g., Mexico, Cuba, Nicaragua, Algeria, Iran, South Africa), as have decolonisation processes (e.g., Kenya, Zimbabwe), external pressures (e.g., AfP in Latin America), and peoples' movements (e.g., *Movimento dos Trabalhadores Rurais Sem Terra* in Brazil). The CSLR framework outlines three broad effects that can result from land redistributions.

First, land redistribution is expected to contribute to the attainment of 'traditional' objectives of land reformers, which consist of a reduction in inequality and in poverty, increase in economic growth, avoidance of conflicts, as well as other economic, social and political goals (e.g., employment creation, political stability, enhancing peasant and peasant-like farmers' freedom). These complex relations are represented by the arrow "1a" linking the land redistribution pillar to the 'traditional' objectives box in Figure 2.1. By reallocating land from large landholders to small landowners or to the landless, land redistribution interventions generate a decrease in within-country inequality. This is often a 'traditional' objective of land reformers per se (Barraclough, 1999; Binswanger-Mkhize *et al.*, 2009; Lipton, 2009). Reduced inequality, in turn, can be a contributor to other 'traditional' objectives, including reducing poverty (via increased land assets to the rural poor) and increasing political stability and economic growth (Aghion *et al.*, 1999; Deininger and Squire, 1998; Van den Brink *et al.*, 2005). Furthermore, land redistribution is expected to generate positive effects on rural employment, both on-farm and off-farm. On-farm employment is created by increased labour demand of land redistribution beneficiaries whose small farms employ more labour per hectare compared to larger farms (Lipton, 2009; Van den Brink *et al.*, 2005). Off-farm employment is generated via the increase in demand for labour involved in input production and output processing, distribution and sale used by land redistribution beneficiaries, as well as by the increased demand for consumption goods and services at the community or local level. These positive pressures on rural employment would also translate into economic growth, political stability and reduction of poverty.[7] In terms of poverty reduction, one caveat should be mentioned. Although land redistribution can have beneficial effects on poverty overall, there may be circumstances where distress sales of land may occur (from very poor, vulnerable beneficiary farmers to wealthier farmers) thus partially cancelling out the beneficial effects. This risk can be mitigated by correcting land market distortions, by enacting and enforcing land ownership floors and ceilings legislation and by temporarily prohibiting the resale of land or taxing (moderately) the sale of reformed land to deter disadvantageous resales of land (Binswanger *et al.*, 1995; Lipton, 2009; Maxwell and Wiebe, 1998). Land redistribution is also considered to be a means to avoid conflicts (Binswanger-Mkhize *et al.*, 2009; Lipton, 2009; Dixon-Gough and Bloch, 2006), which is often a precondition for positive social, economic and political developments. Moreover, land redistribution has the potential to enhance "freedom of the person of the peasant, freedom of the land" (Tuma, 1965:182) and, more generally, to expand human freedom (in the spirit of Sen (Sen, 1999)). Indeed, these positive effects would lead to an improvement in the socio-economic conditions of farmers and rural populations.

[7] "Best-guess generalizations [of the multiplier effects stemming from agricultural to rural non-farm income] probably lie in the range of 1.6 to 1.8 in Asia and 1.3 to 1.5 in Africa and Latin America" (IFPRI, 2007:167). Moreover, "indirect income gains at the national level exceed those for rural regions by 50 to 150 percent, increasing indirect income gains [above those generated in the rural non-farm economy] by 30 to 90 cents for each initial dollar of agricultural income growth" (IFPRI, 2007:159).

Second, land redistribution interventions in lower-income country settings may enhance agricultural productivity, which appears in Figure 2.1 under the CSA objectives box, hence the arrow "1b" linking the land redistribution pillar at the top of the figure to the CSA objectives box.[8] In labour-abundant and capital-scarce contexts, where market imperfections are present, as is the case in most lower-income countries, a 'stylised fact' emerges: the presence of an Inverse Relationship (IR) between farm size and land productivity. Much as some authors have questioned the existence of such an IR (Dorward, 1999; Sender and Johnston, 2004), and indeed there may be, in particular circumstances, exceptions to the rule,[9] the IR has been found in lower-income country settings independently of the agrarian structure, institutional environments and agroecological conditions. From Latin American and Caribbean countries as diverse as Brazil, Colombia, the Dominican Republic or Barbados, to significantly different Sub-Saharan African countries, such as Madagascar, Kenya and South Africa, and in a number of Asian countries such as Bangladesh, the Philippines, Pakistan and India, the IR has been regularly found (Berry and Cline, 1979; Binswanger *et al.*, 1995; Cornia, 1985; Dorner, 1992; Eastwood *et al.*, 2010). In addition, where appropriate methods were used, the IR has been found to be robust to a number of objections raised by authors who suggested that it was induced by biases such as measurement error, sample selection or omitted variables (Carletto *et al.*, 2013; Carter, 1984).

However, it might be questionable whether this IR holds for very small plots of land that may not meet the subsistence needs of rural farmers. Such micro farms may be operated only on a part-time basis - because household members are required to obtain income from other sources - and may be managed less efficiently than more 'viable-sized' farms. Nevertheless, several studies have shown that even micro farms can be more productive than larger-scale farms.

A World Bank study conducted in Kenya, for instance, shows that farms below 0.5 hectares were almost twice as productive as farms in the following category (0.5-0.9 hectares) and over 19 times more productive than farms over eight hectares (World Bank, 1982). Similar findings have been reported for a range of countries, including Colombia, Pakistan, Malaysia (Berry and Cline, 1979), India (Chand *et al.*, 2011), Malawi and Tanzania (Julien

[8] A caveat here is that the agricultural productivity gains derived from land redistribution may not necessarily be sustainable. This factor provides an additional justification for the inclusion of the adoption of CSA practices within this framework as a means to attain the objective of sustainable increases in agricultural productivity.

[9] Cornia (1985) for instance, finds an IR for 12 of the 15 countries studied and indicates that the results from the three countries for which no statistically significant relationship was found (Peru, Bangladesh and Thailand) were "probably due to the limited number of observations [...] scanty information [... and] limited farm differentiation" (Cornia, 1985:524).

et al., 2019; Larson *et al.*, 2014), and Rwanda (Ali and Deininger, 2015). Mitchell and Hanstad (2004), by referring to evidence gathered from countries such as Bangladesh, India, Indonesia, Ghana, Nigeria and Russia, reveal that even very small homegardens can be highly productive and represent a valid strategy to improve "the livelihood of poor families" (Mitchell and Hanstad, 2004:25). Indeed, Lipton (2009) argues that the "very high land productivity of tiny home gardens […] is consistent with a micro-IR among such gardens, and between them and nearby larger farms" (Lipton, 2009:82). Homegardens can also generate other socio-economic and ecological benefits, including enhancing women empowerment, rural households' economic stability and social status, maintaining or increasing biodiversity, and improving the health and nutrition of household members (Galhena *et al.*, 2013; Kumar and Nair, 2006; Mitchell and Hanstad, 2004).

The effect of land redistribution on efficiency (agricultural productivity) can also result from positive effects on nutrition: "Under circumstances of extreme poverty and landlessness redistribution of land can also enhance efficiency by improving the nutritional wellbeing and thus the productive capacity of the population" (Binswanger *et al.*, 1995:2731).

Third, land redistribution interventions can enhance the likelihood of CSA adoption. This effect may occur through the combination of two automatic channels. The first channel relates to the link between the land redistribution pillar and the agroecological conditions box at the bottom of Figure 2.1 (arrow "1c"). In fact, the redistribution of land will define the agroecological conditions under which farmers will be operating their newly obtained land. Land reform beneficiary farmers will obtain land with different agroecological characteristics depending, for instance, on the specific location of the attributed land. In turn, these agroecological conditions will influence the farmer's land use, including whether or not the farmer will be prone to adopt particular types of CSA practices.[10] In this regard, empirical literature is consistent with the intuition that agroecological conditions affect adoption of agricultural practices with climate-smart potential, both quantitatively (i.e., the amount of practices adopted and the intensity of adoption) and qualitatively (i.e., the types of practices adopted) (Arslan *et al.*, 2014; Asfaw *et al.*, 2015a; 2015b; 2016; Di Falco and Veronesi, 2013; Kassie *et al.*, 2010; 2013; Teklewold *et al.*, 2013; 2019).

[10] The propensity of the farmer to adopt particular CSA practice(s) will of course also be dependent upon the farmer's information and knowledge of the CSA practice(s). Moreover, beyond the farmer's intention to adopt particular CSA practice(s), there may exist barriers that limit the possibility for the farmer's intention to translate into actual implementation (e.g. lack of tenure security, poor access to markets, infrastructure and rural advisory services). These aspects further substantiate this paper's thesis that land reforms which combine interventions on the various CSLR pillars can substantially enhance the likelihood of CSA adoption.

Along with the agroecological conditions at the farm level, there exists a second automatic channel linking land redistribution to CSA adoption which can be visualised in Figure 2.1 by arrow “1d” linking the land redistribution pillar to the CSA adoption octagon at the centre of the figure. This channel can be traced back to one of the root causes of the IR described above: the existence of lower labour transaction costs for smaller farms compared to larger ones. This creates an incentive for smaller farms to invest in labour intensive agricultural practices (Boyce *et al.*, 2005; Cornia, 1985; Lipton, 2009). In turn, labour intensive agricultural practices, such as soil and water conservation practices (e.g., building and maintaining contour ditches, live and/or dead barriers, terraces, zaï pits), vegetable growing (in place of, or in addition to, cereals) and more intensive use of by-products (e.g., zacate - for live barriers, for feeding livestock and for sale - green and animal manure) are all practices that have the potential to be considered as climate-smart since they can produce beneficial effects on the three CSA objectives (FAO, 2017). Therefore, redistributing land from farmers with large amounts of land, who experience relatively high labour transaction costs, to the landless or to farmers owning very small land parcels and thus with lower labour transaction costs, can generate positive effects in terms of CSA adoption. In studies that have analysed the determinants of practices with climate-smart potential, there is evidence that farm size affects adoption of such practices (Arslan *et al.*, 2017; Asfaw *et al.*, 2015b; Kassie *et al.*, 2013; Lawin and Tamini, 2018; Nyangena, 2007). This would imply that the IR between farm size and land productivity described above could also apply to farm size and CSA adoption.[11]

In summary, despite the large variation in the triggering factors and characteristics of land redistributions, theory and empirical evidence suggest that land redistributions can produce a wide range of beneficial effects on the livelihoods of rural populations. These include generating social, economic and political improvements (i.e., achieving the ‘traditional’ objectives of land reformers), as well as environmental improvements via farmers’ adoption of CSA, thus contributing to the attainment of CSA objectives (arrow “a” in

[11] It should be noted here, however, that the empirical evidence in this regard is not conclusive. There exist studies that have found a positive relationship between farm size and CSA adoption (Asfaw *et al.*, 2016; Kpadonou *et al.*, 2017; Makate *et al.*, 2019a). Inconclusive results on the relationship between farm size and agricultural technology adoption have also been highlighted in earlier studies (Feder *et al.*, 1985). However, in our view, this is likely to be due to the fact that most studies of adoption of practices with climate-smart potential focus on smallholder farmers only and to the large variation in the specific agricultural practices analysed. This is confirmed by studies that have analysed multiple practices with climate-smart potential and found positive effects of land size on adoption of certain practices and negative effects on adoption of other ones (Abdulai *et al.*, 2011; Arslan *et al.*, 2017; Hassan and Nhemachena, 2008; Pender and Gebremedhin, 2007). Interestingly, studies investigating the effect of CSA adoption on productivity have also confirmed the presence of the IR between farm size and land productivity (Arslan *et al.*, 2015; 2017; Asfaw *et al.*, 2015b; 2016).

Figure 2.1). Indeed, these categories of objectives are interconnected (hence the double-sided arrow "b" in the figure).[12] These effects uncover the first of the two iterative elements present in the CSLR framework.[13]

The combination of beneficial effects of land redistribution on both categories of 'intermediate' objectives. (i.e., 'traditional' and CSA objectives) would result in improved agroecological and socio-economic conditions of the farm and farm-household (arrows "c" and "d" in Figure 2.1, respectively). In turn, these new agroecological and socioeconomic conditions would influence the type of CSA practice(s) most appropriate to the farm and the propensity of farmers to adopt CSA practices/technologies. This is represented by arrow "A", feeding back from the agroecological and socioeconomic conditions box at the bottom of Figure 2.1 to the CSA adoption octagon at the centre of the figure. A farmer in a particular socioeconomic state, experiencing particular agroecological conditions, may be more or less prone to adopt specific CSA practices based on how these conditions are affecting (or have the potential to affect) the farm-household's food security and livelihoods. Thereafter, the adoption of CSA (and its consequent effect on the CSA objectives) would lead to a further improvement in the agroecological and socioeconomic conditions of the farm and of the farm-household giving rise to a potentially virtuous cycle.

2.3.2. Pillar II. Tenure reform

The second pillar presented in the CSLR framework is tenure reform. Prior to describing the channels linking tenure reform to CSA adoption and to the 'intermediate' and 'ultimate' objectives of land reformers summarised in Figure 2.1, an introduction to some of the fundamental concepts underlying tenure reform is provided in the following two paragraphs.

Land tenure corresponds to "the relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land and associated natural resources (water, trees, minerals, wildlife, etc.). Rules of tenure define how property rights in land are to be allocated within societies." (FAO, 2002:46). From this definition, two further clarifications should be made. First, given the prominence of property rights in this definition, it is important to understand and distinguish between different categories of property rights to land, which can be pooled under the 'bundle of rights' metaphor.[14] Rights of control (or of management) correspond to the possibility of deciding what activities shall

[12] Sustainable increases in agricultural productivity, for instance, would translate in agricultural output growth and in economic growth.
[13] The second is described at the end of Section 2.4 below
[14] See, for instance, Baron (2013); Johnson (2007) for information on the origin of the metaphor in property law.

or shall not be undertaken on the land as well as to decide who can or cannot access and use the land. Use rights (or rights of enjoyment) relate to the possibility to concretely undertake the given range of activities on the land. Transfer rights, in turn, determine the possibility to sell, lease, convey or mortgage the land, thereby offering the possibility to reassign use and/or control rights. The existence of these different categories implies that there may be, at any given moment in time, multiple actors with different rights to the same land.[15] The second clarification relates to the different types of land tenure that can be present within a given country. In general terms, it is possible to categorise these under four different types, namely nationalised tenure, freehold tenure, leasehold tenure, and customary tenure (Kasimbazi, 2017).[16] In nationalised (or State) land tenure systems, the State has the rights to the land and can decide to allocate (partial) transfer rights as well as control and use rights to communities or individuals. In freehold (or private) tenure, an individual or a group of individuals is provided with full transfer, control and use rights. In leasehold tenure, an individual or a group of individuals has been transferred, for predetermined periods, use and/or control rights to the land, and in rare circumstances also partial transfer rights (e.g., the rights to sub-lease the land). Finally, in customary tenure, indigenous communities have traditional rights to the land and can allocate, according to customary norms, land use rights to individuals or groups. It is worth noting that although customary tenure rights were once considered to be informal rights, there are now a number of countries across the globe (e.g., Armenia, Bolivia, China, Costa Rica, Dominica, Fiji, Guyana, Malaysia, Mozambique, Papua New Guinea, Peru, South Africa, South Sudan, Tanzania, Uganda, etc.) where customary rights are recognised by statutory legislation and can thus be considered in full effect as formal rights (Alden Wily, 2018).

Against this background, land tenure reform, i.e., the "changes to the rules of tenure" (FAO, 2002:47), can involve very complex and heterogenous processes, but can often be undertaken to enhance the land rights of populations and increase tenure security (Adams, 2000). Tenure security can be defined as "the certainty that a person's rights to land will be protected" (FAO, 2002:48). However, and consistent with the definition of tenure reform indicated above, the definition of tenure security can be extended to refer not only to individuals, but also to groups of individuals and not only to land per se but more generally to natural resources. It could therefore be read as 'the certainty that a person or a group's rights to land and associated natural resources will be protected'. The importance

[15] Indeed, there may be more detailed categories, entailing that a more disaggregated list of sticks compose the bundle of rights (see, for instance, FAO, 2002; Rights and Resources Initiative, 2012 for a subject-specific categorisation; Brasselle *et al.*, 2002 for a disaggregation of two types of rights, namely use rights and transfer rights; Holden *et al.*, 2013).

[16] It often occurs that several tenure types are present within the same country.

of communities for tenure security is recognised in FAO (2002). However, in that volume communities are listed as one of the "sources of [a person's tenure] security" (FAO, 2002:19). We argue that, beyond representing a source of tenure security for its members, communities/groups should also be a subject of tenure security recognised by other sources (such as local, regional, central governmental and legislative institutions). Amongst the prominent tenure reforms, tenancy reducing reforms (including land to the tiller reforms), tenancy rebalancing reforms and land formalisation reforms (including land registration and land titling) all have the potential to increase tenure security. In practice, however, this is not always the case. Whilst tenancy reducing reforms, for example, have had beneficial effects including increasing tenure security by transforming tenancy into ownership in countries such as Japan, Taiwan and South Korea, less positive results (and even increases in tenure insecurity resulting in several cases in forced evictions as a means by the landowner to prevent facing the effects of the reform) have been reported for tenancy reducing or rebalancing reforms in other parts of Asia (Holden *et al.*, 2013) and in Latin America (deJanvry *et al.*, 1997; Kay, 1998). Similarly, it is now recognised in the literature that land registration and land titling programmes do not automatically confer tenure security to participating farmers in all contexts (Deininger, 2003; Deininger and Feder, 2009; deJanvry *et al.*, 1997; Griffin *et al.*, 2002; Platteau, 1996).

Tenure reforms, when effective in enhancing tenure security, can engender a number of positive effects that are likely to stimulate CSA adoption and thus the attainment of the three CSA objectives, as well as the attainment of the 'traditional' objectives of land reformers (Figure 2.1). These effects can be grouped under six categories, namely the collateralisation effect, the assurance effect, the gains from trade effect, the outside investment effect, the community tenure effect and the political stability effect. Besley (1995) and Brasselle *et al.* (2002) describe the first three effects, particularly in the context of land registration and titling; McCarthy and Brubaker (2014) adds to these the outside investment effect and the community tenure effect, providing a detailed analysis of how these five tenure security effects can affect CSA adoption; Dixon-Gough and Bloch (2006) also points out the importance of the political stability effect.

The collateralisation effect implies that tenure security is one of the preconditions for money-constrained farmers to access credit and thus to undertake long-term land-related investments, including adoption of agricultural practices with climate-smart potential. Farmers with tenure security can use land as collateral when approaching a lending institution, provided that the information relating to this secure tenure is easily accessible to the lender. Hence, the relevance of this effect, particularly for land registration types of interventions and the importance within these of establishing a reliable land registry (and/or ensuring that a reliable land registry is in place), which would allow the lender to easily access the required information. By mitigating the moral hazard and adverse selection problems, and the associated transaction costs, land registration (and the presumed tenure security that would accompany it) can transform the land asset from a state of 'dead capital' to one of 'live capital' (Byamugisha, 1999; deSoto, 2000). However, empirical evidence on this effect indicates that the hypothesised automatic link between tenure reform and credit provision does not always occur (Higgins *et al.*, 2018; Lawry *et al.*, 2017). This is due to several possible factors. First, a key aspect related to this effect is that it mostly applies to land formalisation interventions, which can be rendered ineffective under a number of circumstances (for a description of these see, for instance, Deininger and Feder (2009); Meinzen-Dick and Mwangi (2009)). Second, the availability of land as collateral can be insufficient for lending institutions to provide the loan. This is due to aspects such as the presence of covariance risk in rural settings (and possibly also of collateral-specific risk), the costs of collateral registration and of foreclosure, measured against the often relatively small loans demanded by farmers (Binswanger and Rosenzweig, 1986; Deininger and Feder, 2009; Platteau, 1996), but also to the fact that a collateral is only one of the numerous requirements sought by formal lending institutions when considering the issuance of a loan (Domeher *et al.*, 2018). Moreover, there may also be a risk-rationing effect occurring on the demand side, which may limit the amount of credit demanded by risk-averse farmers (Deininger and Feder, 2009).

The assurance effect is more psychological in nature compared to the collateralisation effect. It implies that farmers with a (perceived) secure tenure will have an incentive to undertake long-term land-related investments, including the adoption of practices with climate-smart potential, since they are sufficiently confident that they (and their descendants) will reap the benefits associated with these investments. In other words, if farmers are assured that the rights to their land are protected, they will maintain it in such a way that the farm-households can benefit from it in the long term – they will be better stewards of the land (Dekker, 2005; Thiesenhusen, 1991). Moreover, the assurance effect is also considered to reduce the incentives of farmers to invest resources (including labour and materials) in socially inefficient practices aimed at protecting their land from possible takeovers (e.g., building fences, guarding the land) (Besley and Ghatak, 2010) and/or at resolving conflicts over land (Deininger and Castagnini, 2006).

The gains from trade effect extends the assurance effect by considering that, with enhanced transfer rights, the farm-household can benefit from land-related investments, including investments in adoption of practices with climate-smart potential, not only via farming activity but also via land market activity (i.e., via the sale or rental of the land). In other words, by undertaking land-related investments that improve the quality of the land, the value of the asset will increase, resulting in higher land price if rented out or sold (Besley, 1995; Brasselle *et al.*, 2002).[17]

The outside investment effect (McCarthy and Brubaker, 2014) relates to the positive externalities that particular land uses - including the adoption of CSA practices - can generate and for which a farmer can be compensated (e.g., via the payment for environmental services). In this regard, tenure security can be considered crucially important for both the payor (who might find it inefficient to agree payments if the rights to the land are not clearly defined) and the payee (who might not be willing to undertake land-related investments without the security that she will be the recipient of the compensation).

The community tenure effect (McCarthy and Brubaker, 2014) relates specifically to areas where traditional (customary) rights to the land are present. In these areas, tenure security can be considered crucially important for the realisation of the 'community version' of the assurance as well as the outside investment effects (and of the collateralisation and gains from trade effects in the cases where customary land can be mortgaged and leased), which may thus create an important foundation for the adoption of CSA at the community level. In other words, and as specified in our extension of the FAO definition of tenure security, individuals require security of tenure but so do groups/communities. In this optic, the rights to the land of communities can be granted and protected. This is consistent with provisions from section nine "Indigenous peoples and other communities with customary tenure systems" of the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (VGGT) endorsed by the Committee on World Food Security (FAO, 2012:14-16). It should be noted that such rights can apply not only to cultivated land but also to forest lands, where sustainable forest management is often jeopardised by the lack of tenure security – as has been witnessed in several lower-income countries (Colchester and Lohmann, 1993; FAO, 2006b; Quan and Dyer, 2008). Tenure security within a community can also play an important role in substantially reducing the likelihood of 'land grabbing' by external actors, which have often been found to undermine sustainable land use through deforestation actions and implementation of large-scale cash cropping. There is a consensus in the literature on large-scale land acquisitions upon the positive effect that tenure insecurity exerts on large-scale land investments (De Maria, 2019).

[17] Brasselle *et al.* (2002:374) renames this effect the "realizability effect".

Finally, the political stability effect indicates that tenure security, by "providing small farmers with a more significant stake in society" (Dixon-Gough and Bloch, 2006:163) and reducing their fears of dispossession, would reduce potential conflicts between stakeholders and favour political stability (Colchester and Lohmann, 1993; Platteau, 1996).

A noteworthy aspect relating to tenure reform is the importance it can have in promoting gender equality. Numerous national and global initiatives have been launched in this respect, based on the notion, widely substantiated in the literature (Deere, 2017; Jacobs, 2013; Meinzen-Dick *et al.*, 2019; Quan, 2006) that including gender equality in the provisions for secure land rights (under any of the four land tenure types mentioned above) can lead to substantial improvements in the livelihoods of rural populations, including via CSA adoption (World Bank *et al.*, 2015). National initiatives include, for instance, the explicit reference to means of advancing women's rights to land in national legislation, policies and programmes (for individual country profiles see, for instance, the FAO gender and land rights database (FAO, n.d.)). International initiatives include the consideration of gender equality as a guiding principle of the VGGT (FAO, 2012), the inclusion of two specific land and gender equality related indicators within the Sustainable Development Goals' Agenda 2030 – indicators 1.4.2 and 5.A.1 (United Nations, 2019), the establishment of a legal assessment tool for gender-equitable land tenure (FAO, 2016) and several advocacy initiatives (Global Land Tool Network and UN Habitat, 2008; 2019; The Global Initiative for Economic Social and Cultural Rights, 2014).

As indicated in the description of the above-mentioned effects, tenure reform can, via enhanced tenure security, also stimulate the adoption of agricultural practices with climate-smart potential. This is further confirmed by a large number of empirical studies (Abdulai *et al.*, 2011; Akrofi-Atitianti *et al.*, 2018; Asfaw *et al.*, 2015a; 2015b; 2016; Di Falco and Veronesi, 2013; Kassie *et al.*, 2013; Kpadonou *et al.*, 2017; Lawin and Tamini, 2018; Manda *et al.*, 2016; Nyangena, 2007; Teklewold *et al.*, 2013; 2019).

Tenure reforms, by enhancing tenure security, would therefore generate a wide range of beneficial effects, including enhancing the likelihood of CSA adoption and contributing to the attainment of various economic, social and political objectives. The tenure reform pillar is therefore linked to the CSA adoption octagon at the centre of Figure 2.1 (arrow "2a") and to the 'traditional' objectives box (arrow "2b"). In turn, CSA adoption is expected to have positive effects on the CSA objectives (arrow "a"). Therefore, tenure reform can contribute to the achievement of both sets of 'intermediate' objectives (i.e., CSA and 'traditional' objectives) and consequently lead to improvements in the agroecological and socioeconomic conditions of the farms and farm-households (arrows "c" and "d").

To conclude, it must be emphasised that inclusive processes warranting careful attention to, and consideration of, the contextual environment - including not only the state of institutions and governance, but also the existing cultural and social relations and the existing community-level initiatives and demands - are essential in the design of particular tenure reforms. Neglecting such inclusive processes can lead to the realisation of ineffective tenure reforms, as has been the case in a number of countries, notably in Sub-Saharan Africa (Brasselle *et al.*, 2002; Fenske, 2011; Platteau, 1996).

2.4. Support services: Markets, Infrastructure, Rural Advisory Services

Land reforms can include interventions consisting of enhancing land reform beneficiaries' access to a range of support services. These services are generally directed at facilitating farmers' access to markets (e.g., financial markets, input/output markets, land markets) and to social and economic infrastructure (e.g., rural roads, water supply systems, telecommunication, health and education facilities) - hereafter Markets and Infrastructure (MaI) - as well as at enhancing farmers' access to information, knowledge and technologies (i.e., Rural Advisory Services – RAS).[18] These support services represent the third and fourth pillars included in the CSLR framework (Figure 2.1).

Access to these services is also important for smallholder farmers that are not land reform beneficiaries (Poulton *et al.*, 2010). However, in the presence of agrarian systems with very unequal distribution of land, the demand for infrastructure development, extensive scientific research and the associated advisory services can be deficient (Lipton, 2009). In other words, interventions that redress land inequality, such as land redistribution and/or tenure reform, can generate a stimulus for the demand, and consequent development, of MaI and RAS. As further described below, inadequate (or absent) access to MaI and to RAS on behalf of land reform beneficiaries can limit the efficacy of the land redistribution and/or tenure reform intervention.

Initiatives to foster land reform beneficiaries' access to MaI and to RAS can be viewed as complementary to the first two pillars of the framework. MaI and RAS are also strongly interconnected and thus benefit from combined action. To guarantee, for instance, the success of interventions undertaken to enable land reform beneficiaries' access to financial market services such as index-based insurance, a matching intervention enhancing land reform beneficiaries' information and knowledge upon the functioning of such services and

[18] A comprehensive definition of RAS is provided by Christoplos (2010:3): "systems that should facilitate the access of farmers, their organizations and other market actors to knowledge, information and technologies; facilitate their interaction with partners in research, education, agri-business, and other relevant institutions; and assist them to develop their own technical, organizational and management skills and practices."

upon how to concretely access such services should also be introduced (IFAD and WFP, 2010).

In the case of pre-reform unimodal agrarian structures, such as those present in several East Asian countries, favourable MaI conditions and the gradual acquisition of relevant skills, managerial experience and knowledge for tenant farmers in the pre-reform era represented important factors for the economic, social and political success of land reforms in these countries (Binswanger and Deininger, 1993; Putzel, 2000). Similarly, MaI and RAS played an important role in enhancing agricultural productivity and output growth in several countries where successful de-collectivisation types of reforms were implemented (e.g., China, Vietnam, a few former USSR countries (Lipton, 2009)). Instead, in the presence of bi-modal systems, such as in Latin America, Southern Africa and a minority of Asian countries (Barraclough, 1999), the need to break-up large landholdings into smaller parcels and to settle farmers (who often had little managerial and technological and market access knowledge) onto these required extensive pre- and post-settlement support interventions, the shortage of which is often seen as one of the reasons for the limited economic, social and political successes of these land reforms (Deininger, 1999; Dorner, 1992). A number of other context-specific factors have also contributed to these limited successes. In several Latin American countries, for instance, in the decades that followed the 1961 US-backed Alliance for Progress, the political power of large landowners influenced land reform processes in such a way that these elites resulted as the main beneficiaries of the reforms. In countries such as Ecuador and Colombia, generous subsidies, tax advantages, price support programmes, technological and infrastructural support were skewed towards large-scale farmers, creating an inefficient transition to modern, capitalist, agriculture (deJanvry, 1981; deJanvry and Sadoulet, 1989; Kay, 1998). In Chile, the landed elites strongly supported the 1973 Coup which led to the reversal of a large part of the redistribution efforts undertaken under the Frei and Allende governments.[19] Other relevant factors included "settlements located in remote areas, poor land not well suited to farming poor management and bureaucratic top-down controls, and so forth. These shortcomings are not inherent to land reform as a public policy. Rather, they reflect a lack of commitment and effective political will and, at times, of course, an insufficiency of resources for adequate

[19] The historical vote that took place in October 2020 in Chile, where an overwhelming majority (78 percent) of voters expressed their will to have the 1980 (Pinochet-Era) constitution re-written, is an indication that the conservative interests perpetuating inequality in the country are likely to be overhauled by a new democratic movement ignited by the quest for social rights and equality. Beyond pressing rights such as housing, healthcare, and education, alternative rights to water, to land and enhanced environmental rights compared to those present in the 1980 constitution (and subsequent revisions) may well feature among the key themes that the Chileans elected to form the constitutional convention will be tasked to include in the new constitution.

implementation" (Dorner, 1992:57). In recent years, however, there has been a tendency for several Latin American governments to try and revive land reform efforts, including via market-led land redistribution efforts.

Both MaI and RAS are thus important for the attainment of the 'traditional' objectives of land reformers, and of individual CSA objectives, such as (sustainable) increases in agricultural productivity.[20] These channels are depicted in Figure 2.1 by the arrows labelled "3a" and "3b" linking the MaI pillar to the 'intermediate' objectives and by arrows "4a" and "4b" linking the RAS pillar to the 'intermediate' objectives.

2.4.1. Pillar III. Markets and Infrastructure

Beyond contributing to increases in agricultural productivity and to the realisation of 'traditional' objectives of land reformers, MaI development can enhance farmers' opportunities to adopt CSA practices and technologies. Therefore, the MaI pillar is also linked to the CSA adoption octagon in Figure 2.1 (arrow "3c"). Access to financial markets, including credit and insurance, can generate an important push for farmers to undertake investments in agricultural practices with climate-smart potential, particularly for those farmers who are money-constrained and risk-averse (Abdulai and Huffman, 2014; Hassan and Nhemachena, 2008; Le Dang *et al.*, 2019; Mwungu *et al.*, 2018; Teklewold *et al.*, 2013). Facilitating farmers' access to input and output markets can also stimulate adoption of practices with climate-smart potential (Amare *et al.*, 2012; FAO, 2018b; Murage *et al.*, 2015; Nyangena, 2007; Teklewold *et al.*, 2019). Easier access to input markets results in a reduction in the transaction costs linked to the acquisition of information upon CSA practices. Input providers represent an important source of information for farmers throughout the globe, and increasingly so for small-scale farmers in lower-income country settings. These often lack the myriad of information sources that large-scale farmers in higher-income countries are exposed to and therefore can benefit significantly from information provided by input suppliers (Clark, 2012; World Bank, 2007). Indeed, easier access to input markets also reduces the transaction costs associated to the acquisition of the necessary inputs required for the implementation of CSA practices (e.g., seeds, equipment). Similarly, enhancing farmers' access to output markets can reduce transaction costs related to the sale of produce (reducing therefore the so-called "marketability constraint" (Arslan *et al.*, 2014:83)) and enhance the likelihood of adoption of practices with climate-smart potential, particularly those practices that result in more diverse

[20] The same caveat reported in Section 2.3.1 above applies here: the agricultural productivity gains derived from MaI and RAS interventions that are not determined by CSA adoption may or may not be sustainable.

production, including the use of mixed cropping systems, crop rotation, intercropping and agroforestry.

Measures to facilitate access to these markets can include redressing inequalities in the provision of subsidies, price support programmes and technological and infrastructural support away from large-scale farmers to create a business environment in which small-scale land reform beneficiaries can flourish (Binswanger *et al.*, 1995; Lipton, 1993; Van den Brink *et al.*, 2005). Infrastructure development represents both a means to enhance market access and to foster CSA adoption. Investments in infrastructure can include, for example, construction/rehabilitation of roads, bridges, marketplaces, storage and processing facilities, power plants and electricity networks, water supply systems for irrigation, as well as information and communication technology infrastructure. These are measures that can be taken to facilitate farmers' market access (Teklewold *et al.*, 2013; World Bank, 1994). They also represent interventions that can spur adoption of practices with climate-smart potential, such as sustainable irrigation methods, hermetic storage, crop diversification and changes in crop calendars, among others (Ali and Erenstein, 2017; Bryan *et al.*, 2013; Hassan and Nhemachena, 2008; IPCC, 2019).

In summary, MaI can play a critical role in enhancing the likelihood of CSA adoption, and in contributing to the realisation of the 'intermediate' objectives outlined in the CSLR framework. Land reformers should therefore carefully assess the state of MaI in the context of the land reform and consider the viability of various MaI intervention options and strategies, as well as the risks associated with a lack of intervention on MaI for the overall effectiveness of the land reform.

2.4.2. Pillar IV. Rural Advisory Services

Over the past decades there has been an evolution in the terminology used to describe advisory services provided to farmers, and in the institutional arrangements and methods used for the financing and delivery of these services (Birner *et al.*, 2009). A brief overview of the dynamics witnessed in the field of advisory services is therefore provided prior to discussing the channels linking these to CSA adoption. The terminology has evolved from the commonly used agricultural extension concept to agricultural advisory services and, most recently, Rural Advisory Services (RAS). This reflects a shift in the type of advisory support provided to farmers, in the way that support is conceived and provided to farmers and in the type of stakeholders involved in the process. During the 1950-60s, agricultural extension was conceived as a linear top-down, often one-size-fits-all, transfer of technology (ToT) from a technically knowledgeable agent (commonly an employee of a public institution) to the farmer with the objective of increasing production levels. Subsequently, the understanding that this type of model gave rise to several weaknesses, including the lack of crucial feedback linkages between the farmers and the providers of the extension support, led to the development of new approaches such as the Training and Visit (T&V) system (Anderson, 2007). However, this system, which was strongly advocated by the World Bank and implemented between 1974 and 1998 in a significant number of countries, proved financially unsustainable and its impact difficult to demonstrate. This led to the collapse of T&V at the end of the 20th century in most countries (Anderson *et al.*, 2006). The model that emerged in the early 2000s was the Agricultural Knowledge and Information System for Rural Development (AKIS/RD). This model, conceptualized and promoted by the World Bank and FAO, explicitly considered the importance of feedback loops amongst the three crucial actors of the 'knowledge triangle', namely agricultural educators, researchers and extensionists, as well as with farmers, which were placed at the "heart of the knowledge triangle" (FAO and World Bank, 2000:2). This framework was thus innovative in that it radically changed the dynamics of the relationships between actors, setting at the centre of the stage the farmers, thus rendering the system more demand-driven, and making "agricultural research, extension and education appear as equal partners" (Rivera *et al.*, 2006:585). Moreover, it explicitly considered the possibility of having public and private actors as well as civil society "participate meaningfully in decisions about the design, implementation, funding and evaluation of education, research and extension programmes" (FAO and World Bank, 2000:14). AKIS/RD also recognized, and placed an emphasis on, providing different solutions to different farm households based on their different agroecological and socioeconomic conditions, as well as on the need to address challenges beyond those related to a deficit in agricultural production. From the perspective of the advisory services provided to farmers, this implied considering aspects such as environmental sustainability, health and nutrition, post-harvest handling, marketing and integration in value chains, access to inputs and financial services and even off-farm activities. The framework began contemplating a more holistic approach to advisory services in support of rural populations and their livelihoods. It is in a similar vein that the Agricultural Innovation Systems (AIS) came to light and that international initiatives such as the Global Forum for Rural Advisory Services (GFRAS) were established. The AIS emerged in recognition of the rapid development of Information and Communication Technologies (ICTs) and placed a renewed focus on innovation. In the literature, AIS is often depicted as an expansion of AKIS/RD: in AIS the knowledge triangle framework is augmented by explicitly including other stakeholders (such as consumers, agroprocessors, exporters, producer organizations, input suppliers) due to their capacity to create and spread innovations and knowledge relevant to farmers and rural populations (World Bank, 2012). More recently, a framework was conceptualised by researchers at the International Food

Policy Research Institute (IFPRI) expanding the AIS model to include contextual factors as key inputs for the design of performant agricultural advisory services. The double-sided interaction between farm households and advisory services is maintained in this framework and is recognized as essential for attaining impact (Birner *et al.*, 2009).[21]

Land reforms are expected to play a determinant role in the design and preparation of RAS, notably those destined to land reform beneficiaries. Of course, RAS are commonly present also in contexts where land reforms are not being planned or implemented. Nevertheless, land reforms can play a determining role in tailoring RAS to beneficiary farmers' conditions and demands. This is showcased in Figure 2.1, where the agroecological and socioeconomic conditions box at the bottom of the figure feeds back to the RAS pillar (arrow "B"). In effect, the specific agroecological conditions pertaining to the beneficiary farmer's land and the socioeconomic conditions of the farmer are key elements that are to be considered when designing relevant RAS (Anderson and Feder, 2003; Clarkson *et al.*, 2019). The type of RAS demanded by land reform beneficiary farmers will also be influenced by the pre-reform tenure arrangements existing in the specific context where the land reform is being implemented. In the case of redistributive types of reforms, the quantity and nature of the RAS to be provided will be substantially larger and more complex compared to, for instance, contexts where land reform beneficiaries were already farm operators in the pre-reform era (Binswanger-Mkhize *et al.*, 2009). This is due to the fact that under redistributive types of reform a more radical paradigm shift in the provision of RAS will be required. A transition will need to be planned and implemented from a context where RAS are provided to a given set of farmers (most likely experienced, presumably large, commercially oriented) to a state in which RAS need to be provided to a significantly larger number of farmers with presumably different characteristics (e.g., less experienced or with no experience, particularly farm management experience, with smaller landholdings, primarily oriented at subsistence agriculture). The quantity and nature of RAS demanded by farmers will be, at least in part, determined by the agroecological and socioeconomic conditions of the farm and farm-household and by the quantity and nature of previous farming experience, including experience in agricultural production and farm management (Gido *et al.*, 2015; Swanson, 2008).

This design phase of the RAS system needs to be participatory and inclusive, with the involvement of the various relevant public institutions and of the farmers as key

[21] It should be noted, in passing, that although this overview of the evolution of advisory services describes a close to linear process, whereby models such as the ToT or T&V appear as obsolete and no longer present, in practice advisory service providers continue to perpetuate traditional methods in several rural areas of lower-income countries (see, for instance, Alex *et al.*, 2002; World Bank and IFPRI, 2010).

stakeholders, who appear in Figure 2.1 in the form of an ellipse at the centre of the figure, but also of a multitude of other actors that can contribute according to their comparative advantages to the design and subsequent provision of RAS (Anderson, 2007; Birner *et al.*, 2009; Swanson and Samy, 2004). These various stakeholders, originating from the (national and international) public and private sector, include financial institutions and financial service providers, agricultural research institutions, education and training organisations, agricultural extension service providers, climate and weather information institutions, information and telecommunication companies, input suppliers and farmer organisations, among others, who interact and act in support of farmers' livelihoods enhancement.

In turn, the appropriate design and provision of RAS by multiple stakeholders is expected to stimulate farmers' adoption of practices with climate-smart potential. This channel is portrayed in Figure 2.1 by the arrow "4c" linking the RAS pillar to the CSA adoption octagon. There is longstanding evidence in the literature that extension services can foster technology adoption in agricultural production, mostly by increasing farmers' exposure to, and information on, these technologies (Feder *et al.*, 1985). More recent research has shown that RAS, including but not limited to extension services targeting agricultural production, can represent a key foundation for smallholders' adoption of agricultural practices and technologies with climate-smart potential (IPCC, 2019; FAO, 2018a; 2018b; 2018c). The expansion of advisory services' objectives beyond increasing agricultural production mentioned above has led to the elaboration of guidelines and manuals promoting the adoption of CSA practices and technologies via advisory services (see, for instance, FAO, 2018a; 2018b; 2018c; FAO and Ministry of Agriculture Livestock and Fisheries, 2018; Ngara, 2017; Sala *et al.*, 2016; Sulaiman, 2017). Recent empirical evidence confirms the importance that RAS can have on increasing farmers' awareness of, and information on, practices and technologies with climate-smart potential, thereby positively contributing to adoption of such practices (Ali and Erenstein, 2017; Arslan *et al.*, 2014; 2017; Asfaw *et al.*, 2012; Khonje *et al.*, 2015; Makate *et al.*, 2019b). Indeed, in order for RAS to be impactful, it is not only important that the quantity of advisory services be sufficient, but it is also essential that the RAS provided be of considerable quality (Beyene *et al.*, 2017; Teklewold *et al.*, 2013). In addition, more specific RAS, directed for instance at enhancing smallholder farmers' knowledge upon options and strategies to access input/output and/or financial markets, can prove important to complement MaI interventions and increase the likelihood of CSA adoption (Hassan and Nhemachena, 2008; Makate *et al.*, 2019b). Similarly, providing farmers with timely and localised weather-related advisory services can enable farmers to reduce short-term risks (e.g., lack or excess rainfall at key crop growth stages leading to crop losses) by undertaking specific actions (e.g., changing seeding/fertiliser application dates, setting up irrigation systems). In an era of global warming, these weather-related advisory services should be coupled not only with early warning systems, which can play crucial roles in reducing crop losses (and loss of life), but also with interventions that provide farmers with accurate and timely information and explanations on climate developments. Such climate-related RAS, which would ideally be localised and participatory, integrating local farmer perceptions and knowledge with scientific data, could better prepare farmers to consider and select the more appropriate medium to long term risk-reducing and livelihood-enhancing strategies, including adoption of practices/technologies with climate-smart potential (Arslan *et al.*, 2017; Clarkson *et al.*, 2019; Di Falco and Veronesi, 2013; Dorward *et al.*, 2015; Mulwa *et al.*, 2017).

These relations help uncover the second iterative process of the CSLR framework, which is described in the conclusion of this section. We have seen that RAS have the potential to contribute not only to the attainment of 'traditional' objectives of land reformers, but also to enhance CSA adoption, thereby generating beneficial effects on the three CSA objectives. Now, the (partial) achievement of both sets of 'intermediate' objectives (i.e., CSA and 'traditional' objectives) generates improved agroecological and socioeconomic conditions of the farm and farm-household. In turn, this new state of agroecological and socioeconomic conditions is expected to create a revised demand for RAS on behalf of farmers, which could lead to renewed adoption of CSA, to further positive effects on the 'intermediate' objectives of land reformers and thus to further improved agroecological and socioeconomic conditions.

2.5. Conclusions

In an era of global warming, the numerous challenges faced in rural areas of lower-income countries are being exacerbated by the effects of climate change. Effective policies at the national and local level are required to tackle these challenges whilst ensuring the best possible use of the (limited) resources available. In this sense, policy initiatives can be sought to enhance farm-households' adoption of agricultural practices and technologies that preserve ecosystem services without depressing agricultural production and avoiding environmental resource overexploitation. The CSLR framework introduced in this paper presents an innovative way to conceptualise how land reform programmes can generate beneficial effects not only on the attainment of the more 'traditional' objectives of land reformers (be they social, economic, political) but also of objectives related to environmental sustainability.

The paper describes relevant channels through which 'traditional' objectives of land reformers, as well as the three CSA objectives (sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation) can be attained. The importance of both redistributive and tenure types of reforms, as well as the enhancement of opportunities for land reform beneficiaries to access a wide range of support services are advanced in the paper as the key drivers for the attainment of these 'intermediate' objectives. In turn, the (partial) achievement of 'intermediate' objectives is described as generating positive effects on the 'ultimate' objective of land reformers within the CSLR framework: improved agroecological and socioeconomic conditions of rural areas and populations. Furthermore, two iterative processes are highlighted in the paper, indicating the possibility of a gradual process towards the realisation of this 'ultimate' objective.

The theory and evidence discussed in the paper indicate that interventions related to individual pillars of the CSLR framework can generate positive effects on the attainment of the 'intermediate' objectives of land reformers and may therefore be advisable. However, in order to further enhance the likelihood of widespread CSA adoption, policymakers should carefully assess and consider whether opportunities exist to intervene on the four policy levers (i.e., on the four pillars of the CSLR framework).

In terms of its potential use, the CSLR framework is intended for both applied research and policy. On the former, the framework can be utilised as a basis for the realisation of empirical studies on the specific channels depicted within it in different land reform contexts. This would provide further context-specific validation or refutation of the propositions included in this paper, thereby generating a more solid evidence base that policymakers can rely upon. Moreover, researchers can adapt the framework to study a variety of policy interventions, beyond land reforms, that are aimed at supporting specific groups within a country's population, such as refugees, ethnic minorities or other vulnerable groups, in implementing agricultural practices with climate-smart potential and in attaining economic, social, political and environmental objectives.

On the policy front, the framework can serve as a conceptual guide in the (re)design phase of a land reform programme. It can be used to assist policymakers in decision-making processes related to the CSLR policy levers, both in terms of mode and extent of action. Moreover, the CSLR framework can be used as a basis for the preparation of monitoring tools that can be employed during the implementation phase of the land reform programme in order to track progress (and uncover difficulties) related to the achievement of the 'intermediate' and 'ultimate' objectives outlined in the framework. Finally, elements of the

CSLR framework can be used to support efforts undertaken by governments to raise the financial resources necessary to complement budgetary resources allocated to the implementation of land reform programmes. In effect, by explicitly integrating environmental objectives linked to climate change within the land reform programme, additional financing windows can be explored, including multilateral climate funds (e.g., Green Climate Fund, Green Environment Facility Funds, Adaptation Fund), climate funds linked to international development banks (e.g., World Bank, African Development Bank, Asian Development Bank, InterAmerican Development Bank) and funds sourced through the National Determined Contribution (NDC) partnership (FAO, 2019).

Indeed, both of these intended uses of the framework are ultimately directed at farm-households. Farmers are at the centre of the CSLR framework and adequate platforms and systems must exist (or be created) to ensure that farmers can actively participate in local and national land reform processes.

In terms of its limitations, the CSLR framework, by being purposefully generic, does not include a specific diagnostic approach applicable to the exact circumstances of a given individual country context. In other words, the framework offers a departure point from which further context-specific analyses can be undertaken. Moreover, for reasons of space and focus, this study does not include a detailed analysis of the various additional socio-economic policy interventions, beyond land reforms, that may contribute to farm-households' adoption of CSA (be it in the agricultural, health, education sector). These may indeed represent relevant complements or substitutes to land reform interventions depending on the specific conditions faced by populations within the different country contexts.

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Chapter 3. Examining land reform through satellite lenses – a study of the effects of the Ethiopian tenure reform on the Climate Smart Agriculture objectives[1]

Abstract

In lower-income countries where agriculture represents the main source of domestic income and employment, climate change exerts renewed pressure on policymakers to identify low-cost interventions that can improve agroecological and socioeconomic conditions of rural areas and populations. Achieving Climate Smart Agriculture (CSA)'s triple objective of sustainably increasing agricultural productivity, building resilience to the adverse effects of climate change and mitigating climate change can contribute to the realisation of synergistic effects benefitting rural areas and populations. The aim of this study is to examine the low-cost land registration and certification programme undertaken at the end of the 1990s in the Tigray region of Ethiopia and explore whether the programme generated positive effects on the three CSA objectives. Earth Observation data are used to construct an original balanced panel dataset, and a difference-in-differences approach is employed to compare pixels in the Tigray region (the 'treated' area) with pixels in the neighbouring Amhara region (the 'control' area) before and after the implementation of the programme and uncover its causal effects. Results show positive and persistent effects of the programme on the Normalised Difference Vegetation Index (NDVI), a satellite-based indicator of greenness highly correlated with measures of agricultural productivity and climate change mitigation. By examining years where adverse climate and weather events occurred, we also find suggestive evidence that the programme generated positive effects on climate change adaptation. In combination, these results suggest that the reform led to progress on the three CSA objectives over the landscapes of Tigray. The results are consistent with the reform enhancing farmers' tenure security and inducing an increase in CSA adoption. The findings from this study imply that land tenure reforms - which can be undertaken swiftly at a large scale and at a low cost - can help generate an enabling environment for CSA and support the attainment of rural development objectives, including objectives associated with climate change.

[1] An adapted version of this chapter, with Dr Stefania Lovo as a co-author, has been submitted to an academic journal for publication and is currently under review.

3.1. Introduction

Ethiopia embarked on a land tenure reform in the late 1990s that was initially rolled out in the northernmost region of the country, Tigray. The reform led to a process of land registration and certification expected to increase farm-households' tenure security and thus to enhance their incentives in undertaking long-term land related investments (Deininger and Jin, 2006; Deininger *et al.*, 2008). Such investments appear critical in the context of Ethiopia. In 1998, the year when the Land Registration and Certification Programme (LRCP) was undertaken in Tigray, the agricultural sector contributed to almost 50% of the country's GDP and to close to 80% of its employment (World Bank, 2021). The sector relied almost exclusively on the production from its 9.6 million small-scale farmers, who farmed 95% of all agricultural land area on an average farm size of just under one hectare (FDRE, 2000; Gebre-Selassie and Bekele, 2012). These were operating in areas with significant sloped and often degraded land and were largely dependent on rainfall; the land area under irrigation represented 0.7% of total cultivated area (FDRE, 2000; Diriba, 2020; World Bank, 2006). Such conditions highlighted the vulnerability of farm-households to adverse climate and weather events, in particular droughts and floods; events that risk being exacerbated by the effects of anthropogenic global warming, with potential repercussions on the agricultural sector and the country's economy (Aragie, 2013; Cline, 2007; Deressa and Hassan, 2009; FDRE, 2015; Mideksa, 2010; World Bank, 2008; 2010; You and Ringler, 2010). In such a context, actions that produce positive synergistic effects in terms of climate change adaptation and mitigation, without hampering productivity, would be particularly beneficial to rural landscapes and populations.

Climate Smart Agriculture (CSA) is a sustainable agriculture approach which englobes these three objectives – sustainable increases in agricultural productivity, climate change adaptation, climate change mitigation (FAO, 2017). Albeit the CSA approach emerged only in 2009 (FAO, 2009), that is a decade after the implementation of the LRCP in Tigray, it is an approach that features both modern and traditional agricultural practices and technologies. Indeed, practices that have traditionally been adopted by farm-households in Ethiopia, such as agroforestry, manure management, traditional conservation agriculture, micro-scale irrigation are all practices that have the potential to be considered "climate-smart" (FAO, 2016).

In this study, we re-examine the swift low-cost LRCP undertaken in Tigray at the end of the 1990s through a Climate Smart Agriculture (CSA) lens. We argue that while CSA objectives were not embedded in the LRCP, the programme, by strengthening tenure security, increased land related investments, which enhanced productivity as well as climate change adaptation and mitigation over the landscapes of Tigray, thus contributing to progress towards the CSA objectives.

To perform our analysis, we employ Earth Observation (EO) data and construct a panel dataset containing a rich set of indicators sourced from the Google Earth Engine platform (Gorelick *et al.*, 2017). In particular, we use the Normalised Difference Vegetation Index (NDVI), which is an indicator of plant 'greenness' widely used in the literature and that has been shown to be associated with measures of agricultural productivity and climate change mitigation (Asher and Novosad, 2020; Gazeaud and Stephane, 2022; GEF, 2016; Groten, 1993; Higgins *et al.*, 2015; Lewis *et al.*, 1998; Meshesha and Abeje, 2018; Mkhabela *et al.*, 2005; Sha *et al.*, 2022; Sims *et al.*, 2021; Tucker *et al.*, 1980; 1986; Vlek *et al.*, 2010; Yengoh *et al.*, 2015).[2]

Beyond relying on the evidence from the literature, we also provide formal empirical tests that validate the use of NDVI as a measure of agricultural productivity and carbon uptake in the context of our study. First, we employ an approach similar to that of Gazeaud and Stephane (2022) and regress, at the *woreda* level, agricultural productivity data from the Ethiopian Agricultural Census of 2001 on NDVI.[3] The results show strong positive correlations, suggesting that NDVI can be employed as a measure of agricultural productivity in the context of our study. Second, we regress values of Net Primary Productivity (NPP) obtained from two separate sources on NDVI.[4] Results, again, show significant positive correlations independently of the data source used, confirming NDVI's potential use as a metric of carbon uptake over the study area.

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[2] The NDVI, first introduced by Rouse Jr *et al.* (1973; 1974), is computed by normalising the difference between the near-infrared (NIR) and the red bands of a scene (the formula for the calculation of NDVI is therefore: (NIR - Red) / (NIR + Red)). A healthy green plant is characterised by high absorption of solar radiation by the chlorophyll in the visible red wavelength and by high reflectance by the plant's spongy mesophyll in the near-infrared wavelength (Jensen, 2014). Values of the red and NIR bands correspond to ratios between the reflected and the incoming radiation for each band and thus lie between zero and one. Therefore, values of NDVI range between minus one and plus one, with higher values representing more 'greenness' compared to lower values (Pettorelli, 2013). Further details on the literature supporting the association between NDVI and measures of agricultural productivity and carbon uptake are provided in Section 3.4.2 below.

[3] As further specified below, Ethiopia is sub-divided administratively into regions, zones, districts (*woredas*) and municipalities (*kebeles*). *Woredas* thus correspond to the third administrative level in the country and represent the lowest administrative level for which data from the Agricultural Census are available.

[4] As further detailed in Section 3.4.2, NPP corresponds to the net amount of carbon assimilated by plants after photosynthesis and autotrophic respiration and can thus be considered a direct indicator of carbon sequestration from vegetation (UNCCD, 2017; Sha *et al.*, 2022). The two sources of NPP data that we use in the regressions are FAO (2020) and Running *et al.* (2015). Unfortunately, neither of these two datasets covers the entire timeframe of our study, and no other publicly available dataset includes longer time-series of NPP data. We are therefore constrained by data availability to employ NDVI as a proxy of primary productivity, rather than utilising directly NPP values in our main analysis.

Remote sensing satellite-based data thus allow us to compare agricultural productivity and climate change mitigation dynamics between areas where the LRCP was first implemented (i.e. the Tigray region) and the neighbouring Amhara region. Hence, we employ a difference-in-differences design comparing pixels in Tigray and Amhara, before and after the programme to uncover its causal effects. We find that the LRCP has led to increases in NDVI and the effects are persistent, suggesting a positive effect on agricultural productivity and climate change mitigation over the landscapes of Tigray. By examining years where adverse climate and weather events occurred, we also find suggestive evidence that the LRCP enhanced climate change adaptation, thereby reducing farm-households' vulnerability to such adverse events.

This study complements existing research on the effects of the Ethiopian land tenure reform and contributes to the literature in three fundamental ways.[5] First, this study exploits an original source of data. It is, to the best of our knowledge, the first study that utilises EO data to analyse the effects of the LRCP in Tigray. It therefore contributes to bridge the gap between "people and pixels" (National Research Council, 1998; Kugler *et al.*, 2019). Second, it extends the geographic coverage of the analysis compared to existing literature on the effects of the LRCP in Tigray. Unlike previous research, which was constrained to be localised (due to the nature of the household surveys employed), the use of EO data enables us to undertake an analysis over the entire landscapes of the Tigray region. Third, it complements previous research by analysing the effects of the LRCP on a distinct set of objectives. This study is the first to assess the effects of the LRCP on the CSA objectives.

The paper is structured as follows. In Section 3.2, we provide an overview of the LRCP in Tigray, including a background of the dynamics that led to its implementation and a review of the literature assessing the impact of the programme. In Section 3.3, we summarise the conceptual framework employed in the study. Section 3.4 presents the study area and provides a description of the data used. The fifth section (Section 3.5) describes the empirical approach employed in the study. We then present the main results from our estimations in Section 3.6 and discuss potential mechanisms underlying these results in Section 3.7. The last section (Section 3.8) concludes.

[5] Ayele and Elias (2018) provide a recent review of the existing literature assessing the effects of the programme across Ethiopia on various rural development objectives. We also included at the bottom of Section 3.2 a summary of the literature specifically related to the land registration and certification programme in the Tigray region.

3.2. Background on land tenure in Ethiopia and on the Land Registration and Certification Programme (LRCP)

The Ethiopian revolution of 1974 led to the end of the Empire of Ethiopia and to the instauration of the socialist *Derg* regime, which carried out a radical land reform, seizing all rural land - without payment of compensation - and redistributing it to farmers willing to personally cultivate the land (PMAC, 1975: article 4; Cheru *et al.*, 2019).[6] However, the land redistributions were not accompanied by a transmission of control and transfer rights to the farmers. Instead, land was proclaimed as "the collective property of the Ethiopian people" (PMAC, 1975: article 3.1) and farmers were provided with 'possessory rights' (i.e. usufruct rights) via local peasant associations (Nega *et al.*, 2003). Under the *Derg* regime a ceiling of ten hectares of allotted land per household was set (PMAC, 1975: article 4.3), and all land transactions as well as sharecropping arrangements were outlawed (Alemu *et al.*, 2002). The redistributions and the imposed land ceiling were effective in reducing land inequality, as they led to a reduction in average and median operated land size (EEA/EEPRI, 2002; Lipton, 2009). Yet, the continuous land redistributions that occurred in the years following the revolution, and the hindrance of private sector initiatives increased tenure insecurity and hampered agricultural productivity growth (Belete *et al.*, 1991; Bruce *et al.*, 1994; EEA/EEPRI, 2002; Rahmato, 1984). Despite a victory at the 1987 referendum, which resulted in the establishment of a one-party state - the People's Democratic Republic of Ethiopia (PDRE) - and of a new constitution, a number of combined factors, including the effects of the dramatic famine of the mid-1980s, the continuous military conflicts with rebel forces and the diminishing support from the Soviet Union, led to the capitulation in 1991of the regime and of its recently established Worker's Party of Ethiopia.

The Ethiopian People's Revolutionary Democratic Front (EPRDF) and its allies led the transitional government of 1991-1995 and won the subsequent multiparty election, the first in Ethiopia's history. Despite growing expectations of changes in land tenure arrangements among Ethiopians, the EPRDF 1991 declaration on economic policy and the 1995 constitution gave in fact continuity to the *Derg* approach to land control by maintaining land property of the State and thus prohibiting all land sale and mortgaging (Nega *et al.*, 2003). A few crucial developments nevertheless occurred after the fall of the PDRE in 1991 and became noticeable in the 1995 constitution (FDRE, 1995) and in the subsequent Federal Rural Land Administration Proclamation of 1997 (FDRE, 1997).

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[6] Inspired by the Soviet Union model, State and collective farms were also created by the regime.

First, the new constitution recognised peasants' rights to land and protection against eviction and indicated that such rights would apply equally to women and men (FDRE, 1995: articles 35.7; 40.4). Proclamation 89/1997 clarified the nature and extent of peasants' land 'holding rights'. Although land ownership *per se* remained vested in the State, farmers were given usufruct rights on the land in their possession and such rights could be bequeathed to family members (FDRE, 1997: section 2.3), thus enhancing tenure security. Second, the federal proclamation opened-up a space for land market transactions that had been absent under the *Derg* regime by specifying, among peasants' 'holding rights', the right to lease-out their land (FDRE, 1997: section 2.3). Hence, legislation now enabled farmers to engage in a land rental market and lease-in or lease-out individual holdings. Third, formal recognition was given to land-related investments undertaken by farmers, acknowledging farmers' rights to reap the benefit from these investments (FDRE, 1995: article 40.7; FDRE, 1997: articles 6.8 and 6.9). Finally, inclusion of article 52.2.d. in the 1995 constitution devolved land and other natural resources administration to the regional governments (FDRE, 1995) and Proclamation 89/1997 invited regional governments to enact regional land administration laws (FDRE, 1997, articles 5-8).

Tigray was the first region to pass such a proclamation in 1997 specifying the rights and obligations of populations with respect to land. The proclamation confirmed farmers' rights to use the land in their possession for cultivation, as well as to give it in inheritance to female and male children, insofar as these were not "self-subsistent outside [the] agriculture sector", and the right to lease-out (or lease-in) individual holdings to (or from) other farmers (for a period of up to 10 years) (TNRS, 1997: articles 9.6; 16.3). Furthermore, by including a clear article related to land expropriation, which indicated that land under private possession could only be taken by the State against the payment of fair compensation or the provision of similar land (TNRS, 1997: article 11), the proclamation helped to address the perception of tenure insecurity that prevailed under the *Derg* regime. Other regions followed suit and issued proclamations related to land administration and land use (ANRS, 2000; ONRS, 2002; SNNPRS, 2003).

After the proclamations were issued, a gradual process of land registration and certification was undertaken by regional governments. The process began in Tigray where a swift cost-effective and paper-based first-stage LRCP was implemented in 1998. Reportedly, by 1999, 88% of all land was registered and certified (Deininger *et al.*, 2006; USAID, 2016). Amongst the positive lessons learned from the execution of the LRCP was the localised level of administration and implementation of the programme and the communities' participation in the process (Haile *et al.*, 2005). This enabled the registration process to be widely known to, and accepted by, the farm-households. Many of the communities' farm-household members actively participated in the formal process of demarcation of land, which was done using simple technology (e.g. with physical ropes), validated by the neighbours of the demarcated plots and recorded in paper forms that were maintained at local administration offices (Bezu and Holden, 2014).[7]

In terms of the impact of the LRCP, several studies have been conducted to assess the effects of the programme in the Tigray region on a range of rural development objectives that can be associated with economic, social and political outcomes. In the following paragraphs we provide a brief summary of the key findings of the existing literature.[8]

A large body of evidence suggests that the LRCP reduced tenure insecurity. Holden *et al.* (2011a), for example, use data collected from interviews with 400 conflict mediators across 27 communities of Tigray. Among the main findings of the study, the authors report that the LRCP successfully reduced the number of border disputes in many communities (Holden *et al.*, 2011a: 27). This finding hints towards the effectiveness of the Tigray LRCP in increasing tenure security of farm-households, as land disputes and conflicts can be interpreted as a signal of tenure insecurity. The positive effect of the LRCP on tenure security has also been found in Holden *et al.* (2011b), who deduct from the results of land rental models and from direct information on household perceptions that an increase in tenure security occurred in Tigray following the LRCP. Similar positive effects of the LRCP on tenure security are reported by Holden *et al.* (2009) for a large majority of farm-households across the sampled areas of Tigray.

Positive effects are also found in terms of investment and productivity. Holden *et al.* (2009), for instance, employing a panel dataset based on an initial sample of 400 households, find that the LRCP led to increased investment on maintenance and improvement of soil conservation structures and on tree planting. They also find large positive and significant effects of the LRCP on total value of output per hectare across the majority of their specifications (21 out of 32). Results are confirmed in Mekonnen *et al.* (2013) who show an increase in tree growing in Tigray. Additional evidence on the positive impact of the LRCP on productivity is provided by Holden and Ghebru (2013), who employ the same dataset as Holden *et al.* (2009) but add a gender dimension in their study finding that post-certification productivity gains on land rented out by female-headed households

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[7] For a detailed description of the land registration and certification process in Tigray see e.g. Nega and Atakilt (2006); Haile *et al.* (2005).
[8] A description of the programme and its impact across various regions of Ethiopia, including Tigray, can be found in Deininger *et al.* (2008). A more recent review of the effects of the programme across Ethiopia can be found in Ayele and Elias (2018). Additional studies that have examined the impact of the programme in regions other than Tigray include Bezabih *et al.* (2016); Bezu and Holden (2014); Fors *et al.* (2019); Legesse *et al.* (2018); Melesse and Bulte (2015); Tsegaye *et al.* (2012).

were larger compared to that of male-headed households. Positive investment and productivity effects are also found by Ghebru and Holden (2015), based on a sample of 320 farm-households. In addition to an increase in investment in new, and maintenance of, conservation structures, they find greater use of fertilisers and of improved seed varieties. Hence, they are able to attribute the increase in productivity to the technological advantages induced by the programme (Ghebru and Holden, 2015: 25).

Few other studies have explored wider welfare effects. Holden and Ghebru (2013), for example, examine the effects of the LRCP on household expenditure per adult equivalent as a measure of welfare and find positive welfare improvements, particularly for female-headed households.[9] A study by IFPRI (2013) explores the effects on two measures of food security, calorie availability and body mass index, finding positive effects on both of these measures.

In sum, the available evidence hints towards a consensus among scholars on the beneficial effects of the LRCP in terms of tenure security, long-term land-related investments with climate-smart potential and agricultural productivity. However, none of the studies described above employed data representative at the regional level and, although a few of these could exploit panel data, the panel they used only contained a single snapshot of the pre-LRCP period. In addition, there is no direct evidence of the effect of the LRCP in terms of sustainable increases in agricultural productivity, climate change adaptation and mitigation. Hence, our study complements the above findings by employing an original balanced panel dataset spanning from 1991 (i.e. seven years before the launch of the LRCP) to 2004 (i.e. six years after the LRCP), and covering the entire region of Tigray, to investigate the effects of the LRCP on the three CSA objectives.

3.3. Conceptual framework

In this section, we adapt the conceptual framework of Rampa *et al.* (2020) to the Ethiopian context. In particular, we focus on the channel linking the land tenure reform pillar of the framework to the CSA objectives (Figure 3.1).[10]

[9] For a more in-depth assessment of gender-focused effects of the land tenure reform in Ethiopia the reader may refer to Holden (2020).

[10] Although this study only focuses on the tenure reform pillar of the framework, the importance of the other pillars (e.g. rural advisory services and markets and infrastructure) in fostering CSA adoption and the realisation of the CSA objectives should not be neglected. Due to data limitations, we do not examine these in this study and leave such an analysis for future work.

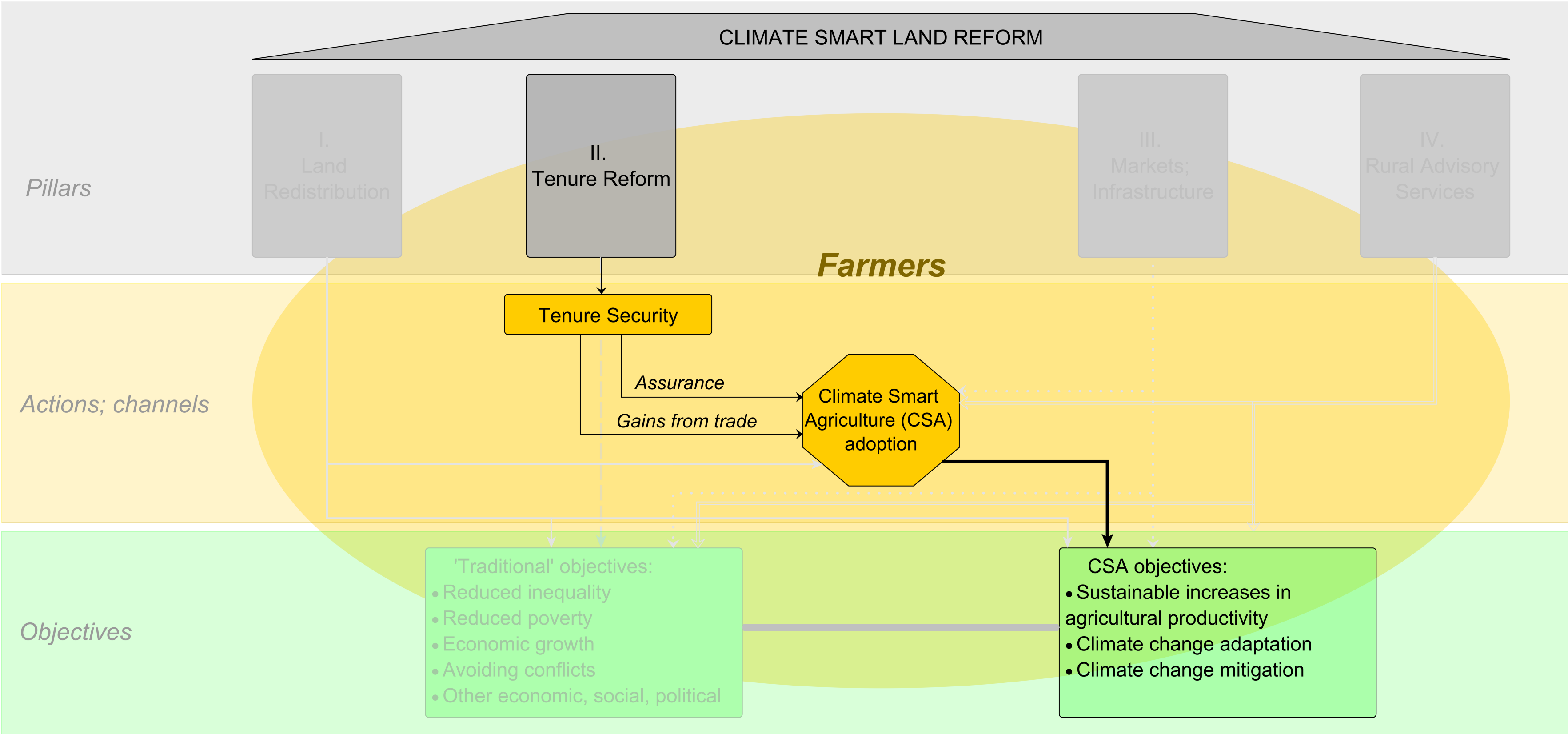

Figure 3.1. Tenure reform and Climate Smart Agriculture in Ethiopia

Source: Adapted from Rampa *et al*. (2020)

Land tenure reforms are generally undertaken to enhance the land rights of populations and increase their tenure security (Adams, 2000). Whilst there have been circumstances where the implementation of a tenure reform did not generate the expected increase in tenure security (Bruce and Migot-Adholla, 1994; Deininger and Feder, 2009; Jansen and Roquas, 1998; Pinckney and Kimuyu, 1994), the empirical evidence available from the LRCP implemented in Tigray suggests that the reform has indeed been successful at enhancing farm-households' tenure security (Holden *et al.*, 2009; 2011a; 2011b).

In turn, increased tenure security amplifies farm-households' incentives to undertake long-term land related investments, including investments in the adoption of practices with climate-smart potential. In the Ethiopian context, two forces are considered to underlie such incentives.[11] The first is the 'assurance' effect. With greater tenure security, farmers gain confidence that the returns from undertaking investments on the land, including in CSA practices, will not be reaped by outsiders but will instead be garnered by them and their heirs. Expected returns from these investments will thus be higher, which will create a stimulus for these investments to be realised (Besley, 1995; Brasselle *et al.*, 2002; McCarthy and Brubaker, 2014). The second effect is associated with potential 'gains from trade' from investing in CSA practices.[12] Two conditions are subsumed in this effect. First, a land market must exist where increased tenure security reduces transaction costs. In the context of Ethiopia, where only land leases are permitted, higher tenure security is expected to reduce the lessor's potential costs of losing their rights to the land.[13] Second, the land market must recognise the value of climate-smart investments undertaken on the land (e.g. the value of terraced land must be greater than the value of non-terraced land).[14] If these conditions are met, farm-households will have an incentive to invest in CSA as they will be able to gain a return from these investments when leasing out their land.[15]

To conclude, the conceptual basis of our study relies upon the effect that the tenure reform has on enhancing tenure security for farm-households and the consequent assurance and

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[11] The literature highlights other positive effects that may emerge with the implementation of a tenure reform (deSoto, 2000; Dixon-Gough and Bloch, 2006; Feder, 1987; McCarthy and Brubaker, 2014; Rampa *et al.*, 2020). Among these, the most prominent is arguably the 'collateralisation' effect, which is impeded in the Ethiopian context by the absence of household ownership rights to land, as all land is vested in the State.

[12] This effect, which is termed here 'gains from trade' following Besley (1995), is also referred to as 'realisability' effect or 'transferability' effect in the literature (Brasselle *et al.*, 2002; McCarthy and Brubaker, 2014).

[13] In Ethiopia land sales remain prohibited after the tenure reform – land market activity can only occur by means of land leases between farm-households (FDRE, 1997; TNRS, 1997).

[14] For a formal model of the gains from trade effect detailing the conditions that ensure a successful bargaining process, see, for instance, Besley (1995: 910-912).

[15] In a similar vein, increased land market activity can also generate allocative efficiency gains, by reallocating land from less productive to more productive farmers (Holden and Ghebru, 2013).

gains from trade (leasing) effects. The combination of these effects is expected to provide incentives for farm-households to invest in long-term land related CSA practices and thus to generate beneficial effects on the CSA objectives.

3.4. Study area and data

3.4.1. Study area

Ethiopia is a landlocked sub-Saharan African country located in an area of eastern Africa often referred to as the horn of Africa, which includes, beyond Ethiopia, neighbouring Eritrea, Djibouti and Somalia. Ethiopia also shares borders with Sudan and South Sudan in the West and with Kenya in the South. Administratively, the country is sub-divided into regions, zones, districts (*woredas*) and municipalities (*kebeles*). In terms of its topography, Ethiopia's land surface extends from areas characterised as lowlands, some of which are located below sea level, to a large proportion (approximately 40%) of land characterised as highlands, reaching over 4,500 meters above sea level (Appendix Figure 3.A.1; Farr *et al.* (2007)). This large heterogeneity, combined with the migration of the Inter-Tropical Convergence Zone, gives rise to a variety of climate conditions and to a multitude of farming systems (Amede *et al.*, 2017; FAO, 2005; Mcsweeney *et al.*, 2010a; 2010b).

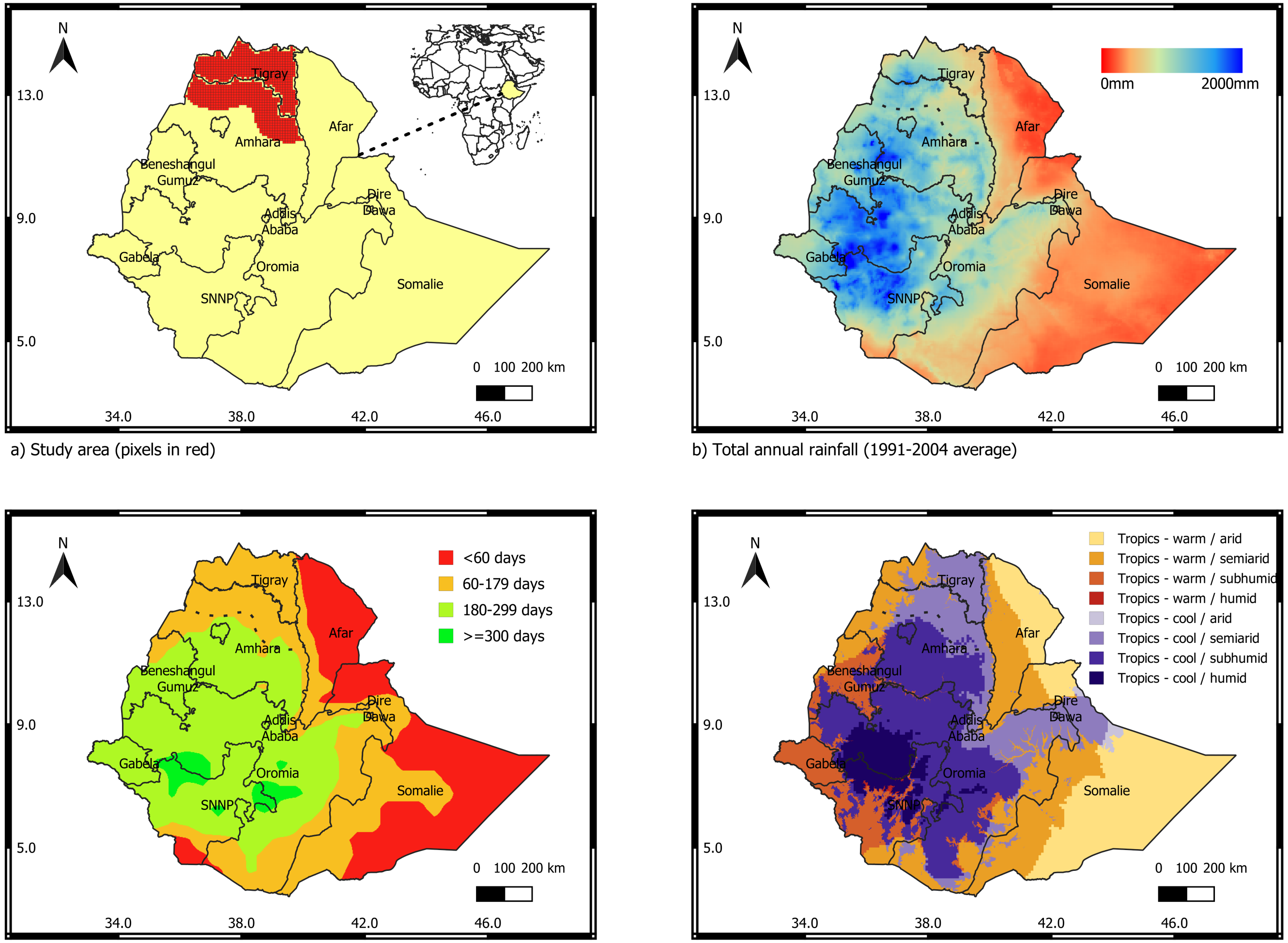
In the hot and dry sparsely populated lowlands of the East and South of Ethiopia the mostly nomadic population relies on pastoralism as its main livelihood. Crop cultivation is close to absent in these areas due to the challenging climate. In the lowlands of the North-West and of the West of the country, where rainfall is higher compared to the arid lowlands, the population typically relies on mixed farming systems with livestock and a prevalence of oilseed crops (especially sesame) in the North-West and maize in the West. The highlands include areas where farming systems rely predominantly on one rainy season occurring during the *kiremt* months (between June and September), such as highlands in Tigray, in large parts of Amhara, or in the highlands of Beneshangul-Gumuz, as well as areas benefitting from two rainy seasons (in the latter *belg* months of March to May and during *kiremt*), mostly located in the SNNP's Southern highlands as well as some areas of Oromia and Amhara (Appendix Figure 3.A.2). Except for areas of Oromia and SNNP where most of Ethiopia's perennial crops are grown, notably cash crops destined to exports such as coffee, farming systems in the highlands are characterised by a mix of livestock and temporary crops (primarily staple cereals including teff, wheat, sorghum, maize or barley complemented in some areas by pulses and/or oilseeds, as well as vegetables and legumes), and accompanied in several areas with perennial shrubs and fruit trees, resulting in complex and highly diverse farming systems in spite of the relatively small landholdings (Amede *et al.*, 2017; FDRE, 2003).

Our study focuses on two specific areas of Ethiopia, the Tigray region (where the LRCP was first implemented – the "treated" region) and the Northern part of Amhara (the "control" region). The Amhara region has a total land surface that is over three times that of Tigray (approximately 155 thousand km^2 compared to approximately 50 thousand km^2). We therefore include in our analysis only a selected area of Amhara, similar in size to Tigray (Figure 3.2, panel a).[16]

This also allows us to ensure that agro-ecological characteristics are not excessively dissimilar between the two study regions. The four panels included in Figure 3.2 show that when considering crucial factors associated with agricultural production such as the agro-ecological zoning, the total amount of annual rainfall and the length of growing period, the study area is indeed more homogenous compared to a possible alternative area containing the entirety of the Amhara region. Furthermore, restricting our study area to the northernmost part of Amhara enables us to exclude areas of Amhara that were selected in the pilot LRCP launched in 2003, namely "Gozamen in East Gojam zone and Dessie Zuria in South Wollo zone" (Adenew and Abdi, 2005: 13) and thus to extend the timeframe of the analysis until 2004.[17]

[16] In addition, a buffer of five km from the Tigray and Amhara borders is excluded to avoid pixel contamination (i.e. to avoid utilising in the analysis pixels with portions of land not within the areas of interest). In total, we obtain 1,008 pixels, 504 pixels representing the Tigray region and 504 pixels representing the corresponding area of Amhara.

[17] It was not possible to ascertain the precise dates at which the LRCP was undertaken in the areas of interest of Amhara. This is due to a lack of information available, as reported in Deininger *et al.* (2008): "In fact, as responsibility is fully with the regions, even information on implementation of certification available at the central level is often quite inaccurate" (Deininger *et al.*, 2008: 1808). However, based on available information, the year 2004 appears to be a conservative estimate, particularly with regards to the certification facet of the programme in the study areas of Amhara: "The first round […] was fielded in 2004 when, except for Tigray and some small local pilots, no land certification had been undertaken anywhere in the country" (Deininger *et al.*, 2008: 1790); "in Amhara […] At the end of 2004, about 30% of farming household plots were registered" (Kanji *et al.*, 2005: 12); "By the end of 2004, about 660,687 landholders received temporary certificates […and] 3.6 million plots were registered"(Adenew and Abdi, 2005: 18). Combining the information from these latter two reports, we can estimate that at the end of 2004 approx. 20% of landholders in Amhara had received certificates.



a) Study area (pixels in red)

b) Total annual rainfall (1991-2004 average)

c) Length of growing period

d) Agro-ecological zones

Figure 3.2. Characteristics of the study area

Source: Authors, based on the following data. For total annual rainfall, Funk *et al*. (2015a); for length of growing period, Fischer *et al*. (2002); for agroecological zones, Sebastian (2009).

3.4.2. Data and measurement of variables

In this study we rely on EO data sourced from the Google Earth Engine platform (Gorelick *et al.*, 2017). Our main variable of interest is the monthly maximum value of the Normalised Difference Vegetation Index (NDVI). As indicated above, NDVI is a measure of plant 'greenness' that has been shown in the literature to be associated with measures of agricultural productivity and climate change mitigation.[18]

In terms of agricultural productivity, early "ground-based *in situ*" studies using hand-held radiometers revealed the effectiveness of spectral data, and in particular of NDVI, in detecting plant vigour and in remotely measuring yields (Tucker *et al.*, 1980). Since then, a large body of research has focused on the crop yield (or production) forecasting potential of NDVI, backed by the strong associations between NDVI and yields (or crop production) (e.g. Groten, 1993; Lewis *et al.*, 1998; Mkhabela *et al.*, 2005). A recent study undertaken in the Amhara region of Ethiopia found NDVI (as well as other vegetation indices) to be correlated with the yields of the main cultivated cereal crops, and particularly strong correlations were found between NDVI and teff and wheat yields, indicating that remote sensing data can have a promising role in predicting crop yields in these areas (Meshesha and Abeje, 2018). NDVI has also been shown to be an effective proxy for agricultural production in crop price forecasting models (Higgins *et al.*, 2015). Furthermore, NDVI has recently been used as a measure of agricultural productivity in studies evaluating the economic impact of public programmes. Asher and Novosad (2020), for instance, estimated the impact of a large-scale rural road programme in India on five broad outcomes, including agricultural investment and yields. Utilising NDVI in their preferred measure of agricultural productivity, the authors found no significant effect of the programme on yields. Gazeaud and Stephane (2022) assessed the impact of the infrastructure component of the Government of Ethiopia's flagship productive safety net programme launched in 2005 on agricultural productivity. The authors first studied the relationship between values of NDVI and survey-based data on agricultural production and productivity in Ethiopia finding positive correlations, which justified the use of NDVI as their indicator of agricultural productivity. They then employed a difference-in-differences design and showed that the infrastructure component of the programme did not appear to have significant effects on agricultural productivity in the country.

In terms of climate change mitigation, the NDVI has been found in the literature to be strongly associated with different measures of carbon capture. Tucker *et al.* (1986) showed

[18] One drawback of the NDVI is that it suffers from saturation at very low and very high index values. However, this is not a concern in the context of this study as the index values over the areas of interest are not extreme.

the presence of an inverse relationship between carbon dioxide (CO_2) concentrations in the atmosphere and NDVI, thereby demonstrating "the measurable link between atmospheric CO_2 drawdown and terrestrial NDVI dynamics" (Tucker *et al.*, 1986:198). Furthermore, the NDVI, due to its strong correlation with the fraction of photosynthetically active solar radiation absorbed by plants, is commonly employed as a proxy of primary productivity (GEF, 2016; Sha *et al.*, 2022; Sims *et al.*, 2021; Vlek *et al.*, 2010; Yengoh *et al.*, 2015).[19] Gross Primary Productivity (GPP) represents the uptake of CO_2 by the standing biomass and Net Primary Productivity (NPP) results from the difference between GPP and autotrophic respiration (Ruimy *et al.*, 1996; Sims *et al.*, 2021). In other words, NPP represents the net amount of carbon assimilated after photosynthesis and autotrophic respiration over a specified time period (IPCC, 2021; UNCCD, 2017). NPP can thus be considered a direct indicator of carbon sequestration from vegetation (Sha *et al.*, 2022). As Field *et al.* (1998) indicate, "NPP is a major determinant of carbon sinks […] In terrestrial systems even modest increases in NPP potentially result in substantial carbon storage in plants and soils" (Field *et al.*, 1998:237,239).

Various raw and processed satellite data can be employed to obtain NDVI values, including collections from the Advanced Very High Resolution Radiometer (AVHRR), the Moderate Resolution Imaging Spectroradiometer (MODIS), or Landsat (see, for instance, Higginbottom and Symeonakis, 2014; Pettorelli, 2013 for summaries of commonly utilised NDVI datasets) and more recently from the European Space Agency's Copernicus Sentinel missions (Aschbacher and Milagro-Pérez, 2012). In our study, we recur to the AVHRR NDVI third generation (3g) dataset (Pinzon and Tucker, 2014), which not only corrects for a number of potential distortions caused by navigation inaccuracy, stratospheric aerosols, orbital drifts, cloud presence (Tucker *et al.*, 2005) but also for potential biases induced by the use of multiple sensors (Pinzon and Tucker, 2014).[20] AVHRR NDVI 3g has the advantage over other datasets of including a long time-series of bi-monthly, consistent and global NDVI data. These strengths make it a very widely used dataset in the literature (Davis *et al.*, 2017; Lamchin *et al.*, 2018; Pettorelli, 2013; Zhou *et al.*, 2018). Crucially,

[19] The basis of such an association is the different spectral signatures of the Earth's surface types. Vegetation has a different spectral signature compared to other surfaces such as bare ground, snow/ice, water, etc., in that plants, through photosynthesis, have strong absorption in the visible red band of the electromagnetic spectrum and high reflection in the near-infrared wavelength, which, as indicated above, are precisely the bands used in the computation of NDVI. Therefore, the NDVI represents a useful index of photosynthetic activity (Myneni *et al.*, 1997; Purkis and Klemas, 2011).
[20] The dataset relies on the National Aeronautics and Space Administration (NASA)/National Oceanic and Atmospheric Administration (NOAA) instruments and is processed by the Global Inventory Modelling and Mapping Studies (GIMMS) group.

the AVHRR NDVI 3g dataset is also the only dataset available that provides reliable NDVI data over the entire timeframe and area of this study.[21]

Additional variables of interest for our study include measures of precipitation, temperature and wind speed - which are considered to potentially affect NDVI - as well as an index enabling us to identify the occurrence of adverse climate and weather events.

Historical precipitation data were obtained from the Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) dataset, a quasi-global rainfall dataset, that incorporates satellite imagery with in-situ station data (Funk *et al.*, 2015a). This dataset has been validated over Eastern Africa (Dinku *et al.*, 2018) and, more specifically, over areas of Ethiopia (Alemu and Bawoke, 2020; Alemu and Wimberly, 2020; Ayehu *et al.*, 2018; Funk *et al.*, 2015b). Due to its reliability, the CHIRPS dataset is increasingly being employed in the literature, including in studies relating to Ethiopia (IPCC, 2019; Osgood *et al.*, 2018; Taye *et al.*, 2018). As the monthly data product was not available on the GEE platform, we recurred to the pentad dataset (consisting of five-day sums of precipitation) and subsequently computed the arithmetic monthly sum from the pentad data for each pixel.

For temperature data, we employ the Famine Early Warning Systems Network (FEWS NET) Land Data Assimilation System (FLDAS) dataset (McNally *et al.*, 2017), which provides monthly average "near surface air temperature".[22] This dataset has a good track record in terms of accuracy, including in areas of Ethiopia. Alemu and Wimberly (2020) study various satellite-based remote sensing temperature and precipitation datasets and compare values from these datasets to those obtained from 22 meteorological stations across the Amhara region of Ethiopia. They find that, amongst the datasets studied, the FLDAS temperature data and the CHIRPS precipitation data were the most closely related to station data.

Average monthly wind speed data were obtained from the TerraClimate dataset, a global long time-series dataset (1958-current) which includes a range of primary climate variables as well as variables derived from a soil water balance model (Abatzoglou *et al.*, 2018).

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[21] Although Landsat, MODIS and Sentinel data provide a finer spatial resolution compared to AVHRR NDVI 3g, we consider the above-stated advantages of this latter dataset to outweigh the benefits of higher spatial resolution, particularly given the regional-scale of the analysis that we undertake. In fact, the long time-series and consistency of AVHRR NDVI 3g data enable us to obtain a balanced panel dataset ranging from 1991 to 2004 over the study area. MODIS and Sentinel data are only available from the years 2000 and 2015, respectively, therefore from only after the implementation of the LRCP in Tigray, and large gaps were found in Landsat data for substantial time periods over the areas of interest. None of these alternative datasets were thus available for the entire timeframe of our study.

[22] Temperature data in the FLDAS dataset is based on NASA's Modern Era Reanalysis for Research and Applications version 2 (MERRA-2) (Bosilovich *et al.*, 2015).

Although the TerraClimate dataset was only released in 2018, it has already been employed extensively in empirical research. Data relating to wind speed from the TerraClimate dataset have been utilised for instance by Gudo *et al.* (2020); Hu *et al.* (2020) and by Fenta *et al.* (2020) in the context of Ethiopia.

The Palmer Drought Severity Index (PDSI) is a widely used index for the objective classification of adverse climate and weather events according to a severity scale. It was originally developed as a tool to allow comparisons across time and space of meteorological drought episodes (Palmer, 1965). Yet, the index includes both negative and positive values and can therefore be employed to determine not only dry spells but also abnormal wet periods. The computation of the index is based on a soil moisture algorithm and a water balance model, which produce values that can be categorised according to a scale of severity (Palmer, 1965). The values of PDSI utilised in this paper were obtained directly from the TerraClimate dataset. The PDSI has been used extensively in research, including in Ethiopia (Asfaw *et al.*, 2018; Temam *et al.*, 2019). In our study, and as further described below, we employ the PDSI as a measure to identify adverse climate and weather events that occurred during the timeframe of the study and that represented a potential threat to agricultural production systems.

A balanced panel dataset was constructed from these data utilising monthly time intervals ranging from 1991 to 2004 and 1,008 pixels of approximately 9km x 9km as cross-sectional units, half of which correspond to the geographic area of Tigray and half to a similar-size area in the neighbouring Amhara region. This resulted in a total of 169,344 observations. Detailed summary statistics are shown in Table 3.A.1 of the Appendix.

3.5. Empirical approach

One of the advantages of recurring to EO data is the possibility of generating (balanced) panel datasets by obtaining comparable time-series data over a refined level of analysis (pixels). Our empirical strategy is based on a difference-in-differences (DiD) approach, that compares pixels on both sides of the Tigray-Amhara regional border before and after the 1998 LRCP. Therefore, this design corresponds to a two-period (pre-treatment and post-treatment) and two-group setting, where the LRCP represents the treatment, and pixels in the Tigray region form part of the treatment group, whilst pixels in the selected area of Amhara represent the control group (which is never-treated during the timeframe of our study). Formally, we estimate the following equation:

$$NDVI_{irt} = \beta(D)_{irt} + \zeta x_{irt} + u_i + v_t + \varepsilon_{irt} \tag{1}$$

where i indicates a pixel in region r (Tigray or Amhara) in month-year t. D is a dummy variable equal to one for pixels in the treated region (Tigray) and for years following the 1998 LRCP, and equal to zero otherwise. x is a vector of pixel-and-time-varying covariates, u is a vector of pixel fixed effects and v a vector of time fixed effects. The coefficient of primary interest is β, which provides an estimate of the Average Treatment effect on the Treated (ATT). The dependent variable NDVI is our satellite-based measure of greenness. Finally, ε is the error term clustered at *woreda* level; there are 71 clusters in our analysis.[23]

The results from the estimation of equation (1) are intended to guide inference on whether the LRCP in Tigray contributed to sustainable increases in agricultural productivity and to climate change mitigation. In order to study the effects of the tenure reform on the second CSA objective (i.e. climate change adaptation), we restrict our dataset to include only years where adverse climate and weather events occurred and apply equation (1) to this sub-set of the dataset. The intuition is the following. If the land tenure reform provided thrust to enhance land-related investments in Tigray, which in turn helped build resilience to the adverse effects of climate change, then the ATT from the estimation of equation (1) with this sub-dataset should be positive. In other words, a positive ATT in the presence of adverse climate and weather events should be indicative of increased adaptation to climate change. A positive ATT does not necessarily require that NDVI values in Tigray during post-treatment years be higher than NDVI values in Tigray in pre-treatment years. Employing a DiD strategy entails, in essence, computing the difference between average NDVI values in Tigray in the post-treatment period and average NDVI values in Tigray in the pre-treatment period ('first difference for Tigray') as well as in Amhara ('first difference for Amhara') and then subtracting the 'first difference for Amhara' from the 'first difference for Tigray' ('DiD'). Therefore, a successful adaptation effort in Tigray following the LRCP, captured by a positive ATT in the presence of adverse climate and weather events, does not necessarily imply that the 'first difference for Tigray' be positive. The 'first difference for Tigray' may in fact be positive, null or even negative and still yield a positive ATT, insofar as the 'DiD' is indeed positive. In other words, what is required is an improvement in NDVI in Tigray over time relative to Amhara (which acts as the 'counterfactual' Tigray, a Tigray without the implementation of the LRCP).

[23] This approach is also referred to as Two-Way Fixed Effects (TWFE) in the literature, due to the inclusion of both unit and time fixed effects. In a two-period and two-group setting, with only one treatment period and one treated group, TWFE estimates have been shown to produce unbiased ATT even in the presence of dynamic treatment effects (Baker *et al*., 2022).

To identify the years when such adverse events occurred, we employ the monthly PDSI values for each pixel and compute the *kiremt* season PDSI average for each year.[24] Following the original PDSI classification (Palmer, 1965), we include in the sub-dataset the years where the *kiremt* season PDSI average is either below minus one (i.e. "mild drought" conditions or worse) or above one (i.e. "slightly wet" conditions or worse).

3.5.1. Identification

The causal interpretation of our estimated ATT relies on the assumption that, in the absence of the reform, pixels in the two regions would have experienced similar trends in greenness (known as parallel trends assumption). This assumption cannot be directly tested. Yet, we can provide some support for this assumption by confirming the absence of pre-treatment differences in trends between the two regions. We do so, first, through a visual inspection of the raw annual averages of NDVI over Tigray and Amhara, which are plotted in Panel a) of Figure 3.3. These raw averages show that trends in NDVI in both regions are broadly aligned in the pre-treatment period, providing descriptive support for the absence of differences in pre-treatment trends. Second, we adopt an event-study approach that includes leads and lags of the treatment:

$$NDVI_{irt} = \sum_{\tau=-q}^{-1} \delta_\tau T_{ir} + \sum_{\tau=0}^{m} \theta_\tau T_{ir} + \zeta x_{irt} + u_i + v_t + \varepsilon_{irt} \qquad (2)$$

Where δ_τ and θ_τ correspond to the coefficients of the leads and of the lags of the treatment T, respectively, and all other terms are as in equation (1).

This event-study enables us to examine pre-treatment coefficients and to conduct formal tests on pre-treatment differences in NDVI between the treated and control areas.

Another advantage of equation (2) is that it allows for treatment estimates to vary over time, and so it offers the possibility to observe post-treatment coefficients and investigate the persistence of the estimated effects.

Besides differences in pre-treatment trends, we are also concerned about pre-treatment differences in the level of NDVI as the underlying causes of such differences could potentially influence post-treatment trends. In fact, we can see in panel a) of Figure 3.3 that Tigray displays lower levels of NDVI, on average, compared to Amhara during the pre-

[24] As described in Section 3.4.1 above, the *kiremt* season (June to September) corresponds to the rainy season in our study area. Farm-households rely on the *kiremt* rains for their agricultural production, and rainfall anomalies during the *kiremt* season can impact farm harvest, total agricultural output and consequently the livelihoods and food security of farm-household members.

treatment period.[25] To address these differences, we conduct an additional analysis by restricting pixels in both treated and control groups to areas that fall within 75 km, 50 km and 25 km from the Tigray-Amhara border (Figure 3.3 panels b, c, and d, respectively).[26] Indeed, as we move closer to the regional border, the pre-treatment differences in NDVI levels shrink significantly.

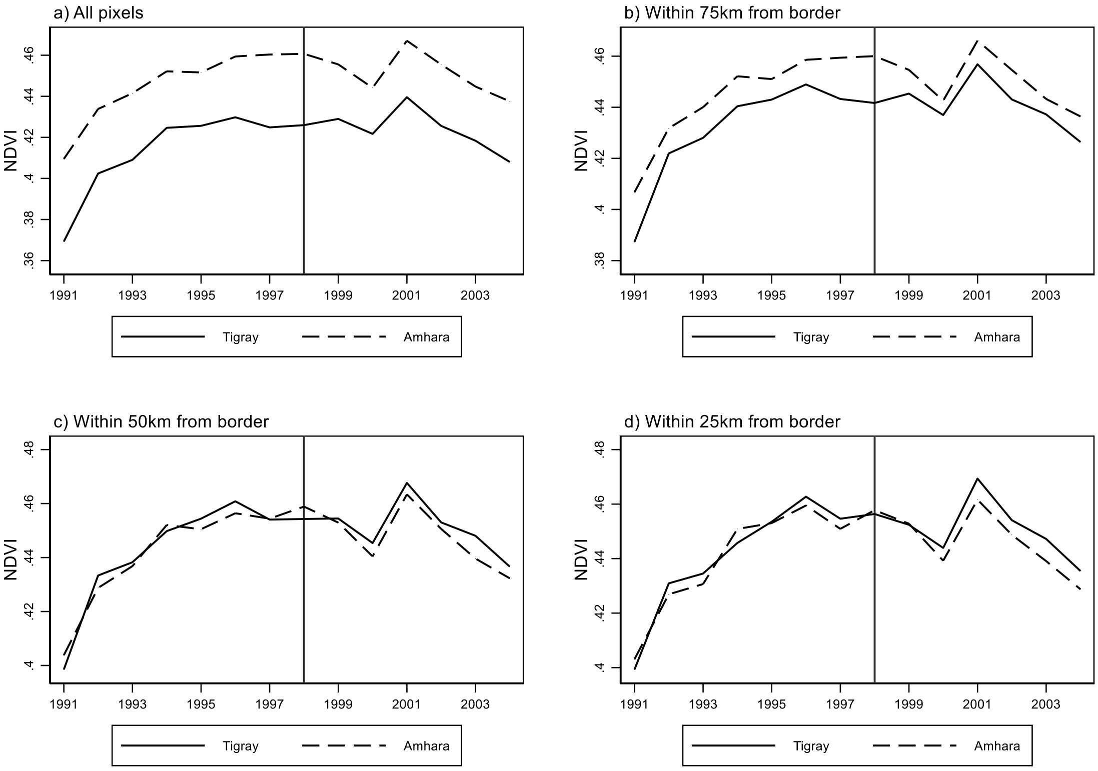

Figure 3.3. NDVI values for treated and control areas (1991-2004)

Notes: NDVI values are annual averages over the treated (solid lines) and control (dashed lines) areas, and are obtained from the dataset constructed based on AVHRR NDVI 3g data (Pinzon and Tucker, 2014). Panel a) includes all pixels from the dataset. Panels b), c) and d) are obtained by restricting the dataset to pixels within 75 km, 50 km and 25 km from the Tigray-Amhara regional border, respectively.

Time-varying factors correlated with the treatment could still challenge the validity of our results. Weather conditions, for instance, could diverge between Tigray and Amhara over the period of analysis and influence post-treatment differences in trends. We therefore check for systematic differences in weather conditions between the two regions, before and after the reform, using an event study where the outcome variables are rainfall, temperature

[25] We are not concerned with possible self-selection (i.e. whether pixels with lower level of NDVI were more likely to be selected into the programme) as all pixels in the Tigray region are considered treated by the reform. Instead, we are concerned about the possibility that any factor that led to the pre-treatment differences in NDVI levels could also lead to post-treatment differences in trends.
[26] Data exclude the five km buffer from the Tigray border to avoid cross-border pixel contamination, as specified in Section 3.4 above.

and wind speed,[27] and control for these variables in the main specification of our model, while also showing results when excluding individual control variables from the model. It is worth noting that the inclusion, as controls, of weather variables that might vary differently between the treated and control group does not affect our identification strategy as such changes are driven by exogenous forces that are unrelated to the outcome and the treatment. We also estimate equation (1) after gradually restricting the area of analysis to pixels that are closer to the regional border. As suggested above, this substantially reduces the possibility that treated and control pixels experience different weather patterns. Finally, we also show results from our main specification estimated with an alternative estimator, namely the doubly robust estimator proposed by Sant'Anna and Zhao (2020), which combines the outcome regression approach (Heckman *et al.*, 1997) and the propensity score weighting approach (Abadie, 2005).

We conduct three final robustness checks. First, we include *woreda*-time trends to control for localised events that could affect NDVI. Second, we employ an alternative outcome variable, the monthly average of NDVI (in place of the monthly maximum), across the entire set of specifications. Finally, we check for additional geographic-based heterogeneities that might be driving the results. In particular, we explore whether the exclusion of the westernmost areas of Tigray and Amhara, where agroecological conditions are slightly different compared to the rest of the study area (Figure 3.2 panel d), affects our results.

3.6. Main results and discussion

3.6.1. CSA objectives I and III: Sustainable increases in agricultural productivity and climate change mitigation.

Table 3.1 shows the results obtained from the estimation of four specifications of the model presented in equation (1). Columns (1) and (2) correspond to the results from specifications without and with the inclusion of the control variables described in Section 3.4.2, respectively. Both columns point toward a positive and significant effect of the LRCP on NDVI. Columns (3) and (4) show that the results are robust to the inclusion of more refined time fixed effects. The estimated average effect reported in column (4), our main specification which includes all control variables and both pixel and month-year fixed effects, corresponds to 7% of a standard deviation (and 2.2% of the mean of NDVI for Tigray, the treated region). Whilst these effects may appear to be small, they should not be perceived as negligible. An indicative benchmark is provided by a 2016 independent

[27] The results from the event studies are presented in the Appendix (Figures 3.A.3; 3.A.4; 3.A.5).

evaluation of Global Environment Facility (GEF) projects that were aimed at combating land degradation. At the global scale, GEF projects were found to have increased NDVI by approximately 0.03 relative to an average NDVI of 0.55 (GEF, 2016: 2). The reported increases for projects in Africa appear to be smaller, with average increases in NDVI of 0.018 (GEF, 2016: 22). While our effects are smaller, it is worth considering that GEF projects were purposefully financed to reduce land degradation and improve land productivity, whilst the LRCP did not explicitly target such outcomes. Hence, the ATT from the LRCP can be considered nontrivial.

Table 3.1. Effects of the LRCP on NDVI: Average Treatment effects on the Treated (ATT)

Dependent variable: NDVI	(1)	(2)	(3)	(4)
ATT	0.005***	0.009***	0.005***	0.009***
	(0.002)	(0.001)	(0.002)	(0.002)
Pixel FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	No	No
Month-Year FE	No	No	Yes	Yes
Controls	No	Yes	No	Yes
NDVI mean (st.dev.)	0.433 (0.137)			
Observations (pixels)	169,344 (1,008)			

Notes: Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1% level. Controls include temperature, temperature squared, precipitation, precipitation squared, and wind speed, as well as an interaction between these variables.

Our results rely on the validity of the main identification assumption mentioned in Section 3.5.1 above, that is the common trends assumption. In this optic, Figure 3.4 illustrates the results from the estimation of equation (2). The pre-1998 estimates confirm the initial impression obtained from the visual inspection of Figure 3.3 and provide evidence of the absence of significant differences in pre-treatment trends between the treated and control regions.[28]

The event study also indicates that the effects of the LRCP are statistically significant in individual post-treatment years. In fact, the effect of the treatment remains present up to

[28] Following Roth (2022), we carefully examined pre-treatment event study coefficients. Our results show that 1) only one pre-treatment coefficient is statistically different from zero, 2) the sum of all pre-treatment coefficients is not statistically different from zero, and 3) the estimated coefficient of the slope of the treatment effect trend line during the pre-treatment period is not statistically different from zero. These results thus strengthen the evidence of the absence of differences in pre-treatment trends and increase our confidence in the non-violation of the common trend assumption.

six years after the treatment, which suggests that the LRCP led to sustainable effects over the landscapes of Tigray.

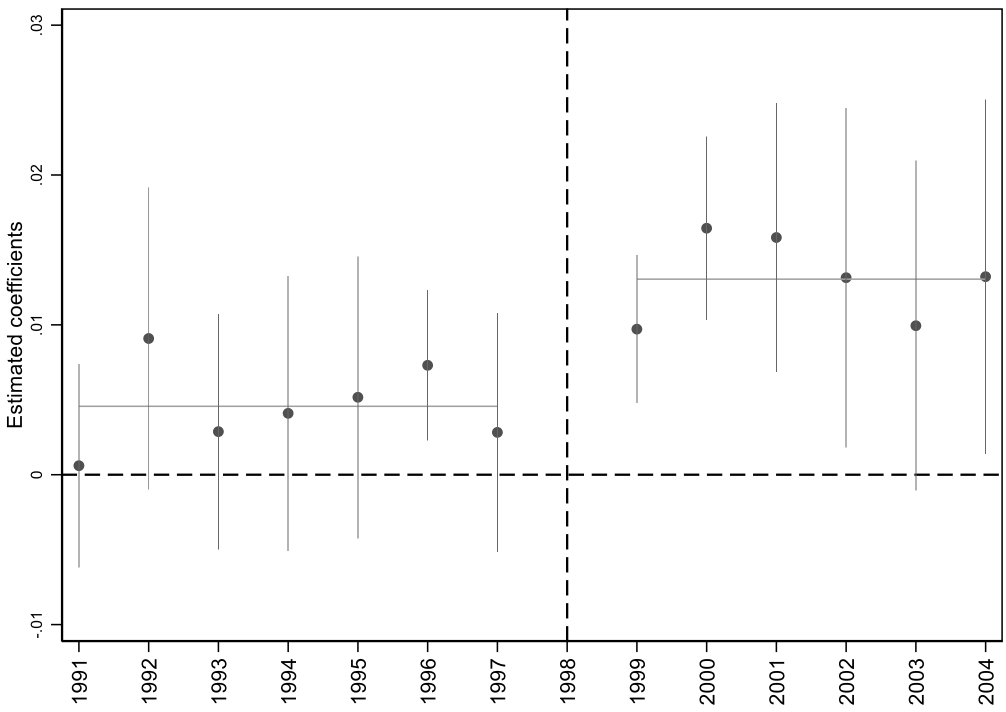

Figure 3.4. Average treatment effects on the treated over the study period

Notes: The figure illustrates the results from an event study on the effect of the treatment (land registration and certification programme) on the outcome variable NDVI over the study period (1991 to 2004). Leads and lags of the treatment indicator are included in the estimated equation (richest specification with all controls, pixel and month-year fixed effects and standard errors clustered at the *woreda* level). Resulting coefficients are shown with 90% confidence intervals (solid vertical lines). For illustration purposes, averages over the pre-treatment and post-treatment periods are also shown (solid horizontal grey lines).

In the context of our study, we consider NDVI to be a relevant proxy for agricultural productivity. This is demonstrated by the results in Table 3.A.4 of the Appendix that show a strong correlation between NDVI and agricultural productivity data from the 2001 Agricultural Census. This is in line with the findings from Meshesha and Abeje (2018) who reported a strong correlation between NDVI and teff and wheat yields in Amhara, and from Gazeaud and Stephane (2022) who validated their use of NDVI as an indicator of agricultural productivity in Ethiopia from the significant correlation between survey-based measures of agricultural productivity and NDVI.

The results from Table 3.1 and from the event study can therefore be interpreted as evidence that the LRCP had a positive effect on agricultural productivity over the landscapes of Tigray. These results are in line with previous findings from studies that employed household-and-plot-level data to analyse the impact of the LRCP on agricultural productivity in Tigray (Ghebru and Holden, 2015; Holden *et al.*, 2009; Holden and Ghebru, 2013). However, survey-based data constrained such studies to a limited geographic and temporal coverage. The use of satellite-based data enables us to extend the spatial and temporal scale of the analysis to all rural areas of Tigray, therefore covering the close to 700 thousand agricultural households of Tigray, over a period of time ranging from 1991 to 2004.

The results from Table 3.1 and from the event study can also be interpreted as suggestive evidence that the LRCP contributed positively to the third CSA objective, climate change mitigation. In effect, the NDVI as a measure of 'greenness' has been associated in the literature not only with agricultural productivity but also with net primary productivity, atmospheric carbon dioxide concentration and carbon stock (GEF, 2016; IPCC, 2019; Tucker *et al.*, 1986; UNCCD, 2017; Vlek *et al.*, 2010; Yengoh *et al.*, 2015). The positive effect of the reform on climate change mitigation would have occurred due to the enhanced adoption of livelihood strategies with climate change mitigation potential. There is indeed evidence that, across Tigray, rural populations were adopting strategies such as tree planting on private plots (Berhe *et al.*, 2013; EEA/EEPRI, 2002; Holden *et al.*, 2009; ICRAF, 2019; Mekonnen *et al.*, 2013), as well as the use of soil and water conservation practices such as conservation tillage, terracing, bunding (EEA/EEPRI, 2002; FDRE, 2003; Ghebru and Holden, 2015; Holden *et al.*, 2009; IFPRI, 2006; Munro *et al.*, 2008). Although most of these practices are commonly advocated for their climate change adaptation benefits, they are also effective at mitigating climate change. The high potential of such practices in reducing soil erosion, and more in general land degradation, can translate in lower carbon dioxide emissions (Altieri and Nicholls, 2017; Lal, 2003b) as well as in increased carbon sequestration (Bruce *et al.*, 1999; Gelaw *et al.*, 2014; Lal, 2003a; 2004; 2013; 2016; Paustian *et al.*, 2016).[29] Indeed, several of these practices can be considered as 'optimal land management practices' that enhance NPP and contribute to climate change mitigation (Sha *et al.*, 2022). The correlations found between NDVI and NPP over our study area (Appendix Table 3.A.5) provide further evidence of a positive effect of the LRCP in terms of carbon uptake. In other words, a positive and significant ATT can be considered as suggestive evidence of a positive effect of the LRCP on climate change mitigation.

The results presented in this section are robust to a series of alternative specifications of our model. Columns (2), (3) and (4) of Appendix Table 3.A.2 show the results when we restrict the analysis to pixels that are closer to the border between the two regions. The

[29] We provide further evidence on the adoption of certain conservation and mitigation strategies in Section 3.7 below.

effects remain quantitatively similar and significant across the different specifications. Our results are also robust to the inclusion of *woreda*-specific time trends, the use of an alternative outcome variable (the monthly mean NDVI in place of the monthly maximum NDVI), the exclusion of individual control variables, and of the westernmost areas of Tigray and Amhara (see Table 3.A.2 and Table 3.A.3 of the Appendix). Finally, Table 3.A.6 of the Appendix shows that our results remain aligned with the baseline results also when employing the doubly robust DiD estimator proposed by Sant'Anna and Zhao (2020).

3.6.2. CSA objective II: Climate change adaptation

The CSA approach emphasises the crucial importance of building resilience to the negative effects of climate change (Lipper *et al.*, 2018). In a context such as that of Ethiopia, where there is unequivocal evidence of a warming of the climate, with mean annual temperatures having increased by 1.3 degrees Celsius between 1960 and 2006 (Mcsweeney *et al.*, 2010a; 2010b) and projected to continue to increase significantly in future decades (Aragie, 2013; Cline, 2007; Deressa and Hassan, 2009; FDRE, 2007; Mcsweeney *et al.*, 2010a), climate-related risks pose a significant threat to farm-households' livelihoods, to agricultural systems and to the nation's economy (Aragie, 2013; Cline, 2007; Deressa and Hassan, 2009; FDRE, 2015; Mideksa, 2010; World Bank, 2008; 2010; You and Ringler, 2010).

Adapting to climate change is therefore paramount for rural populations and adopting CSA practices can contribute to this endeavour. Tenure insecurity is often a barrier to the adoption of agricultural practices with climate-smart potential (Abdulai *et al.*, 2011; Asfaw *et al.*, 2016; FAO, 2017; Kpadonou *et al.*, 2017; Lipper *et al.*, 2018). Removing such a barrier can act as an enabler for CSA adoption, thereby enhancing the resilience of agricultural systems and reducing farm-households vulnerability to the adverse effects of climate change.

The main manifestations of a changing climate which threaten directly agricultural production systems in Ethiopia, including in the specific areas studied in this article, are abnormal dry and abnormal wet spells, which often result in droughts and floods (FDRE, 2015; Mersha and van Laerhoven, 2018; World Bank, 2006; 2010; 2011).

During the timeframe of our study, the use of the methodology presented in Section 3.5 led us to identify nine years where abnormally dry or abnormally wet conditions occurred during the *kiremt* season.[30] As described in Section 3.4.1, the *kiremt* season (June to

[30] In particular, five years were identified where conditions could be categorised as "mild" or "moderate" drought, namely the years 1991, 1992, 1997, 2002 and 2004, and four years - the years 1993, 1996, 1998 and 2000 - where conditions corresponded to the "slightly", "moderately" or "very" wet class (Palmer, 1965). As discussed in Section 3.5, we employ the same threshold (in

September) corresponds to the rainy season in our study area.[31] Farm-households rely on rainfall during these months for their agricultural production and rainfall anomalies occurring during *kiremt* can impact farm harvest, total agricultural output and consequently the livelihoods and food security of farm-household members. Such impacts are indeed expected to be lower for farm-households having adopted climate change adaptation strategies, including the adoption of CSA.

Table 3.2 illustrates the results from the estimation of equation (1) when restricting our dataset to the years where adverse climate and weather events occurred. The results in Table 3.2 show that the effect of the treatment is positive and strongly statistically significant across the various specifications employed. The treatment effect is similar in magnitude to the results in Table 3.1, while the lower average NDVI confirms that greenness is lower, in general, in the years of excess/deficit of rainfall. The results reported in Table 3.2 provide evidence of the positive effect of the treatment on NDVI in the Tigray region when in presence of abnormal dry or wet spells. These results suggest that the treatment, by enhancing tenure security and adoption of CSA strategies, reduced farm-households' vulnerability to adverse climate and weather events. In other words, the LRCP appears to have contributed to progress on the second objective of CSA, that is supporting farm-households in adapting to climate change.

Table 3.2. Effects of the LRCP on NDVI (climate change adaptation sub-dataset): Average Treatment effects on the Treated (ATT)

Sub-dataset (PDSI-based) Dependent variable: NDVI	(1)	(2)	(3)	(4)
ATT	0.007*** (0.002)	0.010*** (0.002)	0.007*** (0.002)	0.010*** (0.002)
Pixel FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	No	No
Month-Year FE	No	No	Yes	Yes
Controls	No	Yes	No	Yes
NDVI mean (st. dev.)	0.429 (0.133)			
Observations (pixels)	108,864 (1,008)			

Notes: Sub-dataset contains the years where adverse dry/wet conditions were identified, based on the PDSI data. Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1% level. Controls include temperature, temperature squared, precipitation, precipitation squared, and wind speed, as well as an interaction between these variables.

absolute value) to identify dry and wet anomalies. The fact that three wet classes and two dry classes appear in our results is due to the PDSI values over the areas of interest during the timeframe of this study. In other words, our data show the presence of specific wet years that can be categorised as more extreme compared to the dry years.

[31] See also Figure 3.A.2 of the Appendix, which displays the total monthly rainfall across Ethiopia averaged over our study period (1991-2004).

The results from Table 3.2 remained largely persistent after we carried out a series of robustness checks to assess the sensitivity of our findings to alternative specifications of our model. The effect of the treatment was positive and statistically significant when we refined the treated and control areas (employing different distances from the Tigray-Amhara regional border; excluding the westernmost areas of the two regions), when we excluded individual control variables; when we employed a different outcome variable (i.e. the monthly mean of NDVI instead of the monthly maximum of NDVI), and when we applied Sant'Anna and Zhao (2020)'s estimator (see Tables 3.A.7, 3.A.8, and 3.A.6 of the Appendix).

3.7. Mechanisms

The results reported above show that the Tigray LRCP had positive effects on NDVI, both when employing our full dataset and when using a sub-dataset of years where adverse climate and weather events occurred. We argued that these results are indicative of a positive effect of the programme on the three CSA objectives over the landscapes of Tigray.

In the above sections we also pointed out that, due to the nature of our dataset, we are constrained to rely primarily on theory and on the empirical evidence available from the literature to uncover the mechanisms underlying such effects. We hypothesised that the positive effects of the LRCP on the CSA objectives occurred via an increase in tenure security and a consequent increase in CSA adoption.[32] Whilst data limitations prevent us from undertaking a formal causal analysis of such underlying mechanisms, we explore, in this section, the association between NDVI and CSA adoption to gauge the consistency of our main results with the hypothesised mechanisms.

Our choice of CSA strategies is constrained by data availability. In particular, the only official and publicly available source of data at the sub-national level is the Ethiopian Agricultural Census of 2001 (FDRE, 2003).[33] The Census provides information at the *woreda* level on rural holders' adoption of specific agricultural strategies.[34] By combining

[32] Evidence from the literature on the positive effects of the LRCP in Tigray on tenure security and on the adoption of agricultural practices with climate-smart potential is provided in the literature review section (Section 3.2 above); see also Section 3.3 for a detailed description of the underlying channels via which those effects are hypothesised to occur.

[33] Datasets made publicly available by researchers, such as the Ethiopian Rural Household Surveys (ERHS) 1989-2009, have also been explored. However, the ERHS only include two villages in the Tigray region (Geblen and Haresaw), both located in the North-East of the region, very close to the Tigray-Afar regional border and four villages in the Amhara region, three of which are located in the South of the region, and can therefore not be considered as representative of the study area.

[34] Whilst the Central Statistical Agency of Ethiopia conducts agricultural surveys on an annual basis, 2001 represents the only year, within our period of analysis, for which data are available at the *woreda* level (employing the higher zonal or regional administrative levels would not provide sufficient observations for a relevant analysis to be undertaken). For this reason, we are not able to

such data with NDVI values from our dataset, we can investigate, at the *woreda* level, the relationship between NDVI and CSA adoption.

We begin by examining the correlation between NDVI and the proportion of rural holders who planted permanent crops. According to the Agricultural Census, over 98% of rural holders growing permanent crops in Tigray and Amhara also planted temporary crops on their holdings (FDRE, 2003). This implies that close to all rural holders growing permanent crops in Tigray and Amhara were operating an agroforestry type of system, which is indeed a prime example of climate-smart integrated production system (FAO, 2017: module B5; ICRAF, 2019).

When investigating the relationship between NDVI and the proportion of rural holders planting permanent crops, we find a positive correlation between the two variables (column (1) of Table 3.3 and panel a of Appendix Figure 3.A.6). The positive correlation persists when including both time-variant and time-invariant control variables (slope, elevation and weather variables). These results suggest that investment in permanent crop production may indeed be associated with a positive effect on the three CSA objectives.

Yet, we cannot exclude that the permanent crops (trees/shrubs) might have been planted by farmers to secure their farmland, rather than being planted as a result of increased tenure security. The literature on land tenure security and farm-level investments, and in particular tree planting, reveals that a reverse causality may exist between the two variables (Brasselle *et al.*, 2002; Deininger and Jin, 2006; Place, 2009). In particular, due to tenure insecurity, farmers may be prone to plant trees/shrubs at the boundaries of rural holdings (Kassa *et al.*, 2011; Lovo, 2016). Ali *et al.* (2011), however, find reassuring evidence on the direction of causality in the context of Ethiopia. By studying the effects of tenure security on investment in trees/shrubs, they find that tenure security increases investment in coffee and chat, two of the most widely grown permanent crops in Ethiopia.

investigate changes before and after the reform, yet we can still provide evidence of correlation between these types of investment and NDVI to support the mechanism discussed above.

Table 3.3. Correlations between NDVI and CSA adoption

Dependent variable: NDVI	(1)	(2)	(3)	(4)
	Proportion of rural holders with permanent crops	Proportion of rural holders' land area with permanent crops	Number of trees per rural holders' land area	Proportion of rural holders with contour ridges
Without controls	0.159*** (0.054)	1.498** (0.671)	0.003* (0.002)	0.089* (0.050)
With controls:				
Slope and altitude	0.136** (0.058)	1.331** (0.655)	0.003 (0.002)	0.102** (0.048)
Slope, altitude and temperature	0.197*** (0.055)	1.655** (0.612)	0.004** (0.002)	0.071 (0.043)
Slope, altitude, temperature, rainfall	0.149*** (0.050)	1.464*** (0.462)	0.004** (0.002)	-0.017 (0.053)
Slope, altitude, temperature, rainfall and wind speed	0.096* (0.048)	1.036** (0.486)	0.003* (0.001)	-0.049 (0.060)
Observations (*woredas*)	55	43	47	63

Notes: Each coefficient is from a separate regression. Robust standard errors are reported in parentheses. The difference in the number of observations is due to missing data for certain *woredas* and practices in the 2001 Agricultural Census.

As a robustness check, we examine two additional indicators related to permanent crop production, namely the proportion of rural holders' land area planted with permanent crops and the number of planted trees per land area. The use of these complementary indicators strengthens our analysis, as these indicators can also help account for the distribution of trees/shrubs within the holdings. In other words, a higher density of permanent crops (in terms of land area and number of trees) can be indicative of tree/shrub planting within the holding, rather than at its boundaries. The correlations between NDVI and these two additional indicators are shown in columns (2) and (3) of Table 3.3, respectively (see also Appendix Figure 3.A.6 panels b and c for scatterplots illustrating these correlations). These results confirm the presence of a positive and significant correlation between NDVI and investment in permanent crops.

We also explore data on contour ploughing, a CSA strategy that can improve water infiltration and help enhance soil moisture, whilst reducing runoff, soil loss and erosion. Contour ploughing is considered a traditional soil and water conservation practice in Ethiopia (Mushir and Kedru, 2012; Amsalu and de Graaff, 2006), with traditional systems such as *terwah* and *derdero* showing clear benefits in terms of reduced runoff and soil loss (Gebreegziabher *et al.*, 2009; Nyssen *et al.*, 2011) . We find some evidence of a positive correlation between NDVI and the use of contour ridges (column (4) of Table 3.3 and

Appendix Figure 3.A.6 panel d), although the correlation disappears when we control for average rainfall.

In summary, while the information provided in this section is merely suggestive of an association between NDVI and CSA adoption, it is reassuring to observe such a correlation. The presence of a positive relationship between NDVI and CSA adoption is in fact consistent with the mechanisms hypothesised to underlie our main results.

3.8. Conclusions

In this study, we re-examined the land tenure reform undertaken at the end of the 1990s in the Tigray region of Ethiopia. Albeit the effects of this reform have been studied extensively (see, e.g., Ayele and Elias, 2018 for a review), our research complements the existing literature by employing a different source of data, by amplifying the geographic extent of the analysis, and by exploring the effects of the reform on a distinct set of objectives. In particular, this study employed an original panel dataset constructed from EO data to analyse, at a regional scale, the causal effects of the LRCP implemented in Tigray on the Climate Smart Agriculture (CSA) objectives. By applying a difference-in-differences strategy, we found that the LRCP contributed to progress on the CSA objectives.

These findings have relevant implications for both research and policy. They confirm and extend earlier findings from household-level surveys on the positive effects of the LRCP, specifying that such effects appear to have occurred at a regional scale on measures of productivity, climate change adaptation and climate change mitigation. As such, they provide a first empirical validation of the linkages between tenure reforms and the CSA objectives, thereby suggesting that land tenure reform programmes can play an important role in generating an enabling environment for CSA and in supporting the achievement of rural development objectives, including objectives associated with climate change. This is particularly encouraging for policymakers given that CSA objectives were not embedded in the original goals of land reformers in Ethiopia. In other words, further scope for enhancing sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation by means of a land tenure reform exists. Land reformers can, for instance, ensure that participatory spaces are adequately set-up during the design of a tenure reform to engage with farmers (among other stakeholders) and subsequently prioritise interventions that are the most demanded and likely to incentivise farmers to adopt CSA strategies.

This research also confirms the importance of remote sensing satellite-based data for research and policy. EO data can prove a valuable source of data to analyse the effects of a policy on areas of interest. Such data can be particularly useful when other data sources, such as household-level surveys or census are scarce, do not comprise sets of relevant variables for the research questions at hand and/or may be prone to measurement error. The increased range of EO data consistently available at a high temporal and spatial resolution, developments in computing power and machine learning, as well as advances in modelled 'ready-to-use' data products, offer growing opportunities for the use of such data in social science research and policy.

Indeed, this study is not immune to limitations. First, the NDVI can only be considered as a proxy for agricultural productivity and climate change mitigation. Although the evidence provided in this paper, combined with previous findings from the literature, supports the validity of NDVI as a measure of agricultural productivity and carbon uptake, more refined indicators of agricultural productivity and of greenhouse gas emissions/carbon sequestration could be investigated to corroborate or refute the results from this study. Second, additional quantitative and/or qualitative localised data sourced, for instance, from regionally representative household-level surveys and/or focus group discussions could be combined with remote sensing data to provide a deeper understanding on the various contextual factors surrounding the effects of the land tenure reform programme. In particular, these could help examine the underlying channels leading to the effects of the reform on the CSA objectives (i.e. increased tenure security and CSA adoption). In this study, data limitations prevented us from carrying out a formal causal analysis of these underlying mechanisms.[35] Finally, the research could be spatially and temporally extended to investigate the effects of the reform beyond the Tigray region and beyond 2004. This would require more precise information compared to what we were able to obtain on the specific dates and specific location of the implementation of the reform across the other regions of Ethiopia. We hope that the above elements can translate into valuable inputs for the realisation of further research.

[35] Due to the nature of our dataset, we were constrained to rely primarily on the conceptual framework and on the available empirical literature to uncover these mechanisms. Nonetheless, we also found reassuring evidence of a correlation between NDVI and CSA adoption (Section 3.7), suggesting that our main results are indeed consistent with the outlined theory and with the empirical literature examining the effects of the LRCP in Tigray on tenure security and adoption of agricultural practices with climate-smart potential.

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Appendix 3.A. Additional tables and figures

Table 3.A.1. Summary statistics

		Pre-treatment period (1991-1998)						Post-treatment period (1999-2004)						All dates (1991-2004)					
		All pixels		**Amhara_area**		**Tigray_area**		**All pixels**		**Amhara_area**		**Tigray_area**		**All pixels**		**Amhara_area**		**Tigray_area**	
		mean	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
NDVI	January	0.35	0.08	0.37	0.08	0.34	0.07	0.37	0.08	0.38	0.08	0.36	0.08	0.36	0.08	0.37	0.09	0.35	0.08
	February	0.31	0.07	0.32	0.07	0.31	0.07	0.33	0.08	0.34	0.08	0.32	0.07	0.32	0.07	0.33	0.08	0.31	0.07
	March	0.30	0.08	0.31	0.08	0.29	0.08	0.30	0.07	0.31	0.07	0.29	0.07	0.30	0.08	0.31	0.08	0.29	0.07
	April	0.30	0.09	0.31	0.09	0.30	0.08	0.30	0.08	0.31	0.08	0.29	0.07	0.30	0.08	0.31	0.09	0.29	0.08
	May	0.36	0.09	0.37	0.09	0.34	0.09	0.34	0.08	0.35	0.09	0.33	0.07	0.35	0.09	0.36	0.09	0.34	0.08
	June	0.40	0.13	0.42	0.14	0.38	0.12	0.37	0.13	0.39	0.15	0.35	0.11	0.38	0.13	0.40	0.15	0.37	0.11
	July	0.48	0.15	0.51	0.16	0.45	0.14	0.50	0.16	0.52	0.16	0.47	0.14	0.49	0.16	0.51	0.16	0.46	0.14
	August	0.59	0.13	0.61	0.13	0.56	0.13	0.60	0.12	0.62	0.12	0.58	0.12	0.59	0.13	0.61	0.13	0.57	0.12
	September	0.62	0.13	0.64	0.13	0.61	0.13	0.64	0.12	0.65	0.11	0.63	0.11	0.63	0.12	0.65	0.12	0.62	0.12
	October	0.56	0.14	0.58	0.14	0.54	0.13	0.58	0.14	0.59	0.15	0.57	0.13	0.57	0.14	0.59	0.14	0.56	0.13
	November	0.47	0.11	0.49	0.12	0.45	0.10	0.50	0.12	0.52	0.13	0.48	0.11	0.48	0.12	0.51	0.12	0.46	0.11
	December	0.41	0.10	0.43	0.10	0.40	0.09	0.41	0.10	0.42	0.10	0.39	0.09	0.41	0.10	0.43	0.10	0.40	0.09
	Annual avg.	**0.43**	**0.16**	**0.45**	**0.16**	**0.41**	**0.15**	**0.44**	**0.16**	**0.45**	**0.17**	**0.42**	**0.15**	**0.43**	**0.16**	**0.45**	**0.16**	**0.42**	**0.15**
observations		**96768**		**48384**		**48384**		**72576**		**36288**		**36288**		**169344**		**84672**		**84672**	

Table 3.A.1 (*Continued*). Summary statistics

		Pre-treatment period (1991-1998)						Post-treatment period (1999-2004)						All dates (1991-2004)					
		All pixels		**Amhara_area**		**Tigray_area**		**All pixels**		**Amhara_area**		**Tigray_area**		**All pixels**		**Amhara_area**		**Tigray_area**	
		mean	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
Precipitation (mm)	January	7.50	9.53	9.67	11.61	5.33	6.11	7.00	8.06	8.73	9.75	5.26	5.36	7.28	8.93	9.27	10.86	5.30	5.80
	February	8.25	10.13	11.26	11.99	5.23	6.56	6.34	7.22	8.54	8.22	4.15	5.19	7.43	9.04	10.09	10.63	4.77	6.04
	March	27.71	28.15	32.81	31.75	22.60	22.91	20.09	24.10	24.61	28.07	15.56	18.25	24.44	26.76	29.29	30.50	19.59	21.32
	April	42.47	34.94	48.20	37.39	36.75	31.29	32.70	26.28	38.00	27.74	27.40	23.58	38.28	31.89	43.83	33.97	32.74	28.62
	May	76.26	38.36	83.91	41.75	68.60	32.91	35.42	25.09	42.37	30.02	28.47	16.18	58.76	38.98	66.11	42.48	51.40	33.55
	June	111.18	75.69	114.74	76.47	107.63	74.74	105.73	69.11	111.58	72.69	99.87	64.81	108.84	72.99	113.38	74.89	104.30	70.75
	July	240.31	66.73	257.22	67.01	223.39	62.00	267.43	73.76	287.93	67.90	246.94	73.70	251.93	71.10	270.38	69.08	233.48	68.26
	August	263.90	76.01	275.32	66.08	252.48	83.24	291.99	67.38	303.97	52.93	280.01	77.42	275.94	73.76	287.60	62.42	264.28	81.93
	September	98.84	67.46	103.88	65.41	93.80	69.10	102.40	74.26	110.71	72.48	94.09	75.10	100.36	70.48	106.80	68.61	93.93	71.72
	October	40.04	38.02	49.64	43.45	30.44	28.64	40.93	40.33	51.76	47.40	30.10	27.79	40.42	39.03	50.55	45.19	30.29	28.28
	November	14.77	12.61	17.04	14.24	12.50	10.25	9.67	6.91	11.51	8.04	7.83	4.90	12.58	10.85	14.67	12.29	10.50	8.70
	December	6.05	7.24	7.41	8.49	4.70	5.40	5.93	6.67	7.64	7.82	4.22	4.68	6.00	7.00	7.51	8.21	4.49	5.11
	Annual avg.	**78.11**	**96.84**	**84.26**	**99.90**	**71.95**	**93.27**	**77.13**	**106.33**	**83.94**	**110.02**	**70.33**	**102.06**	**77.69**	**101.01**	**84.12**	**104.36**	**71.26**	**97.13**
observations		**96768**		**48384**		**48384**		**72576**		**36288**		**36288**		**169344**		**84672**		**84672**	

Table 3.A.1 (*Continued*). Summary statistics

		Pre-treatment period (1991-1998)						**Post-treatment period (1999-2004)**						**All dates (1991-2004)**					
		All pixels		**Amhara_area**		**Tigray_area**		**All pixels**		**Amhara_area**		**Tigray_area**		**All pixels**		**Amhara_area**		**Tigray_area**	
		mean	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**	**mean**	**sd**
Temperature (°C)	January	19.74	4.80	19.46	5.02	20.03	4.54	19.99	4.83	19.71	5.05	20.27	4.59	19.85	4.81	19.56	5.03	20.13	4.56
	February	20.64	4.70	20.35	4.92	20.93	4.44	21.67	5.11	21.31	5.31	22.03	4.88	21.08	4.91	20.76	5.11	21.40	4.66
	March	22.23	4.98	21.76	5.23	22.71	4.66	22.66	5.16	22.17	5.40	23.15	4.86	22.42	5.06	21.93	5.31	22.90	4.75
	April	23.37	5.31	22.60	5.55	24.15	4.95	23.70	5.34	22.94	5.60	24.46	4.95	23.51	5.33	22.75	5.58	24.28	4.95
	May	23.11	4.71	22.22	4.98	24.00	4.25	24.74	4.68	23.88	4.98	25.60	4.19	23.81	4.77	22.93	5.05	24.68	4.30
	June	22.17	3.87	21.35	4.34	23.00	3.13	22.80	4.07	21.85	4.51	23.74	3.31	22.44	3.97	21.56	4.42	23.32	3.23
	July	19.39	3.53	18.72	4.05	20.06	2.77	20.13	3.91	19.31	4.36	20.94	3.21	19.70	3.72	18.97	4.20	20.44	3.00
	August	19.15	3.45	18.51	3.98	19.78	2.68	19.68	3.60	18.96	4.12	20.41	2.82	19.38	3.52	18.71	4.04	20.05	2.76
	September	20.25	3.80	19.44	4.23	21.06	3.12	21.12	3.98	20.18	4.37	22.06	3.28	20.62	3.90	19.76	4.30	21.49	3.23
	October	19.90	4.61	19.12	4.89	20.68	4.17	21.20	4.86	20.31	5.07	22.09	4.46	20.46	4.76	19.63	5.00	21.29	4.35
	November	19.65	5.01	19.09	5.27	20.20	4.68	20.67	5.33	20.02	5.57	21.32	4.98	20.09	5.17	19.49	5.42	20.68	4.84
	December	19.52	5.03	19.13	5.25	19.90	4.76	20.00	5.02	19.60	5.26	20.41	4.74	19.73	5.03	19.33	5.26	20.12	4.76
	Annual avg.	**20.76**	**4.76**	**20.15**	**5.03**	**21.38**	**4.38**	**21.53**	**4.94**	**20.85**	**5.21**	**22.21**	**4.56**	**21.09**	**4.85**	**20.45**	**5.12**	**21.73**	**4.48**
observations		**96768**		**48384**		**48384**		**72576**		**36288**		**36288**		**169344**		**84672**		**84672**	

Table 3.A.1 (*Continued*). Summary statistics

		Pre-treatment period (1991-1998)						Post-treatment period (1999-2004)						All dates (1991-2004)					
		All pixels		Amhara_area		Tigray_area		All pixels		Amhara_area		Tigray_area		All pixels		Amhara_area		Tigray_area	
		mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd	mean	sd
Wind speed (m/s)	January	1.60	0.35	1.58	0.39	1.62	0.31	1.62	0.30	1.60	0.34	1.63	0.26	1.61	0.33	1.59	0.37	1.62	0.29
	February	1.62	0.38	1.62	0.40	1.62	0.35	1.81	0.28	1.79	0.31	1.84	0.24	1.70	0.35	1.69	0.38	1.71	0.33
	March	1.72	0.39	1.68	0.41	1.75	0.37	1.86	0.37	1.79	0.39	1.93	0.33	1.78	0.39	1.73	0.41	1.83	0.36
	April	1.77	0.44	1.75	0.49	1.80	0.38	1.92	0.40	1.89	0.44	1.94	0.36	1.84	0.43	1.81	0.47	1.86	0.38
	May	1.91	0.40	1.87	0.45	1.95	0.35	2.05	0.36	2.00	0.40	2.10	0.31	1.97	0.39	1.93	0.43	2.01	0.34
	June	1.86	0.36	1.76	0.40	1.95	0.28	1.95	0.38	1.83	0.43	2.06	0.28	1.90	0.37	1.79	0.41	2.00	0.29
	July	1.71	0.44	1.63	0.50	1.79	0.34	1.76	0.46	1.70	0.53	1.82	0.37	1.73	0.45	1.66	0.52	1.80	0.35
	August	1.60	0.39	1.47	0.45	1.73	0.28	1.70	0.42	1.59	0.48	1.80	0.33	1.64	0.41	1.53	0.46	1.76	0.30
	September	1.60	0.35	1.52	0.40	1.67	0.27	1.55	0.33	1.52	0.40	1.59	0.24	1.58	0.35	1.52	0.40	1.64	0.26
	October	1.81	0.33	1.73	0.39	1.89	0.25	1.82	0.42	1.78	0.45	1.87	0.38	1.81	0.37	1.75	0.42	1.88	0.31
	November	1.51	0.36	1.47	0.38	1.55	0.33	1.67	0.27	1.68	0.29	1.67	0.23	1.58	0.33	1.56	0.36	1.60	0.30
	December	1.46	0.36	1.47	0.37	1.45	0.34	1.48	0.30	1.50	0.32	1.46	0.26	1.47	0.33	1.48	0.35	1.46	0.31
	Annual avg.	**1.68**	**0.40**	**1.63**	**0.44**	**1.73**	**0.36**	**1.77**	**0.40**	**1.72**	**0.43**	**1.81**	**0.35**	**1.72**	**0.40**	**1.67**	**0.44**	**1.76**	**0.36**
observations		**96768**		**48384**		**48384**		**72576**		**36288**		**36288**		**169344**		**84672**		**84672**	

Notes: The table contains summary statistics (mean and standard deviation “sd”) of the outcome variable (NDVI) and of the control variables (precipitation, temperature and wind speed) included in the preferred specification of the model presented in Section 3.5 (equation (1)). Both monthly and annual averages are provided, by treatment area (Amhara area, the never treated area, and Tigray, the treated area after 1998, as well as the combined area including all pixels in the Amhara area and in the Tigray area), and by treatment period (pre-treatment period and post-treatment period, as well as the combined period including the entire timeframe of the study).

Table 3.A.2. Effects of the LRCP on NDVI: Results of robustness checks

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: NDVI	Incl. Annual trend	75km from border	50km from border	25km from border	Excl. temperature	Excl. rainfall	Excl. wind speed	Excl. westernmost areas
ATT	0.011***	0.008***	0.008***	0.007***	0.008***	0.010**	0.008***	0.009***
	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)	(0.002)	(0.002)
Pixel FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NDVI mean (st. dev.)	0.433 (0.137)	0.442 (0.140)	0.445 (0.140)	0.444 (0.140)	0.433 (0.137)	0.433 (0.137)	0.433 (0.137)	0.412 (0.118)
Observations (pixels)	169,344 (1,008)	131,208 (781)	88,536 (527)	41,328 (246)	169,344 (1,008)	169,344 (1,008)	169,344 (1,008)	125,160 (745)

Notes: Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1%, ** at 5% level. Controls include temperature, temperature squared, precipitation, precipitation squared, and wind speed, as well as an interaction between these variables for columns (1) to (4) and column (8); columns (5), (6) and (7) report results when omitting temperature, rainfall, and wind speed from the set of control variables, respectively. Column (8) reports results excluding pixels falling in the westernmost areas of each region (i.e. below 38-degree longitude for Tigray and below 37-degree longitude for Amhara).

Table 3.A.3. Effects of the LRCP on NDVI: Results of robustness checks with alternative outcome variable

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: NDVI (mean)	Incl. Annual trend	75km from border	50km from border	25km from border	Excl. temperature	Excl. rainfall	Excl. wind speed	Excl. westernmost areas
ATT	0.010***	0.008***	0.007***	0.008***	0.007***	0.009**	0.007***	0.007***
	(0.003)	(0.002)	(0.002)	(0.002)	(0.001)	(0.004)	(0.002)	(0.002)
Pixel FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NDVI mean (st. dev.)	0.410 (0.129)	0.418 (0.132)	0.421 (0.133)	0.421 (0.133)	0.410 (0.129)	0.410 (0.129)	0.410 (0.129)	0.390 (0.111)
Observations (pixels)	169,344 (1,008)	131,208 (781)	88,536 (527)	41,328 (246)	169,344 (1,008)	169,344 (1,008)	169,344 (1,008)	125,160 (745)

Notes: Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1%, ** at 5% level. Controls include temperature, temperature squared, precipitation, precipitation squared, and wind speed, as well as an interaction between these variables for columns (1) to (4) and column (8); columns (5), (6) and (7) report results when omitting temperature, rainfall, and wind speed from the set of control variables, respectively. Column (8) reports results excluding pixels falling in the westernmost areas of each region (i.e. below 38-degree longitude for Tigray and below 37-degree longitude for Amhara).

Table 3.A.4. Correlations between NDVI and agricultural productivity

	Cereals yields		Grains yields		Temporary crops yields	
	(1)	(2)	(3)	(4)	(5)	(6)
NDVI	2.153***	2.698***	1.892***	2.375***	1.899***	2.326***
	(0.432)	(0.448)	(0.426)	(0.460)	(0.424)	(0.478)
Region FE	No	Yes	No	Yes	No	Yes
Observations: *woredas*	63	63	63	63	63	63

Notes: Data on agricultural productivity (crop yields) are from the 2001 Ethiopian Agricultural Census (FDRE, 2003). Cereal yields correspond to the average production of all cereals (in quintals) per hectare; Grains yields include, beyond yields of cereals, also yields of pulses and of oilseeds; Temporary crops include, beyond yields of grains, also yields of vegetables and of root crops. All measures of yields were log-transformed prior to estimation to facilitate interpretation. Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1% level.

Table 3.A.5. Correlations between NDVI and Net Primary Productivity (NPP)

Datasets (years)	NPP_WaPOR (2009-2013)				NPP_MODIS (2001-2013)			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
NDVI	5.386***	5.382***	5.341***	5.933***	4.606***	4.590***	4.516***	5.682***
	(0.137)	(0.137)	(0.137)	(0.143)	(0.214)	(0.215)	(0.213)	(0.224)
Year FE	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Region FE	No	No	Yes	Yes	No	No	Yes	Yes
Pixel FE	No	No	No	Yes	No	No	No	Yes
Observations (*woredas*)	60,480 (71)	60,480 (71)	60,480 (71)	60,480 (71)	157,248 (71)	157,248 (71)	157,248 (71)	157,248 (71)

Notes: In columns (1) to (4) data on NPP are from the FAO Water Productivity Open Access Portal (WaPOR) (FAO, 2020), which are available from the year 2009. In columns (5) to (8) data on NPP are from the MODIS Terra dataset (Running *et al.*, 2015), which are available from the year 2001. Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1% level.

Table 3.A.6. Results from the use of the 'doubly-robust' DiD estimator

	(1)	(2)
Dependent variable: NDVI	Full dataset	Sub-dataset (PDSI-based)
ATT	0.009***	0.009***
	(0.003)	(0.003)
NDVI mean (st. dev.)	0.433 (0.137)	0.429 (0.133)
Observations (pixels)	169,344 (1,008)	108,864 (1,008)

Notes: The estimates are calculated using the doubly robust DiD estimator from Sant'Anna and Zhao (2020). Sub-dataset contains the years where adverse dry/wet conditions were identified, based on the PDSI data. Standard errors (in parentheses) are clustered at the *woreda* level. *** indicates significance at 1% level.

Table 3.A.7. Effects of the LRCP on NDVI (climate change adaptation sub-dataset): Results of robustness checks

Sub-dataset (PDSI-based)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: NDVI	Incl. Annual trend	75km from border	50km from border	25km from border	Excl. temperature	Excl. rainfall	Excl. wind speed	Excl. westernmost areas
ATT	0.013***	0.009***	0.008**	0.007*	0.009***	0.013**	0.010***	0.010***
	(0.004)	(0.002)	(0.003)	(0.003)	(0.002)	(0.005)	(0.002)	(0.002)
Pixel FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NDVI mean (st. dev.)	0.429 (0.133)	0.437 (0.136)	0.441 (0.136)	0.440 (0.137)	0.429 (0.133)	0.429 (0.133)	0.429 (0.133)	0.409 (0.114)
Observations (pixels)	108,864 (1,008)	84,348 (781)	56,916 (527)	26,568 (246)	108,864 (1,008)	108,864 (1,008)	108,864 (1,008)	80,460 (745)

Notes: Sub-dataset contains the years where adverse dry/wet conditions were identified, based on the PDSI data. Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1%, ** at 5%, * at 10% level. Controls include temperature, temperature squared, precipitation, precipitation squared, and wind speed, as well as an interaction between these variables for columns (1) to (4) and column (8); columns (5), (6) and (7) report results when omitting temperature, rainfall, and wind speed from the set of control variables, respectively. Column (8) reports results excluding pixels falling in the westernmost areas of each region (i.e. below 38-degree longitude for Tigray and below 37-degree longitude for Amhara).

Table 3.A.8. Effects of the LRCP on NDVI (climate change adaptation sub-dataset): Results of robustness checks with alternative outcome variable

Sub-dataset (PDSI-based)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable: NDVI (mean)	Incl. Annual trend	75km from border	50km from border	25km from border	Excl. Temperature	Excl. Rainfall	Excl. wind speed	Excl. westernmost areas
ATT	0.012**	0.008***	0.007**	0.007*	0.007***	0.011**	0.008***	0.007***
	(0.005)	(0.003)	(0.003)	(0.004)	(0.002)	(0.005)	(0.002)	(0.002)
Pixel FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Month-Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
NDVI mean	0.405	0.413	0.417	0.416	0.405	0.405	0.405	0.386
(st. dev.)	(0.124)	(0.128)	(0.128)	(0.129)	(0.124)	(0.124)	(0.124)	(0.106)
Observations	108,864	84,348	56,916	26,568	108,864	108,864	108,864	80,460
(pixels)	(1,008)	(781)	(527)	(246)	(1,008)	(1,008)	(1,008)	(745)

Notes: Sub-dataset contains the years where adverse dry/wet conditions were identified, based on the PDSI data. Standard errors (in parentheses) are clustered at the *woreda* level. *** Indicates significance at 1%, ** at 5%, * at 10% level. Controls include temperature, temperature squared, precipitation, precipitation squared, and wind speed, as well as an interaction between these variables for columns (1) to (4) and column (8); columns (5), (6) and (7) report results when omitting temperature, rainfall, and wind speed from the set of control variables, respectively. Column (8) reports results excluding pixels falling in the westernmost areas of each region (i.e. below 38-degree longitude for Tigray and below 37-degree longitude for Amhara).

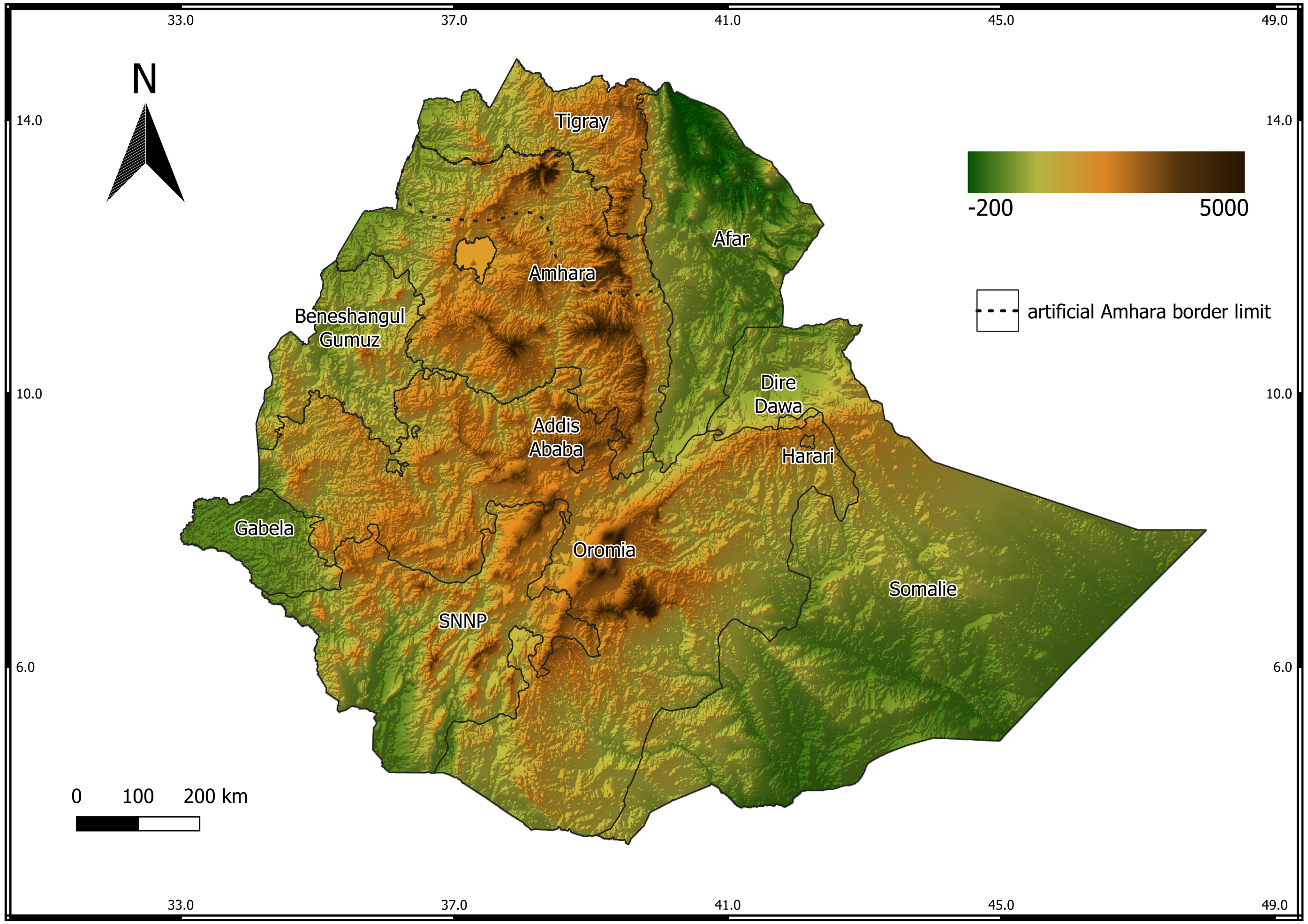

Figure 3.A.1. Elevation (meters above sea level) across Ethiopia

Source: Authors, based on Shuttle Radar Topography Mission (SRTM) digital elevation data (Farr *et al.*, 2007)

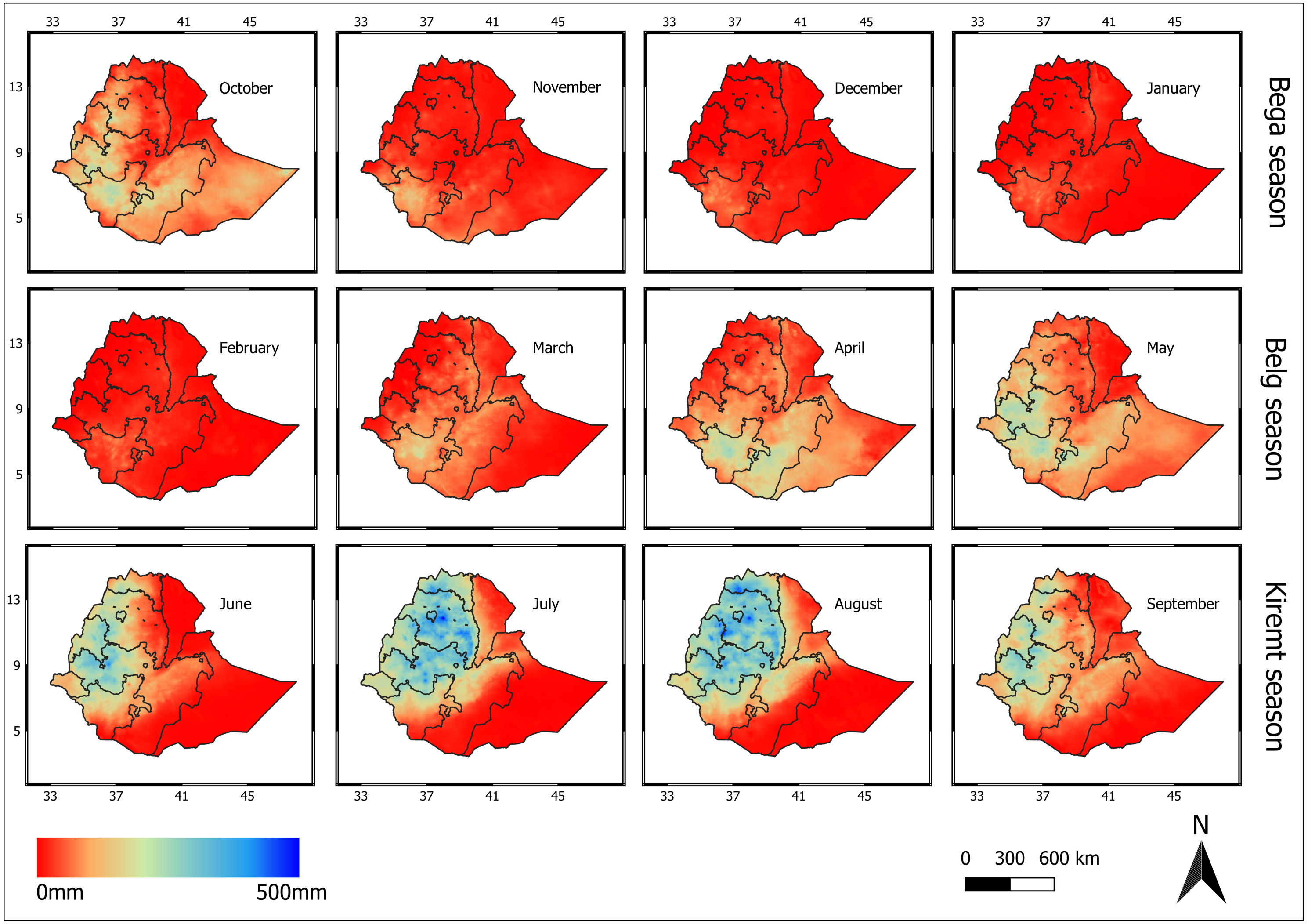

Figure 3.A.2. Monthly rainfall (in mm) across Ethiopia: 1991-2004 average

Source: Authors based on Climate Hazards Group InfraRed Precipitation with Station Data (CHIRPS) data (Funk *et al*., 2015a)

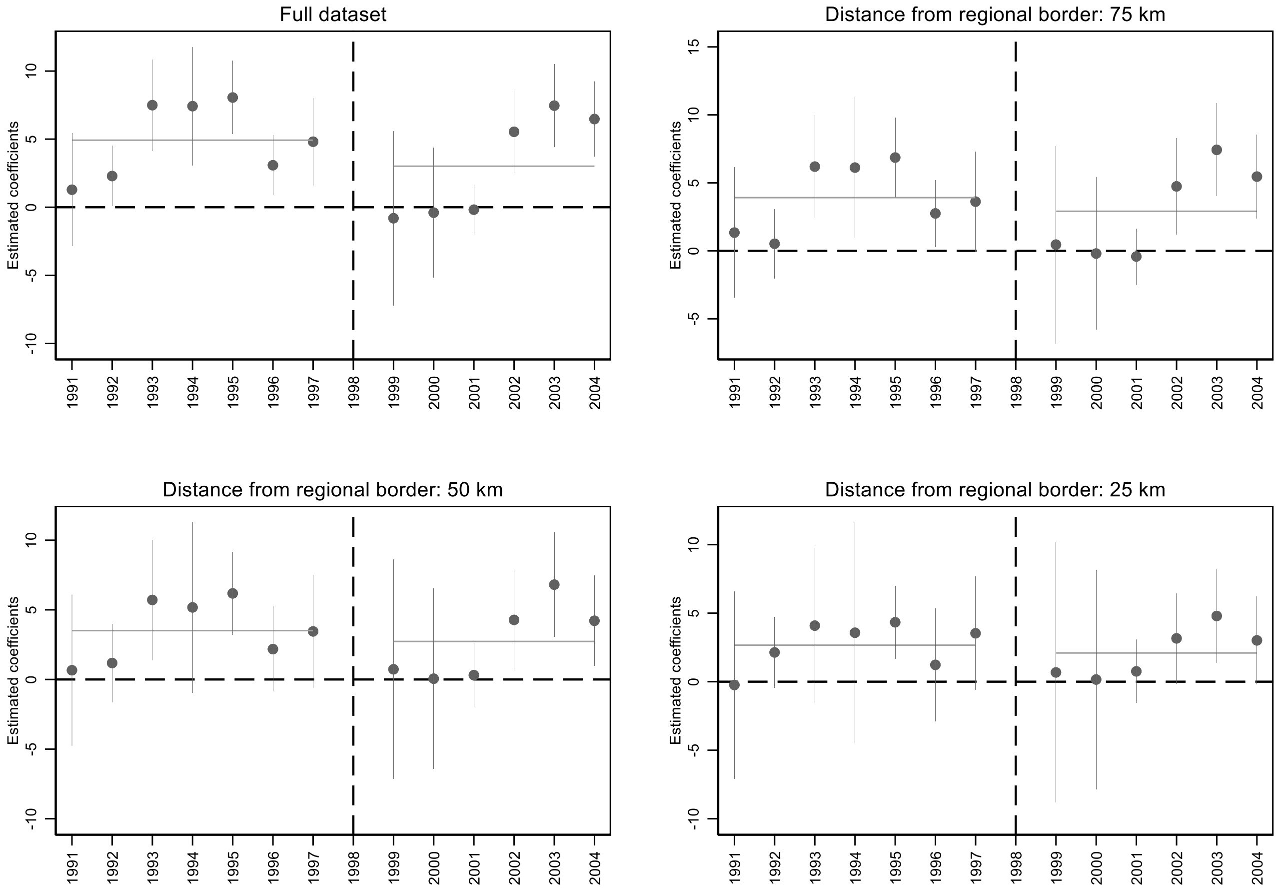

Figure 3.A.3. Results from event study with precipitation as dependent variable

Notes: The coefficients are obtained from the estimation of event studies with precipitation as an outcome variable regressed on the treatment indicator (interacted with year dummy variables) and without controls. Standard errors are clustered at the *woreda* level, and the vertical bars represent 90% confidence intervals. Each panel corresponds to the results from the estimations based on different distances from the Tigray-Amhara regional border.

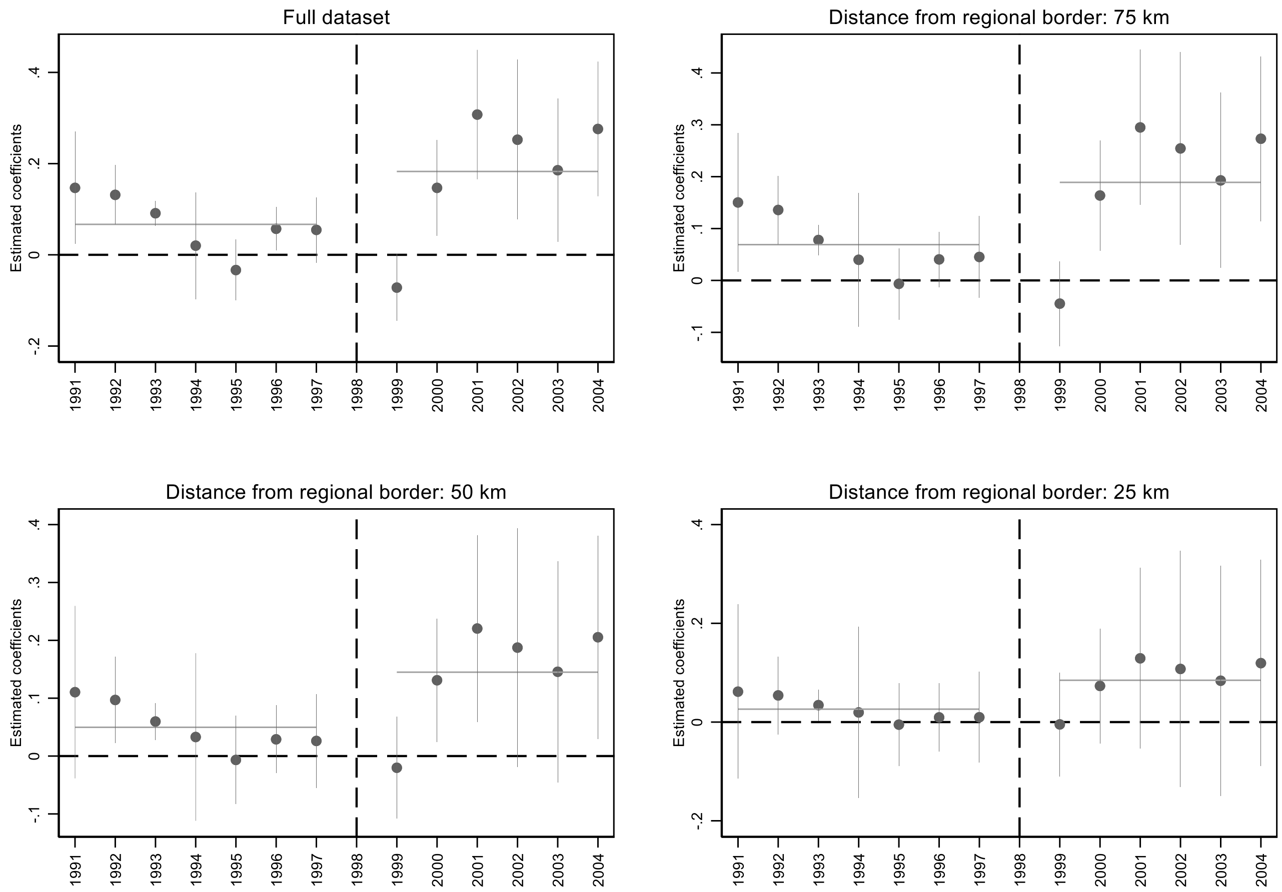

Figure 3.A.4. Results from event study with temperature as dependent variable

Notes: The coefficients are obtained from the estimation of event studies with temperature as an outcome variable regressed on the treatment indicator (interacted with year dummy variables) and without controls. Standard errors are clustered at the *woreda* level, and the vertical bars represent 90% confidence intervals. Each panel corresponds to the results from the estimations based on different distances from the Tigray-Amhara regional border.

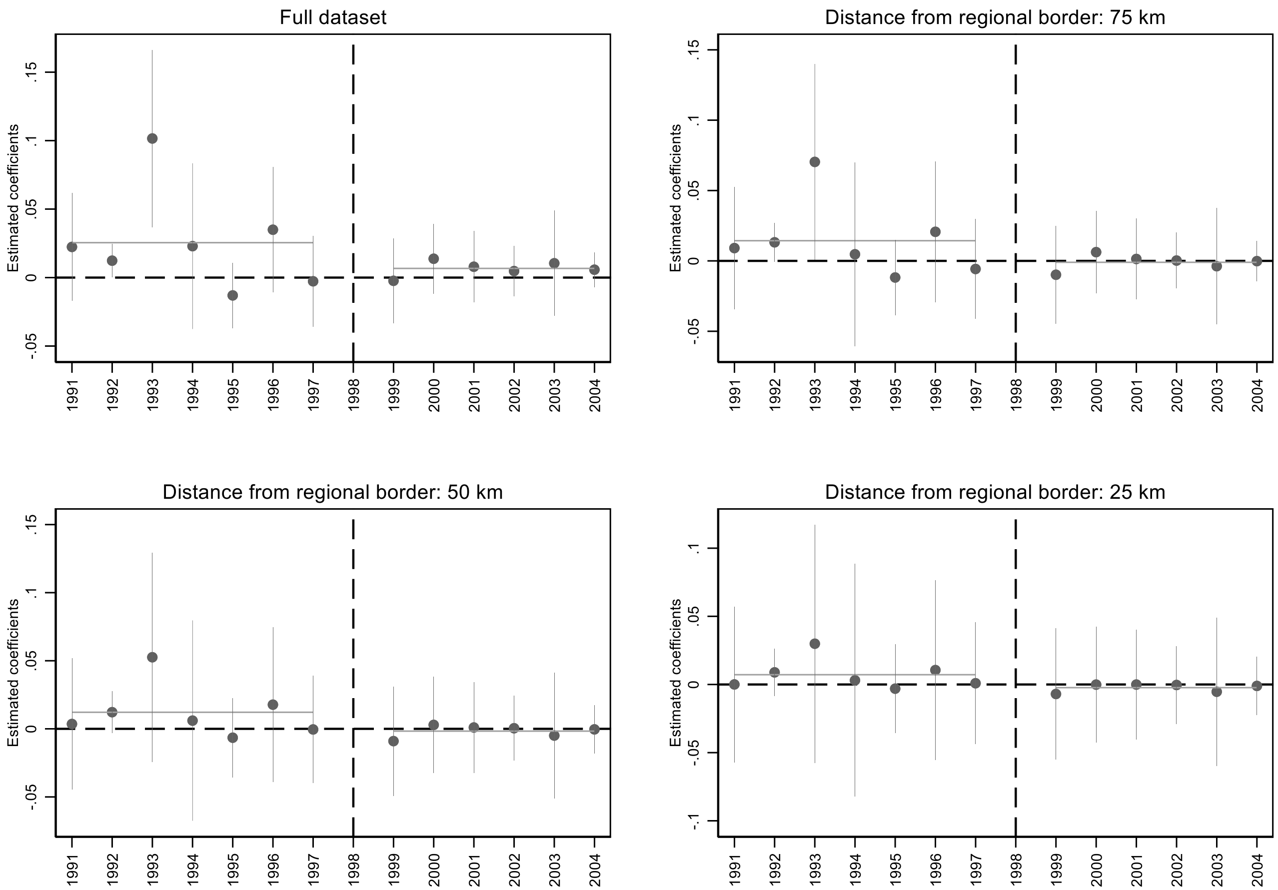

Figure 3.A.5. Results from event study with wind speed as dependent variable

Notes: The coefficients are obtained from the estimation of event studies with wind speed as an outcome variable regressed on the treatment indicator (interacted with year dummy variables) and without controls. Standard errors are clustered at the *woreda* level, and the vertical bars represent 90% confidence intervals. Each panel corresponds to the results from the estimations based on different distances from the Tigray-Amhara regional border.

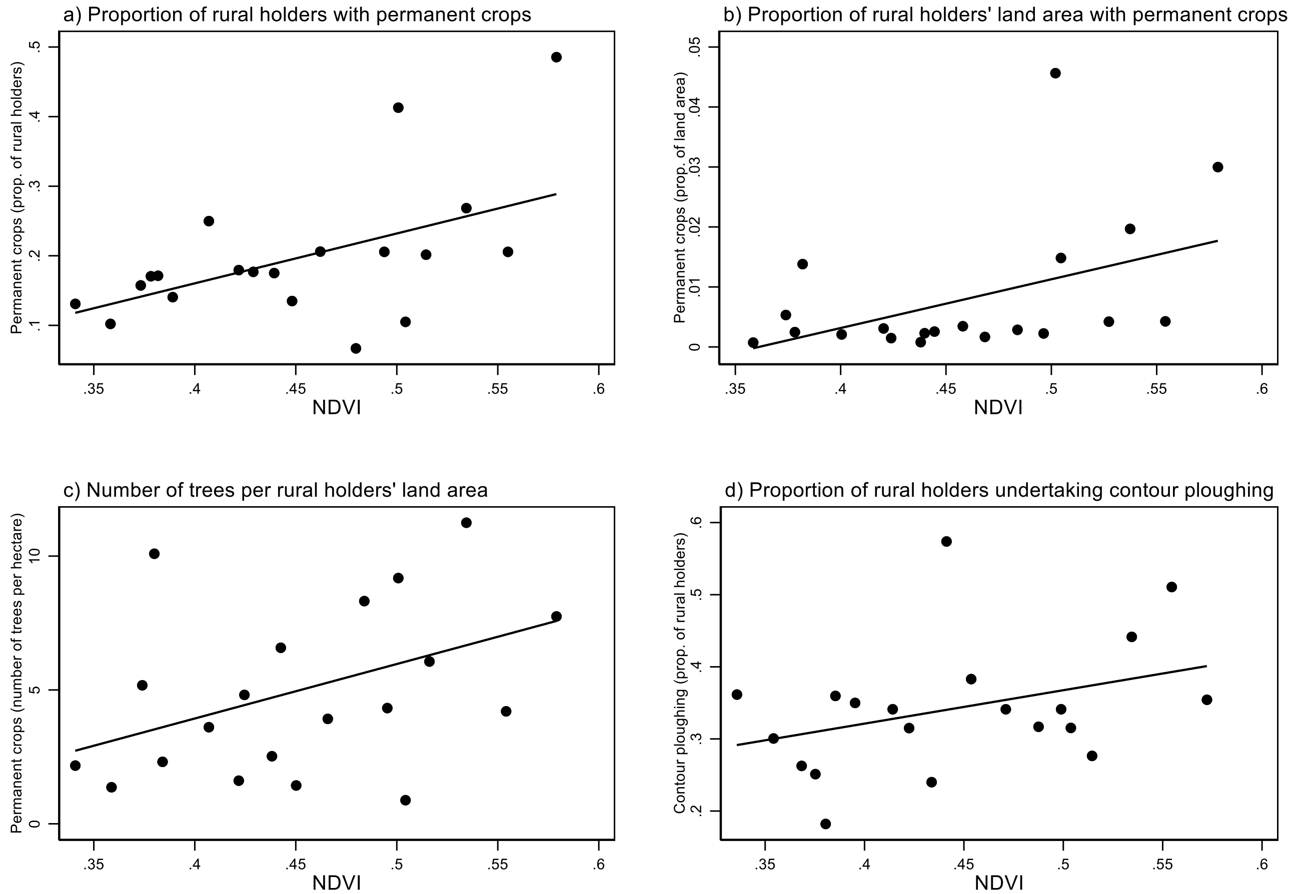

Figure 3.A.6. Correlations between NDVI and CSA strategies

Notes: All four panels of the figure are obtained with data from AVHRR NDVI 3g (Pinzon and Tucker, 2014) and from the Ethiopian Agricultural Census of 2001 (FDRE, 2003); 20 equal-size bins are used for the variable NDVI.

Chapter 4. Land reform in South Africa – laudable intentions, implementation challenges, and opportunities for Climate Smart Agriculture[1]

Abstract

This study examines the South African land reform launched at the dawn of post-apartheid democratisation. The first part of the study provides a background on the land reform. A historical summary of the land dispossessions and administrative control suffered by Africans, first under settler colonisation and subsequently under apartheid, describes the process that led to the land reform. With post-apartheid democratisation, an ambitious land reform programme was launched to redress past injustices, contribute to political stability, and provide a pathway towards sustainable rural development in South Africa. The programme encompasses restitution of rights to the land lost due to racially discriminatory laws and practices, equitable redistribution of land, and tenure reform to ensure legally secure land tenure. As the land reform was being launched, emphasis was also made on the importance of providing post-settlement support, including Rural Advisory Services (RAS), to the beneficiary farmers to enable land 'gainers' to contribute to the development of a more sustainable agricultural system. A critical analysis comparing land reformers' initial intentions with the actual implementation of the reform shows that several implementation challenges, including inadequate measures for the restitution and redistribution of land, and severe deficiencies in the provision of support services to land reform participants have limited the reform's success. The second part of the study builds on these findings and employs a conceptual framework associating land reform and Climate Smart Agriculture (CSA) and secondary data from a cross-sectional survey of farm-households to investigate possible correlations between the South African land reform and CSA adoption. The results from the estimation of binary response models show that land redistribution participation is associated with a higher likelihood of adopting CSA, but only in the absence of RAS. These results are in line with the conceptual framework's hypothesis that land redistribution can positively affect CSA adoption, but they also challenge the expected positive complementary effect of RAS in stimulating CSA adoption. The overall findings of this study support long-awaited policy shifts in South Africa's land redistribution programme towards a more radical demand-led subdivision of farmland favouring landless and land-poor farmers and underscore the need to enhance efforts to improve the RAS system for land reform participants.

[1] An abridged version of this chapter has been submitted to an academic journal for publication and is currently under review.

4.1. Introduction

The strong interconnection between climate change and agriculture posits increased emphasis on the need to transition towards sustainable agricultural approaches. The agricultural sector is a significant contributor of global greenhouse gas emissions (Dhakal *et al.*, 2022) and at the same time one of the sectors most vulnerable to the adverse effects of climate change (Bezner Kerr *et al.*, 2022). Sustainable agricultural approaches are therefore required to minimise the environmental impacts of agriculture and help make agricultural systems more resilient to the adverse effects of climate change. Climate Smart Agriculture (CSA) is an outcome-oriented approach to sustainable agriculture that seeks to achieve sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation (FAO, 2017). CSA can therefore help guide the required transformation of agricultural systems in an era of climate change. Since the emergence of the CSA concept in 2009 (FAO, 2009), extensive research has been conducted to study factors that can stimulate CSA adoption (e.g. Arslan *et al.*, 2015; Asfaw *et al.*, 2016a; 2016b; Kpadonou *et al.*, 2017; Makate *et al.*, 2019; Westermann *et al.*, 2018). Several articles and reports suggesting pathways for CSA implementation and for scaling CSA adoption have also been produced. These have highlighted that policy interventions and institutional levers are crucial for the development of an enabling environment that can stimulate CSA adoption (FAO, 2010; 2017; 2021; Harvey *et al.*, 2014; Loboguerrero *et al.*, 2018). Among such interventions, land reforms have received little attention despite their potential to generate beneficial effects in terms of equity and efficiency, and at the same time to stimulate CSA adoption and thereby enhance environmental sustainability (Rampa *et al.*, 2020). In fact, empirical evidence on the linkages between land reforms and CSA adoption is extremely scant. Whilst a few articles have reported the importance of land tenure security in their analyses of drivers of (or barriers to) CSA adoption (Akrofi-Atitianti *et al.*, 2018; Asfaw *et al.*, 2014; 2016a; Kpadonou *et al.*, 2017; Teklewold *et al.*, 2019), so far no study appears to have explicitly examined the linkages between land reforms and CSA adoption.[2]

[2] In addition, most of the studies that included measures of land tenure security as explanatory variables in their analyses of drivers of (or barriers to) CSA adoption employed a simplified indicator of tenure security, namely land ownership, and did not therefore consider interventions such as land reforms that may have affected tenure security. Whilst to the best of the author's knowledge no published work is available on land reforms and CSA adoption, there do exist various studies considering the relationship between land tenure reform and adoption of specific agricultural practices with climate-smart potential (for recent reviews that investigate the effects of land tenure reforms, including on agricultural investments with climate-smart potential see, for instance, Higgins *et al.* (2018), Lawry *et al.* (2017), Tseng *et al.* (2021)).

The South African context provides a particularly interesting case to examine such relationships.

Climate change is already being felt across South Africa, with average temperatures having increased by approximately 0.6 degrees Celsius between 1960 and 2006, an average of 0.14 degrees Celsius per decade, and projected to further increase by 1.6-4.3 degrees Celsius by the 2090s (Karmalkar *et al.*, 2010; Mcsweeney *et al.*, 2010). In turn, climate change has been found to have already affected yields of major food crops in South Africa, with resulting decreases in food calorie production (Ray *et al.*, 2019). With the projected future increases in temperature, further negative effects are likely to occur, raising the risk of food insecurity in the country. Agricultural approaches, such as CSA, that can produce synergies in terms of both climate change adaptation and mitigation, whilst fostering agricultural productivity are therefore relevant for food security and sustainable agricultural development in South Africa.

With the end of apartheid and the election of its first non-racial democratic government in 1994, an ambitious land reform programme was launched in South Africa. The land reform programme gathers three components, a land restitution sub-programme aimed at restoring the rights to the land to those dispossessed of such rights after the passing of the Natives Land Act (Act No. 27 of 1913); a land redistribution sub-programme aimed at reducing the large racially skewed land inequalities existing in South Africa; and a tenure reform sub-programme aimed at securing land tenure rights for all South Africans (Hall, 2004a). As the land reform was being launched, emphasis was also made in key programme and policy documents on the importance of providing post-settlement support to the beneficiary farmers (ANC, 1994; DLA, 1997). Indeed, such a support was seen as essential to enable land 'gainers' to contribute to the development of a more sustainable agricultural system (ANC, 1994: section 4.3.8). The South African land reform programme can therefore be considered, in principle, as a comprehensive land reform, as it includes land transfers (via the land restitution and land redistribution sub-programmes), tenure reform, and the provision of support services.

This study first examines the land reform programme by providing a summary of the history of land dispossessions that occurred in South Africa and by reviewing the implementation of the three land reform sub-programmes – gauging the progress made on the three sub-programmes against the initial intentions of land reformers. The study then empirically examines the association between land reform and CSA adoption. In particular, it applies binary response models to secondary farm-household data from a survey undertaken in the Limpopo river-basin of South Africa to explore the association between two pillars of the Climate Smart Land Reform (CSLR) framework introduced in Rampa *et al.* (2020), namely land redistribution and rural advisory services, and CSA adoption.

This study contributes to bridging the gap between two strands of the rural development literature, namely the literature on land reform and the literature examining factors associated with CSA adoption. Beyond providing an up-to-date perspective on the status of the land reform in South Africa and highlighting critical issues in the implementation of the three land reform sub-programmes, this study is, to the best of the author's knowledge, the first to explicitly analyse the connections between land reform and CSA adoption in the South African context.

The study is organised in two parts. The first part is broadly aimed at providing a background on the land reform programme in South Africa. It includes three sections. The first section (Section 4.2.1) summarises the process that led to the land reform in South Africa. In particular, it highlights the historical complexity of the dispossession of land from Africans, emphasising that the process of dispossession began long before the passing of the Natives Land Act (1913), and can be traced back to the arrival of settlers in the seventeenth century. The second section (Section 4.2.2) frames the initial intentions of policymakers for the land reform programme, which included redressing past injustices linked to the dispossession of land and providing a pathway towards sustainable rural development in South Africa. The third section (Section 4.2.3) provides a summary of the implementation of the three land reform sub-programmes, land restitution, land redistribution and tenure reform, and discusses specific challenges and critical issues that occurred with the actual implementation of the three sub-programmes. Section 4.2.4 concludes the first part of the study. Indeed, several of the key issues that emerged with the implementation of the land reform and that are highlighted in Section 4.2.3 and Section 4.2.4 also prove relevant for the second part of this study, which is more narrowly aimed at providing empirical evidence on the association between land reform and CSA adoption. Section 4.3.1 presents the conceptual framework employed for the empirical analysis and describes its application in the context of this study. Section 4.3.2 provides an overview of the data and of the empirical methods utilised. The subsequent section (Section 4.3.3) presents and discusses the main results of the study and the last section (Section 4.3.4) concludes.

4.2. Part I. Land reform in South Africa

4.2.1. Historical summary

The roots of the dispossession of Africans' land in South Africa lie in the conquest of the Cape of Good Hope by the Dutch's United East India Company (the *Vereenigde Oostindische Compagnie*) in 1652 (Mahlati *et al.*, 2019). What was originally intended to be a resupply outpost for the Company to support ships engaged in trading with East Asian colonies soon transformed into an outright settler colony (the "Cape Colony"). The multinational character of the Company, in terms of both sources of finance and workforce, implied that the settlers were from multiple origins, including Dutch, German, and French Huguenots (Davenport and Saunders, 2000). As the settlements began to grow, slaves from West and East Africa as well as Asia were brought to the colony and the Afrikaan language, a simplified form of Dutch spoken between the Afrikaner people (mostly white early settlers) and the slaves, gradually emerged (Davenport and Saunders, 2000; Thompson, 2001). During most of the seventeenth and eighteenth centuries the Company authorities opposed an unfettered expansion of the colony and sought to entertain trading relationships with the local *Khoikhoi* and *San* populations. Nevertheless, localised conflicts between the settlers and Africans did occur, largely due to controversies over cattle trading and to assaults and thefts of livestock and property (Davenport and Saunders, 2000:23). Conflicts began to expand when more adventurous settlers, the *trekboers*, started migrating northwards and eastwards and invaded the natural resources on which Africans were relying for their livelihoods. Due to their superior weaponry, the conflicts that emerged with the African population mostly resulted in victories for the *trekboers*, who occupied the land and seized substantial shares of the Africans' cattle. Deprived of their main sources of livelihood, large fractions of the local African population had to recur to the supply of cheap labour to the settlers (Thompson, 2001:49).

These conflicts were the antecedents of the 'frontier wars' that characterised a century of hostilities between Africans and the colonial powers. Colonisers continued in fact to gain ground eastwards and entered into contact with the *Xhosa* chiefdoms, as well as with other *Nguni* populations – including the neighbouring *Thembu* and *Mpondo* chiefdoms and the *Mfengu* who had been pushed westwards by the conflicts with more powerful *Zulu* kingdoms (Bundy, 1988). This gave rise to a sequence of intermittent wars between 1798 and 1898. The result of these frontier wars was a gradual process of dispossession of land from Africans extending the Cape Colony to the boarder of Natal (Laband, 2020 and Figure 4.1).

The frontier wars, from the colonisers' side, involved both the Dutch and the British. The British took advantage of the French invasion of the Dutch Republic and stroke an attack on the Cape, seizing the colony from the Dutch in 1795. The Batavian Republic (the Dutch client state of the French Republic) re-took the colony in 1803 under the terms of the treaty of Amiens, but only for three years. The Napoleon wars nullified the treaty of Amiens and the British re-gained control of the colony in 1806, a control that was formalised in 1814 with the treaty of Paris (Thompson, 2001:52).

As the frontier wars unfolded and as the British imposed political, legal and cultural changes to the Colony - including measures unfavourable to the original settlers, such as the abolition of slavery, the instauration of a quitrent system of land tenure, as well as the imposition of English as the sole official language in public offices, courts and schools - malcontent grew among the Afrikaner population. This led to an exodus - often referred to as the 'Great Trek' - of approximately six thousand Afrikaners (the *Voortrekkers*), representing one tenth of the white population of the Cape Colony (Thompson, 2001:88).

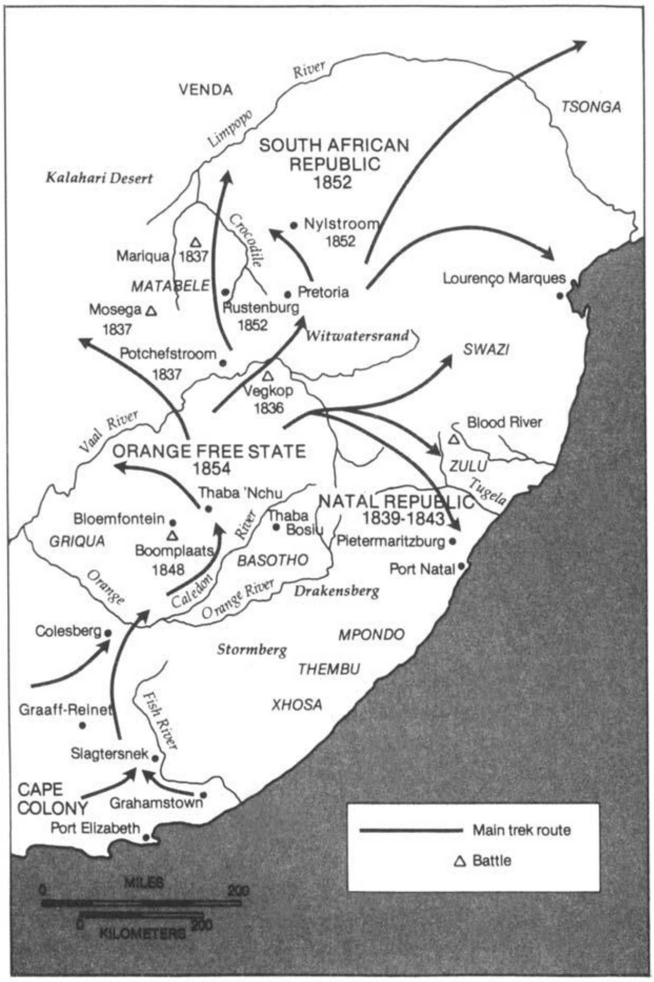

Figure 4.1. The Afrikaner Great Trek

Source: Thompson (2001:89)

The Great Trek resulted in further conflicts with the various chiefdoms that the *Voortrekkers* encountered, including the *Ndebele* in the highveld and the *Zulu* in the Natal area. Further occupation of land ensued from these conflicts and notable precedents to the laws and policies of apartheid emerged. For instance, in the Natal area the *Voortrekkers* founded the Natalia Republic and in 1841 a resolution of the Republic's *Volkstraad* (its legislative body) was passed with the intention of forcing the 'surplus' African population to be relocated outside of the borders of the Republic (Brookes, 1924:325). The brutal attempts to enforce the resolution were not well accepted by the British, who launched their own attack on Natal and incorporated Natal into the British Empire in 1843. Nonetheless, the *Volkstraad* in Natal remained temporarily operational and passed a resolution forbidding African ownership of land in what was now considered white area (Brookes, 1924:325). Whilst it forbid land ownership, the resolution did not oppose residence of Africans in these so-called white areas, who were allowed to live and work in these areas. A large supply of cheap labour was thus made available to the British settlers that came to Natal.

At the same time, growing rivalries among factions of the *Zulu* kingdom led to a large inflow of *Zulu* to Natal (Thompson, 2001:97). The number of Africans living on so-called white areas in Natal soon became unmanageable in the eyes of the settlers and further measures to control the African population were devised. Under the guidance of Theophilus Shepstone, the British colonial government created the 'locations', reserved to Africans, and a system of indirect rule where chiefs were selected by, and made responsible to, the colonial government (Thompson, 2001:98).[3] Furthermore, the British imposed a dual legal system, with customary African law, as codified by Shepstone, prevailing among Africans, and colonial Roman Dutch law applying to the white population and to white-African relations (Thompson, 2001:98). Location land, was to be held in trust for the African population by the Natal Native Trust, established in 1864 (Brookes, 1924:58).

Meanwhile, after having been pushed out of Natal, the *Voortrekkers* concentrated in the highveld area, both North and South of the Vaal river, where the two republics of Transvaal (also known as "South African Republic") and the Orange Free State were established in 1852 and 1854, respectively (Barthorp, 1987:12 and Figure 4.1 above). As the Afrikaners sought land for settlement, new conflicts occurred with the local African populations, resulting in further land grabs (see, e.g., chapter seven of Davenport and Saunders, 2000 for a detailed description of such confrontations).

[3] Similar location schemes were also subsequently established in the Cape Colony with acts such as the 1879 Native Locations Lands and Commonage Act No.40, the 1902 Native Reserve Location Act No.40, the 1905 Native Locations amendment Act No.8 (Elias, 1984).

The discovery of diamonds in 1866 in *Griqualand*, an area at the border between the two Afrikaner republics and the Cape Colony, led to the British annexation of *Griqualand* West in 1871, a move that increased tensions between the Afrikaners and the British (Meredith, 2007). These tensions were further fuelled by the British annexation of the Transvaal in 1877 and eventually culminated in the 'Anglo-Boer wars' of 1880-81 and 1899-1902, from which the British would exit victorious (Barthorp, 1987). A notable event that occurred prior to the outbreak of the first Anglo-Boer war, and which marked a further episode of settler-imposed breakdown of African administrative systems as well as of land dispossession, was the 'Anglo-Zulu war' of 1879. This war would lead to the dismantlement of arguably one of the greatest African kingdoms in South Africa. The British, after having suffered an initial defeat at Isandlwana, won the war (Greaves and Mkhize, 2013). They first proceeded to divide the *Zulu* territory in 13 separate chiefdoms, appointing the chiefs and thus extending the indirect rule system to *Zululand* (Knight, 2003). Then, realising that the artificially imposed system created malcontent among the population, which turned rapidly into violent civil wars, the British annexed the territory altogether in 1887 (Knight, 2003:89) incorporating it as a province of Natal ten years later (Greaves and Mkhize, 2013). This area of land would later become the Kwazulu-Natal province of South Africa.

The British victory in the second Anglo-Boer war paved the way for the creation of a united South Africa, composed of four provinces, the Cape, Orange Free State, Transvaal and Natal (Davenport and Saunders, 2000). The Union of South Africa was granted independence through the South Africa Act 1909 and became formally established on 31st May 1910. During the following decades, the measures undertaken by colonial powers to relegate Africans to marginal land areas and to impose administrative and individual controls upon them were imprinted in the Union's legislation and gradually enforced.

In 1913, the Natives Land Act (Act No. 27 of 1913) formally established "scheduled native areas" destined to "any person, male or female, who [was] a member of an aboriginal race or tribe of Africa" (Natives Land Act, 1913: section 10). The Act forbid 'natives' from owning or renting land outside of the scheduled areas and non-'natives' from owning or renting land inside of the scheduled areas.[4] The Act also forbid sharecropping arrangements between 'natives' and non-'natives', effectively leaving only two types of arrangements possible between African farmers and white land owners: labour tenancy and wage labour. The scheduled areas were initially set at approximately 11 million morgen (ca. 9 million

[4] The restrictions on land purchases were valid for the Transvaal and Natal (Feinberg and Horn, 2009:48) and exceptions could be granted by the Governor General (Natives Land Act, 1913: section 1).

hectares) of land, just over seven percent of the Union's land area, and largely matched the 'African reserves' (i.e. the 'locations') that existed prior to the passing of the Act (Natives Land Act, 1913: Schedule of Native Areas). The scheduled areas were to be refined based on the field work and recommendations of an appointed commission – the Natives Land Commission (also known as Beaumont commission, from the name of its chairman), which produced a report in 1916 outlining possible areas to be added but also highlighting critical challenges associated with the relocation of white farmers from some of these areas (Union of South Africa, 1916a:11-12). As a result, the scheduled areas remained those set in 1913 until the passing of Act 18 of 1936, which made provisions to increase the scheduled areas to approximately 13% of the Union's land area via the purchase of land by the newly instituted South African Native Trust (Platzky and Walker, 1985:92; Thompson, 2001:163).

However, it wasn't until after the National Party's victory at the 1948 elections and the enactment of apartheid legislation that rigid, nation-wide, enforcement and massive relocations occurred (Platzky and Walker, 1985:93,99). According to estimations from the Surplus People Project, between 1960 and 1983 over 3.5 million Africans were forcefully removed from the land they were residing on and relocated onto the 'reserves'.[5] Amongst the key pieces of legislation that spurred such relocations the Group Areas Act of 1950 stands out as one of the first radical apartheid laws. The Group Areas Act (1950) formally sub-divided South Africa's population according to three groups, namely "white", "natives" and "coloured", with the possibility of specifying additional groups at the discretion of the Governor General (Group Areas Act, 1950: section 2). The Act also gave the Governor General the powers to define the areas that each group could occupy (Group Areas Act, 1950: section 2). The Bantu Authorities Act (1951) gave a new administrative structure to the 'reserves', with a pyramidal scheme consisting of Tribal, Regional and Territorial authorities, reinforcing the system of indirect rule and of artificially established authorities governing Africans in the 'reserves' (Mamdani, 1996:191). As Platzky and Walker (1985) describe:

> [With the passing of the Bantu Authorities Act, the] traditional elite of chiefs and headman became more firmly embedded in the overall structures of domination in the reserves than before. Their powers were increased. They became salaried officials with a vested interest in

[5] These figures exclude the additional large-scale internal resettlements that occurred as a result of the 'betterment' plans implemented in the 'reserves' in the decades following the passing of Government Proclamations No. 31 of 1939 and No. 116 of 1949 (Platzky and Walker, 1985:9; deWet, 1994). These betterment plans were intended to rationalise land use within the 'reserves', by specifying, for instance, separate areas dedicated to arable farming, animal grazing and residential use (Lovo, 2014:681). However, the implementation of such plans had dire consequences as it generated massive internal resettlements, landlessness, further overcrowding of residential areas and the impoverishment of most of the households affected (Letsoalo and Rogerson, 1982:312; deWet, 1994).

> the apartheid system, local agents of control for the central government. Their cooperation with the government assured them of more than their salaries. It also gave them power over the allocation of such precious resources as land, welfare and pension system, and any development money that might filter down to their district. The final transformation of their role in the rural areas had been achieved – from one-time leaders of the resistance to colonisation to (with some notable exceptions) representatives of the white government, lowly officials of state. (Platzky and Walker, 1985:111)

The Promotion of Bantu Self-government Act of 1959 established that all Africans were to belong to one of eight (later increased to ten) 'national units' with territories falling within 'Bantu areas' (Promotion of Bantu Self-Government Act, 1959: section 9). These 'Bantu areas' would become known as *Bantustans*, or 'homelands' and corresponded to the original scheduled areas specified by Act 27 of 1913 as well as the additional 'released areas' envisaged under Act 18 of 1936. Despite the label of self-government attached to this Act, the Bantustan policy envisioned the creation of client states subdued to the central South African government, with the powers of the territorial authorities being made conditional to the satisfactory administration of their territories (Platzky and Walker, 1985:113). With the enactment of the Bantu Homeland Citizenship Act (1970) and of the Bantu Homelands Constitution Act (1971) apartheid legislators went one step further and made provisions for all Africans to obtain the nationality of their respective 'homeland', regardless of whether they were in fact residing within it. Such provisions were intended to gradually deprive all Africans of the South African nationality, thereby ensuring that South Africa would be populated only by whites (Dugard, 1980).

In the following decades, however, a combination of national and international circumstances led to the diminishment of the National Party's strength. These included wide-ranging national socio-economic difficulties, mounting international pressures against apartheid, and the shift in actions of the African National Congress (ANC) - a national liberation movement originally founded in 1912 to unite the African people in the pursuit of socio-political and economic change - from non-violent protests to intensified uprisings. Eventually, the National Party's leaders were forced to enter into negotiations with the ANC and, in 1990, the recently appointed president de Klerk rescinded the banning orders on the ANC and other organisations that had been outlawed and released Nelson Mandela (the historical ANC leader) after 27 years of prison (Clark and Worger, 2011:103-111).

In 1990 and 1991, the South African parliament passed several acts repealing apartheid legislation. Notably, with the Abolition of Racially Based Land Measures Act passed in 1991 (Act No. 108 of 1991), the main racially discriminatory land acts were repealed, including the Native Land Act of 1913 and the Development Trust and Land Act of 1936.

The following year, de Klerk agreed with Mandela to launch a process that would lead to national non-racial democratic elections open to all South Africans by April 1994 (Clark and Worger, 2011:116).

Conclusions

The historical summary presented in this section shows the intricacies of the land dispossessions that occurred during the three centuries that preceded post-apartheid democratisation in South Africa. By no means was land seized from Africans only after the passing of the 1913 Act. Africans suffered colonial dispossessions since the seventeenth century. In fact, most land dispossessions occurred prior to the twentieth century: the distribution of land among the population of South Africa in the early twentieth century was already extremely unequal, with over four million Africans (67% of the population) largely confined to live on ‘location’ land representing approximately seven percent of South Africa’s land area, or on white owned land (Feinberg, 1993:82; Union of South Africa, 1916b:5). This historical summary also shows that the imposition of a system of indirect rule upon African communities has artificially moulded the pre-existent administrative systems and thus impeded spontaneous customary structures to develop. The current systems of chieftaincy administration, notably present in today’s communal areas, can therefore not be disassociated from the interventionist actions of colonial powers.

Indeed, the draconian legislation passed, and gradually enforced, after 1913 - and most notably under apartheid - amplified over two centuries of dispossession and exploitation. With the post-apartheid democratisation of South Africa, a land reform programme was designed to redress the large land inequalities and the history of injustices suffered by Africans. As described in the next section, land reformers opted for a programme gathering three components (or sub-programmes), land restitution, land redistribution and land tenure reform (DLA, 1997).

4.2.2. Initial intentions of land reformers

As the first post-apartheid elections of 1994 approached, the ANC released the Reconstruction and Development Programme (RDP), which included general policy principles as well as specific time-bound objectives and corresponding measures intended to guide the land reform programme. The RDP referred to the land reform as consisting of two “aspects: redistribution of residential and productive land to those who need it but cannot afford it, and restitution for those who lost land because of apartheid laws” (ANC, 1994: section 2.4.5). It also stated the importance of implementing land tenure interventions to enhance tenure rights and ensure tenure security for South Africans (ANC, 1994:

sections 2.4.2; 2.4.4; 2.4.10). Land redistribution, land restitution and tenure reform would effectively become the three official land reform sub-programmes. Furthermore, the RDP set as an overall objective that of transferring "30 per cent of agricultural land within the first five years of the [land reform] programme" (ANC, 1994: section 2.4.14).[6] The RDP also highlighted the importance of providing support services to land reform participants as these were deemed essential for the effectiveness of the land reform (ANC, 1994: sections 2.4.2; 2.4.9; 2.4.12; 4.3.14; 4.5.2.4; 4.5.2.6). It further recognised the contribution that land reform would have in addressing several of South Africa's deep-rooted problems, including environmental degradation, unemployment/under-employment, food insecurity and inequalities (ANC, 1994: sections 2.10.4; 2.11.3; 4.2.9). In essence, the RDP considered land reform to be the guiding force for rural development in South Africa:

> The RDP aims to improve the quality of rural life. This must entail a dramatic land reform programme to transfer land from the inefficient, debt-ridden, ecologically-damaging and white-dominated large farm sector to all those who wish to produce incomes through farming in a more sustainable agricultural system. (ANC, 1994: section 4.3.8)

The premises for a profound and far-reaching transformation in South Africa via land reform were thus set in this often-overlooked document.

Commitment to the implementation of the land reform received the highest legal backing with the promulgation of the 1996 Constitution. In its Section 25, the Constitution details the rights to restitution of property and to legally secure tenure for individuals and communities victim of past racially discriminatory laws or practices (RSA, 1996: section 25, sub-sections 6 and 7). It also promotes redistribution of land indicating that "The state must take reasonable legislative and other measures, within its available resources, to foster conditions which enable citizens to gain access to land on an equitable basis" (RSA, 1996: section 25, sub-section 5). The three central elements of the land reform, namely restitution, redistribution and tenure reform were thus being recognised in the nation's supreme law.[7] Furthermore, the redactors of the Constitution included a provision for the expropriation of property "for a public purpose or in the public interest; and subject to compensation" (RSA, 1996: section 25, sub-section 2), thus offering land reformers the opportunity to obtain and

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[6] This corresponds to approximately 25-30 million hectares of land (Deininger and May, 2000; Hall, 2004a; Lahiff, 2008).

[7] Indeed, and as further described below, earlier legislation had been enacted in accordance with the interim Constitution of 1993 (RSA, 1993) to specify citizens' rights with respect to land restitution (Restitution of Land Rights Act, 1994), tenure security (Land Titles Adjustment Act, 1993; amended by the Land Affairs General Amendment Act, 1995; Upgrading of Land Tenure Rights Act, 1991; amended by the Upgrading of Land Tenure Rights Amendment Act, 1996; Interim Protection of Informal Land Rights Act, 1996 renewed every year until 2004; Land Reform (Labour Tenants) Act, 1996; Communal Property Associations Act, 1996), and to provide a legislative framework for the financing of land acquisition and for its redistribution/allocation (Provision of Certain Land for Settlement Act, 1993; Distribution and Transfer of Certain State Land Act, 1993).

transfer additional land under the land reform programme by means of expropriation. The Constitution also includes a section dedicated to the protection of the environment, indicating that:

> Everyone has the right –
> (a) to an environment that is not harmful to their health or well-being; and
> (b) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that –
>   i. prevent pollution and ecological degradation;
>   ii. promote conservation; and
>   iii. secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development. (RSA, 1996: section 24)

Policymakers are thus legally required to ensure that laws and policy interventions, including land reform, do not impair environmental sustainability (Wynberg and Sowman, 2007:786).

A third key document released during the initial phase of the South African land reform is the 1997 White Paper on Land Policy (DLA, 1997). This document represents the building block for the land reform programme, detailing the issues to be addressed with the land reform and the modalities through which those issues would be addressed. The policy document formally distinguishes the three land reform sub-programmes, land restitution, land redistribution and tenure reform (DLA, 1997: forward; section 2.3).

Land restitution policy was to be "guided by the principles of fairness and justice" (DLA, 1997: section 4.14.1). It included both urban and rural land taken after 1913 by means of racially discriminatory legislation and practices and provided a framework for alternative forms of compensation – ranging from the restoration of the rights to the land from which claimants were dispossessed, provision of alternative land, payment of compensation, to hybrid options combining different forms of compensation (DLA, 1997: section 4.14.4). Consideration was also to be given to cases that did not conform with the requirements set in the Restitution of Land Rights Act 22 of 1994, such as dispossessions pre-dating the defined 1913 cut-off date (DLA, 1997: section 4.14.3). The Commission on Restitution of Land Rights (CRLR) and the Land Claims Court, established via the Restitution of Land Rights Act (1994), were confirmed as the institutions responsible for receiving/processing claims and for adjudicating claims, respectively.

In terms of the land redistribution sub-programme, the White Paper on Land Policy in South Africa stated that the aim of the sub-programme was "to provide the disadvantaged and the poor with access to land for residential and productive purposes, in order to improve their income and quality of life" (DLA, 1997: section 2.3). To do so, the government opted for a market-based approach to land redistribution and formally introduced in the White

Paper the 'willing-buyer-willing-seller' (WBWS) principle, strongly advocated by the World Bank (Kepe and Hall, 2016). Under this approach, land reform participants would be able to access grants from the government and obtain land from willing sellers through market transactions. The White Paper set out a number of grants to be made available under the land redistribution sub-programme, but highlighted that the "primary source of direct financial assistance to potential beneficiaries [would] be the Settlement/Land Acquisition Grant [SLAG]" (DLA, 1997: section 4.7).[8] The SLAG was set at a maximum of 15,000 Rand per household, an amount equal to the National Housing Subsidy, and could be used "for land acquisition, enhancement of tenure rights, and investments in infrastructure, home improvements, and farm capital investment according to the plans put forward by applicants" (DLA, 1997: section 4.21 (a)).[9] To be eligible for the maximum amount of the grant, the gross monthly household income of the potential beneficiary could not surpass 1,500 Rand (DLA, 1997: section 4.23.2).

The relatively low value of the grant and the reluctance of willing sellers - who were mostly large-scale farmers - to undergo the transaction costs associated with a subdivision of their land, implied that a clear risk of the WBWS model was that SLAG beneficiaries would find themselves constrained to pool their grants and purchase land as a group. The White Paper recognised this risk and stated that "Measures being examined [to address this issue] include expedited subdivision of land to encourage individual or family smallholder ownership" (DLA, 1997: section 4.7).

The tenure reform sub-programme was recognised as being "the most complex area of land reform" (DLA, 1997: section 4.1). Legislation and measures to assure its application were to be designed to enable multiple types of tenure to co-exist, including nationalised, freehold, leasehold and customary tenure. All South Africans would be guaranteed secure rights to land and citizens would be allowed to "choose the tenure system [most]

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[8] The SLAG was to be made primarily available to beneficiaries of the land redistribution sub-programme. However, SLAG was also accessible to complement the compensation received under the land restitution sub-programme and to support the realisation of the tenure reform sub-programme. Its stated objective was in effect to "improve land tenure security and to extend property ownership and/or access to productive resources to the historically disadvantaged and the poor" (DLA, 1997: section 4.23.1). In addition to SLAG, the White Paper outlined the procedures for citizens to obtain a settlement planning grant, aimed at covering "legal and financial-planning assistance, land use planning, infrastructure planning, land valuation, and assistance with land purchase negotiations, including the formation of a legal entity" (DLA, 1997: section 4.25.1). Further grants were also envisaged to support local authorities in their land reform efforts, including the grant for the acquisition of land for municipal commonage and the grant for determining land development objectives (DLA, 1997: sections 4.24 and 4.26).

[9] If used exclusively for land acquisition, the amount of the SLAG would have been sufficient to purchase approximately 16 hectares of land, as the average market price for land was 900 Rand per hectare (Aliber *et al.*, 2016:9), or "20 to 30 hectares of extensive grazing land" (DLA, 1997: Box 4.4).

appropriate to their circumstances" (DLA, 1997: section 4.16). In order to prevent (or manage) potential conflicts arising due to overlapping claims to land rights by multiple parties, the White Paper envisaged the use of the SLAG or other forms of compensation to "assist people to acquire land in instances where others have stronger rights to the land which is currently occupied" (DLA, 1997: section 4.16). The White Paper also highlighted the need to ensure that all legally recognised tenure systems conform with the human rights and equality principles entrenched in the Constitution (RSA, 1996: section 9). This was of course relevant in light of the past racial discriminations affecting land rights, but it was also very relevant from a gender perspective. Women often faced unequal rights to land compared to men and tenure reform would therefore need to ensure gender equality, independently of the type of tenure. At the time of the release of the White Paper, several acts related to the tenure reform sub-programme had been signed and additional crucial legislation was in the pipeline (e.g. Upgrading of Land Tenure Rights Act, 1991; Upgrading of Land Tenure Rights Amendment Act, 1996; Interim Protection of Informal Land Rights Act, 1996; Communal Property Associations Act, 1996; Extension of Security of Tenure Act, 1997; see also DLA, 1997: boxes 4.1, 4.9, 4.10 and 4.11; and sections 3.25, 4.17 and 4.19).

4.2.3. The reality

Despite what appeared as a well-intended and comprehensive overarching framework for the South African land reform programme, the actual implementation of the land reform in South Africa has uncovered substantial limitations in both its design and execution. Whilst an extensive review of the implementation of the land reform programme and of its limitations is beyond the scope of this study, this section provides a summary of the implementation of the three sub-programmes highlighting specific critical issues associated with land restitution, land redistribution and tenure reform.[10]

4.2.3.1. Land restitution

The implementation of the land restitution sub-programme during the initial phase of the land reform saw large numbers of claims lodged, but an astonishingly low number of claims settled. By the end of 1998, only 31 of the 63,455 lodged claims had been settled (Lahiff, 2001:3). The pace of the execution of the sub-programme increased dramatically in the following years, particularly between financial years 2000/01 and 2005/06 when an average of 11,288 urban and rural claims were settled each year, including via payment of

[10] For recent in-depth descriptions and commentaries on the implementation of the South African land reform programme and of its challenges, the reader may refer to Ainslie *et al.* (2019); Cousins (2016); Cousins *et al.* (2020); High Level Panel (2017); Mahlati *et al.* (2019).

compensation (Ainslie *et al.*, 2019; CRLR, 2007).[11] Overall, the land restitution sub-programme provided close to 3.5 million hectares of land between 1995 and 2018 (DRDLR, 2018), a significant achievement. The sub-programme has also been lauded as "possibly the most important example of public redress for the wrongs of colonialism and apartheid" (Lahiff, 2008:32). However, it is evident that the land restitution sub-programme suffered from several critical issues in terms of its design and implementation.

A first issue relates to the two contentious cut-off dates, selected and imprinted in legislation, marking the starting period of the dispossession of rights to land which could be claimed back via the restitution sub-programme and the date limit for lodging claims to restitution. Concerning the former, the date of 19 June 1913, when the colonial government passed the Natives Land Act (1913), was selected and embedded in Section 121(2)(a) of the Interim Constitution of 1993 (RSA, 1993), in the subsequent Restitution of Land Rights Act (1994) and in Section 25(7) of the 1996 Constitution (RSA, 1996). This implied that, according to the law, only land taken away after 19th June 1913 could be claimed back, and the rights to that land restored. By that date, Africans had already suffered from over two centuries of land dispossessions, implying that the land restitution sub-programme would redress historical injustices only to a very limited extent. Regarding the latter, the 1997 amendment to the Restitution of Land Rights Act set the cut-off date for lodging land restitution claims to 31st December 1998 (Land Restitution and Reform Laws Amendment Act, 1997). Various initiatives were subsequently undertaken in an attempt to reopen the lodgement of restitution claims and provide further opportunities to citizens having missed-out of the 1998 cut-off date. Eventually, an amendment Act reopening the lodgement of restitution claims for five additional years was promulgated in 2014 (Restitution of Land Rights Amendment Act, 2014). Yet, the amendment was judged unconstitutional and the processing of claims lodged after 2014 was halted (Mahlati *et al.*, 2019; CRLR, 2020). The ambitious commitment to redress historical injustices through restitution of rights to the land to citizens victim of racially discriminatory laws/practices remains therefore incomplete.

A second key issue associated with the design of the restitution sub-programme is the emergence of conflictual group dynamics, particularly over claims to rural land. In several instances, claims have been lodged in the name of large groups of individuals, pooled based on the original date at which land was dispossessed from them or their ancestors. This often resulted in artificially reconstituted communities, gathered into legal entities with rights to

[11] The total number of lodged claims was revised repeatedly after the official cut-off date of December 1998 due to the split up of group claims (Lahiff, 2001; PLAAS, 2016). In 2017, there were reportedly 7,418 outstanding claims (High Level Panel, 2017:238).

the restored land, generating high levels of dysfunction in the management and operation of the land (Ramutsindela *et al.*, 2016:49). Similarly, overlapping and conflicting claims to the same land have been lodged, contributing to tensions between ethnic and tribal groups with legitimate claims to the dispossessed land (High Level Panel, 2017:234). Practical solutions have been attempted by policymakers, including the provision of alternative restoration mechanisms (either in the form of cash compensation or of alternative land). However, these solutions have reportedly led to confusion and dissatisfaction on behalf of beneficiaries who often considered that the alternative settlements did not provide just and equitable redress and therefore challenged the settlements at the land claims court, which rapidly became overwhelmed with cases and lacked the capacity to resolve these in a timely manner (High Level Panel, 2017).

A third key issue is the inadequacy of the services provided to the beneficiaries of the land restitution sub-programme to support an effective use of restituted land. This has been widely recognised as one of the main shortcomings of the sub-programme (CASE, 2006; High Level Panel, 2017; PLAAS, 2016). Indeed, the lack of adequate support services - including services that facilitate access to infrastructure (both on and off farm) and to markets (input and output markets as well as markets for financial services), along with Rural Advisory Services (RAS)[12] - is a solid barrier to the adoption of sustainable agricultural practices (e.g. Ali, 2021; Hassan and Nhemachena, 2008; Teklewold *et al.*, 2013). In fact, in the absence of adequate provision of support services, farmers have faced challenges in making a sustainable use of the land (CASE, 2006). In several cases, beneficiaries of the land restitution sub-programme have reportedly been constrained to recur to "straddling" strategies, whereby they renounced to fully settling on the regained land for fear of it not generating sufficient livelihood opportunities (Andrew *et al.*, 2003:21; Hall, 2004b).

One of the attempts made by the government to address deficient post-settlement support has been the establishment of settlement support and development planning units within the regional land claims commissions (Hall, 2003). Yet, controversy emerged on the adequacy of rendering the CRLR responsible for such tasks and activities. The report from an evaluation of the land restitution sub-programme conducted in 2013 for the Presidency's Department of Performance Monitoring and Evaluation (DPME) clearly highlighted that the CRLR should not be undertaking nor financing post-settlement support activities:

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[12] RAS can be defined as "systems that should facilitate the access of farmers, their organizations and other market actors to knowledge, information and technologies; facilitate their interaction with partners in research, education, agri-business, and other relevant institutions; and assist them to develop their own technical, organizational and management skills and practices"(Christoplos, 2010:3).

> Beyond facilitation and coordination activities (which take place before a claim is settled) the CRLR should be formally absolved of any responsibility for post-settlement support, local economic development processes and funding of related activities (beyond that associated with the financial settlement of claims). The CRLR should concern itself exclusively with the adjudication of restitution claims and the restoration of rights in land. (Genesis, 2014:64)

Provision of support services to land restitution beneficiaries therefore remains a critical outstanding issue for the effectiveness of the sub-programme (Cousins, 2016).

In sum, despite significant progress achieved through the land restitution sub-programme, notably in terms of number of claims settled, several critical issues have limited the impact of the sub-programme on the livelihoods of South African citizens. Various South Africans have felt deceived by the governments' measures. Individuals and communities whose land was dispossessed prior to the 1913 cut-off date or who did not lodge their claim to restitution before December 1998 have altogether been excluded from this sub-programme. Others whose claims are yet to be settled have been awaiting for over two decades for the processing of their claims. And amongst those whose claims have indeed been settled, few have been able to successfully operate the restituted land and overcome challenges associated with dysfunctional group dynamics and inadequacy of support services. A recent review of findings about the impact of the land restitution sub-programme reveals that "successfully operating settled rural land claims […] are the exception rather than the rule" (Ramutsindela *et al.*, 2016:39-40). Furthermore, settling the 'last leg' of outstanding claims, which correspond mainly to complex claims on rural land, will undoubtedly represent a greater challenge compared to the cash settlements made on the large number of urban claims. This implies that the task of land reformers in fulfilling the commitments made on land restitution at the dawn of the land reform programme is far from complete.

The numerous issues associated with the land restitution sub-programme and its limited impact have generated outspoken, and at times controversial, criticisms on the sub-programme. Ben Cousins, arguably one of the most prominent academic thinkers on land reform in South Africa, recently qualified the restitution sub-programme as "a mistake" (Cousins, 2016:150).

4.2.3.2. Land redistribution

The land redistribution sub-programme has been the object of multiple changes throughout the decades following the launch of the land reform programme.

Prior to 1999, land redistribution was mainly undertaken via the provision of a Settlement/Land Acquisition Grant (SLAG), initially set at a maximum of 15,000 Rand per household and later increased to 16,000 Rand (Weideman, 2006:216). As indicated above, only households with gross monthly income of less than 1,500 Rand were eligible for the maximum amount of the grant (DLA, 1997: section 4.23.2). Indeed, the risk of land redistribution participants pooling their grants to obtain the land made available by willing sellers - who were unwilling to undergo the transaction costs associated with a subdivision of their land - soon became a reality (Hall, 2004a:25). Although this risk was acknowledged in the White Paper on Land Policy, there is no evidence that the auspicated remedial measures of "expedited subdivision of land to encourage individual or family smallholder ownership" (DLA, 1997: section 4.7) were ever implemented in this initial phase of land redistribution. As a consequence, inefficient group dynamics emerged and generated an ineffective use of the land leading in several cases to a collapse of the communal property institutions established by the groups to purchase the land (Aliber and Cousins, 2013; Lahiff, 2008).

With the advent of the Mbeki government in 1999, the new Minister of Agriculture and Land Affairs launched an internal review of the land redistribution sub-programme and imposed a moratorium on land redistribution (Hall, 2004a:25). As a result of the review, a new flagship Land Redistribution for Agricultural Development (LRAD) initiative was launched in 2001. Beyond the slow progress in terms of hectares of land redistributed (only approximately one percent of commercial farmland was redistributed during the first five years of the land reform (Cousins, 2016)), the main challenge that the government aimed to address with the LRAD was the ineffective group dynamics that resulted from the pooling of grants by land redistribution participants to acquire land made available by willing sellers. Yet, the government did not address such an issue by enhancing opportunities for individual or family small-scale ownership. Rather, the DLA opted for a policy framework oriented at increasing the size of the grants made available whilst requiring a contribution (in cash or in kind) from the beneficiaries (MALA, 2001). As such, LRAD grants were provided in amounts ranging between 20,000 Rand and 100,000 Rand per person, according to a sliding scale based on the own contribution of the beneficiary (MALA, 2001). Furthermore, with the LRAD, the 1,500 Rand per household per month income ceiling required to access the grant was abolished, thus formally opening-up the land redistribution sub-programme to better-off citizens. This represented a clear deviation from the original policy intentions of providing the disadvantaged and the poor with access to land and a reorientation of the sub-programme towards an emergent class of black commercial farmers (Hall and Cliffe, 2009). In the absence of a proactive strategy to enable subdivision of farmland, LRAD did not prove successful in tackling the ineffective group dynamics that emerged with SLAG. Most farmers did not have sufficient cash or in-kind resources to obtain grants at levels necessary for the purchase of the large farms available on the market and therefore had to pool their contributions in ways not too dissimilar to what had occurred under SLAG (Hall, 2009; Lahiff, 2007a; Kepe and Hall, 2016). Whilst the pace of land redistribution in terms of number of hectares of land redistributed increased during the Mbeki years, it remained significantly below what would have been required to successfully contribute to the achievement of the 30% target (DRDLR, 2009; Lahiff, 2008; PLAAS, 2016).[13]

In 2006, the government introduced the Proactive Land Acquisition Strategy (PLAS), initially complementing LRAD and, from 2011 under the Zuma presidency, substituting it altogether (Kepe and Hall, 2016:15). PLAS represented a radical shift in the government's land redistribution *modus operandi*, as it transformed the State's role from that of provider of grants (to willing buyers of land) to that of a direct buyer of land on the market. Under PLAS, the State purchased land from willing buyers and subsequently transferred the acquired land through the issuance of long-term leases; these leases were also convertible to ownership, but only for medium and large-scale commercial farmers (DRDLR, 2013). The inclusion of, and privileged status granted to, better-off farmers in the 2013 State Land Lease and Disposal Policy (DRDLR, 2013) demonstrates the resistance of South African policymakers to employ land reform as a means to support the development of the majority of small-scale farmers, in spite of the policy intentions expressed at the dawn of the land reform and recommendations from prominent land reform scholars (Kepe and Hall, 2016; Lahiff, 2007a; 2016; Lahiff and Li, 2012; Lipton and Lipton, 1993).

The transition from private to State purchase of land has also reignited debates upon the adequacy of a market-based approach to land reform in South Africa. In particular, the long-standing discourse of employing more radical measures of obtaining land for redistribution, either through the use of the current constitutional dispositions of expropriation subject to just and equitable compensation, or through expropriation without compensation, has strongly re-emerged (Ainslie *et al.*, 2019; Mahlati *et al.*, 2019). Whilst land expropriation could potentially increase the amount of land made available for land redistribution and reduce the costs of land purchases, thus freeing-up budgetary resources that could be employed, for instance, to provide additional support to land redistribution

[13] The overall 30% target for the land reform programme, originally intended to be achieved by 1999, was extended by fifteen years in the year 2000 (Hall, 2004a:25); in 2009, the Director General of the Department of Rural Development and Land Reform (DRDLR) suggested extending the deadline for the 30% target to 2025 (Lahiff and Li, 2012:9). Reportedly, this suggestion has indeed been followed and the target therefore appears to have been deferred until 2025 (Byamugisha, 2013:81; Greenberg, 2010:vii).

participants, it cannot by itself be a panacea for the various challenges faced by land reformers with respect to the land redistribution sub-programme.[14]

Beyond a variety of long-standing challenges that have often been featured as hampering the progress of land redistribution - including administrative and budgetary constraints, complex programme application and approval procedures, elevated land prices (Lahiff, 2007a) - it is worth highlighting two critical issues that have accompanied the implementation of the land redistribution sub-programme.

The first, which was alluded to above, is the lack of a clear and actionable pathway for the transfer of land from white large-scale farmers to the landless and land-poor majority of black South Africans. Under a WBWS model without State support for land subdivision, the land redistribution sub-programme has, under the SLAG and LRAD, mostly neglected the needs and demands of landless and land-poor farmers and often constrained them to dysfunctional group-based forms of land ownership, land management and land operation. With PLAS, policymakers had a renewed opportunity to intervene directly in the subdivision of State-acquired land for redistribution to the landless and land-poor. Yet, the available evidence shows that land redistributions have continued to favour better-off farmers, as the number of hectares of land redistributed per household appears to have increased dramatically with PLAS (Aliber *et al.*, 2016:11). The reluctance of policymakers to follow-through with the initial intentions enshrined in the RDP and White Paper, and seize the opportunity provided by a land reform to redistribute land from large-scale farmers to the landless and land-poor is likely to have substantially limited the social, economic and environmental benefits that land redistributions can generate.

Second, despite numerous measures launched since the start of the land redistribution sub-programme,[15] the inadequacy in the provision of support services - and in particular RAS - to land redistribution participants has remained one of the most critical issues limiting the effectiveness of this sub-programme (Aliber *et al.*, 2016). At least three inter-related factors

[14] For a discussion on land expropriation, and particularly land expropriation without compensation, see e.g. CDE (2018). In terms of recent legislative initiatives to explicitly specify circumstances where land may be expropriated with payment of nil compensation, a Second Reading of the Bill amending Section 25 of the Constitution (Constitution Eighteenth Amendment Bill, 2021) was rejected by the National Assembly in December 2021 (RSA, 2021). Yet, at the time of writing, an Expropriation Bill (Expropriation Bill, 2020), which includes a clause specifying that the payment of nil compensation where land is expropriated in the public interest may be just and equitable (Expropriation Bill, 2020: clause 12(3)) remains under consideration by the National Assembly (PMG, n.d.).

[15] e.g. the Comprehensive Agricultural Support Programme (CASP) (DOA, 2004), the establishment of the Norms and Standards for Extension and Advisory Services in Agriculture (DOA, 2005), the Extension Recovery Plan (ERP) (DAFF, 2011), the Recapitalisation and Development Programme (DRDLR, 2015), and most recently the 2016 National Policy on Extension and Advisory Services (DAFF, 2016).

can be considered to have contributed to this issue. The first is the absence of a well-coordinated participatory and multi-stakeholder approach. Participatory approaches placing farmers at the centre of the RAS system are crucial to identify and thus cater for the needs and demands of land redistribution participants. And a multi-stakeholder approach enables a RAS system to include and involve actors beyond central and provincial government, such as research institutions, civil society, development partners and the private sector, who can present and implement collaborative solutions for the financing and delivery of the demanded RAS/support services. Indeed, the design and implementation of such an approach can help circumvent the second often-stated factor having caused ineffective provision of support services, namely the insufficient budgetary and human resources allocated to the government departments responsible for the provision of such services. This is undoubtedly an area of concern and requires policy commitment for the adequate funding of central and local government offices to enable the recruitment and ongoing capacity development of personnel (Greenberg, 2010; Hall, 2004a). Yet, a well-coordinated participatory and multi-stakeholder approach to RAS can relieve some of the pressures on government and generate efficiency and effectiveness gains. By engaging with farmers and truly contemplating their needs and demands, the scene can be set for an effective service delivery and for a significant reduction in the wasteful use of resources. And a multi-stakeholder approach can spur efficiency gains by allowing multiple actors to contribute to the financing and provision of RAS according to their comparative advantage.

The third inter-related factor is the top-down ‘transfer of technology’ model that has been guiding the provision of support services to land redistribution participants. The reliance on such a model has been driving support services to land redistribution participants from the design of the business plan required for participation in the sub-programme (Aliber and Cousins, 2013; Aliber *et al.*, 2016; Lahiff, 2007b; PLAAS, 2016) to the post-settlement support provided, notably in terms of advisory services (deSatgé, 2020). With this type of support, advisors tend to impose on land redistribution participants a farming model based on the pre-existing large-scale commercial farming operation present at the farm, often entailing single enterprise specialisation (Obi, 2013). This translates into a support that is too detached from what is actually demanded by farmers and that often does not account for the substantial differences between the previous farm owners and the land gainers in terms of conditions (e.g. financial resources, market-access, infrastructure) and intended use of the land (Hall, 2004a; Lahiff, 2007a; 2007b).

In sum, the dynamics related to the implementation of the land redistribution sub-programme show not only disappointing results in terms of number of hectares redistributed (the main indicator by which the sub-programme is generally assessed), but also a regrettable departure from the initial policy intentions expressed in the RDP (ANC, 1994) and the White Paper on Land Policy (DLA, 1997). Insufficient priority (at the central government level) appears to have been given to a sub-programme that was launched as a means to ensure a more equitable distribution of land ownership, to relieve human-related environmental pressures on the land and to improve the livelihoods and quality of life of rural populations. Policymakers in successive governments have been reluctant to depart from the large-scale commercial farming model and facilitate the transition - through a subdivision of farmland and the establishment of a functional RAS system - from the few white-owned large-scale farms to family-owned small-scale farming operations. Instead, they have attempted to perpetuate such a large-scale commercial farming model without sufficiently acknowledging the divergent conditions, needs and demands of the land poor and disadvantaged population groups who were originally the intended beneficiaries of the land redistribution sub-programme.

4.2.3.3. Tenure reform

The implementation of a tenure reform in accordance with the policy intentions expressed in the RDP and in the White Paper on Land Policy in South Africa represents a challenge of gargantuan proportions. The land tenure landscape in South Africa is in fact of a profound complexity due to the historical dynamics that occurred after colonisation. Prior to settler occupation, customary tenure was prevalent among the African population, albeit in different forms and manifestations (Bundy, 1988). The Dutch and British expansion in South Africa led to the introduction of Roman Dutch law and English Common law (Pienaar, 2012) and to the imposition, in several African communities, of artificial transformations to the prevalent systems of customary law (Clark and Luwaya, 2017; Lahiff, 2000). Inevitably, these dynamics also marked the land tenure structure of South Africa. Currently, the four tenure types that are generally distinguished in the literature, namely nationalised, freehold, leasehold and customary tenure (Kasimbazi, 2017) are present in the country. According to the 2019 Advisory panel report, “approximately 72% of land is held privately in freehold and leasehold, whilst 14% is held by the state and a further 14% held in terms of the customary law” (Mahlati *et al.*, 2019:43). Customary tenure prevails in the so-called communal areas (the former *Bantustans*), home to approximately 17 million South Africans (Clark and Luwaya, 2017). These areas are largely characterised by tenure insecurity due to the history of forced removals and the fragile and often overlapping rights to land that ensued (Cousins, 2007). In addition, due to colonial dispossessions and racially discriminatory laws and practices, approximately three million black South African (Cousins and Hall, 2011:30; Wegerif *et al.*, 2005) who held customary (and in some circumstances private) rights to land were converted into tenure insecure labour tenants and farm dwellers on white-owned land (Mahlati *et al.*, 2019:47). In such a context, land reformers were required to perform an arduous balancing act to ensure tenure security not only to freeholders and leaseholders but also to labour tenants, farm dwellers and residents of communal areas, i.e. to all South Africans. Various pieces of legislation were enacted to support the realisation of the tenure reform sub-programme. Among these, the Extension of Security of Tenure Act (1997) (ESTA) was enacted primarily to enhance tenure security for farm dwellers, the Land Reform (Labour Tenants) Act (1996) (LTA) was devoted to labour tenants' rights to land, and the Interim Protection of Informal Land Rights Act (1996) (IPILRA) was intended to temporarily fill the legislative vacuum for the protection of informal rights to land, most notably for rural populations living in communal areas. The IPILRA was due to elapse at the end of 1997, but it was renewed annually until the Communal Land Rights Act (2004) (CLARA) was promulgated in 2004. The CLARA, however, was declared unconstitutional in 2010 by the Constitutional Court following a legal challenge undertaken by community groups shortly after the enactment of the law (Cousins and Hall, 2011). As such, CLARA was never truly operational and tenure rights in communal areas remain protected by IPILRA.[16]

Arguably the most critical issue related to the implementation of tenure reform in South Africa is the lack of effective legislation enhancing tenure security, particularly for farm dwellers on white-owned land and farm-households residing in communal areas. The ESTA was enacted to clarify the rights and duties of both owners and occupiers of rural land and to specify the conditions and procedures for termination of right of residence and eviction of the occupiers of land (Extension of Security of Tenure Act, 1997). The provisions of the act placed the procedural burden of evictions on the owners of land: "an occupier may be evicted only in terms of an order of court issued under this Act" (Extension of Security of Tenure Act, 1997: section 9, sub-section 1) and required that all court orders be reviewed by the Land Claims Court (Extension of Security of Tenure Act, 1997: section 19, sub-section 3; and confirmed in the Land Affairs General Amendment Act, 2000: section 11, paragraph a), a measure intended to reduce the likelihood of unfair judgements made by magistrates (Wegerif *et al.*, 2005:73). Yet, in practice, reports indicate that such a measure has in fact had the opposite effect: "The Land Claims Court has, through its interpretation of the law, systematically and gradually eroded the rights contained in the tenure legislation that was aimed to protect farm dwellers." (Wegerif *et al.*, 2005:vi). The

[16] A new Communal Land Tenure Bill was published for public comment in 2017 (DRDLR, 2017). After provincial consultations, the Department set out to draft a tenure security policy under the guidance of the advisory panel, which would refine the Bill (PMG, 2019). At the time of writing, a new version of the Bill has not been released, but mention was made that a Bill would be introduced in Parliament for consideration and adoption (PMG, 2021).

enacted legislation is also considered to have produced adverse incentives for farm owners, who have become increasingly reluctant to accept new farm dwellers given the potential costs associated with the legal procedure required for eviction, even under just cause (Wegerif *et al.*, 2005:89). Overall, estimated numbers of farm displacements and evictions are astonishing. According to results from a National Evictions Survey published in 2005, close to 4.2 million farm dwellers were displaced and close to 1.7 million were evicted from farms between 1984 and 2004 (Wegerif *et al.*, 2005:43). Of these, approximately 930,000 evictions and 2.3 million displacements occurred between 1994 and 2004, with clear peaks arising in the years that legislation was published (Wegerif *et al.*, 2005:46). Furthermore, only approximately one percent of all evictions were found to have followed a legal process, indicating clear deficiencies in compliance with, and enforcement of, legislation.

With respect to tenure reform legislation applicable to communal areas, the dynamics surrounding the CLARA are emblematic of the (unresolved) challenges faced by land reformers in devising appropriate legislation addressing issues of land rights and land administration. The CLARA was signed into law on 15 July 2004 and was the result of a lengthy policy and legislative process. A Land Rights Bill had been prepared under the Mandela presidency and presented in 1999 (Hall, 2004c). With the instatement of the new government in that same year, the incoming Minister of Agriculture and Land Affairs asked to reassess the Bill, which she deemed too costly, excessively bureaucratic, lacking recognition of the institutions of traditional leadership, and making insufficient provisions for the transfer of land ownership to communities (PMG, 2004). As a consequence, the Department proceeded to redraft the bill, which was renamed the Communal Land Rights Bill and approved by Cabinet in October 2003 (Hall, 2004c:50). The Bill was enacted in 2004 and thus became referred to as CLARA (from its official name Communal Land Rights Act). The CLARA set out measures to provide juristic personality to communities, transfer ownership of land to the communities and devolve land administration to community committees – which could consist of the same members of traditional councils (Communal Land Rights Act, 2004). However, the act was soon challenged by four applicants representing four community groups, and the Constitutional Court declared in 2010 the act invalid in its entirety. Although the ruling from the court was based on procedural matters, the underlying reasons are expressed in the text of the ruling:

> The communities […] are concerned that their land will now be subject to the control of traditional councils which, as is apparent from the record, they consider to be incapable of administering their land for the benefit of the community […] CLARA replaces the living indigenous law regime which regulates the occupation, use and administration of communal land. […] CLARA also gives traditional councils new wide-ranging powers and functions.

> They include control over the occupation, use and administration of communal land. (Constitutional Court of South Africa, 2010:21;57)

The core issues that were raised by community groups, namely that due to the legally insecure tenure landscape present in communal areas the provision of additional power to traditional councils would endanger residents' use and occupation of land, were thus acknowledged by the Court. Indeed, among community members the institution of traditional councils is often seen as a perpetuation of the system of traditional authorities shaped under colonial rule and apartheid legislation, leading communities to question their legitimacy (Ntsebeza, 2005; Weinberg, 2015). Whilst the Constitutional Court ruling led to the invalidation of CLARA, the issues surrounding the authoritarian and despotic nature of traditional authorities remain present in land tenure reform debates. Despite warnings upon conflicts between constitutional principles, the most recent Communal Tenure Bill (DRDLR, 2017) continues to lean towards the recognition of traditional authorities as the main vehicle for the formal transfer of land ownership and land administration to communities in communal areas.

Overall, the lack of appropriate legislation strengthening tenure security remains a pressing issue that land reformers must address if progress is to be made on the land tenure reform sub-programme.

4.2.4. Conclusions

The first part of this study began with a contextualisation of the land reform programme in South Africa, providing a brief account of the history of land dispossessions suffered by the indigenous African population. It highlighted that the dispossessions of land have roots deeper than the racially discriminatory laws and practices that occurred after 1913, and can in fact be traced back to the settler occupation of the seventeenth century.

The following section summarised three key documents that were released during the initial phase of the land reform and that reflect both the policy intentions of land reformers and the provisions related to the land reform that were enshrined in the nation's supreme law. These initial intentions - expressed in the RDP and in the White Paper on Land Policy - included the realisation of a land reform programme encompassing restitution of rights to the land lost due to racially discriminatory laws and practices, equitable redistribution of land, and tenure reform to ensure legally secure land tenure, as well as measures to enable access to the required support services, including RAS (ANC, 1994; DLA, 1997). Such a programme was intended to contribute to reduce inequality, poverty, unemployment/underemployment, land-related conflicts, food insecurity and environmental degradation, thereby improving rural quality of life and fostering social, economic and environmental sustainability (ANC, 1994; DLA, 1997). Furthermore, an overall objective of transferring 30% of agricultural land within the first five years of the land reform programme was set in the RDP (ANC, 1994: section 2.4.14). With the inclusion of Section 25 in the Constitution, the three sub-programmes of the land reform - land restitution, land redistribution and tenure reform - can effectively be considered as ‘rights-based’, as they are backed by the nation’s supreme law.

The last section of the first part of this study presented an overview of the actual implementation of the land reform programme in South Africa and critically gauged the progress made on the three land reform sub-programmes against the initial intentions of land reformers. Notwithstanding the plethora of policy documentation released and legislation enacted to advance the three sub-programmes, the South African land reform can be considered to have fallen short in realising land reformers’ initial intentions. Not only has the 30% target been repeatedly missed and postponed, but also, and crucially, the measures implemented by policymakers have substantially deviated from those required to enable the realisation of the initial intentions. Significant progress was made on lodging and settling land restitution claims. Yet, measures to ensure that pre-1913 dispossessions be addressed have not been implemented, numerous claims have thus far not been settled, and several of the settled claims have not generated substantial benefits to the livelihoods of rural populations. Similarly, the successive governments have largely failed in generating opportunities for the landless and land-poor farmers to obtain land and engage in sustainable farming through the land redistribution sub-programme. Amongst the various limiting factors, a lack of subdivision of farmland and an inadequate provision of support services appear to have significantly hampered the land redistribution sub-programme’s potential to promote sustainable rural development in South Africa. Lastly, land tenure reform can continue to be considered as the “orphan [sub-]programme” of the land reform (Cousins, 2016:138). Enacted legislation relevant to this sub-programme is largely incomplete and fails to comprehensively ensure the constitutional right to tenure security for South Africa’s citizens.

In closing to this first part of the study, and ahead of the empirical analysis included in the second part of the study, some brief reflections can be advanced on the South African land reform experience, notably in light of the Climate Smart Land Reform (CSLR) framework introduced in Rampa *et al.* (2020). Several of the features present in the design of the South African land reform and highlighted in Section 4.2.2 are in line with various of the elements depicted in the CSLR framework.

The design of the South African land reform included all four of the pillars presented in the CSLR framework. The land redistribution and land restitution sub-programmes of the South African land reform can be grouped under the more general 'land redistribution' pillar of the CSLR framework. In effect, in the CSLR framework land redistribution is broadly defined as "the passage of an asset (the land) from individuals or groups of individuals (the "land losers") to other individuals (the "land gainers")" (Rampa *et al.*, 2020:6). Now, although land restitution and land redistribution represent two distinct sub-programmes within the South African land reform programme, with different proximate goals, participation criteria and implementation mechanisms, the essence of both of these programmes constitutes a transfer of land from "land losers" to "land gainers" and can therefore generally be seen as coinciding with the land redistribution pillar of the CSLR framework. The land tenure reform component, present in the South African land reform programme, is also included as one of the four pillars in the CSLR framework. Finally, the "support services", considered as fundamental in the design of the South African land reform programme, is a broad category which is decomposed in the CSLR framework into services directed at facilitating farmers' access to markets (e.g. financial, input/output markets) and to infrastructure (both on and off-farm), as well as services enhancing farmers' access to information, theoretical and practical knowledge, and technologies. Support services therefore appear as two separate pillars in the CSLR framework, namely Markets and Infrastructure and RAS.

Similarly, the objectives of the South African land reform gathered social, economic, political and environmental goals, which can be paralleled to the 'intermediate' objectives presented in the CSLR framework – the 'traditional' objectives including social, economic and political goals, and the CSA objectives including socio-economic and environmental goals.

Therefore, considering merely the three sub-programmes emerging from the design phase of the South African land reform programme, and the objectives stated in the policy documents issued at the dawn of the programme, the South African land reform programme can be considered to be broadly well aligned with several of the elements of the CSLR framework.

The shortcomings of the South African land reform discussed in the first part of this study, and the similarities that can be found in elements of the South African land reform and of the CSLR framework, lead to a reflection on policy-related aspects of the South African land reform and on the care required for potential uses of the CSLR framework at the policy level.

The first part of this case study exemplifies the complexities associated with the design and implementation of a land reform programme. In terms of design, of course, historical dynamics shaping the state of land distribution and the relationships among rural populations need to be carefully considered by land reformers. Section 4.2.1 illustrates the immense complexities of such historical dynamics in the South African case, which are intrinsically linked to the history of dispossessions and segregation suffered by Africans. These have led to an unprecedented pattern of racially-based socio-economic inequalities and environmental degradation, generating unique pressures on land reformers to design a comprehensive land reform programme that could redress past injustices, contribute to political stability and foster a pathway towards sustainable development.

The various shortcomings summarised in Section 4.2.3, however, seem to hint towards a possible excess in ambition of land reformers, who may have attempted to design a comprehensive land reform whilst overestimating, and over-relying on, the available capacity and will to implement it. Land reformers most likely have sought to attain too much too quickly compared with the actual means of implementation (which include fundamental political will and indeed adequate budgetary resources). Intending to redistribute 30% of land within five years of the launch of the land reform, through a market-based land redistribution programme combined with land restitution guaranteeing restoration of rights to land to dispossessed populations as well as broad-based tenure reform, whilst ensuring adequate provision of support services, can indeed be considered a very ambitious land reform programme. Contextualising these intentions to the South African landscape in the early 1990s, where a process of national reconciliation and, in effect, nation building, was getting underway, leads to question whether these intentions corresponded in reality more to aspirations.

In retrospect, the land restitution sub-programme, for instance, could have been limited to financial compensation for claims to urban land, which have been more easily settled compared to the rural ones. Rural land restitution could have instead been integrated into the land redistribution sub-programme, with a localised and gradual demand-led process of redistribution, which would have further eased pressures on land tenure reform. Such a process of land subdivision and redistribution would have enhanced landless and land-poor farmers' access to land, potentially also creating the preconditions for a gradual shift from an ecologically damaging to a more sustainable land use, including via small-scale farmer adoption of agricultural strategies with climate-smart potential.

The main implication is simple but too often unheeded. Key decisions made by land reformers when forging a land reform programme need to take into account not only the proximate and ultimate objectives that land reformers are setting, but also a contextual and sensible appreciation of the realistic means to enable their realisation. In this sense, it may at times be preferable to opt for a more limited extent of the programme, or to plan for a gradual implementation of diverse interventions rather than to raise excessive expectations, which are likely to remain unfulfilled, particularly in the short run.

This aspect is indeed emphasised in the description of the CSLR framework, which "recognises that in specific country contexts it might not be feasible (or in particular cases necessary) to act on all four pillars [of the framework] simultaneously" (Rampa *et al.*, 2020:4). With respect to CSA adoption, for instance, the CSLR framework indicates that individual pillars can contribute to CSA adoption and to the realisation of CSA as well as other 'traditional' objectives. If context-specific issues prevent an effective implementation of a comprehensive land reform, it may very well be desirable to design a more limited (or more gradual) programme. In other words, it is crucial to avoid reading the CSLR framework under a "don't do anything until you can do everything" lens. In fact, the CSLR framework does not prescribe that only land reforms designed to intervene simultaneously on all four pillars and to englobe all 'intermediate' objectives are advisable. Actions on individual pillars can indeed be appropriate to foster CSA adoption and to contribute to the achievement of one (or more) intermediate objectives.

4.3. Part II. Land reform and CSA adoption in South Africa: empirical evidence from farm-households in the Limpopo river-basin.

4.3.1. Conceptual framework

To empirically examine the association between land reform and CSA adoption in the South African context this study employs, as a conceptual basis, the "Climate Smart Land Reform" (CSLR) framework introduced in Rampa *et al.* (2020). Focus is placed on two of the CSLR 'pillars', namely land redistribution and RAS, and on the association between these two pillars and the adoption of two CSA strategies, localised irrigation and integrated crop-livestock systems (Figure 4.2).[17]

This section first introduces and describes the two CSA strategies examined, and then discusses the hypothesised linkages between the two CSLR pillars and the adoption of these strategies in the context of the South African land reform.

[17] Due to data limitations, the linkages between the other two 'pillars' of the CSLR framework, namely tenure reform and markets and infrastructure, and CSA adoption could not be explored; nor was it possible to examine the effects of the four pillars and of CSA adoption on the intermediate/ultimate objectives of land reformers. Investigating such relationships in the context of the South African land reform represents an opportunity for future research.

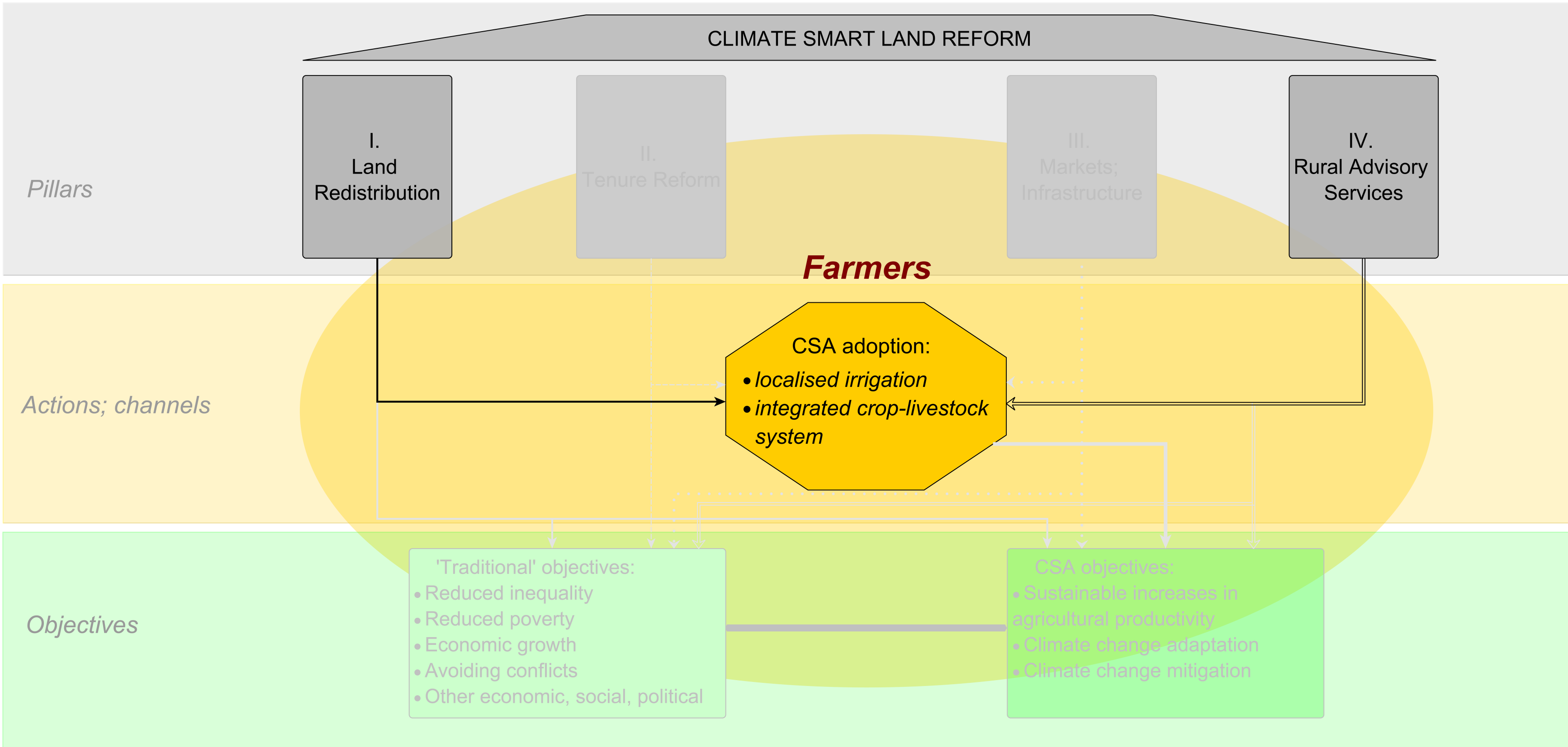

Figure 4.2. Conceptual framework

Source: Adapted from Rampa *et al*. (2020)

4.3.1.1. CSA adoption: localised irrigation and integrated crop-livestock systems

Farm-level strategies can be considered as climate-smart insofar as they generate beneficial (or at least non-negative) effects on the three CSA objectives, sustainable increases in agricultural productivity, climate change adaptation and climate change mitigation. In principle, this implies that a given agricultural strategy may be categorised as climate-smart in a given context only *a posteriori*, that is once its effects have been assessed on measures of the three CSA objectives. Yet, it is possible to consider an agricultural strategy as having *a priori* climate-smart potential on theoretical grounds and based on the available empirical evidence from its adoption in similar contexts.

Two types of agricultural strategies with climate-smart potential are hereby examined, namely employing 'localised irrigation' technologies and diversifying the farming system through the integration of crop and livestock production.

Localised irrigation is defined in this study as a root targeted/individual plant irrigation method involving the use of either traditional or modern precision-based irrigation technologies that are characterised by water and energy use efficiency (e.g. drip irrigation/trickle, micro sprayer, individual – hose, water bucket, watering can). The CSA literature offers extensive theoretical as well as empirical evidence of the beneficial effects of employing such irrigation technologies on the CSA objectives (Batchelor and Schnetzer, 2018; Bell *et al.*, 2018; Dinesh, 2016; McCarthy and Brubaker, 2014; Partey *et al.*, 2018; Senyolo *et al.*, 2018; World Bank, 2016; 2018). Likewise, Integrated Crop-Livestock Systems (ICLS) offer opportunities for improvements in terms of productivity, climate change adaptation and climate change mitigation (FAO, 2017: module B5; Harvey *et al.*, 2014; Pretty *et al.*, 2006; Rosa-Schleich *et al.*, 2019; Thornton and Herrero, 2015; Thornton *et al.*, 2017).

Furthermore, both agricultural strategies can be deemed relevant to the South African context. With regards to localised irrigation, South Africa has been experiencing dramatic effects due to water scarcity (Otto *et al.*, 2018; Pienaar and Boonzaaier, 2018) and better water management practices, including at the farm-level via the use of localised irrigation technologies, can be helpful to both mitigate and adapt to these effects. The expansion of more efficient irrigation methods features among government documentation promoting CSA adoption. For instance, the draft strategic framework for CSA in South Africa recognises the importance of supporting farmers, notably small-scale farmers, in adopting water and energy efficient irrigation methods (DAFF, 2018: section 6.3.4.c; 6.4.5; 6.4.6). Water use efficiency through drip irrigation is also showcased as a strategy for climate smart agricultural water management in the Department of Environment, Forestry and Fisheries' actionable guidelines for the implementation of CSA in South Africa (Mnkeni *et al.*, 2019:39). In South Africa's third national communication under the United Nations Framework Convention on Climate Change, the adoption of CSA, including via the adoption of low water-use irrigation systems, is considered an area of priority, particularly in terms of adaptation to climate change (DEA, 2018).

With regards to ICLS, such a farming strategy can be considered as both culturally appropriate and relevant to the South African context. Historically, livestock played a key role amongst farming communities. They provided an essential source of protein for the diets of rural household members - through both milk and meat production - and supported crop production by providing draught power and organic fertiliser (Ainslie, 2002; Andrew *et al.*, 2003; Bundy, 1988). Livestock were also a key asset employed for transport, for paying dowries, and to obtain cash (either via the sale of meat, hides and skins, or in gross animal form) (Ainslie, 2002; Andrew *et al.*, 2003). Recently, the integration at the farm-level of livestock alongside crop production has gained relevance, notably to support rural livelihoods in the face of climate change (Cousins *et al.*, 2020; Mnkeni and Mutengwa, 2014; Nciizah and Wakindiki, 2015).

4.3.1.2. Land redistribution

As highlighted in Section 4.2.4 above, when applying the CSLR framework to the South African land reform programme, the land redistribution pillar of the framework can be considered to englobe both the land restitution and land redistribution sub-programmes. In effect, both of these sub-programmes consist in a transfer of land from "land losers" to "land gainers", which is a defining characteristic of the land redistribution pillar of the CSLR framework. This part of the study follows the nomenclature used in the CSLR framework and employs the concept of 'land redistribution' broadly to include both land redistribution and land restitution.

According to the CSLR framework, a key channel through which land redistribution can affect CSA adoption relates to the potential inverse relationship between farm size and CSA adoption (Rampa *et al.*, 2020). This channel indicates that insofar as two conditions are met, namely that (i) CSA options are labour intensive and (ii) lower labour transaction costs exist for the "land gainers" compared to the "land losers", a land redistribution can contribute to CSA adoption.[18]

[18] Indeed, the CSLR framework also considers other enabling (and disabling) factors that may crucially affect land redistribution participants' likelihood of CSA adoption, including agroecological and socioeconomic conditions faced by land redistribution participants, their

The first condition, which relates to the additional labour requirements in the implementation of the given CSA strategy compared to a counterfactual scenario of non-adoption, is likely to be met. Adopting localised irrigation technologies, such as drip irrigation, requires, in principle, more labour than relying exclusively on rainfall or adopting less precise forms of irrigation, such as centre pivot. Similarly, mixed farming systems that integrate crop and livestock production are generally more labour intensive compared, for instance, to specialised systems of monocropping (Amadu *et al.*, 2020; Rosa-Schleich *et al.*, 2019).

The presence of the second condition, which relates to labour transaction costs, is more difficult to determine in the complex South African land reform context. Classic land redistributions consist in transferring land from large-scale farmers to the landless and/or land poor farmers. This implies a transformation of the given large-scale farm, whose owner typically relies on hired labour, into individual family holdings owned and predominantly operated by family members. Therefore, transaction costs of labour, including costs associated with information asymmetries and in particular moral hazard, are substantially reduced with the land redistribution. However, the design of the land reform in South Africa was of a much more complex nature and did not envisage a subdivision of the transferred farmland *per se*. Various characterising elements of the South African land reform, such as the market-based willing-buyer-willing-seller (WBWS) model of land reform, the relatively low grants provided to land redistribution participants, the policy orientation towards large-scale commercial production, the process followed to lodge claims to land restitution (i.e. the pooling of large groups of individuals based on the original date at which land was dispossessed and resulting in artificially reconstituted communities) have led, in most land redistribution and restitution cases, to the necessity for land gainers to obtain, manage and operate the land under group structures involving up to hundreds of households (Hall, 2009:26; Lahiff, 2008:34). Under such collective arrangements, the expected gains in labour transaction costs are very likely to diminish.

Yet, evidence from case studies suggests that in certain circumstances, communal property institutions were only established to comply with the formal processes required to obtain the land. Thereafter, the group members acted individually on portions of the land, often in violation of the original business plan (Aliber, 2018:17). In other words, there is evidence that in particular cases the land transfers have *de facto* mimicked a classic land redistribution, with large farms being subdivided in favour of more labour intensive smallholdings:

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knowledge upon the given CSA option and the expected costs and benefits associated with its adoption, the cultural acceptance of the given CSA option, among others.

> The two projects that contributed most to poverty reduction were restitution projects which experienced influxes of settlers who set up residences and pursued gardening and/or small-scale crop farming. In both instances this was in violation of the business plan […]. Especially on the one project where there was a relative abundance of space, it is not a stretch to suggest the image of a classic land reform in which a large farm was subdivided to make space for labour-intensive smallholdings. (Aliber, 2018:17)

The net effect from both conditions, in terms of CSA adoption, is therefore ambiguous in the South African land reform context. Based on the CSLR framework and on the information available from the literature on the South African land reform, it is difficult to ascertain *a priori* whether the likelihood of CSA adoption may be higher for land redistribution participants compared to non-participants.

4.3.1.3. Rural advisory services

Rural Advisory Services (RAS) can be defined as:

> [S]ystems that should facilitate the access of farmers, their organizations and other market actors to knowledge, information and technologies; facilitate their interaction with partners in research, education, agri-business, and other relevant institutions; and assist them to develop their own technical, organizational and management skills and practices. (Christoplos, 2010:3)

In a land reform context, RAS can complement land redistribution efforts and be expected to further enhance CSA adoption among land redistribution participants (Rampa *et al.*, 2020). Indeed, RAS can prove critical in providing land redistribution participants with information, advice and training on various CSA options that may be suitable to their needs. RAS can be helpful to assist farmers in making informed decisions upon the adoption of the chosen farming strategies, and they can support farmers in adjusting their strategies due to potential changes/challenges faced over time. In other words, RAS can be instrumental in dynamically supporting farmers during the decision-making processes related to the adoption, maintenance, and revisal of relevant CSA options. Yet, in the South African land reform context, there are factors that may cast doubt upon the presence of a positive association between RAS and CSA adoption.

The first broad factor relates to the overall RAS system present in South Africa and involving land reform participants. As highlighted in Section 4.2.3 above, both the land restitution and land redistribution sub-programmes have been marked by an inadequate provision of support services, including RAS. Despite attempts made at improving the support services provided to land reform participants by successive governments, there does not appear to be a well-designed and well-functioning RAS system in South Africa that can adequately cater for the needs and demands of land reform participants. The lack of a demand-driven, multi-stakeholder and participatory approach to RAS, the low level of coordination among institutions responsible for the design, financing and provision of

RAS, combined with deficiencies in terms of number and skills of advisors, inevitably leads to inadequacies both in the quantity and quality of services provided (Cliffe, 2009; Cochet *et al.*, 2015; Lahiff, 2007a; 2008).

A narrower and related factor is the continued fixation on the large-scale conventional commercial farming model guiding land reform policy and the top-down approach to RAS provision that ensues. As Lahiff (2007a) points out:

> [A] defining characteristic of South African land reform policy is that beneficiaries – no matter how poor or how numerous – are required to step into the shoes of former white owners and continue to manage farms as unitary, commercially oriented enterprises, while alternative models, based on low inputs and smaller units of production, are actively discouraged […] Post-settlement support is clearly in need of a major overhaul, although the problems being encountered lie not only with the quality of services on offer but also with the inappropriate – often unworkable – farming models being imposed by officials. (pp.1590,1593)

In such a context, it is altogether possible that RAS, including farm-level trainings, might have disincentivised farmers from adopting the CSA strategies under consideration. Drawing from the above-stated argument made by Lahiff (2007a), farmers might have, for instance, been encouraged by advisors and trainers to replicate the business model of previous large-scale farmers and maintain a single enterprise specialisation approach to farming leading to, say, single enterprise specialisation as opposed to more diversified crop-livestock systems. Similarly, the use of more capital and water intensive forms of irrigation commonly employed on large-scale commercial farms, such as centre-pivot, may have been advised in place of a farming strategy involving more labour-intensive irrigation technologies.

In sum, whilst the presence of a functional RAS system in a land reform context can in principle contribute to CSA adoption, the elements described above suggest that in the South African case a positive correlation between RAS provision and CSA adoption might not be observed. Whether the provision of RAS generated positive, neutral or negative effects on CSA adoption for land redistribution participants therefore remains an empirical question in the South African context.

4.3.2. Data and methods

4.3.2.1. Data

The dearth of quantitative empirical studies on land reform in South Africa is largely due to the scarcity of available data. Although one of the government's intended means for monitoring the impacts of the land reform was the regular implementation of 'Quality of Life' (QoL) surveys, significant challenges, including issues related to sampling and to the methodology employed, as well as the lack of public availability of the data from the surveys have constrained their use (see, e.g., Hall *et al.*, 2003 for a discussion on these surveys; Hall, 2007; Quan *et al.*, 2003).[19] A report from South Africa's Human Sciences Research Council (HSRC) summarises the shortcomings of the QoL surveys in an emblematic manner:

> To date, the QoL has failed to provide credible and informative data about land reform, let alone being a tool to evaluate if transferred land has been or could be sustaining agrarian-based livelihoods. Earlier intentions and subsequent recommendations to conduct the QoL on an annual basis have not been realised. (HSRC, 2013:21)

No other nationally representative survey includes specific modules on land reform, and the agricultural census conducted regularly by Statistics South Africa only covers the approximately 40,000 large-scale commercial farms of the country, thus providing an extremely narrow overview of the sector.[20] As a consequence, less than a handful of studies exist providing nationally representative quantitative analyses of the effects of the South African land reform.

Deininger and May (2000) utilised data from an early QoL survey conducted by the DLA in 1999 and found that only 16% of the land reform projects surveyed could be classified as generating sustainable revenues (Deininger and May, 2000:14). The authors highlighted three characteristics linked to project success: making a cash contribution to the project, taking out a loan, and having small-sized projects (in terms of number of participating households) along with lighter management structures (i.e. having a single main decision-maker as opposed to relying on a trust or common property association).

Keswell and Carter (2014) exploited data from a subsequent QoL survey to estimate the effects of the LRAD on living standards.[21] They found that the land transfers generated positive effects on per-capita expenditures and that these effects appeared to reach a maximum approximately 2.5 years after the occurrence of the land transfer.[22]

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[19] Several attempts were made to obtain a copy of the datasets related to the QoL surveys, including via informal and formal requests to individual researchers and research institutions. Yet, these datasets were not made available and could therefore not be explored for the purpose of this study.

[20] Three specific questions related to agriculture were incorporated in the 2011 Population Census and enabled to draw an updated picture of the relevance of non-commercial agriculture in the country: approx. 2.9 million South African households had members that were engaged in agriculture (Stats SA, 2013). However, these three questions did not include a reference to the land reform programme and thus did not enable the identification of land reform participants among households that had members engaged in agriculture.

[21] The data source is not explicitly stated in the article. However, the use of QoL data to produce the study was confirmed by one of the authors (Carter, M.R., 2019, *personal communication*).

[22] In particular, the authors estimate both binary and continuous treatment effects. The binary treatment effects reveal an increase in per-capita expenditures of 25%, whilst the continuous treatment estimates show an initial dip in expenditures followed by a subsequent increase, reaching a maximum approximately 2.5 years after the land transfer and stabilising approximately 3.5 years after the land transfer (Keswell and Carter, 2014).

Valente (2009; 2011) employed non-agricultural nationally representative surveys to uncover the effects of the land reform on a specific measure of food security.[23] Irrespective of the wave of the survey used for the quantitative analysis, the author finds a positive relationship between land redistribution and suffering from food needs, suggesting that land transfers were not successful in reducing food insecurity among the beneficiary households.

To overcome some of the challenges associated with land reform data availability and access, this study employs a dataset publicly made available by researchers from the International Food Policy Research Institute (IFPRI) (Ringler and Sun, 2010). The dataset originates from a cross-sectional survey of farm-households located in the Limpopo river-basin of South Africa, distributed between the provinces of Gauteng, Limpopo, Mpumalanga and North West (Figure 4.3). The survey was carried out between August and November 2005 by the Center for Environmental Economics and Policy in Africa (CEEPA), and it covers the agricultural season of April/May 2004 to April/May 2005.

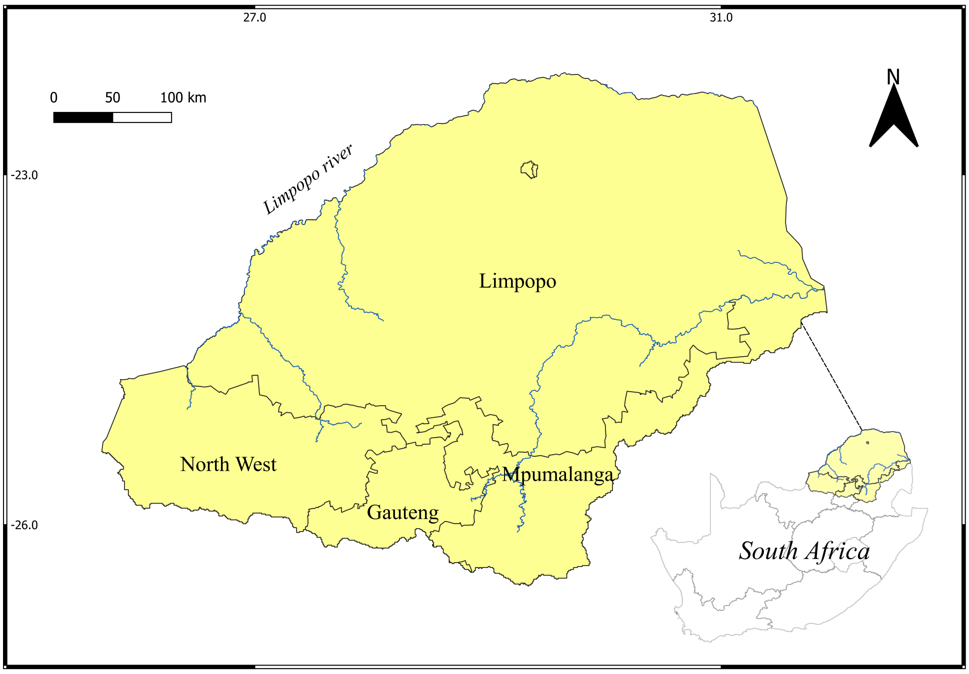

Figure 4.3. Map of the Limpopo river-basin

Source: Author, based on Lehner *et al*. (2008); South African Municipal Demarcation Board (2016); Stats SA (2001)

[23] For the main quantitative analysis of the two articles, the author employs four waves of the Labour Force Survey (LFS). Although the LFS included one question - whether the household received a land grant - that can be related to the land redistribution programme and a question related to food security ("In the past 12 months, how often, if ever, did this household have problems satisfying their food needs?"), the LFS does not contain a module on land reform *per se* nor on agricultural activities and could therefore not be employed to address the research questions of this study.

The dataset allows the exploration of associations between the land redistribution and RAS pillars of the CSLR framework, and CSA adoption, for a sizeable portion of the surveyed farm-households. Specific variables relating to characteristics of the farm, of the farm-household and of farm-household members could be extracted from the dataset and employed in this study (Table 4.1). In particular, two binary variables were constructed to identify farm-households that adopted the agricultural strategies with climate-smart potential considered in this study, namely ICLS and localised irrigation. Furthermore, a categorical variable was computed to distinguish land redistribution participants as well as farm-households whose members had attended trainings in crop/livestock production in the two years preceding the survey (as a proxy for RAS), resulting in a set of four farm-household categories: (i) farm-households that benefitted from the land redistribution and whose members attended trainings in crop and/or livestock production; (ii) farm-households that benefitted from the land redistribution and whose members did not attend trainings in crop and/or livestock production; (iii) farm-households that did not benefit from the land redistribution and whose members participated in trainings in crop and/or livestock production; and (iv) farm-households that neither benefited from the land redistribution nor had members attending trainings in crop and/or livestock production.

The two binary variables related to the adoption of CSA are employed as the dependent variables in the specified models, whilst the categorical variable combining land redistribution and RAS represents the key regressor of interest. Other observed binary, categorical and continuous variables describing farm-household, household members and farm-level characteristics listed in Table 4.1 are included as control variables. The selection of these covariates is guided by previous findings from the empirical literature on the determinants of CSA adoption and on data availability (Appendix Table 4.A.1 provides summary information on the expected signs of the correlations between the control variables and CSA adoption).

Table 4.1. Variables and summary statistics

Variable	Description	Mean (% for binary or categ. var.)	Min	Max
ICLS	Binary variable of 1 if the farm-household adopted Integrated Crop Livestock farming systems and 0 otherwise	21.12	-	-
Localised irrigation	Binary variable of 1 if the farm-household adopted 'localised irrigation' and 0 otherwise	24.06	-	-
Gender	Binary variable of 1 if the household head is a female and 0 otherwise	26.20	-	-
Age	Years of age of the household head	55.05	19	100
Married	Binary variable of 1 if the household head is married and 0 otherwise	79.95	-	-
Education	Binary variable of 1 if the household head completed at least primary education and 0 otherwise	72.46	-	-
HH size	Number of household members	6.32	1	17
Water access	Binary variable of 1 if the household has domestic access to water 24 hours per day and 0 otherwise	57.49	-	-
Cooking energy	Binary variable of 1 if electricity is employed as the main source of energy for cooking and 0 otherwise	58.82	-	-
Asset car	Binary variable of 1 if household members own at least one car and 0 otherwise	41.98	-	-
Asset tv	Binary variable of 1 if at least one television set is present in the household and 0 otherwise	74.87	-	-
Farm. Org.	Binary variable of 1 if the respondent is part of a farmers group and 0 otherwise	14.44	-	-
Soil_fertility	Binary variable of 1 if the respondent reported infertile or moderately fertile soil on the farmland and 0 for highly fertile soil	70.86	-	-
Shock_dr_fl	Binary variable of 1 if the household was affected by a drought or a flood in the five years preceding the survey and 0 otherwise	69.79	-	-
Province	Categorical variable distinguishing the farm location (by province)			
	Categ. 0: Mpumalanga	37.43	-	-
	Categ. 1: Gauteng	4.55	-	-
	Categ. 2: North West	10.16	-	-
	Categ. 3: Limpopo	47.86	-	-
Treatment var.	Categorical variable representing the key regressor of interest			
	Categ. 0: No Land redist. No RAS	19.79	-	-
	Categ. 1: Yes Land redist. No RAS	13.64	-	-
	Categ. 2: No Land redist. Yes RAS	41.44	-	-
	Categ. 3: Yes Land redist. Yes RAS	25.13	-	-

Note: Observations = 374

4.3.2.2. Methods

The empirical approach for this study consists in the use of binary response models. In effect, the dependent variables employed, which relate to the adoption of the two CSA strategies under consideration, are discrete dichotomous variables. Three models are commonly utilised in such circumstances, namely the Linear Probability Model (LPM), the probit model and the logit model (Greene, 2012; Maddala, 1983; Wooldridge, 2016). Although the LPM has desirable properties (it is simple to estimate - via Ordinary Least Squares (OLS) - and to interpret), it also suffers from important drawbacks, such as the fact that the fitted probabilities in an LPM cannot be constrained to lie between zero and one (i.e. both negative values and values above one can occur), which is difficult to justify since probabilities must be between zero and one. Nonlinear binary response models, such as the probit and logit, overcome the limitations of the LPM. The probit and logit are very similar models and differ mostly in the underlying distribution utilised (logistic in the case of the logit model and normal in the case of the probit). In practice, the results from either of these models tend to be very similar, particularly for sample sizes that are not extremely large (Amemiya, 1981; Long, 1997; Maddala, 1983), which is indeed the case with this dataset.

Following common practice, a latent variable approach is applied to this study (Cameron and Trivedi, 2005; Greene, 2012). With this approach, there is an unobserved response variable, y_i^*, defined by the regression relationship:

$$y_i^* = x_i\beta + e_i \tag{1}$$

The variable y_i^* can be considered to correspond, for instance, to farm-household i's propensity to adopt a given CSA strategy. What is instead observed is y_i, a binary variable that takes the value one if the farm-household adopted CSA and zero if it didn't. In equation (1), the subscript i therefore represents the farm-household; x relates to the vector of independent variables, which includes the key regressor of interest; β is the vector of parameters to be estimated; and e corresponds to the error terms, assumed to be independent of x and symmetrically distributed around zero.

The observed outcomes can be specified as:

$$y_i = \begin{cases} 0, & y_i^* \leq 0 \\ 1, & y_i^* > 0 \end{cases} \tag{2}$$

From equations (1) and (2) it follows that the probability of $y_i = 1$ for the given values of x_i is:

$$\begin{aligned} P(y_i = 1|x_i) &= P(y_i^* > 0|x_i) \\ &= P(x_i\beta + e_i > 0|x_i) \\ &= P(e_i > -x_i\beta|x_i) \\ &= F(x_i\beta) \end{aligned} \tag{3}$$

Where $F(.)$ is the Cumulative Distribution Function (CDF) of the errors e_i, which in the case of the probit model, are assumed to follow a standard normal distribution (with mean equal to zero and variance equal to one) and in the case of the logit model follow a logistic distribution, and thus for both probit and logit have a Probability Density Function (PDF), $f(.)$, symmetric about zero (Wooldridge, 2010:565).

Both probit and logit models are commonly estimated by maximum likelihood, which allows signs and statistical significance to be promptly obtained for the resulting coefficients. To obtain interpretable quantitative effects, marginal effects for continuous variables can be computed as:

$$\frac{\partial P(y_i = 1|x_i)}{\partial x_{ij}} = f(x_i\beta)\beta_j \tag{4}$$

With j representing the continuous j'th regressor (Cameron and Trivedi, 2005:467-471; Maddala, 1983:23).

If instead variables of interest are binary or categorical, which is indeed the case for the key regressor of interest in this study, the partial effects can be computed as:

$$\begin{gathered} P(y_i = 1|x_{iT-1}, T = 1) - P(y_i = 1|x_{iT-1}, T = 0) \\ = F(x_{iT-1}\beta_{T-1} + \beta_T) - F(x_{iT-1}\beta_{T-1}) \end{gathered} \tag{5}$$

With T representing the binary (or categorical) regressor of interest, which can take values of one (for the 'treated' category) or zero (for the 'base' category), and x_{iT-1} representing all other regressors included in the model.

Given the nonlinear nature of the model, marginal and partial effects will vary depending on the values of the various independent variables. Following current practice (Cameron and Trivedi, 2005:467; Greene, 2012:690), marginal and partial effects in this study are computed using the actual observed values of the independent variables. The resulting quantity is commonly referred to as the "average partial effect (APE)" (Wooldridge, 2010:577) or the "average marginal effects (AMEs)" (Williams, 2012:323) and is estimated, for the $N = 374$ farm-households, as:

$$\widehat{\beta_J}\left[N^{-1}\sum_{i=1}^{N} f(x_i\hat{\beta})\right] \tag{6}$$

For a continuous j regressor, and as:

$$N^{-1}\sum_{i=1}^{N}\left[F\left(x_{iT-1}\hat{\beta}_{T-1}+\hat{\beta}_{T}\right)-F\left(x_{iT-1}\hat{\beta}_{T-1}\right)\right] \quad (7)$$

For a binary (or categorical) variable T.

This approach has the additional benefit of providing more meaningful policy interpretation, compared to, say, the use of "marginal effects at the means".[24] Equation (7), for instance, enables a comparison to be made between two hypothetical groups of farm-households, which will only differ by the value of the binary (or categorical) variable of interest. All other independent variables are in fact set at their actual (observed) values and will thus be identical between the two groups. This gives rise to an estimate that in the treatment effects literature is commonly known as the average treatment effect (Wooldridge, 2010:578).

The preferred nonlinear binary model utilised in this study is the probit and two particular probit models are estimated. The only difference between the two models is the dependent variable that is used. In the first, adoption of ICLS is used as the dependent variable, whilst in the second model adoption of localised irrigation represents the dependent variable. In both models the key regressor of interest is a categorical variable, which, as indicated above, contains four categories of farm-households, based on their participation to the land reform and to training activities (as a proxy for RAS).[25]

Robustness

A bivariate probit model combining the two probit models is also estimated and a test for the absence of correlation between the error terms of the individual probits is conducted. This procedure is used to understand whether the individual probits can be estimated separately or if instead they should be jointly estimated (Greene, 2012:742). In addition, the estimations of the probits are also replicated using the logit model.

To further refine the empirical analysis, and in an attempt to reduce possible sources of bias that may affect the identification of a causal effect between the key parameter of interest and the outcome variables, an Inverse Probability Weighting Regression Adjustment (IPWRA) approach is used. IPWRA has gained considerable traction in empirical research,

[24] Marginal effects at the means (or partial effects at the average) consists in using the average values of the independent variables instead of the actual observed values (Williams, 2012).

[25] The use of a categorical variable, which combines variables related to land redistribution and RAS, enables comparisons to be made between categories of farm-households based on the combination of both land redistribution and RAS rather than based individually on these two variables.

particularly in cross-sectional studies aimed at estimating treatment effects with multiple treatment categories (e.g. Binam *et al.*, 2015; Ma *et al.*, 2018; Smale *et al.*, 2018). The approach underlying the use of the IPWRA estimator can be described as follows (Wooldridge, 2010:930-934). First, a 'treatment model' is devised where the treatment variable is regressed on the observed covariates. The treatment variable considered in this study corresponds to the categorical variable defined above, implying that four different, mutually exclusive, treatment categories exist for each one of the 374 farm-households composing the sample. The categorical treatment variable T_i is coded as:

$$T_i = \begin{cases} 0, & no\ LR\ no\ RAS \\ 1, & yes\ LR\ no\ RAS \\ 2, & no\ LR\ yes\ RAS \\ 3, & yes\ LR\ yes\ RAS \end{cases} \tag{8}$$

Due to the categorical (non-ordered and mutually exclusive) nature of the treatment variable, a multinomial logit (MNL) model is employed as the 'treatment model' (Imbens, 2000:708):

$$\begin{aligned} P(T_i = 1|x_i) &= \frac{e^{x_i\beta_1}}{1 + e^{x_i\beta_1} + e^{x_i\beta_2} + e^{x_i\beta_3}} \\ P(T_i = 2|x_i) &= \frac{e^{x_i\beta_2}}{1 + e^{x_i\beta_1} + e^{x_i\beta_2} + e^{x_i\beta_3}} \\ P(T_i = 3|x_i) &= \frac{e^{x_i\beta_3}}{1 + e^{x_i\beta_1} + e^{x_i\beta_2} + e^{x_i\beta_3}} \\ P(T_i = 0|x_i) &= \frac{1}{1 + e^{x_i\beta_1} + e^{x_i\beta_2} + e^{x_i\beta_3}} \end{aligned} \tag{9}$$

The conditional probabilities of treatment assignment given the vector of observed covariates x_i presented in equation (9) are also commonly referred to as "propensity scores" (Rosenbaum and Rubin, 1983), and can be expressed as:

$$r(T_i, x_i) \equiv P(T_i = 0,1,2,3|x_i) \tag{10}$$

The inverse of the estimated propensity scores are then employed as weights in weighted logit regression models, which enable predicted outcomes for each farm-household and each treatment category to be estimated.[26] The final step of the IPWRA approach consists in estimating pair-wise Average Treatment Effects (ATEs) by the average of the difference of the predicted outcomes:

[26] Formally, the weights $1/\hat{r}(T_i, x_i)$ are used when solving the inverse probability weighted quasi-maximum likelihood estimation problem (Wooldridge, 2010).

$$\widehat{\text{ATE}_{(1,0)}} = N^{-1} \sum_{i=1}^{N} [\widehat{m_1}(x_i) - \widehat{m_0}(x_i)] \tag{11}$$

Equation (11) represents one of the estimated pair-wise ATEs. It shows the estimated ATE of treatment category one *vis-à-vis* treatment category zero, with $\widehat{m_1}$ and $\widehat{m_0}$ corresponding to the estimated outcomes from the weighted logits related to treatment categories one and zero, respectively. Similar pair-wise ATEs can be estimated for each combination of treatment categories, resulting in six different estimated ATEs (namely $\widehat{\text{ATE}_{(1,0)}}$; $\widehat{\text{ATE}_{(2,0)}}$; $\widehat{\text{ATE}_{(3,0)}}$; $\widehat{\text{ATE}_{(2,1)}}$; $\widehat{\text{ATE}_{(3,1)}}$; $\widehat{\text{ATE}_{(3,2)}}$).

The use of an estimator such as the IPWRA is beneficial in the context of this study as it helps account for possible selection bias due to a non-random 'assignment' to the given treatment category. In other words, in the sample of surveyed farm-households, it is possible that a farm-household's participation to a given category of the treatment may not be random, which would give rise to sample selection bias. The IPWRA exploits observable characteristics related to the farm-households to construct comparable sets of farm-households and thus substantially reduce the potential bias related to a non-random assignment of a farm-household to the given treatment category. Yet, by relying only on observable characteristics, the IPWRA does not account for possible selection bias based on unobservable characteristics. This shortcoming implies that the use of the IPWRA relies on the Conditional Independence Assumption (CIA), which indicates that, conditional on a set of observable characteristics, the treatment assignment is 'as good as random'. In other words, conditional on the observable characteristics, the counterfactual outcomes are independent of the treatment (see Appendix 4.A.i for a presentation of the potential outcomes framework, which includes the concept of 'counterfactual outcomes', and for a formal discussion on the two key assumptions underlying the use of the IPWRA). A final advantage of the IPWRA compared to several other estimators is its 'double-robustness' property. This implies that the estimator is robust to possible misspecification of either the 'treatment' model or the 'outcome' model. In other words, the IPWRA estimator does not require both models to be correctly specified, it will produce consistent estimates of the ATE as long as one of the two models is correctly specified (Uysal, 2015; Wooldridge, 2010).

4.3.3. Results and discussion

4.3.3.1. Results

The results from the estimation of the two probit models are presented in Table 4.2. The two models only differ in terms of the dependent variable; in the first ICLS is employed as the dependent variable, whilst the second model employs localised irrigation as the dependent variable. The first two columns of Table 4.2 thus report the estimated coefficients and the marginal effects (M.E.) for the first model (with ICLS as dependent variable), and the last two columns of the table contain the corresponding results (estimated coefficients and M.E.) when employing localised irrigation as a dependent variable.[27]

[27] Results from the estimation of the corresponding logit models are provided in Appendix Table 4.A.2. As indicated in Section 4.3.2 above, a biprobit model was also estimated and a test for the absence of correlation between the error terms of the individual probits was conducted. Results (provided in Appendix Table 4.A.3) suggest that the two individual probits can indeed be estimated separately.

Table 4.2. Results of probit estimation

Variable	ICLS Coeff. Estimate	ICLS M.E.	Localised irrigation Coeff. Estimate	Localised irrigation M.E.
Gender	-0.249	-0.061	0.080	0.022
	(0.195)	(0.045)	(0.179)	(0.050)
Age	0.074*	0.019*	-0.001	-0.000
	(0.044)	(0.011)	(0.032)	(0.009)
Age squared	-0.001*	-0.000*	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Married	-0.085	-0.022	-0.194	-0.055
	(0.202)	(0.053)	(0.197)	(0.057)
Education	0.241	0.059	-0.193	-0.054
	(0.208)	(0.049)	(0.182)	(0.052)
HH size	0.014	0.004	-0.011	-0.003
	(0.027)	(0.007)	(0.027)	(0.007)
Water access	-0.028	-0.007	0.446***	0.122***
	(0.174)	(0.044)	(0.170)	(0.045)
Cooking energy	0.128	0.032	-0.143	-0.040
	(0.173)	(0.043)	(0.170)	(0.047)
Asset car	0.292*	0.076*	-0.028	-0.008
	(0.173)	(0.045)	(0.173)	(0.047)
Asset tv	-0.132	-0.034	0.274	0.072
	(0.209)	(0.055)	(0.203)	(0.051)
Farm. Org.	0.022	0.006	0.603***	0.173***
	(0.170)	(0.043)	(0.163)	(0.047)
Soil_fertility	-0.299	-0.079	0.064	0.017
	(0.187)	(0.051)	(0.189)	(0.051)
Shock_dr_fl	0.031	0.008	-0.050	-0.014
	(0.179)	(0.045)	(0.185)	(0.051)
Province_Gauteng	-0.207	-0.066	-0.163	-0.048
	(0.395)	(0.120)	(0.404)	(0.114)
Province_NorthWest	-0.056	-0.019	-0.773**	-0.183**
	(0.286)	(0.093)	(0.369)	(0.070)
Province_Limpopo	-0.899***	-0.227***	-0.191	-0.056
	(0.218)	(0.053)	(0.200)	(0.059)
Constant	-2.470*		-0.879	
	(1.272)		(0.895)	
Treatment var. combinations:				
Categ. 1vs.0	0.518*	0.152*	0.506*	0.149*
	(0.281)	(0.083)	(0.270)	(0.080)
Categ. 2vs.0	0.013	0.003	0.052	0.013
	(0.224)	(0.056)	(0.221)	(0.057)
Categ. 3vs.0	-0.247	-0.057	0.166	0.045
	(0.263)	(0.061)	(0.248)	(0.066)
Categ. 2vs.1	-0.505**	-0.149**	-0.454*	-0.136*
	(0.240)	(0.074)	(0.270)	(0.073)
Categ. 3vs.1	-0.765***	-0.209***	-0.339	-0.105
	(0.260)	(0.074)	(0.250)	(0.078)
Categ. 3vs.2	-0.260	-0.060	0.115	0.031
	(0.215)	(0.048)	(0.201)	(0.055)
Observations	374			
Pseudo-R2	0.122		0.117	
Chi2	46.95 [0.0004]		40.96 [0.0024]	

Notes: *** Indicates significance at 1%, ** at 5%, * at 10% level. Values in parentheses are standard errors; values in square brackets are P-values. The categories (categ.) related to the 'treatment variable' are as follows. Category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land redistribution farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey.

The results reported in Table 4.2 show that there are both differences and similarities among the factors associated with the adoption of the CSA strategies under consideration. The age of the household head, for instance, is significantly correlated with the likelihood of ICLS adoption but not with the likelihood of adopting localised irrigation. In particular, age exhibits an 'inverted-u' pattern with respect to the likelihood of ICLS adoption, in that the relationship between age and likelihood of ICLS adoption is initially a positive one, but subsequently becomes negative (after reaching a maximum at *circa* 56 years of age). In other words, being either in the youngest or in the elderly parts of the age distribution is associated with a lower likelihood of ICLS adoption compared to 'mid-age' farmers, who might be more experienced farmers (compared to the younger farmers) and more motivated/physically adept to practice mixed farming (compared to the older farmers). Having reliable domestic water access is positively (and highly significantly) correlated with the likelihood of adopting localised irrigation. This result is in line with a 'multiple water use approach', whereby farmers employ water from a given source both to meet basic needs (such as drinking, cooking, hygiene, sanitation) and for productive use (Naidoo *et al.*, 2009; Soussan *et al.*, 2004; Van Koppen *et al.*, 2009). Instead, no significant correlation is found between reliable domestic water access and the likelihood of ICLS adoption. Among the two variables linked to asset ownership, car ownership exhibits a positive and marginally significant correlation with the likelihood of ICLS adoption, but a negative (although not significant) association with the likelihood of adoption of localised irrigation. Owning a television set is instead negatively correlated with the likelihood of ICLS adoption and positively correlated with the likelihood of adopting localised irrigation, but neither of the estimated coefficients are found to be statistically significant. Therefore, overall, there does not seem to be a clear association between asset ownership and CSA adoption in the sample under consideration. Being part of a farmer organisation is positively associated with the likelihood of adopting ICLS and with the likelihood of adopting localised irrigation, although only the coefficient related to the latter CSA strategy is found to be statistically significant. Such a positive association is consistent with the argument that farmer organisations can be a useful social medium through which information on the use of a given technology can be shared (Abdulai and Huffman, 2014; Bedeke *et al.*, 2019), thereby enhancing farmers' knowledge, attitudes and skills, and potentially inducing them to adopt CSA. Farm location also appears to be associated with CSA adoption. Being located in the Mpumalanga province (the base category) is associated with a higher likelihood of adopting ICLS and localised irrigation *vis-à-vis* farms located in Limpopo and in the North West province, respectively. These results are in line with data from the 2011 Census, which indicate that a lower proportion of agricultural households were engaged in mixed farming in Limpopo compared to Mpumalanga, and that, in proportion, agricultural households in the North West had less access to piped water inside the dwelling/yard compared to agricultural households located in the Mpumalanga province (Stats SA, 2013).

Turning to the key regressor of interest for this study, Figure 4.4 illustrates the results shown at the bottom of Table 4.2.[28]

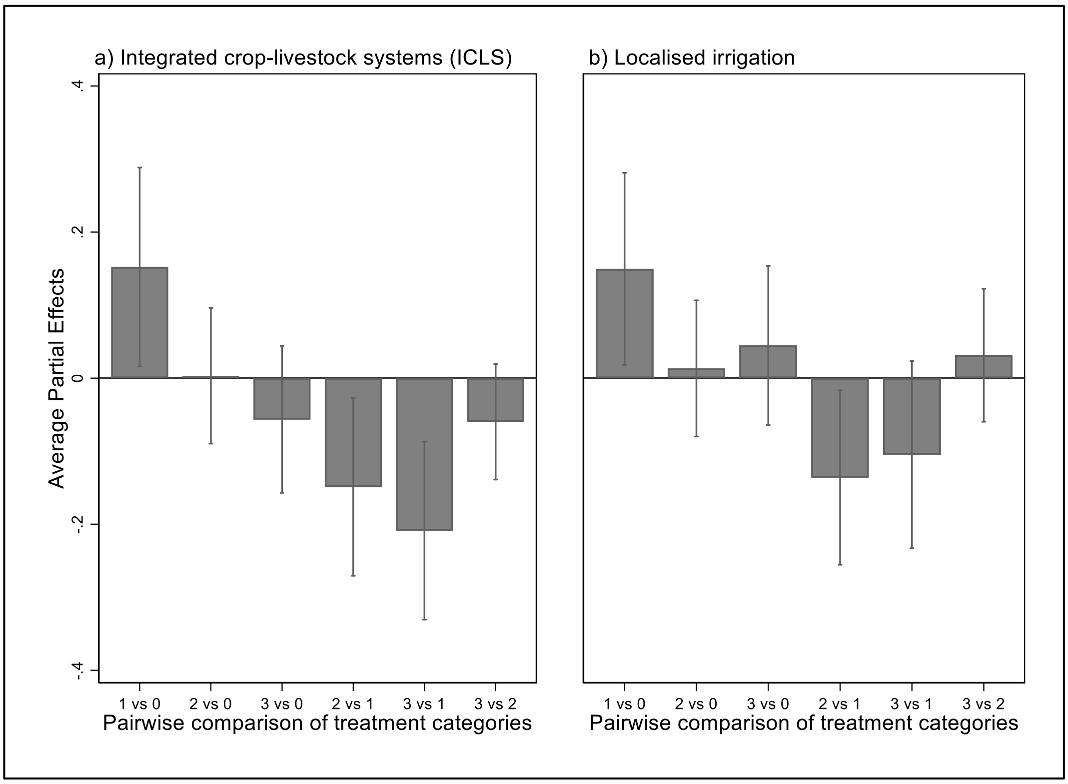

Figure 4.4. Average partial effects of treatment categories on CSA adoption

Notes: Panel a) depicts the Average Partial Effects (APEs) from the estimation of the probit model with Integrated Crop and Livestock systems adoption as a dependent variable, whilst panel b) depicts the APEs from the estimation of the probit model with localised irrigation adoption as the dependent variable. In both panels the bars show the APEs for all six pairwise comparisons between the four categories of the treatment variable (category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey), and the spikes show the 90 percent confidence intervals.

The two panels of Figure 4.4 show a similar pattern with respect to the two CSA strategies. Being in treatment category one (i.e. farm-households that benefitted from land

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[28] See also Appendix Figure 4.A.1 for charts depicting the predicted probabilities of adopting the CSA strategies for the four treatment categories.

redistribution but not from RAS) is positively associated with CSA adoption *vis-à-vis* treatment categories zero (i.e. farm-households that neither benefitted from land redistribution nor from RAS), two (i.e. farm-households that did not benefit from land redistribution but were provided with RAS) and three (i.e. farm-households that benefitted from land redistribution and from RAS).[29] These positive associations are all statistically significant (at conventional levels), except for the pair-wise comparison between treatment category one and three for the adoption of localised irrigation. The Average Partial Effects (APEs) related to the other pair-wise comparisons (i.e. treatment category two versus zero, three versus zero and three versus two) are not statistically significant (Figure 4.4 and Table 4.2).

Results from the estimations of the corresponding logit models are provided in Appendix Table 4.A.2. Unsurprisingly, given the relatively small sample size and the similarity between the two models, the results are close to identical in terms of sign of the coefficients, magnitude and statistical significance.

Finally, Figure 4.5 illustrates the Average Treatment Effects (ATEs) obtained from employing the IPWRA estimator (see also Appendix Table 4.A.4 for more detailed results). As described in Section 4.3.2 the use of the IPWRA estimator enables a more refined analysis to be undertaken, as it helps to account for possible selection bias that may affect the results presented in Table 4.2 and Figure 4.4.

[29] All pair-wise comparisons represented in Figure 4.4 are symmetric, in the sense that a negative average partial effect (APE) for treatment category '*x*' versus '*y*' is equivalent (in magnitude) to a positive APE for treatment category '*y*' versus '*x*'. For this reason, the pair-wise comparison between treatment category three and one, for instance, appears as negative in the figure, whilst it can equivalently be read as a positive APE between treatment category one and three. In other words, the magnitude of the correlations will not change if one considers the APE of treatment category one versus three, or of treatment category three versus one, only the sign will change.

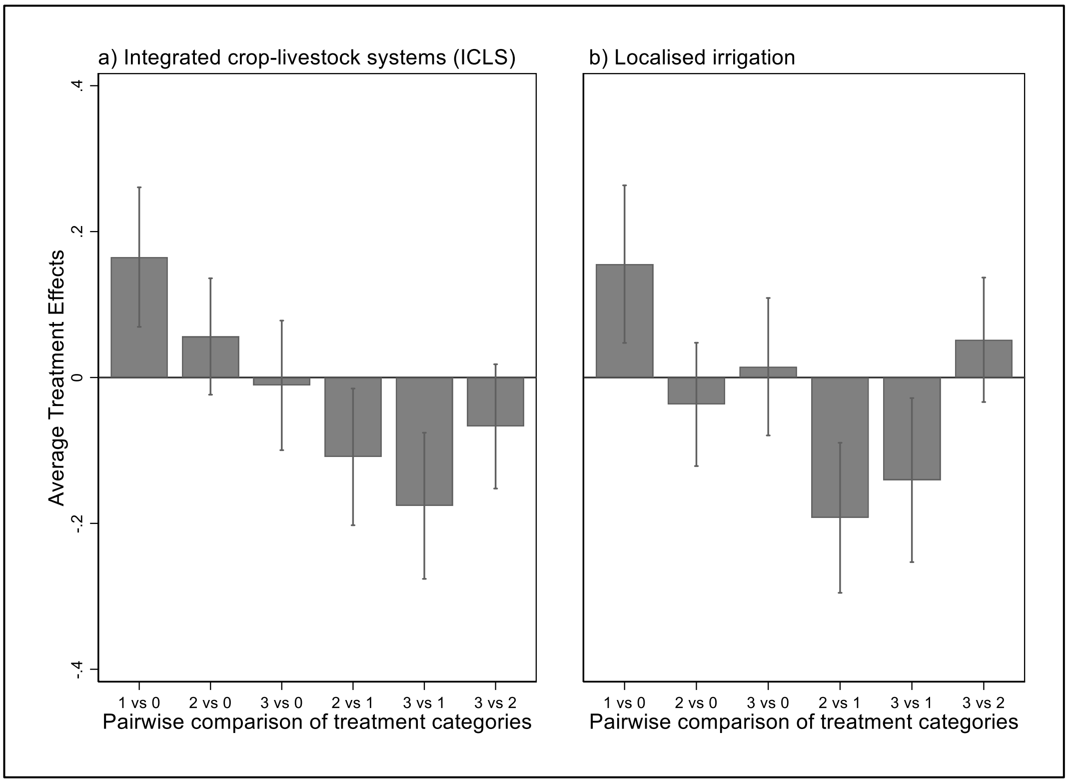

Figure 4.5. Average treatment effects on CSA adoption

Notes: Panel a) depicts the Average Treatment Effects (ATEs) resulting from the use of the IPWRA estimator with Integrated Crop and Livestock systems adoption as a dependent variable, whilst panel b) depicts the ATEs from the estimation with localised irrigation adoption as the dependent variable. In both panels the bars show the ATEs for all six pairwise comparisons between the four categories of the treatment variable (category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey), and the spikes show the 90 percent confidence intervals.

Whilst the ATEs depicted in Figure 4.5 show some slight differences in terms of magnitude and statistical significance compared to the APEs discussed above, it is reassuring to see that the ATEs resulting from the use of the IPWRA estimator are broadly in line with the APEs obtained from the probit model. Figure 4.5 shows that being in treatment category one is positively (and significantly) associated with CSA adoption *vis-à-vis* treatment categories zero, two and three.

In terms of magnitude of effects, the pair-wise comparison between treatment category one and treatment category zero suggests that, for both ICLS and localised irrigation, farm-households benefitting from land redistribution (but not from RAS) would have approximately 16 percentage points higher likelihood of adopting CSA compared to farm-households not benefitting from land redistribution nor from RAS (Figure 4.5 and

Appendix Table 4.A.4). Similarly, farm-households benefitting from land redistribution (but not from RAS) would be expected to have approximately 11 percentage points and approximately 19 percentage points higher chance of adopting ICLS and localised irrigation compared to farm-households not benefitting from land redistribution but benefitting from RAS, respectively. Instead, farm-households in category three (benefitting from both land redistribution and RAS) would have close to 18 percentage points lower likelihood of adopting ICLS and an approximately 14 percentage point lower likelihood of adopting localised irrigation compared to farm-households in category one (benefitting from land redistribution but not from RAS).

4.3.3.2. Discussion

Overall, the results obtained in this part of the study indicate the presence of a positive association between land redistribution and the likelihood of CSA adoption, but only in the absence of RAS, and the magnitude of the correlations appear to be nontrivial.

When assessed against the CSLR framework, these results seem to confirm the potential positive linkages between land redistribution and CSA adoption. Yet, they also seem to challenge the expected positive association between RAS and CSA adoption for land redistribution participants in South Africa. Whilst the latter of these findings may appear surprising, contextualising it to the case of the South African land reform helps uncover possible explanations, which were already alluded to in Part I of this study and in Section 4.3.1 and are further discussed in the next paragraphs.[30]

In spite of laudable intentions expressed during the early phases of the land reform programme in official policy documents, such as the Reconstruction and Development Programme (ANC, 1994), the White Paper on Land Policy (DLA, 1997), and the 1998 Agricultural Policy (MALA, 1998), to ensure the provision of well coordinated, multi-stakeholder, demand-driven participatory RAS to land reform participants, available evidence from the literature shows that few improvements were made to the South African RAS system by 2004/05 – the reference agricultural season for the household survey employed in this part of the study. The provision of RAS in the land reform programme was in fact devolved to short-staffed and budget constrained provinces, with under-funded and under-trained extension workers, and with little cooperation and coordination with

[30] In terms of the association between RAS and CSA adoption in South Africa, Branca and Perelli (2020) also report a seemingly counter-intuitive result. The authors find that, among the sampled South African farmers, RAS had a negative (and highly statistically significant) correlation with intensity of CSA adoption. They attribute this result to the "low quality of services provided" (Branca and Perelli, 2020:8), which is a general argument that is in line with the more specific arguments made in this study.

national-level governmental departments and other potential stakeholders (DOA, 2004; Worth, 2012).

RAS, and in particular trainings and advice on farm management and operation, were generally undertaken following a top-down ‘transfer-of-technology’ approach guided by the pre-existent large-scale commercial farming model (Cousins, 2016; deSatgé, 2020; Hall *et al.*, 2003; Lahiff, 2007a; Perret and Stevens, 2006). In other words, advisors often overlooked the differences between previous farm owners and land redistribution participants in terms of socio-economic conditions and intended land use, and instead tended to impose on land redistribution participants a farming model based on the pre-existing large-scale commercial farming operation present at the farm. Therefore, advisors appeared to have drawn farmers into the implementation of less labour and more capital-intensive systems of farming, including for instance monocropping as opposed to ICLS, and the use of less labour-intensive irrigation methods, which could help explain the results obtained in this part of the study.

Several of the challenges related to the provision of support services, including RAS, that were faced during this phase of the land reform were indeed recognised by subsequent governments. These have thus attempted to pursue reforms in the system of support services, including those destined to land reform participants. Initiatives such as the Comprehensive Agricultural Support Programme (CASP) launched in 2004 (DOA, 2004), the establishment of the Norms and Standards for Extension and Advisory Services in Agriculture in 2005 (DOA, 2005), the Extension Recovery Plan (ERP) in 2007 (DAFF, 2011), the Recapitalisation and Development Programme (RADP) in 2009 (DRDLR, 2015), and most recently the 2016 National Policy on Extension and Advisory Services (DAFF, 2016), were geared towards the launch of programmes to improve the provision of support services and the establishment of a national overarching framework for extension and advisory services. These represented encouraging developments, as they translated the initial intentions from broad-based policy documents into more specific texts, policies and programmes specifically directed at support services, and that attempted to address the longstanding shortcomings faced in the provision of such services. And indeed, according to evaluations of the above-mentioned programmes, progress has been made with regards to several indicators. Capacity, in terms of number of extension staff and technical skills (including ICT skills), has increased under the ERP (Alcinof, 2012) and some employment and agricultural production benefits were found on farms receiving CASP or RADP support (Business Enterprises, 2013; 2015). Yet, the task seems far from complete. Recommendations from the evaluation of the ERP indicate that recruitment efforts need to continue as the ratio of farmers to extension officers “is still unacceptably high” (Alcinof, 2012:78), partnerships need to be strengthened, and essential soft skills for the provision of more demand-driven and participatory extension and advisory services need to be enhanced (Alcinof, 2012:80). Findings from the CASP and RADP evaluations reveal limited transfer of skills to participants and clear insufficiencies in the programmes' ability to provide timely and needs-based support (Business Enterprises, 2013:59-60; 63-66; Business Enterprises, 2015:69).

In sum, the available evidence suggests that land reform participants are still in practice suffering from inadequate provision of support services, including RAS, and that further efforts are required to establish an effective and accountable demand-driven, multi-stakeholder and participatory RAS system that can cater to the needs and demands of land reform participants (Binswanger-Mkhize, 2014; deSatgé, 2020). In this regard, inspiration can be found among several approaches and methodologies which have been developed and have demonstrated their effectiveness in a variety of contexts (Andrieu *et al.*, 2019; Aggarwal *et al.*, 2018; Clarkson *et al.*, 2020; Dayamba *et al.*, 2018; FAO, 2018; Sala *et al.*, 2016).

4.3.4. Conclusions

This part of the study has exploited data from a cross-sectional survey of farm-households located in the Limpopo river-basin of South Africa to investigate the relationships between two of the pillars of the CSLR framework - namely land redistribution and RAS - and CSA adoption. Two agricultural strategies have been examined, diversifying the farming system through the integration of crop and livestock production and the use of localised irrigation. Both integrated crop-livestock systems and localised irrigation can be considered to be promising strategies in terms of their climate-smart potential as well as appropriate and relevant to the South African context.

The results from the estimation of binary response models are in line with the CSLR framework hypothesis that a land redistribution can positively affect CSA adoption, but they also challenge the expected positive complementary effect of RAS in stimulating CSA adoption. In fact, the results from the estimated probit and logit models, as well as from the use of the IPWRA estimator - which accounts for selection on observables - show that being a land redistribution beneficiary is associated with a higher likelihood of adopting CSA, but only in the absence of RAS. Although the specific mechanisms underlying such results could not be investigated in detail due to data limitations, these findings are consistent with a transition from large-scale capital-intensive farming to smaller-scale and more labour-intensive farming (as has been reportedly occurring *de facto* among particular South African land reform participants), as well as with evidence from the literature indicating severe deficiencies in the provision of support services to land reform participants.

In terms of limitations, this part of the study has been constrained by data availability. A common criticism related to the South African land reform is in fact the paucity of quantitative data that researchers and analysts would require to adequately study the effects of the land reform. To overcome the challenge of data availability and access, this study employed a publicly available dataset which includes variables that can assist to address the research question at hand. However, it suffers from limitations, including a non-national representativeness of the sample, which prevents the results from having external validity beyond the study area, as well as the presence of large numbers of missing values, which reduced the number of valid observations exploitable for this study. Data limitations also precluded the analysis of other channels present in the CSLR framework. Furthermore, although the results from the use of a more robust estimator (the IPWRA estimator) confirmed those from the baseline specifications, these results rely on the (untestable) assumption of conditional independence, which is indeed a strong assumption. Finally, the survey only provides a snapshot of the 2004/05 agricultural season, thereby limiting the results to that particular year and preventing a longitudinal analysis to be undertaken and panel data methods to be employed.

In spite of these caveats, the following implications can be drawn from the above findings. First, in a context such as South Africa, with abundant labour and a demand for relatively small plots of land from potential land reform participants (Hall, 2004a; Lahiff, 2007a; 2007b), land redistribution appears to be compatible with enhanced CSA adoption. This implies that land redistribution can represent an opportunity not only to generate socio-economic improvements by reducing inequality, unemployment/under-employment, social conflicts, and poverty, but also to foster CSA adoption, leading to further potential socio-economic as well as environmental improvements. Efforts, including fundamental political will, are however required to move away from the obstinate attempts to avoid a transition in the agrarian structure and instead revive prospects of a demand-driven subdivision of redistributed land favouring landless and land-poor farmers.

Second, further efforts are required to improve the RAS system in South Africa and render it effective in supporting the land reform programme. This may indeed entail completing the process initiated under the ERP and enhance the number and capacities of public sector personnel (including in both technical and ‘soft skills’, such as communication and participatory approaches), as well as their accountability to farmers. But it also requires doubling down on the efforts to establish a well-coordinated multi-stakeholder and participatory RAS system, by involving a range of stakeholders (e.g. development partners, research institutions, meteorological offices, private sector – including farmers and their organisations) and leveraging on their comparative advantages to help design, finance and provide the required RAS. Indeed, an improved RAS system could support the formulation and application of CSA strategies tailored to farmers' conditions and demands, thus providing further thrust to farmer adoption and sustained implementation of CSA in the South African land reform context.

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Appendix 4.A.i. Set-up and key assumptions for the use of the Inverse Probability Weighting Regression Adjustment (IPWRA) estimator

The set-up for the potential outcome framework draws on early work from Splawa-Neyman (1923) and Rubin (1974). Such a set-up has been used extensively in the treatment effects literature and is considered to be the *lingua franca* for causal analysis (Cunningham, 2021). The basic set-up employs binary treatments (i.e. only two categories of treatment are possible, for instance 'treated' and 'non-treated'). In this set-up, the causal effect of a given treatment is the difference between two potential outcomes: an outcome (say the 'factual' outcome) resulting from the participation to the treatment and an outcome (say the 'counterfactual' outcome) resulting from a non-participation to the treatment.

This basic set-up has been adapted to the case of multiple treatments by Imbens (2000). In the context of this study, there is a non-ordered categorical and mutually exclusive treatment T . In particular, there are four categories of treatment that are possible, based on participation to the Land Redistribution (LR) and to training activities (as a proxy for Rural Advisory Services – RAS):

$$T = \begin{cases} 0, & no\ LR\ no\ RAS \\ 1, & yes\ LR\ no\ RAS \\ 2, & no\ LR\ yes\ RAS \\ 3, & yes\ LR\ yes\ RAS \end{cases} \qquad (A1)$$

In what follows, for each farm-household i in the sample of N farm-households drawn from a large population, T_i represents the treatment category, Y_i represents the outcome variable, and x_i the vector of (observed) covariates.

This implies that, for each farm-household, there are four potential outcomes:

$$Y_i(T_i) = \begin{cases} Y_i(0), & T_i = 0 \\ Y_i(1), & T_i = 1 \\ Y_i(2), & T_i = 2 \\ Y_i(3), & T_i = 3 \end{cases} \qquad (A2)$$

The effect (δ) of, say, treatment category one *vis-à-vis* treatment category zero for farm-household i would thus be given by:[1]

$$\delta_i(1,0) = Y_i(1) - Y_i(0) \qquad (A3)$$

As interest lies in the treatment effect over the larger population, the Average Treatment Effect (ATE) can be expressed as:

[1] Indeed, six different pair-wise treatment effects exist based on the different combinations of the categorical treatment (i.e. $\delta_i(1,0)$; $\delta_i(2,0)$; $\delta_i(3,0)$; $\delta_i(2,1)$; $\delta_i(3,1)$; $\delta_i(3,2)$).

$$\begin{aligned} ATE(1,0) &= E[\delta(1,0)] \\ &= E[Y(1) - Y(0)] \\ &= E[Y(1)] - E[Y(0)] \end{aligned} \tag{A4}$$

In words, the ATE is the difference between the average potential outcome of treatment category one and the average potential outcome of treatment category zero. However, given that farm-households can only pertain to one treatment category, only one of the potential outcomes (the 'factual' outcome) can be observed. This represents the "fundamental problem of causal inference" (Holland, 1986:947), which is in fact a missing data problem: to obtain an unbiased ATE in the context of an observational study where treatment assignment is not randomised, one requires access to a factual and a counterfactual, whilst only the factual is available.

To overcome such a problem with cross-sectional data, the conditional independence assumption (CIA) can be invoked. The CIA, which is also referred to as "unconfoundedness" or "ignorability" in the literature (Wooldridge, 2010:908), indicates that, conditional on a set of observable characteristics, the treatment assignment can be considered 'as good as random'. In other words, conditional on the observable characteristics, the counterfactual outcomes are independent of the treatment. The CIA is the first key assumption necessary for the operationalisation of the IPWRA. Formally, the CIA can be expressed as:

$$Y_i(T_i)|x_i \perp T_i \tag{A5}$$

Based on earlier findings from Rosenbaum and Rubin (1983), Imbens (2000) shows that the CIA can be equivalently expressed in terms of the propensity score:

$$Y_i(T_i)|r(T_i, x_i) \perp T_i \tag{A6}$$

With the propensity score defined as:

$$r(T_i, x_i) \equiv P(T_i = 0,1,2,3|x_i) \tag{A7}$$

The second key identification assumption necessary for the operationalisation of the IPWRA estimator is the so-called overlap (or 'common support') assumption. The overlap assumption can be expressed as:

$$0 < P(T_i = 0,1,2,3|x_i) < 1 \tag{A8}$$

Or, equivalently:

$$0 < r(T_i, x_i) < 1 \tag{A9}$$

This assumption requires that the probability of assignment to each one of the treatment categories, given the values of the covariates, be strictly within the unit interval. In terms of the propensity score, this means that the propensity score needs to be bounded away from zero and one, that is there needs to be an overlap in the propensity score among the treatment categories (Hirano and Imbens, 2001).

Whilst the CIA is in practice not testable, the overlap assumption can be verified by plotting and observing the densities of the estimated propensity scores related to each treatment category (Cunningham, 2021; Linden *et al.*, 2016; Ma *et al.*, 2018). If most of the mass is at or very near zero or one, then the overlap assumption is likely to be violated. Figure 4.A.2 of the Appendix shows that in the case of the present study there is sufficient overlap for the four treatment categories, and therefore the assumption does not appear to be violated.

Appendix 4.A.ii. Additional tables and figures

Table 4.A.1. Variables and expected signs of regression coefficients

Variable	Expected sign of coefficient	Indicative reference
Gender	Positive or Negative	Ali (2021); Aryal *et al.* (2018); Asfaw *et al.* (2015; 2016a; 2016b); Beyene *et al.* (2017); Branca and Perelli (2020); Kpadonou *et al.* (2017); Teklewold *et al.* (2019)
Age	Positive or Negative	Akrofi-Atitianti *et al.* (2018); Aryal *et al.* (2018); Asfaw *et al.* (2015; 2016b); Beyene *et al.* (2017); Kurgat *et al.* (2020); Branca and Perelli (2020); Mango *et al.* (2018); Maguza-Tembo *et al.* (2017)
Married	Positive	Ali (2021); Beyene *et al.* (2017)
Education	Positive	Aryal *et al.* (2018); Asfaw *et al.* (2016a; 2016b); Beyene *et al.* (2017); Mazhar *et al.* (2021); Teklewold *et al.* (2019)
Household size	Positive or Negative	Ali (2021); Arslan *et al.* (2020); Aryal *et al.* (2018); Asfaw *et al.* (2016a; 2016b); Beyene *et al.* (2017); Branca and Perelli (2020); Kpadonou *et al.* (2017); Kurgat *et al.* (2020); Teklewold *et al.* (2019)
Water access	Positive	Arslan *et al.* (2020); Mango *et al.* (2018)
Assets/wealth (incl. cooking energy; car; tv)	Positive	Ali (2021); Arslan *et al.* (2020); Asfaw *et al.* (2015; 2016a; 2016b)
Farmer Organisation	Positive	Arslan *et al.* (2020); Aryal *et al.* (2018); Mazhar *et al.* (2021); Teklewold *et al.* (2019)
Soil fertility	Negative	Aryal *et al.* (2018); Asfaw *et al.* (2016a; 2016b); Kpadonou *et al.* (2017)
Shocks	Positive	Arslan *et al.* (2020); Beyene *et al.* (2017); Teklewold *et al.* (2019)
Location	Positive or Negative	Akrofi-Atitianti *et al.* (2018); Asfaw *et al.* (2015); Branca and Perelli (2020); Kpadonou *et al.* (2017); Kurgat *et al.* (2020)

Table 4.A.2. Results of logit estimation

	ICLS		Localised irrigation	
Variable	Coeff. Estimate	M.E.	Coeff. Estimate	M.E.
Gender	-0.439	-0.061	0.146	0.024
	(0.361)	(0.047)	(0.315)	(0.052)
Age	0.136	0.020*	-0.001	-0.000
	(0.083)	(0.012)	(0.054)	(0.009)
Age squared	-0.001*	-0.000*	-0.000	-0.000
	(0.001)	(0.000)	(0.000)	(0.000)
Married	-0.096	-0.014	-0.364	-0.060
	(0.366)	(0.055)	(0.346)	(0.059)
Education	0.465	0.065	-0.381	-0.063
	(0.372)	(0.049)	(0.318)	(0.053)
HH size	0.019	0.003	-0.019	-0.003
	(0.048)	(0.007)	(0.046)	(0.007)
Water access	-0.040	-0.006	0.797***	0.126***
	(0.321)	(0.047)	(0.306)	(0.046)
Cooking energy	0.223	0.032	-0.265	-0.042
	(0.312)	(0.045)	(0.296)	(0.047)
Asset car	0.549*	0.082*	-0.017	-0.003
	(0.309)	(0.046)	(0.304)	(0.048)
Asset tv	-0.234	-0.035	0.528	0.080
	(0.387)	(0.059)	(0.371)	(0.052)
Farm. Org.	0.112	0.016	1.034***	0.171***
	(0.303)	(0.044)	(0.289)	(0.048)
Soil_fertility	-0.526	-0.081	0.060	0.010
	(0.331)	(0.052)	(0.337)	(0.053)
Shock_dr_fl	0.050	0.007	-0.118	-0.019
	(0.310)	(0.045)	(0.321)	(0.052)
Province_Gauteng	-0.399	-0.075	-0.289	-0.049
	(0.706)	(0.125)	(0.733)	(0.120)
Province_NorthWest	-0.158	-0.031	-1.444**	-0.189***
	(0.484)	(0.093)	(0.735)	(0.072)
Province_Limpopo	-1.625***	-0.233***	-0.327	-0.055
	(0.407)	(0.055)	(0.349)	(0.060)
Constant	-4.570*		-1.418	
	(2.438)		(1.511)	
Treatment var. combinations:				
Categ. 1vs.0	0.898*	0.153*	0.862*	0.149*
	(0.504)	(0.085)	(0.465)	(0.081)
Categ. 2vs.0	0.049	0.007	0.087	0.013
	(0.401)	(0.058)	(0.389)	(0.057)
Categ. 3vs.0	-0.381	-0.049	0.254	0.039
	(0.478)	(0.063)	(0.436)	(0.067)
Categ. 2vs.1	-0.849**	-0.146*	-0.775*	-0.136*
	(0.423)	(0.076)	(0.398)	(0.073)
Categ. 3vs.1	-1.279***	-0.202***	-0.609	-0.110
	(0.468)	(0.077)	(0.430)	(0.078)
Categ. 3vs.2	-0.430	-0.056	0.167	0.026
	(0.391)	(0.050)	(0.352)	(0.056)
Observations	374			
Pseudo-R2	0.123		0.119	
Chi2	42.73 [0.0014]		38.73 [0.0048]	

Notes: *** Indicates significance at 1%, ** at 5%, * at 10% level. Values in parentheses are standard errors; values in square brackets are P-values. The categories (categ.) related to the 'treatment variable' are as follows. Category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land reform redistribution farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey.

Table 4.A.3. Results of biprobit estimation

	ICLS	Localised irrigation
Variable	Coeff. Estimate	Coeff. Estimate
Gender	-0.251	-0.011
	(0.196)	(0.027)
Age	0.072*	-0.002
	(0.043)	(0.032)
Age squared	-0.001*	-0.000
	(0.000)	(0.000)
Married	-0.094	-0.201
	(0.201)	(0.194)
Education	0.249	-0.192
	(0.207)	(0.182)
HH size	0.014	-0.011
	(0.027)	(0.027)
Water access	-0.024	0.450***
	(0.175)	(0.170)
Cooking energy	0.130	-0.138
	(0.173)	(0.169)
Asset car	0.291*	-0.023
	(0.173)	(0.172)
Asset tv	-0.132	0.278
	(0.209)	(0.205)
Farm. Org.	0.025	0.605***
	(0.169)	(0.163)
Soil_fertility	-0.298	0.062
	(0.187)	(0.188)
Shock_dr_fl	0.033	-0.048
	(0.180)	(0.184)
Province_Gauteng	-0.205	-0.173
	(0.395)	(0.406)
Province_NorthWest	-0.061	-0.795**
	(0.287)	(0.367)
Province_Limpopo	-0.898***	-0.199
	(0.217)	(0.200)
Constant	-2.430*	-0.845
	(1.257)	(0.891)
Treatment var. combinations:		
Categ. 1vs.0	0.517*	0.512*
	(0.281)	(0.269)
Categ. 2vs.0	0.016	0.054
	(0.224)	(0.220)
Categ. 3vs.0	-0.257	0.157
	(0.264)	(0.248)
Categ. 2vs.1	-0.501**	-0.457*
	(0.240)	(0.231)
Categ. 3vs.1	-0.774***	-0.355
	(0.260)	(0.249)
Categ. 3vs.2	-0.272	0.103
	(0.215)	(0.201)
Observations	374	
Chi2	91.42 [0.0000]	
Rho	-0.158 (0.110)	
Wald test	1.987 [0.1587]	

Notes: *** Indicates significance at 1%, ** at 5%, * at 10% level. Values in parentheses are standard errors; values in square brackets are P-values. The result from the Wald test of *rho*=0 (i.e. that the correlation between the error terms of the two probits is equal to zero) indicates that the null hypothesis of zero correlation cannot be rejected. This implies that the two probits can be estimated separately. The categories (categ.) related to the 'treatment variable' are as follows. Category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land reform redistribution farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey.

Table 4.A.4. IPWRA results: Average Treatment Effects

	ICLS	Localised irrigation
Treatment var combinations		
Categ. 1vs.0	0.165***	0.155**
	(0.058)	(0.066)
Categ. 2vs.0	0.056	-0.037
	(0.049)	(0.051)
Categ. 3vs.0	-0.011	0.015
	(0.054)	(0.057)
Categ. 2vs.1	-0.109*	-0.192***
	(0.057)	(0.063)
Categ. 3vs.1	-0.176***	-0.141**
	(0.061)	(0.068)
Categ. 3vs.2	-0.067	0.052
	(0.052)	(0.052)
Observations	374	

Notes: *** Indicates significance at 1%, ** at 5%, * at 10% level. Standard errors are reported in parentheses. The categories (categ.) related to the 'treatment variable' are as follows. Category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land reform redistribution farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey.

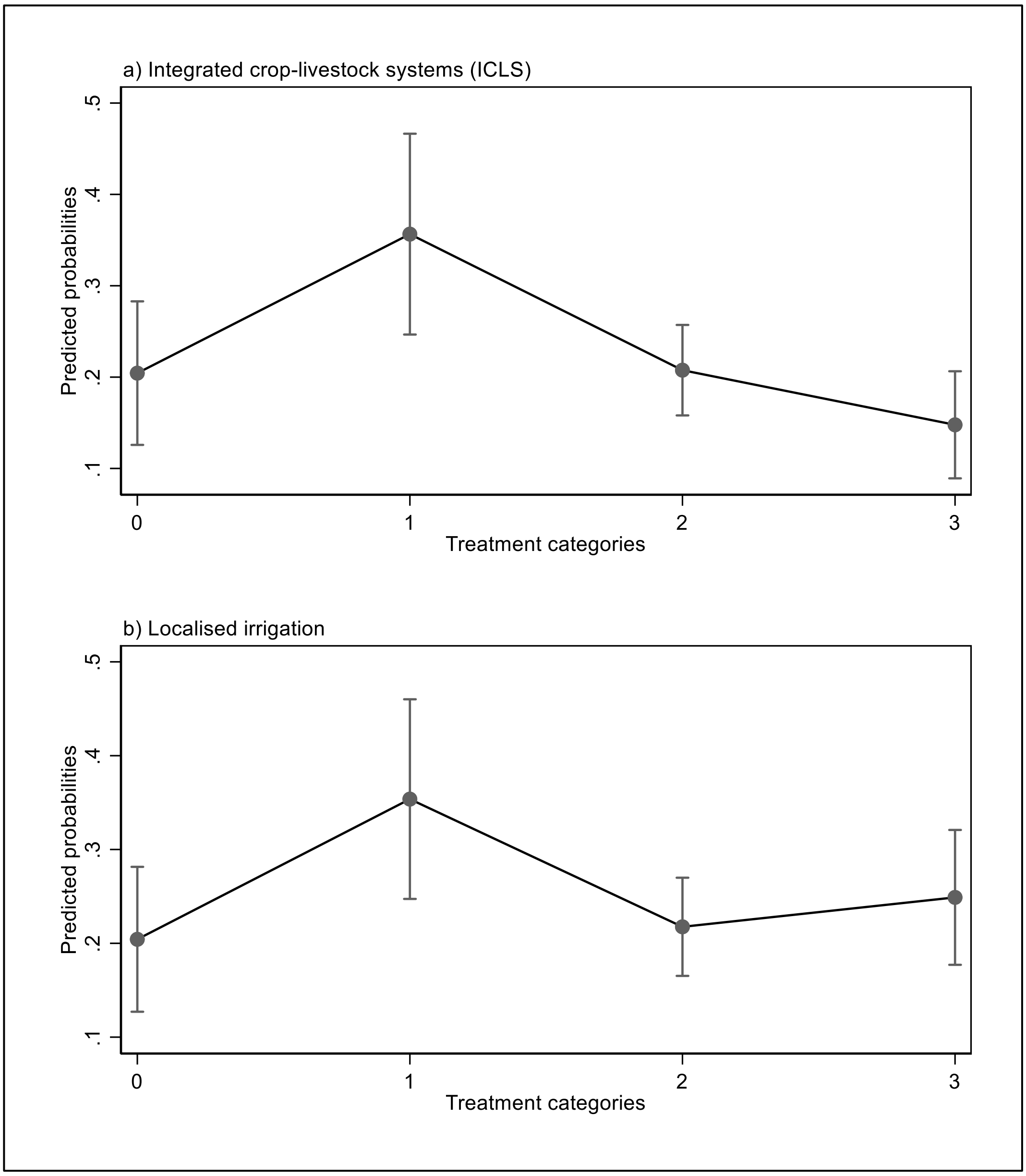

Figure 4.A.1. Predicted probabilities of CSA adoption

Notes: The figure shows the predicted probabilities of CSA adoption for each one of the four treatment categories (Category zero: non land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category one: land redistribution beneficiary farm-households that did not attend trainings in crop and/or livestock production in the two years preceding the survey; category two: non-land redistribution beneficiary farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey; category three: land reform redistribution farm-households that did attend trainings in crop and/or livestock production in the two years preceding the survey). These predicted probabilities are obtained from the estimation of the two probit models described in Section 4.3.2. Panel a) shows such probabilities with respect to adoption of integrated crop-livestock systems and panel b) shows these probabilities with respect to the adoption of localised irrigation.

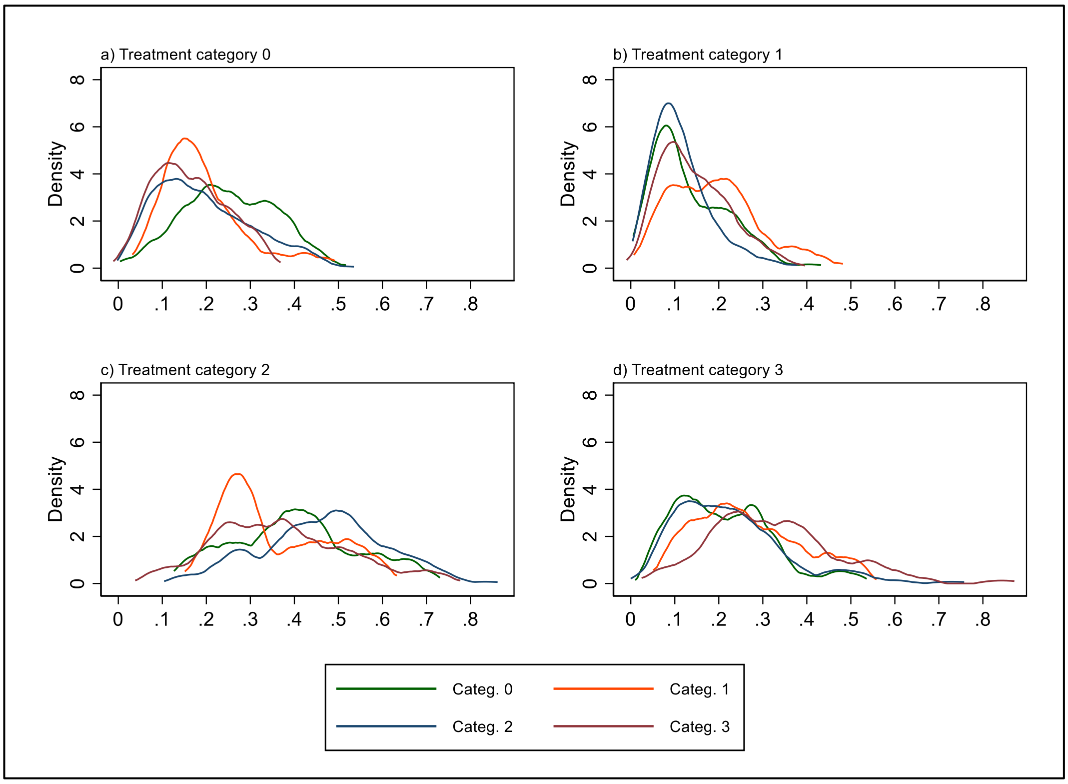

Figure 4.A.2. Density of propensity scores for the four treatment categories

Notes: The figure displays the kernel density of the propensity scores for the four treatment categories, based on the observations from the sample used for this study (N=374) and the covariates presented in the data section (Section 4.3.2). Category zero corresponds to farm-households that neither benefitted from the land redistribution nor from RAS; category one corresponds to farm-households that benefitted from the land redistribution and whose members did not benefit from RAS; category two corresponds to farm-households that did not benefit from land redistribution and whose members benefitted from RAS; category three corresponds to farm-households that benefitted from both land redistribution and RAS. Panel a) of the figure therefore shows the density of the propensity scores (for each one of the four treatment categories) corresponding to the (conditional) probability of being in the treatment category zero. And panels b), c), and d) of the figure show the density of the propensity scores (for each one of the four treatment categories) corresponding to the (conditional) probability of being in the treatment categories one, two, and three, respectively.

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Chapter 5. Conclusions

Key challenges for agricultural systems in an era of climate change include feeding a growing population while reducing the magnitude and severity of food insecurity, building resilience to the adverse effects of climate change and at the same time minimising the environmental impact of the agricultural sector. The Climate Smart Agriculture (CSA) approach provides a framework for the development of context-specific actions that can contribute to address these challenges as it seeks to sustainably increase agricultural productivity, enhance climate change adaptation, and lower the concentration of greenhouse gases in the atmosphere. Yet, in contexts experiencing widespread inequality in the distribution of land, a key natural resource for agricultural production, and/or a high prevalence of land tenure insecurity, opportunities for broad-based farmer adoption of CSA may be limited. Policy interventions, such as land reforms, that can redress land inequality, foster secure land tenure rights and enhance access to markets, infrastructure and advisory services, may contribute to build an enabling environment for CSA.

The three papers contained in this thesis explored the association between CSA and land reforms.

The first paper, *Land reform in the era of global warming – can land reforms help agriculture be climate-smart?*, introduced a conceptual framework, the Climate Smart Land Reform (CSLR) framework, and provided a detailed description of the pathways through which the 'pillars' of the CSLR framework can affect CSA adoption and contribute to the realisation of land reformers' objectives. Building on theoretical and empirical literature on land reform and CSA, it was demonstrated conceptually that both redistributive and tenure types of reforms, as well as the enhancement of opportunities for land reform participants to access markets, infrastructure and a wide range of advisory services, can generate beneficial effects on traditional objectives of land reformers (be they social, economic, political) and at the same time positively affect CSA adoption and contribute to achieve the three CSA objectives. Hence, the main contribution to the literature of the first paper included in this thesis is the introduction of an original conceptual framework that combines land reform and CSA, and shows how land reforms can generate beneficial effects on both traditional objectives of land reformers and on the CSA objectives, thereby contributing to enhance equity, efficiency, and environmental sustainability.

At the policy level, the CSLR framework can serve as a conceptual guide that can assist decision-makers in the (re)design phase of a land reform. Elements of the framework can also be useful for the preparation of monitoring tools to track progress and uncover challenges in the execution of a land reform, for instance by measuring progress in land reform participants' adoption of effective CSA strategies. In addition, by explicitly incorporating objectives associated with climate change, the framework can help open-up climate-financing windows that policymakers can explore during resource mobilisation efforts for the financing of a land reform.

The second paper, *Examining land reform through satellite lenses – a study of the effects of the Ethiopian tenure reform on the Climate Smart Agriculture objectives*, considered the case of the Land Registration and Certification Programme (LRCP) implemented in 1998 in Tigray, Ethiopia, to analyse the linkage between the land tenure reform pillar of the CSLR framework and the three CSA objectives. An original panel dataset was constructed with Earth Observation (EO) data and a difference-in-differences strategy was employed, where pixels in Tigray (the 'treated' area) were compared to pixels in the neighbouring Amhara region (the 'control' area), before and after the implementation of the LRCP to uncover its causal effects. Results showed the presence of positive and significant effects of the reform on measures of agricultural productivity, climate change adaptation and climate change mitigation, suggesting that the reform did contribute to progress on the three CSA objectives over the landscapes of Tigray.

At least three original contributions to the literature stem from this research. First, this study employs an original source of data. For the first time, EO data are used to analyse the effects of the Ethiopian land tenure reform. In particular, the study exploits a unique panel dataset containing a rich set of indicators sourced from publicly available EO data to investigate the effects of the LRCP in Tigray. The second contribution can also be ascribed to the dataset generated from EO data. With this original panel dataset, the analysis could be extended both spatially and temporally compared to existing studies that relied on (relatively scarce) household-level survey data to examine the effects of the LRCP. In fact, previous quantitative research analysing the effects of the reform was constrained to a limited geographic coverage and could only provide snapshots over specific time-periods (the years when surveys had indeed been undertaken). Instead, by employing a long time-series of consistent and globally available EO data, the effects of the LRCP could be examined, in this paper, over the entire landscapes of Tigray (covering the close to 700 thousand agricultural households of the region) during a continuous time-period ranging from 1991 (i.e. seven years before the implementation programme) to 2004 (i.e. six years after programme). Finally, this is the first study that analyses the causal effects of the reform on the three CSA objectives. This paper represents the first empirical analysis of the conceptual linkage between the land tenure reform pillar of the CSLR framework and the three CSA objectives, and further contributes to the literature by providing evidence of the positive effect that land tenure reforms can have on the CSA objectives.

Policy wise, this research supports the use of remote-sensing satellite-based data for evidence-based decision-making, particularly in data-scarce contexts. Furthermore, the novel evidence generated on the positive effects of the Tigray LRCP on the three CSA objectives can be seen as particularly encouraging for policymakers given that CSA objectives were not embedded in the goals of land reformers when designing and implementing the LRCP. Land reformers can potentially obtain larger effects on measures of CSA adoption and of the CSA objectives by ensuring that stakeholders are adequately informed and engaged - for instance via participatory consultations - during the design of a land tenure reform. Opening-up participatory spaces can help raise farmer awareness upon CSA and at the same time provide opportunities to uncover the elements of a reform that are most demanded by farmers and most likely to enhance their incentives to invest in the adoption of CSA strategies.

The third paper, *Land reform in South Africa – laudable intentions, implementation challenges, and opportunities for Climate Smart Agriculture*, was dedicated to the study of the South African land reform. The first part of the paper described the process that led to the land reform programme in South Africa and critically analysed the progress made on the various components of the land reform against the initial intentions of land reformers. It showed how key implementation challenges, including inadequate measures for the restitution and redistribution of land, for the provision of support services, and for the guarantee of the constitutional right to tenure security, have hampered the realisation of land reformers' initial intentions. The first part closed by providing a first reading of the CSLR framework based on the concrete experience of the South African land reform. A broad alignment between the design of the South African land reform and various elements of the CSLR framework was recognised, and the disjuncture between design and implementation of the South African land reform was reemphasised. The paper also analysed empirically the association between the land redistribution and RAS pillars of the CSLR framework and CSA adoption in the South African land reform context. The use of binary response models applied to secondary data from a cross-sectional survey of South African farm-households revealed that, among the studied farm-households, land redistribution participation was associated with a higher likelihood of adopting CSA, but only in the absence of RAS.

The contribution of this study to the literature is twofold. First, it provides an up-to-date perspective on the status of the South African land reform, gauging progress made in the implementation of the land reform against land reformers' initial intentions and uncovering critical issues that occurred during the implementation of the various components of the land reform programme. Second, this study adds to the growing empirical literature that investigates factors associated with CSA adoption. In particular, it represents the first quantitative empirical investigation of the channels associating the land redistribution and RAS pillars of the CSLR framework with CSA adoption. The evidence provided from this South African case study is in line with the CSLR framework hypothesis that a land redistribution can positively affect CSA adoption, but it also challenges the expected positive complementary effect of RAS in stimulating CSA adoption.

Such findings support long-awaited policy shifts in South Africa's land redistribution programme towards a more radical demand-led subdivision of farmland favouring landless and land-poor farmers, as well as increased policy efforts to establish a well-coordinated, multi-stakeholder and participatory RAS system for land reform participants. These policy developments would potentially bring far-reaching socio-economic and environmental improvements, by helping to reduce inequality, poverty, unemployment/under-employment, social conflicts, and at the same time contributing to enhance CSA adoption.

In conjunction, the three papers contained in this thesis achieve the two objectives set forth in the introductory chapter. The first objective of the thesis, namely to introduce a conceptual framework that describes potential associations between CSA and land reform (p.16) is achieved in the first paper, *Land reform in the era of global warming – can land reforms help agriculture be climate-smart.* The paper presents and describes the CSLR framework, which results from the use of a qualitative research method (the conceptual framework analysis), and contributes to the generation of new knowledge by identifying the main pathways through which different types of land reform, potentially complemented by the provision of a broad range of support services, can contribute to generate an enabling environment for CSA. This framework provides the backbone of the thesis, as it links the first paper with the subsequent two papers.

The second and third papers, *Examining land reform through satellite lenses – a study of the effects of the Ethiopian tenure reform on the Climate Smart Agriculture objectives*, and *Land reform in South Africa – laudable intentions, implementation challenges and opportunities for Climate Smart Agriculture*, combine to achieve the thesis' second objective of providing empirical evidence upon specific channels of the conceptual framework in different land reform contexts (p.16). These two papers examine two different types of land reform, a land registration and certification programme undertaken in Ethiopia and a comprehensive land reform implemented in South Africa, which includes land redistribution and RAS components. Distinct channels of the CSLR framework were thus investigated in two different land reform contexts, in line with the second objective of the thesis. Whilst the findings from the Ethiopian case study confirm the conceptual framework's hypothesis of a positive linkage between the tenure reform pillar and the CSA objectives, the empirical study on the South African land reform provides more mixed results. In particular, and as specified above, land redistribution is found to be positively associated with the likelihood of adopting CSA, but only in the absence of RAS. Such a finding demonstrates the usefulness of empirical case studies to capture the nuances that may exist in different land reform contexts with respect to the channels of the conceptual framework.

Overall, the thesis, by achieving the two objectives presented in the introduction, accomplishes its main aim of advancing knowledge on the associations between land reform and CSA (p.16). The thesis shows that land reform interventions can be helpful not only to improve equity and efficiency, but also to build an enabling environment for CSA. It therefore provides a foundation for the incorporation of land reforms in the CSA discourse, and at the same time offers a renewed climate change related environmental focus for land reform interventions.

Limitations and avenues for future research

This thesis also offers several opportunities for future applied research. The case study on the Ethiopian land tenure reform exploited EO data and a difference-in-differences design to provide evidence of a causal effect between the Tigray LRCP and the three CSA objectives. Yet, only suggestive evidence could be provided upon the mechanisms underlying these results. A causal analysis of the effect of the reform on the intermediate channels linking the reform to the three CSA objectives could not be undertaken due to data limitations. Further research would be valuable to ascertain the reform's positive effects on tenure security and on CSA adoption at a regional scale. Additional research would also be needed to examine these effects beyond the Tigray region. The land tenure reform was in fact undertaken with a high degree of autonomy by different regions of Ethiopia. A comparative study analysing the effects of the reform across these regions on tenure security, CSA adoption and on the three CSA objectives would thus prove valuable to expand the evidence base on these channels of the CSLR framework. With regards to the South African case study, the quantitative analysis uncovered several findings with significant policy implications. However, the analysis was limited to a non-nationally representative sample of farm-households surveyed during a single agricultural season. An analysis undertaken with more recent and, preferably, longitudinal and nationally representative data would be particularly useful to provide up-to-date evidence on a national scale of the impact of the land reform on CSA adoption.

Finally, ample scope exists to conduct further empirical work exploiting the CSLR conceptual framework. The two empirical case studies presented in this thesis provided a first exploration into specific channels of the CSLR framework in two land reform contexts. Further empirical work can be conducted to investigate the channels examined in this thesis in different land reform contexts and, indeed, to study the channels of the framework that are not explored in the quantitative chapters of this thesis. Comprehensive studies investigating all channels of the conceptual framework across different land reform contexts would be particularly welcome.

To conduct such studies, access to datasets containing rich sets of plot, farm, household, and landscape-level characteristics, ideally observed over time, would be required to enable researchers to construct the necessary indicators. In particular, researchers would need to generate indicators related to the pillars of the framework (participation in land redistribution and/or land tenure reform; access to markets, infrastructure and RAS), to CSA adoption, and to the range of intermediate and ultimate objectives presented in the framework. During the course of this PhD programme, time and resource constraints, and most notably constraints in terms of data availability and access, prevented such a comprehensive investigation. Datasets from land reform contexts containing variables exploitable to construct all necessary indicators were either unavailable or inaccessible in the public domain. The issue of data scarcity was partially addressed in this thesis by limiting, for both empirical case studies, the quantitative analysis to specific channels of the CSLR framework, and, in chapter three, also by recurring to innovative EO data sources. Yet, to undertake a comprehensive quantitative study investigating all channels of the framework, further data would be required. This stresses the need to enhance data production in land reform contexts and, above all, to render available data accessible to researchers and analysts.