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From the Pixel to the Globe

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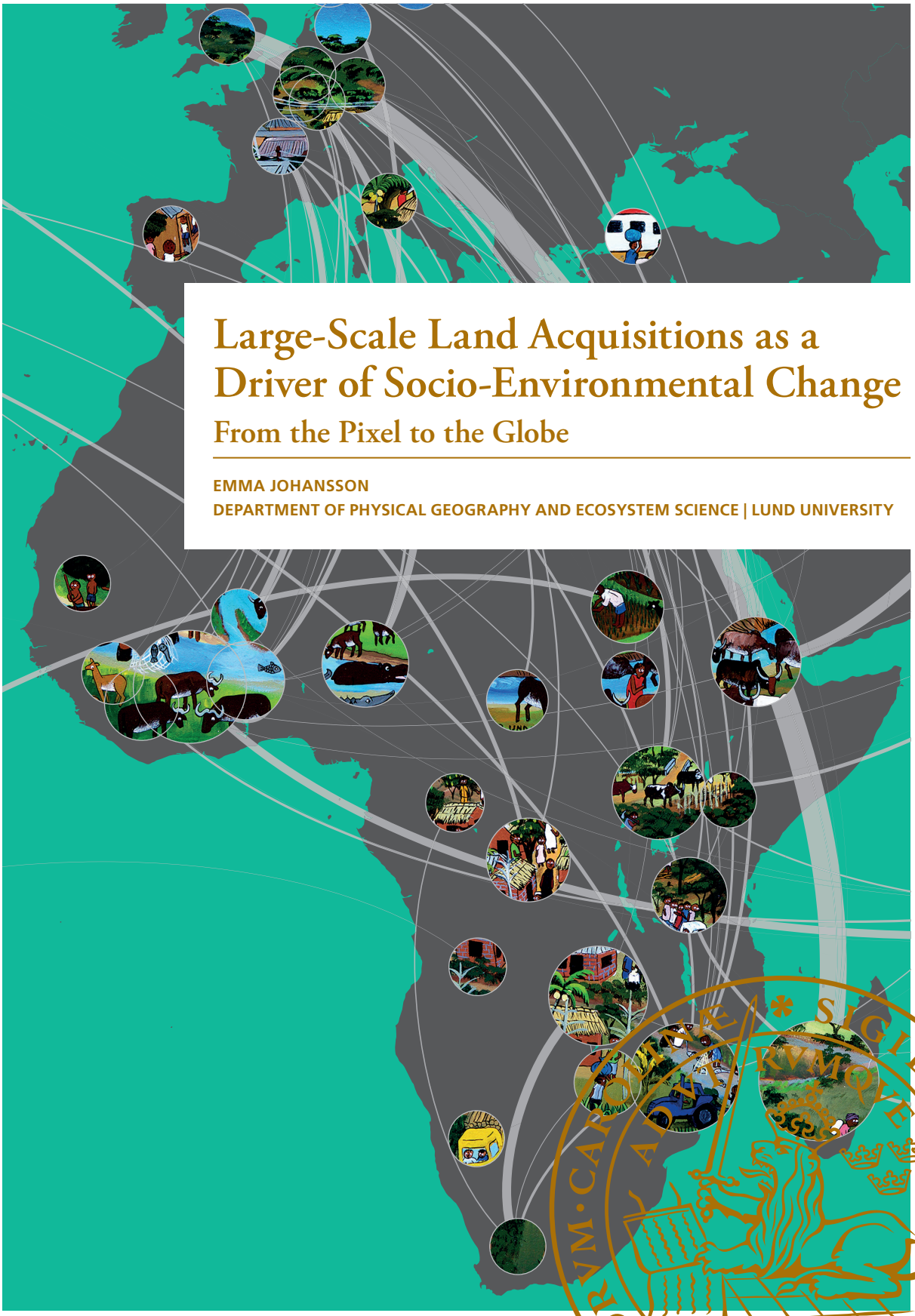

Large-Scale Land Acquisitions as a Driver of Socio-Environmental Change

From the Pixel to the Globe

EMMA JOHANSSON
DEPARTMENT OF PHYSICAL GEOGRAPHY AND ECOSYSTEM SCIENCE | LUND UNIVERSITY

Around the globe, and particularly in low-income countries, large tracts of land are acquired by foreign and domestic actors for the production of food, biofuel crops and non-edible forestry. This huge shift in land ownership from small-scale farmers to large-scale users has widespread and long-term implications for people and the environment.

In this thesis I examine drivers, impacts, and feedbacks of land system change in areas that experience large-scale land acquisitions. I do this from a global to local analytical entry point, and outline global relations between countries, land deals with high water requirements in Africa, as well as local experiences and spatial quantification of socio-environmental change in Tanzania.

Emma Li Johansson is a physical geographer interested in understanding both the social and the natural dimensions of land system change and sustainability.

LUND UNIVERSITY CENTRE OF EXCELLENCE FOR INTEGRATION OF SOCIAL AND NATURAL DIMENSIONS OF SUSTAINABILITY (LUCID).

LUCID is a Linnaeus Centre at Lund University. It is funded by the Swedish Research Council Formas, comprises six disciplines from three faculties and is coordinated by LUCSUS as a faculty independent research centre. Research aims at the integration of social and natural dimensions of sustainability in the context of grand sustainability challenges such as climate change, biodiversity loss, water scarcity and land use change. The scope is broad, the ambition is bold and the modes of operation are collaborative. Over the course of ten years we will develop sustainability as a research field from multidisciplinarity to interdisciplinarity to transdisciplinarity.

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Large-Scale Land Acquisitions as a Driver of Socio-Environmental Change

From the Pixel to the Globe

Emma Li Johansson

LUND UNIVERSITY

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Abstract:

A major challenge of our time is to sustainably produce food and other goods for a growing global population, without putting additional pressures on land and water resources and local people's quality of life. Large-scale agriculture has brought many benefits to humanity in terms of food production but has also caused multiple sustainability challenges, including land and water degradation, deforestation, and biodiversity loss in areas of production. In order to better inform consumers, producers, and other decision- and policy makers about trade-offs between agricultural production and socio-environmental change, there is a need to better understand land system change across spatial and temporal scales. This requires interdisciplinary and creative research that can integrate both social and natural dimensions of sustainability. This dissertation investigates socio-environmental change in the context of large-scale land acquisitions, by integrating natural- and social science methods at different scales of analysis.

The four papers of this dissertation investigate the drivers, impacts and feedbacks of large-scale land acquisitions from the general global perspective, to the detailed local case study. *Paper I* explores the global connectivity of large-scale land acquisitions in terms of virtual land export and import. The land-trade pattern is visualised and analysed as a network, which reveals that a few countries are responsible for providing network connectivity (China, the UK, and the US), while Africa is the most targeted region. We highlight that the network structure is prone to propagate socio-environmental risks and vulnerability for both importers and exporters of land. These results led to the development of *Paper II*, which is an in-depth analysis of water requirements for crops currently grown on acquired land in Africa. We used a dynamic vegetation model (LPJmL) to model blue and green water requirements of crops in order to identify hotspots of blue water use (irrigation water from e.g. groundwater, rivers, dams) that indicate areas of high risk for water-related conflicts. We found that crops grown on acquired land require more water than traditional crops, and even with the most efficient irrigation system 18% of the land acquisitions would be blue water hotspots. *Paper III* aims to better understand the local context in which land acquisitions occur, exploring people's perceptions of change in Kilombero Valley, Tanzania. Participatory methods were used to discuss and visualise perceptions of socio-environmental change, which point to rapid degradation of forests and wetlands. This is explained as a coupled effect of large-scale land acquisitions (farmers are forced off their land and need to find other areas for farming), population growth (more people have to share less land for farming), and areas set aside for conservation (prohibiting expansion of farmland). *Paper IV* complements and compares the experienced socio-environmental changes with land change detection, using satellite images. We found that local perceptions of farmland expansion to the wetland area align with the land change detection, while narratives of rapid deforestation could not be identified in the satellite images. This underscores the need to integrate qualitative and quantitative methods (so-called mixed methods) in order to find strengths and limitations within scientific knowledge production.

Based on the findings of this dissertation, I suggest that crops grown on acquired land should be edible, and primarily produced to increase local and domestic food security. I also suggest that crops planted should be suitable for that local climate, and low in water requirements in order to avoid water conflicts. If agribusinesses use irrigation, the irrigation systems should be of highest water use efficiency. Consequently, if land acquisitions are to be considered as investments, they must be at the forefront of exploring more sustainable pathways of farming, by accounting for local needs, improving environmental conditions, and applying the latest scientific knowledge, no matter the economic cost.

Key words: large-scale land acquisitions; telecoupling; socio-environmental change; land system science; network analysis; environmental modelling; participatory research; remote sensing; mixed methods

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From the Pixel to the Globe

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"Land has become scarce now since people have increased in this area. People are forced to cultivate the same piece of land over and over again, and this has lead to decreased productivity and fertility of the land, so the soil quality has also decreased. This together with the decreasing water levels and changes in the rain, has lead to drying of the land. So, land is more dry than it used to be in the past."

Farmer interviewed during fieldwork in Kilombero Valley, Tanzania, March 2015

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Abstract

A major challenge of our time is to sustainably produce food and other goods for a growing global population, without putting additional pressures on land and water resources and local people's quality of life. Large-scale agriculture has brought many benefits to humanity in terms of food production but has also caused multiple sustainability challenges, including land and water degradation, deforestation, and biodiversity loss in areas of production. In order to better inform consumers, producers, and other decision- and policy makers about trade-offs between agricultural production and socio-environmental change, there is a need to better understand land system change across spatial and temporal scales. This requires interdisciplinary and creative research that can integrate both social and natural dimensions of sustainability. This dissertation investigates socio-environmental change in the context of large-scale land acquisitions, by integrating natural- and social science methods at different scales of analysis.

The four papers of this dissertation investigate the drivers, impacts and feedbacks of large-scale land acquisitions from the general global perspective, to the detailed local case study. *Paper I* explores the global connectivity of large-scale land acquisitions in terms of virtual land export and import. The land-trade pattern is visualised and analysed as a network, which reveals that a few countries are responsible for providing network connectivity (China, the UK, and the US), while Africa is the most targeted region. We highlight that the network structure is prone to propagate socio-environmental risks and vulnerability for both importers and exporters of land. These results led to the development of *Paper II*, which is an in-depth analysis of water requirements for crops currently grown on acquired land in Africa. We used a dynamic vegetation model (LPJmL) to model blue and green water requirements of crops in order to identify hotspots of blue water use (irrigation water from e.g. groundwater, rivers, dams) that indicate areas of high risk for water-related conflicts. We found that crops grown on acquired land require more water than traditional crops, and even with the most efficient irrigation system 18% of the land acquisitions would be blue water hotspots. *Paper III* aims to better understand the local context in which land acquisitions occur, exploring people's perceptions of change in Kilombero Valley, Tanzania. Participatory methods were used to discuss and visualise perceptions of socio-environmental change, which point to rapid degradation of forests and wetlands. This is explained as a coupled effect of large-scale land acquisitions (farmers are forced off their land and need to find other areas for farming), population growth (more people have to share less land for farming), and areas set aside for conservation (prohibiting expansion of farmland). *Paper IV* complements and compares the experienced socio-environmental changes with land

change detection, using satellite images. We found that local perceptions of farmland expansion to the wetland area align with the land change detection, while narratives of rapid deforestation could not be identified in the satellite images. This underscores the need to integrate qualitative and quantitative methods (so-called mixed methods) in order to find strengths and limitations within scientific knowledge production.

Based on the findings of this dissertation, I suggest that crops grown on acquired land should be edible, and primarily produced to increase local and domestic food security. I also suggest that crops planted should be suitable for that local climate, and low in water requirements in order to avoid water conflicts. If agribusinesses use irrigation, the irrigation systems should be of highest water use efficiency. Consequently, if land acquisitions are to be considered as investments, they must be at the forefront of exploring more sustainable pathways of farming, by accounting for local needs, improving environmental conditions, and applying the latest scientific knowledge, no matter the economic cost.

Sammanfattning

En av de största utmaningarna i modern tid är att på ett hållbart sätt producera mat och andra varor för en ökande global befolkning, utan att utsätta mark- och vattenresurser för ytterligare belastning och därmed ha negativ inverkan på människors livskvalitet. Storskaligt jordbruk har genererat många fördelar för människan gällande matproduktion, men har även bidragit till många hållbarhetsutmaningar, som försämring av mark och vatten, avskogning, och minskad biologisk mångfald. För att bättre informera konsumenter, producenter, och andra beslutsfattare om samverkan mellan jordbruk och markanvändningsförändring krävs en djupare förståelse för drivkrafter, effekter, och feedbacks förändringar i samhälle och natur över olika rumsliga och temporala skalor. Detta kräver interdisciplinär och kreativ forskning som kan integrera både sociala och miljömässiga dimensioner av hållbarhet. Den här avhandlingen utforskar dessa samhälleliga och miljömässiga förändringar inom kontexten storskaliga markförvärv (large-scale land acquisitions, även känt som land grabbing), genom att integrera metoder from natur- och samhällsvetenskap över olika analytiska skalor.

De fyra artiklarna i denna avhandling utforskar drivkrafter, effekter och feedbacks av storskaliga markförvärv, från det generella globala perspektivet, till den detaljerade lokala fallstudien. *Artikel I* ger en global överblick över vilka länder som virtuellt importerar eller exporterar mark genom storskaliga markförvärv. De globala markförvärven visualiseras och analyseras som nätverk, vilket visar att få länder har en stor roll i det globala nätverket (Kina, Storbritannien och USA), samt att Afrika är den kontinent där mest mark köps eller hyrs ut till externa aktörer. Vi understryker att den globala strukturen av markförvärv är benägen att sprida sociala och miljömässiga risker och sårbarhet, både för länder som importerar och exporterar mark. Dessa resultat ledde till utvecklingen av *Artikel II*, som är en detaljerad analys av hur vattenanvändning ändras in samband med markförvärv i Afrika. Vi använde en vegetationsmodell (LPJmL) för att modellera blått och grönt vattenbehov av olika grödor för att identifiera hotspots för blå vattenanvändning, vilket i sin tur kan indikera områden med hög risk för vattenrelaterade konflikter. Vi kom fram till att grödor som odlas på markförvärv kräver mer vatten än traditionella grödor, och även om de mest effektiva bevattningssystemen används så klassas 18% av markförvärven som hotspots. *Artikel III* har som mål att förstå den lokala kontexten där storskaliga markförvärv sker. Baserat på fältarbete i Tanzania användes deltagandemetoder för att diskutera och visualisera upplevda sociala och miljömässiga förändringar. Lokala erfarenheter pekar på snabb avskogning och degradering av våtmark eftersom fler människor måste dela mindre mark för jordbruk, vilket är en kombinerad effekt av befolkningstillväxt och storskaliga markförvärv. *Artikel IV* jämför de lokala

upplevelserna av förändring med kvantifieringar av marktäcke genom satellitbildstolkning. Genom denna jämförelse kan berättelserna om jordbruksexpansion mot våtmarken stärkas och kartläggas, medan den snabba avskogningen i detta fall inte kan identifieras i satellitbilderna. Detta understryker ett behov att integrera kvalitativa och kvantitativa metoder för interdisciplinär forskning, för att hitta styrkor och begränsningar inom vetenskaplig kunskapsproduktion.

Baserat på resultaten i denna avhandling föreslår jag att grödor som odlas på markförvärv ska vara ätbara, och primärt produceras för att bidra till lokal och nationell matsäkerhet. Jag föreslår även att grödor som odlas ska vara lämpliga för det lokala klimatet, och kräva lite vatten för att undvika vattenkonflikt. Om jordbruksföretag använder bevattning bör dessa system vara av bästa vatteneffektivitet. Följaktligen, om markförvärv ska kunna kallas investeringar bör de vara i framkant av en mer hållbar jordbruksutveckling, genom att ta hänsyn till lokala behov, förbättra miljö, och omsätta de senaste vetenskapliga rönen i praktiken, oavsett ekonomisk kostnad.

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The first quote of this dissertation is from a Tanzanian farmer who described to me how the availability, accessibility, and quality of farmland and water have changed since a foreign agribusiness acquired land in his village. During my visits to Tanzania, I started to reflect on vulnerability to, and responsibility for, environmental change. I realized that I am part of a society that demands products derived from natural resources elsewhere, which in turn cause increasing challenges for people who require those same natural resources for survival. With this dissertation I therefore hope to contribute with new knowledge and awareness, from a scientific perspective, of those challenges that have their roots in consumption and production in an unequal world. I do this by focussing on socio-environmental drivers, impacts, and feedbacks of land system change in the context of large-scale land acquisitions.

During the past five years, I have met so many people that have inspired, and supported me while developing this dissertation. I would like to express my gratitude to you all, and to some people in particular (sorry in advance if you feel forgotten).

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List of papers

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II. Johansson, E. L., Fader, M., Seaquist, J. W., & K. Nicholas (2016). "Green and blue water demand from large-scale land acquisitions in Africa." *Proceedings of the National Academy of Sciences,* 113(41):11471-11476.

III. Johansson, E. & E. Isgren (2017). "Local perceptions of land-use change: using participatory art to reveal direct and indirect socioenvironmental effects of land acquisitions in Kilombero Valley, Tanzania." *Ecology and Society,* 22(1).

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Contribution to papers

Paper I: EJ contributed to research design, performed most of the data preparation and analyses, and contributed to the writing of the manuscript.

Paper II: EJ designed the research, performed the analysis of the quantitative data and model output, and led the writing of the manuscript.

Paper III: EJ designed the research, performed the fieldwork, prepared and analysed most of the data, and led the writing of the manuscript.

Paper IV: EJ designed the research, prepared and analysed most of the data, and led the writing of the manuscript.

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Introduction

The world is experiencing rapid societal and environmental change. Since 1900, the global population increased fivefold from 1.5 to 7.5 billion, and is projected to reach close to 10 billion by 2050 (United Nations 2017). The growing population, coupled with unequal distribution of wealth and demands for food, energy, and other goods, has led to unsustainable patterns of land and water use, as well as dangerous rates of CO_2-emissions (Foley et al. 2011; Peterson et al. 2003; Steffen et al. 2015; Turner et al. 2007). Demand for land and water for agricultural production will only increase under current trends in population growth, shifts to more meat-based diets (Erb et al. 2009a; Kastner et al. 2012), and replacement of fossil fuels with biofuels (Goldemberg et al. 2014).

Large-scale agro-industrial expansion is a major driver of land use and land cover change, which is a key process by which humans influence the functioning of ecosystems, in turn affecting people who critically depend on terrestrial and aquatic ecosystems for food and freshwater provision (Foley et al. 2005; Lambin & Meyfroidt 2011; Turner et al. 2007). Currently, about 37% of the Earth's ice-free surface is used for agriculture (World Bank 2018). As much as food is needed for survival, modern agriculture has caused complex and multi-scalar sustainability challenges, including losses in carbon storage, wildlife habitats, and watershed degradation (Brink & Eva 2009; Foley et al. 2011; Gibbs et al. 2010). Agriculture is also responsible for up to 85% of global freshwater withdrawals, affecting downstream water users in terms of water quality, quantity and accessibility (Foley et al. 2005; Kabat 2013; Shiklomanov 2000), sometimes leading to conflicts over land and water resources (Gleick 2014; Shiva 2002).

In Sub-Saharan Africa, the world's poorest region, global development institutions like the World Bank emphasise agricultural development as a key to economic development and poverty reduction (World Bank 2007). About 70% of the population is intimately linked with land and water resources through their livelihoods as farmers (Falkenmark et al. 2004). Urgent challenges relate to extreme poverty and hunger, low access to basic infrastructure like clean water and sanitation, and low rates of sustainable industrialization (Sachs et al. 2017). The World Bank's promotion of agricultural modernization has to a large extent facilitated foreign investments in agriculture to take place in many Sub-Saharan countries, and spurred large-scale acquisition of land by agribusinesses and private investors. Some see such

investments as an opportunity for agricultural development and greater self-sufficiency, as agribusinesses can enhance food security by reducing the yield gaps, bring technological development like irrigation systems and industry, and create socio-economic benefits through employment in areas in need of economic development (Cotula 2009; Deininger & Byerlee 2011; FAO 2009). Others see such investments as controversial and raise concerns about neo-colonialism, land grabbing, land tenure rights, and negative impacts on local livelihoods (Anseeuw et al. 2013; Robertson & Pinstrup-Andersen 2010; Rulli & D'Odorico 2017). They highlight that foreign investors look for land and water resources to satisfy the needs of their own region, for example to mitigate national CO_2 emissions by planting trees elsewhere (Andersson & Carton 2017; Hunsberger et al. 2017; Lyons & Westoby 2014), or to meet directives for reducing fossil fuels by producing biofuel crops (Acheampong et al. 2017; Harnesk & Brogaard 2017; Robledo-Abad et al. 2017).

Whether they are framed as "investments" or "land grabs", large-scale land acquisitions have been at the forefront of agro-industrial expansion since 2000, and are currently a major driver of land use and land cover change, especially in low- and middle-income countries with abundant and "untapped" resources of land, water, and labour (Anseeuw et al. 2012; Borras et al. 2011; Dell'Angelo et al. 2018; Lazarus 2014). Land acquisitions involve public and private actors, including governments and agribusinesses, leasing or purchasing large tracts of land for the production of goods of their choosing (Anseeuw et al. 2013; D'Odorico et al. 2017). Even though land acquisitions were noted as far back as 2000, the phenomenon escalated in 2008 as a consequence of the global crisis in food, energy, and finance (Borras et al. 2011). Acquired land areas primarily expand into forests, grasslands, wetlands, and marginal lands, but also into areas previously used for small-scale food production (Borras & Franco 2012).

Just as there has been a "rush for land" in the Global South over the last two decades, much research has focussed on the social impacts of such agricultural expansion. Societal costs relate to the violation of local farmers' land rights, and negative effects on economic development (Bergius et al. 2018; De Schutter 2011; Dell'Angelo et al. 2017), human rights (Grant & Das 2015), land tenure (Doss et al. 2014) and food security (Nyantakyi-Frimpong & Bezner Kerr 2017; Yengoh & Armah 2015). Environmental impacts on land and water resources have remained relatively understudied (Dell'Angelo et al. 2018). Current findings however point to biodiversity loss and deforestation (Feintrenie 2014; Schoneveld et al. 2010), lost access and degradation of natural resources on which people depend for their livelihoods (D'Odorico et al. 2017; Deininger 2011), as well as reduced water availability and quality due to irrigation of water intensive crops (Chiarelli et al. 2016; Mehta et al. 2012; Williams et al. 2012). There are large knowledge gaps in the scientific literature regarding water requirements of land acquisitions (Chiarelli et al. 2016; Dell'Angelo et al. 2018; Woodhouse & Ganho 2011; Woodhouse 2012).

Investments in water infrastructure (e.g. efficient irrigation) could lead to local benefits and increased food production while also making the agricultural sector less vulnerable to climate variability (e.g. erratic rainfall). However, the long-term contracts (often between 33 and 99 years) rarely include any restrictions to water use, which might lead to drastic changes in water quality, availability, and accessibility for local, as well as distant, natural resource users (Jägerskog et al. 2012).

Large-scale land acquisitions are truly a rapidly growing force for land use and land cover change (also referred to as land system change). Seto and Reenberg (2014) underscore the need to investigate and understand a wide range of contemporary trends in global land use, which involves the growing competition for land and water resources through large-scale land acquisitions. In particular, there is a need to identify new forms of agents and practices regarding distal land connections and non-local interests in land, and to investigate the effects these global land connections have on local land use and governance.

Aim and objectives

The overall aim of this dissertation is to map, and quantify, patterns of land use and land cover change in the context of large-scale land acquisitions, as well as to clarify some of the drivers, impacts, and feedbacks of socio-environmental change. I focus on four key challenges (three empirical, and one epistemological): *the global shift in land ownership (Paper I), risks of water conflict (Paper II), local experiences of socio-environmental change (Paper III), and how to co-create knowledge about local socio-environmental change (Paper III and IV)*. I approach these challenges by analysing relational and spatial patterns as snapshots in time from global to local scales by fulfilling the following research objectives: 1) To map countries involved in the virtual trade of land through large-scale land acquisitions, and to describe their connectivity (global level), 2) To calculate water requirements of land acquisitions currently in production in Africa, and analyse how water demand has changed across a range of irrigation scenarios (continental level), 3) To document perceptions of socio-environmental change, and to visualize the narratives as paintings (local level), 4) to map and quantify land cover categories established in field with remote sensing, and to combine this land change detection with narratives of land use from the ground (local level). The aims and research questions of each paper in this dissertation are outlined in Table 1.

Table 1. Aims and research questions of articles in PhD dissertation.

Paper	Scale	Aim	
I	Global	*Describe and analyse the structure of the global land acquisition system as a network to explore the connectivity and vulnerability of involved countries.*	
		Research questions	1) What does the global pattern of large-scale land acquisitions look like, and how does it function? 2) What countries are virtually exporting and importing land? 3) Which countries dominate land trade? 4) What countries are vulnerable to changes in the land acquisition network arising from the connectivity patterns?
II	Continental (Africa)	*Delineate hotspot areas that are at risk of water conflicts due to high levels of freshwater use by large-scale land acquisitions in Africa.*	
		Research questions	1) What are the water demands from crop production of land acquisitions? 2) What areas are vulnerable to increased water stress and related water conflicts?
III	Local	*Create paintings through participatory art, in order to visualize how local farmers perceive land use changes due to large-scale land acquisitions in Kilombero Valley, Tanzania.*	
		Research questions	1) What are the most important natural resources for people who live in areas of large-scale land acquisitions? 2) How do farmers, fishermen, and pastoralists perceive that natural resources have changed since the arrival of large-scale agribusinesses? 3) What are the main reasons for socio-environmental change? 4) How do the participants want the future to develop?
IV		*Quantify land cover categories established in field with remote sensing, and compare with local perceptions of change.*	
		Research questions	1) What are the dominant narratives of socio-environmental change identified with participatory research approaches? 2) What are the land use and land cover changes between 2004 and 2014 observed with remote sensing? 3) How do local perceptions of change in forest, shrubland, grazing land, farmland, wetland, and water, compare to identified land cover changes through land cover classification of the same categories?

Conceptual background

This section introduces and defines some key concepts of this dissertation: socio-environmental change, land system change, scale, telecoupling, and co-production of knowledge. These are also key concepts within land system science that acknowledge that there is a need to explore socio-environmental connectedness, and consequences of distant natural resource use in order to address global challenges of land degradation and water conflicts (Eakin et al. 2014; Liu et al. 2013a; Seto & Reenberg 2014).

Socio-environmental interactions and land system change

A central concept in this dissertation is socio-environmental change, which is the constant and complex interaction between people and nature (Berkes & Folke 1998; Young et al. 2006). Social processes (e.g. economy, policies, demography) have impacts on ecosystems (e.g. forests, wetland), and changes in ecosystems (e.g. deforestation, water use) have impacts on people and societies (e.g. health, food security).

Land systems, in turn, are the result of cross-scale socio-environmental interactions, and land system change is both a driver and impact of socio-environmental change (Verburg et al. 2015). For example, land systems are a consequence of human decision making on local (e.g. land owners), regional/national (e.g. land use planning), and global scales (e.g. trade agreements). The combined effects of local land system changes have effects on the Earth System (e.g. climate change), which in turn cause new feedbacks on ecosystems, human-well being, and decision making (Crossman et al. 2013; Verburg et al. 2015).

Land system science is an interdisciplinary field that has emerged with the aim to understand drivers, impacts, feedbacks, and trends of land use (human use) and land cover (biophysical condition) change, and how land system change in turn affects the functioning of socio-ecological systems (Rindfuss et al. 2004; Verburg et al. 2015). Initially, the field (also called land change science) relied heavily on quantitative approaches like geographical information systems (GIS), remote sensing, and environmental modelling in order to map, monitor, and model different types,

magnitudes, and locations of land use and land cover change across spatial and temporal scales (Reenberg 2009; Rindfuss et al. 2004; Turner et al. 2007; Turner 2009). The growing interest to understand land systems in terms of natural resource governance, conflicts, and other socio-environmental trade-offs has, however, led to an increased use of qualitative ground-based approaches commonly used in e.g. political ecology (Bryant 1998; Rocheleau 2008; Turner & Robbins 2008), such as ethnography, historical narrative constructions, interviews, and participatory research approaches (Verburg et al. 2013; Verburg et al. 2015).

Scale and telecoupling

Scale

The subtitle "from the pixel to the globe" highlights the importance of scale in this dissertation. Socio-environmental change needs to be understood as an outcome of cross-scale political, economic, and ecological drivers, impacts, and feedbacks (Blaikie & Brookfield 1987; Verburg et al. 2015). Scale can be defined as the "spatial, temporal, quantitative or analytical dimensions used by scientists to measure and study objects and processes" (Gibson et al. 2000). Scale thereby includes an extent, which is the spatial area or timeframe covered in the analysis, and a resolution, which is the finest spatial and temporal level of detail at which the data can be analysed. Levels refer to the position in a certain scale (Gibson et al. 2000; Vervoort et al. 2012), e.g. national (macro), sub-national (meso), and individual (micro). For example, global scale studies might analyse a system on a national level, and country-scale studies might analyse a phenomenon on a community-based level.

Socio-environmental changes (e.g. demographic change, resource extraction and consumption) can be viewed as a consequence of cross-scale and cross-level linkages, that historically and contemporarily shape new and unique outcomes, in turn posing site-specific challenges for natural resource use and management (Boda & Ramasar 2014). The choice of spatiotemporal scale critically affects the patterns and processes that can be observed, and certain patterns might be lost if the scale of analysis is not consistent with those patterns and processes. For example, rapid (e.g. floods, droughts) and slow (e.g. sea level rise, desertification) processes operate on different spatial and temporal scales. Scale therefore also has consequences for the methodological choice, analysis, and interpretation, which might enable or restrict scientific insights.

Another scale-related challenge relates to trade-offs between *generality, realism, and precision* (Chowdhury 2013). Generality aims to identify general principles and trends with emphasis on simplicity and broad applicability, and therefore comes at the cost

of either precision or realism. Realism describes the representation of essential constructs and components of systems, and their connectivity, while precision lays in the details the components of the system can be measured and represented. Precise explanations privilege detail, nuance, and fine-scale differences rather than characterizing aggregate components, patterns, or processes. This categorization is based on a study by Levins (1966) who claims that models for predicting nature cannot maximize these three goals simultaneously, but by optimizing two of the goals (e.g. precision and realism) one must sacrifice performance in the third (e.g. generality). Similar trade-offs exist for understanding socio-environmental change in the context of large-scale land acquisitions, which is why I use different scales as analytical entry points for obtaining multiple insights on drivers, impacts, and feedbacks related to the phenomenon.

Telecoupling

According to Tobler's first law "everything is related to everything else, but near things are more related than distant things" (Tobler 1970). Socio-environmental drivers, impacts, and feedbacks can however be distant to each other in geographical space, but close to each other in relational space, which poses new challenges as to how to treat scale within land system science (Manson 2008). Globalization, teleconnections, and telecoupling are three concepts that have emerged in order to deal with increasingly distant connections between social and environmental systems.

Globalization is the socio-economic interactions between human systems over distances (Liu et al. 2013a), and has increased the speed, spatial stretch, and spatial allocation of socio-environmental change and sustainability challenges (Young et al. 2006), for example through improved transport and communication systems, and international trade (Clapp & Dauvergne 2011; Meyfroidt et al. 2013; Young et al. 2006). Even though the world is more connected than ever before, people have never been so disconnected from their individual environmental and social impacts caused by consumption (Erb et al. 2009b; Mills Busa 2013; Moran et al. 2013).

Teleconnections focus on describing distant environmental drivers of land system change (Adger et al. 2009; Friis et al. 2015; Seto et al. 2012). Specifically, the term 'teleconnections' is used in climate- and atmospheric sciences to study geographically distant (typically thousands of kilometers) climate anomalies that are related to each other through ocean-atmosphere circulations (Chase et al. 2006). An example is El Niño, which originates from high-pressure systems in the western Pacific Ocean and can have effects on precipitation and drought in the southern Great Plains in Texas (Wang et al. 2015).

Telecoupling (Eakin et al. 2014; Friis et al. 2015; Liu et al. 2013a) is a framework that has been developed in order to integrate the social dimensions of globalization,

with the natural dimensions of teleconnections, linking geographically distant and spatially unconnected places as coupled human and natural systems (Figure 1). Telecoupling is more complex than teleconnections, as it considers both the environmental and socio-economic drivers, feedbacks, and multidirectional flows that increasingly characterise interactions between people and nature. The framework is useful for understanding telecoupled land use, and tracing virtual transfers of natural resources (e.g. land, water, CO_2 emissions) that are embedded in the production and consumption of agricultural goods (Baird & Fox 2015; Eakin et al. 2014; Friis et al. 2015). Virtual, in this context, refers to natural resources that are not physically embedded in the trade of agricultural products, but that were required at some stage of production (Fader et al. 2010). Telecoupling is also useful for disentangling and understanding distant drivers and impacts of socio-environmental change across scales, such as land changes related to soybean production within and among trading countries (Sun et al. 2017), distant linkages between local land use and livelihood vulnerability in relation to global environmental change (Challies et al. 2014; Lenschow et al. 2016), and global demands for rubber that drive large-scale land-use changes in Cambodia (Baird & Fox 2015).

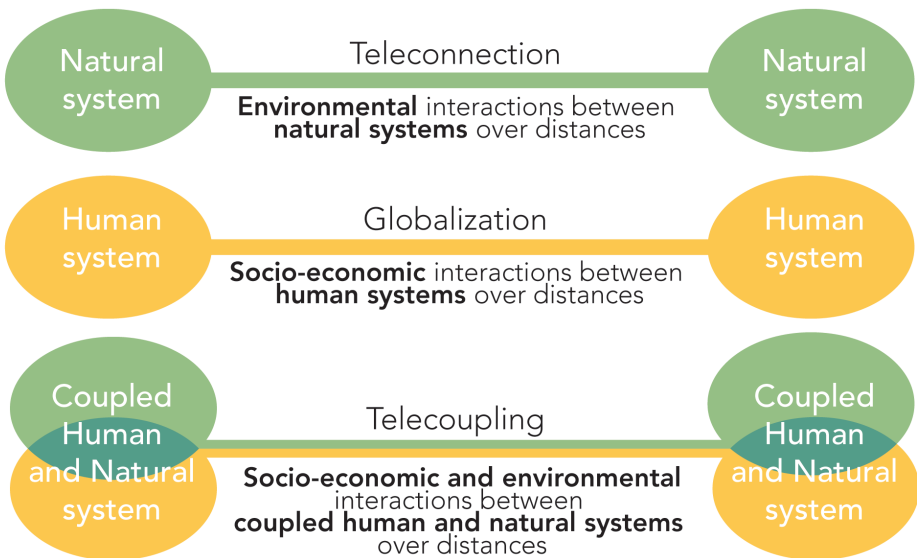

Figure 1. Definitions of teleconnections, globalization, and telecoupling. Figure adapted from Liu et al. (2013a).

Co-production of knowledge

Land system science acknowledges the need to reflect on what, and how knowledge is useful for society, and stresses the need to find new ways of integrating knowledge across the natural and social divides in science (Verburg et al. 2013; Verburg et al. 2015). Also sustainability science has such ambitions, and provides theory and insights regarding knowledge production for understanding problems of, and solutions to, sustainability challenges (Clark & Dickson 2003; Jerneck et al. 2011; Kates et al. 2001). In order to make science more useful for society, it is increasingly important to do research *with* and *for*, rather than *about* people in place (Chambers 1994; Rocheleau 2008; Rosendahl et al. 2015). Co-production of knowledge is when academic and non-academic perceptions meet, and is essential for integrating science and society in order to develop shared solutions for a more sustainable world (Pahl-Wostl et al. 2013; Pohl et al. 2010; Verburg et al. 2015). When engaging in co-production of knowledge, the traditional role of the scientist as an expert is replaced by a more equal role in learning from, and incorporating, experiences and knowledge from local partners/participants (Berkes 2010; Bryant 1998; Robbins 2003; Zurba & Berkes 2013). For example, the research focus and questions might be developed in field, as opposed to entering a case study area with a predetermined agenda and set of questions. Co-production of knowledge can therefore enable people most vulnerable to socio-environmental change to inform the researcher about the most pressing challenges, which can make the research focus more relevant for that local context, and socially robust as a whole, since it is based on local concerns (Rosendahl et al. 2015).

Study area

This chapter presents the study area of this dissertation, which stretches over global to local domains. The first paper is global in its scope, focussing on large-scale land acquisitions as a global land trade system. The second paper is continental and focus on large-scale land acquisitions that are in operation in Africa. The third and fourth papers are local in their scope, focussing on Kilombero Valley in Tanzania as case-study area.

Africa on a global land market

Large-scale land acquisitions are truly a global phenomenon. Since 2000, land has been acquired in most continents of the world: Africa, South America, Central America, Asia, (Eastern) Europe, and Oceania (Figure 2). The land acquisitions are mainly for agribusiness purposes, by multi-national corporations, investment funds, or government-owned companies (D'Odorico et al. 2017; Zoomers 2010). Currently about 69 million hectares (ha) of land have been acquired globally (estimated by Land Matrix (2018)), which equals the combined size of France and Costa Rica. Most land has been contracted in Africa (33 million ha, equal to the size of Vietnam), particularly the Eastern, Western and Central African regions. There is, however, a large difference between how much land that is contracted (i.e. current area that has been leased or purchased by the investor), and how much that is in production (i.e. land area that is already operational). About 21% of globally acquired land is estimated to be in production, which equals the size of Bangladesh. However, only 3.6% of the contracted land in Africa is currently in production (Figure 3).

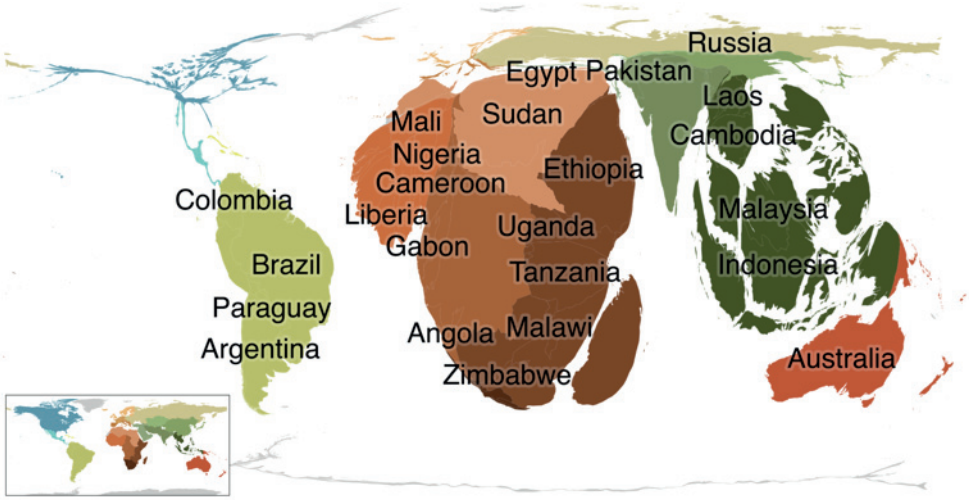

Figure 2. Cartogram (distorted map) where each country's size has been re-scaled to represent the total amount of acquired land: the more land acquired, the larger the country size in the map. Countries where more than 100,000 hectares of land is contracted are labelled with country name, and countries are coloured by sub-region. Data from Grain (2012) and Land Matrix (2014).

The low proportion of land deals in production can partly be explained by financial land speculations by private firms, who hope to gain financial benefits from the increased food- and energy-driven demand for agricultural land (Kugelman & Levenstein 2012). Another reason is that many investments have failed at the implementation stage, resulting in either abandonment, or transfer to a new investor (Cotula, 2013). This has especially been the case for land acquisitions related to biofuel production from crops like sugarcane and jatropha (Ahmed et al. 2017; Borras et al. 2010; Hashim 2014; Sanderson 2009).

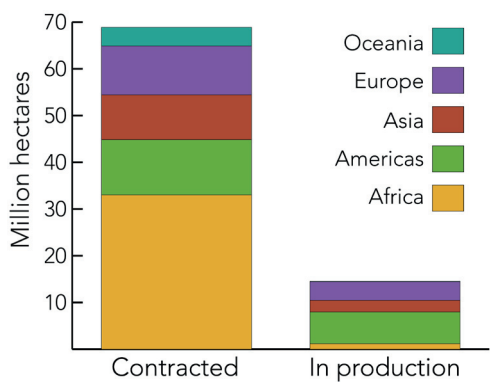

Figure 3. Total area of land acquisitions in the world, grouped by continent. The graph shows the difference in contracted land leases, and acquired land currently in agricultural production. Data from Land Matrix (2017).

The global scope of large-scale land acquisitions led to the development of *Paper I*, in order to understand how countries and land systems are connected to each other through virtual trade of land and water resources. *Paper II* focus on Africa as a whole, since it is the continent where most land has been contracted. Tanzania was selected in order to investigate what effects the global and continental patterns of land- and water-use changes have in selected areas subject to large-scale land acquisitions (*Paper III & IV*).

The case of Kilombero Valley, Tanzania

Tanzania is one of the highly targeted countries for land in East Africa, where in total about 256 000 ha of land has been acquired (of which approximately 14% is in production according to Land Matrix (2018)). I conducted my fieldwork in Kilombero Valley, located in the Kilombero and Ulanga Districts of southern Tanzania (Figure 4). The fieldwork site was selected in collaboration with a Tanzanian NGO working on land right issues, with the motivation that it is one of the areas experiencing rapid socio-environmental change due to large-scale land acquisitions. However, a range of further factors makes it an ideal place for this study. The Kilombero Valley is a biodiversity hotspot and has one of the largest freshwater wetlands in East Africa (Kangalawe & Liwenga 2005b). It is referred to as the bread basket of East Africa due to its perfect conditions for agriculture with year-round warm temperatures, fertile soils, and abundance of water (Mombo 2011). Most people (76%) live in rural areas and primarily engage in food production through small-scale farming, fishing and pastoralism. These livelihoods closely connect people to the environment, and make them particularly vulnerable to environmental change (Kangalawe & Liwenga 2005a). The area is experiencing rapid population growth. Between 2002 and 2012 the rural population grew by 24%, from 230,774 to 304,241 (NBS 2016). Population growth is not only an effect of high birth rates, but also due to rapid migration to the area, particularly by the influx of Masaai, Sukuma, and Barbaig pastoralist groups, who are leaving other parts of Tanzania due to land degradation, or land investors forcing them to find land elsewhere (Nindi et al. 2014).

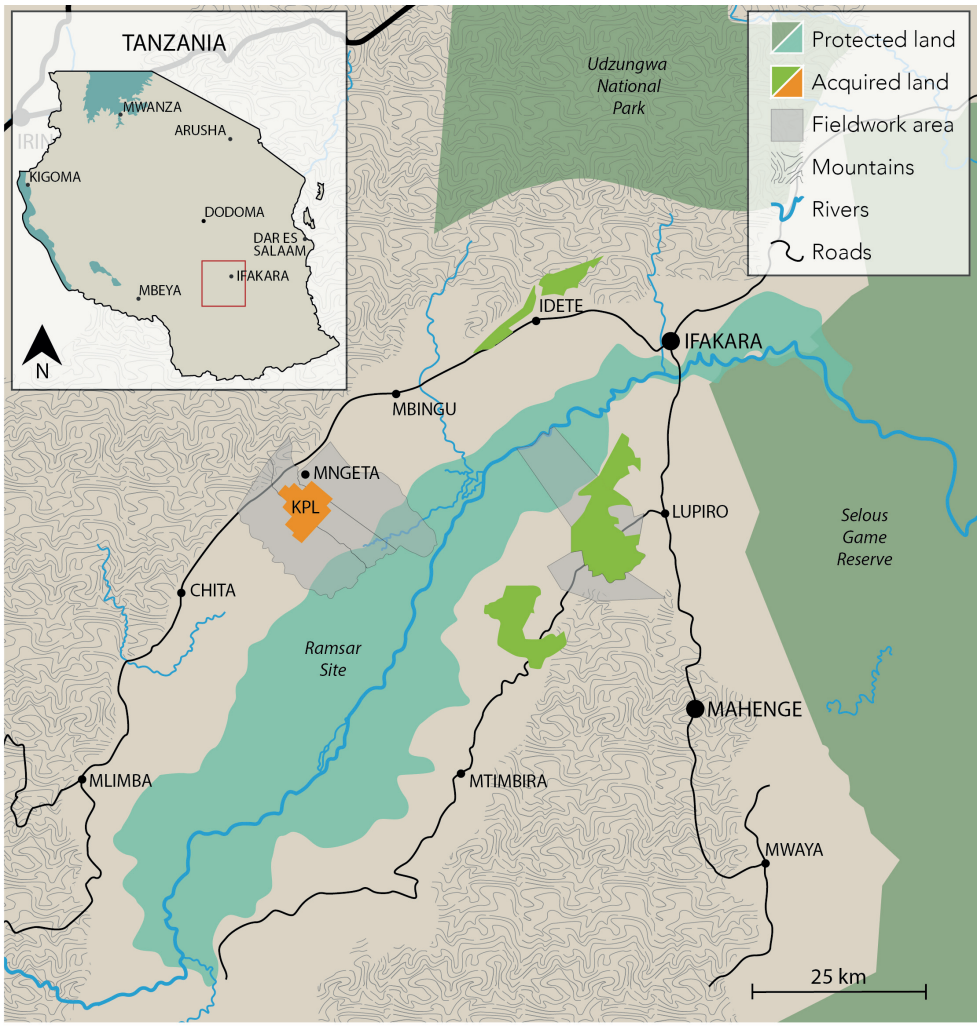

Figure 4. Map of study area for fieldwork. Dark green and turquoise land is protected by global or national initiatives, while light green and orange areas indicate areas for large-scale land acquisitions in the Valley. The light grey area delineates the village land of the case study areas.

There are many actors engaged in land- and natural resource management of the Kilombero Valley, mainly for conservation or agricultural purposes. These actors range from individuals (e.g. farmers), local NGOs (e.g. Kilombero Valley Development Organization, KIVEDO), domestic agribusinesses (e.g. ILLOVO), transnational agribusinesses (e.g. Kilombero Plantations Limited, Kilombero Valley Teak Company), and global conservation initiatives (e.g. Ramsar). The area became increasingly attractive for foreign agribusinesses since the national initiative Southern Agricultural Growth Corridor of Tanzania, SAGCOT, was launched in 2011.

SAGCOT coordinates agribusiness partnership between the Government of Tanzania, private companies, and international donors, and aims to mobilize 3 billion USD in investments, bring 350,000 hectares of land into commercial farming, create 420,000 new jobs, and lift 2 million people out of poverty (Scherr 2013). Conservation initiatives are based on global interests to protect the wetland area, which was declared as a Ramsar site in 2006, and is thereby protected under the Convention on Wetlands of International Importance (Ramsar 2016). There are also national initiatives to protect biodiversity with extensive areas of national parks and forest reserves (e.g. Selous Game Reserve, and Udzungwa National Park).

I conducted fieldwork in two areas in Kilombero Valley where large-scale land acquisitions have been in operation over an extensive period of time (highlighted in grey in Figure 4). This made it possible to explore socio-environmental change in relation to land use and land cover changes that have occurred since land was acquired in the two areas. The two areas of focus are affected by large-scale land use changes by Kilombero Plantations Limited, growing rice on 5,800 ha of land for non-local markets since 2007, and Kilombero Valley Teak Company, growing teak on 28,132 ha of land for export since 1992. Figure 5 gives a glimpse of the study area, and shows some of the main drivers of socio-environmental change in the region.

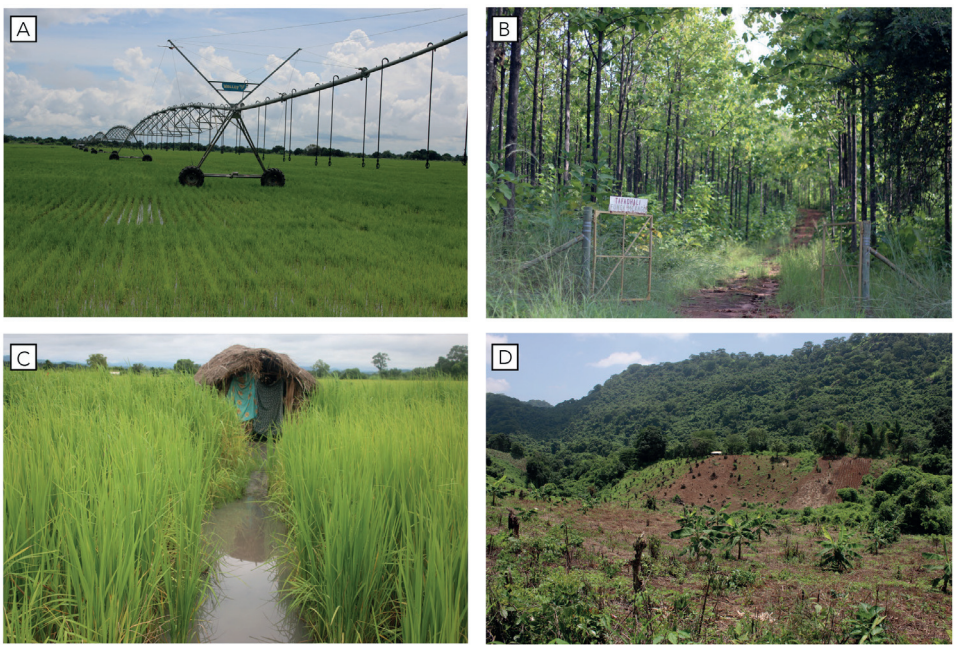

Figure 5. A) Rice fields of Kilombero Plantations Limited are managed with sprinkler irrigation systems with water extracted from one of the rivers that feed the wetland area with freshwater. B) Teak plantation of Kilombero Valley Teak Company, fences disturb the migration of wildlife in the area. C) Farmland expansion by local small-scale farmers to the protected Ramsar wetland area. D) Farmland expansion by small-scale farmers to the protected mountain forest. Also charcoal production is a reason for deforestation.

Data and methods

I have applied different research approaches in the four papers of this dissertation, spanning global, continental, and local scales (Figure 6). On the global to continental scale, I use available data for large-scale land acquisitions in order to quantify environmental change with a focus on land and water (*Paper I & II*). The purpose is to generate an understanding of the relational patterns that emerge, and what implications these patterns might have on people and the environment on a national, and sub-national level. At the local scale, I combine qualitative and quantitative methods in order to understand people's perceptions of socio-environmental change (*Paper III*), and compare these with satellite image observations (*Paper IV*).

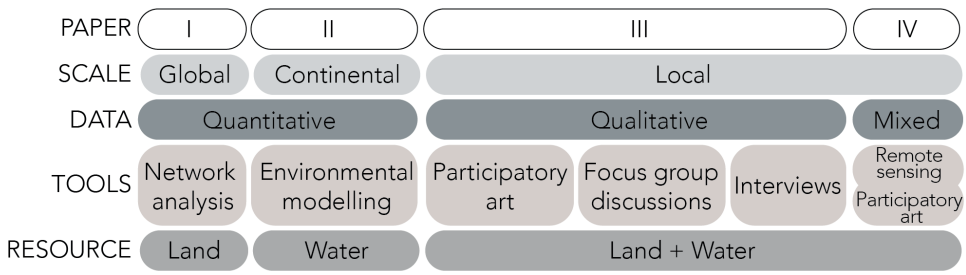

Figure 6. Overview of the different research approaches in the four papers of this dissertation.

Paper I: Network analysis of global patterns

Paper I was developed in order to investigate the spatial and relational pattern that has emerged between countries that engage in large-scale land acquisitions. This is one of the first attempts of analysing global land acquisitions as a telecoupled system.

Global datasets of large-scale land acquisitions

The network analysis is based on data from two online databases: Grain (2012) and Land Matrix (2014). Grain (www.grain.org) is an international non-profit

organization, and the first to provide a large dataset about land acquisitions. The database has, however, not been updated since it was first uploaded to the Grain website. Land Matrix is an independent global initiative to monitor large-scale land acquisitions, and the data is continuously updated and freely available online at www.landmatrix.org. The databases include information about:

- Investor name.
- Origin of investor (one or many countries).
- Where land is acquired (on a local or national level).
- How much land is contracted, and how much land is currently in operation.
- What crops are grown (or planned to be grown).

The global datasets from Grain and Land Matrix were merged and edited (e.g. duplicates were removed) to obtain the full extent of the global pattern of land acquisitions. The data were re-shaped into a format that enabled network analysis.

Network analysis

Network analysis is a method for observing and analysing the patterns and connectivity of a system (Newman 2010), and has good potential for operationalizing the telecoupling framework (Liu et al. 2016), but the research is still in its infancy. In this dissertation, a network approach was chosen in order to investigate the relational connections between countries that participate in global land trade through large-scale land acquisitions. The land acquisition network was created with the open access software Gephi (Bastian et al. 2009), which provided a platform to visualize the network geographically. The software package UCINET was also used for some of the analyses (Borgatti et al. 2002).

As illustrated in Figure 7, the basic building blocks of networks are nodes and links (represented as circles and lines). In *Paper I*, the nodes represent countries that participate in the global land acquisition network, either as "importers" (represented by the investor's country of origin) or "exporters" (i.e. countries where land is acquired) of land. Links appear if there is a connection between two countries, in this case represented by a virtual trade of land, and a shift in land ownership.

The statistics provided by network analysis are local and global, in this context meaning that a measure can say something about a specific node (local), or the node's role in the network as a whole (global). Degree centrality (a local measure) and betweenness centrality (a global measure) are two centrality measures that have been used to identify key players in the land acquisition system, and the role of countries for providing network connectivity. These measures and network statistics can be used to understand how risks and vulnerabilities may propagate throughout the network.

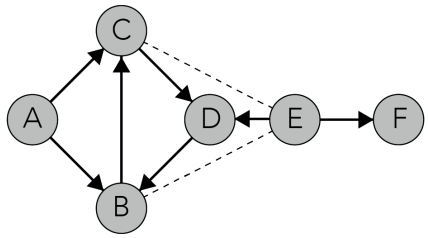

Figure 7. Conceptual model to explain network features and metrics used in Paper I. The figure shows a directed network with six nodes and seven links. Dashed lines are added in order to explain how the local clustering coefficient is calculated.

Degree centrality is a local network measure that have been used to describe the number of land trade partners associated with a country, as it represents the number of links connected to a specific node (Figure 7, A = 2, D = 3, E =2). If a network is directed, each link has a direction to or from a node, which gives each node a certain in- or out-degree (Figure 7, $D_{in\text{-}degree} = 2$, and $D_{out\text{-}degree} = 1$).

Betweenness centrality is a global network measure that describes how often a node appears on the shortest path between all other nodes in the network (Figure 7, $D_{undirected} = 6$ times: A-E, A-F, B-E, B-F, C-E, C-F, and $D_{directed} = 3$ times: E-B, C-B, E-C). It can therefore be used to understand the importance of nodes for providing network connectivity, as nodes with high betweenness centrality act as a bridge between many other nodes in the network. Hence, if a node with high betweenness centrality is removed from the network (e.g. acquired countries banning land acquisitions, acquiring countries withdrawing from investments, temporary export bans, harvest losses due to extreme weather events) it will affect many other nodes in the network, as well as their connectivity. In *Paper I*, the measure is normalized by dividing each node's betweenness centrality by the total number node pairs in the network, which produces a value between 0 (0%) and 1 (100%). A value near 1 indicates a central player in the network, and a value near 0 means that a node is peripheral and rather uninfluential.

The local clustering coefficient has been used to describe the tendency for countries to form tight groups, which depends on how well connected a given node is to its neighbours, and in turn how well the neighbours are connected to each other. The clustering coefficient is calculated as the ratio of how many partners are linked to a node, in relation to the theoretical maximum of land trades that could occur between those linked partners. For example, in Figure 7, D is linked to three partners (B, C, E). The nodes B, C, and E could be tied to each other with three links (indicated with dashed lines), but there is only one other link between B and C, the local clustering coefficient of D is therefore calculated as 1/3 = 0.33 (or 33%). In *Paper I*,

the local clustering coefficient was used to identify land trade submarkets, representing groups of countries with tight land trading relationships.

Finally, the average nearest neighbour degree can be used to indicate the likelihood that nodes are connected to other nodes of similar degree (assortative relationship), or dissimilar degree (dissassortative relationship). In *Paper I*, this measure was used in order to understand if countries with many (or few) trading partners tend to engage with countries with similar (i.e. assortative trade orientation) or dissimilar (i.e. dissassortative trading orientation) number of trading partners. For this measure, the direction of trade (import or export) was also taken into consideration, which makes it is possible to gain general insights regarding country-level factors that may lie behind any observed asymmetries of trade relationships.

Paper II: Modelling water demand for land acquisitions in Africa

Paper II was developed in order to add the element of freshwater to the understanding of socio-environmental change, since changes in land use are also accompanied with changes in water resources, which in turn might lead to conflicts between water users.

Data for modelling blue and green water requirements

For the continental-scale analysis, focus was on land acquisitions in operation in Africa. The sub-national coordinates[1] of data from Land Matrix allowed for modelling and mapping place-specific green and blue water requirements for crops in production based on local climate data (approximately 55 km in resolution), as opposed to aggregated country-level data. Focussing on land acquisitions in production also made it possible to crosscheck the data with satellite imagery from Google Earth.

When accounting for water requirements of agricultural products, it is important to distinguish the type of freshwater that is appropriated. This can facilitate an understanding of what type of water is used (i.e. if water is from green or blue water sources), and point to trade-offs between human water use and ecosystems needs. Green water is the water that is available to crops as soil moisture from precipitation. Blue water is the above or below ground water in e.g. rivers, dams, and groundwater (Falkenmark et al. 2004). For irrigated agriculture, the soil moisture is enhanced with

[1] Sub-national coordinates for each land deal were obtained through personal communication with Matthias Brück, 24/7 2014, at the time developing the Land Matrix webpage.

freshwater from blue water sources, and the blue water use of crops therefore varies depending on the water use efficiency of the irrigation system.

Agro-ecological and hydrological modelling

Blue and green water demand was estimated using the dynamic agro-ecological and hydrological model Lund-Potsdam-Jena Managed Land (LPJmL), as it enables site-specific simulation of crop production, and blue and green water use for different irrigation scenarios. Agro-ecological and hydrological modelling made it possible to estimate a range of water requirements for different irrigation scenarios, which is essential since there is little information about irrigation systems on acquired land (Chiarelli et al. 2016). Modelling also made it possible to compare water requirements of crops grown on acquired land, to a baseline scenario of traditional crops.

LPJmL uses gridded (0.5 degrees resolution, approximately 55 km) monthly climate inputs (temperature, cloudiness, rainy days and precipitation from CRU 3.10), soil textures, and global atmospheric CO_2-concentrations to model hydrological variables, phenology, agricultural outputs, and the carbon cycle. LPJmL has a detailed hydrology module, with a river routing and irrigation scheme (Rost et al. 2008), management of dams and reservoirs (Biemans et al. 2011), and a five soil-layer hydrology (Schaphoff et al. 2013). LPJmL's hydrological scheme, including the simulation surface and subsurface runoff, soil evaporation, plant transpiration, infiltration and percolation, has been demonstrated in numerous studies and validation efforts (Elliott et al. 2014; Fader et al. 2016).

The extended version of LPJmL from Fader et al. (2015) represents 26 crops or groups of crops: 13 annual crops, two bioenergy crops, 7 agricultural trees and shrubs, and three other categories (vegetables, fodder grasses and managed grasslands). Most of the crops in production on acquired land in Africa are included in LPJmL, but some, including acacia, cacao, castor oil plant, coffee, flowers, jatropha, oil palm, pongamia pinnata (a legume tree for biodiesel production), rubber, sesame, tea, teak and teff were represented through the class "managed grasslands", which was parameterized as a mixture of C3 and C4 grass and gives an estimate for the behaviour of these crops.

Paper III: Local perceptions of socio-environmental change

For *Paper III*, it was crucial to understand how people that are affected by large-scale land acquisitions experience land system change, and what changes they observe. With the aim to co-produce knowledge, the research focus and questions were

developed during fieldwork in Kilombero Valley, Tanzania, by combining established qualitative methods (focus group discussions, interviews, narrative walks, field observations), with novel participatory art workshops inspired by ethnography and participatory research (Chambers 1994).

Focus group discussions, interviews, narrative walks, and field observations

Firstly, I arranged focus group discussions with farmers, fishermen, and pastoralists in order to get an overview of local experiences, observations, and opinions of socio-environmental change in communities that lease land to large-scale agribusinesses. The aim of a focus group discussion is to obtain data from a purposively-selected group of people, rather than from a statistically representative sample of the broader population, and thereby gain in-depth understanding of issues, since the group dynamic can help participants to explore and clarify their views (Kitzinger 1994; O Nyumba et al. 2018). I consciously decided to include people who are highly dependent on natural resources in the communities where land is being leased, and therefore vulnerable to land system changes.

Questions were developed with the overarching aim to understand past, present, and future changes in natural resources, and natural resource use. The discussions were open ended, in order to illuminate what socio-environmental changes and challenges are most important for the participants (Figure 8). Questions were related to what natural resources are important in the area, how people use them, and what benefits they obtain from those resources. From there, discussions focussed on if there have been any changes in natural resources, and what the participants think are the reasons for change. Thereafter, the discussion revolved around the future of the community and natural resource use, how the participants want natural resource use to change, and how to make change happen.

Spending time in the field also allowed me to arrange interviews with other key actors that influence natural resource management in the Kilombero and Ulanga Districts. This includes people working for the agribusinesses (Kilombero Plantations Ltd., Kilombero Valley Teak Company), district level authorities, the local Ramsar office staff, agricultural research institutes, local NGOs, and other sporadic encounters with people that live in the area. Interviews are useful when wanting to understand individual experiences, opinions, and values without interference from others (Kvale 2008). The interviews were based on the same questions as those posed in the focus group discussions in the villages, and helped me understand if, and how, the perceptions of natural resource managers overlap or diverge from the perceptions of the farmers, fishermen, and pastoralists.

Figure 8. Qualitative methods during fieldwork. A) Focus group discussions in one of the fieldwork communities. B) Interviews with a family that was re-settled to another area when the foreign agribussines acquired land.

Narrative walks, and field observations were conducted with people from the village who showed me different areas mentioned in the focus group discussions, such as the wetland, mountain forest, as well as new and old village and farmland areas (Figure 9). This enabled me to understand place-specific social and natural dimensions of the landscape, and additional local experiences of socio-environmental change (Fienup-Riordan et al. 2013; Jerneck & Olsson 2013).

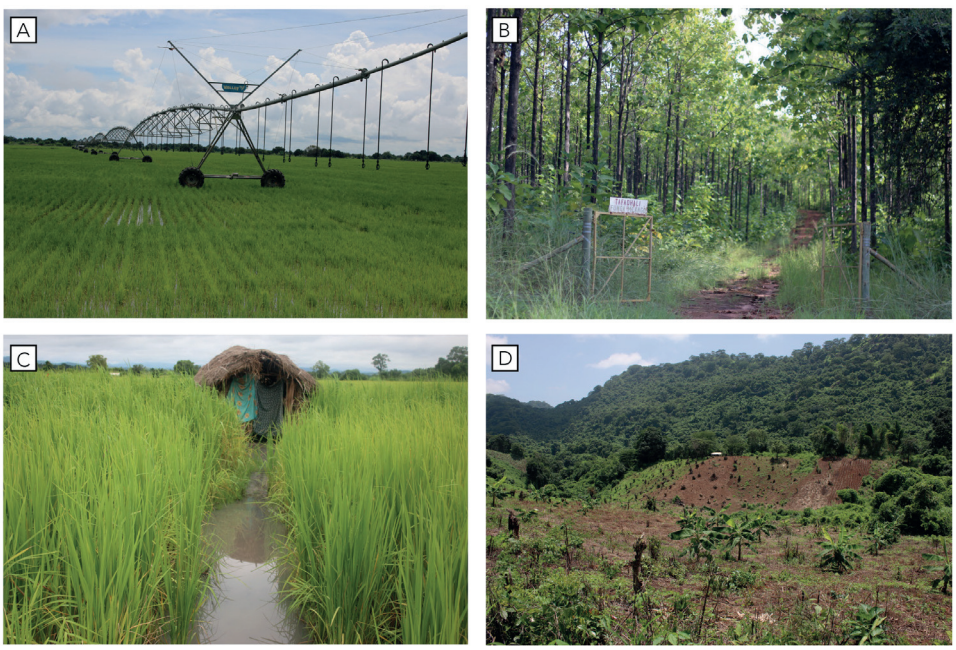

Figure 9. Qualitative methods during fieldwork. A) Field observations with farmers showing land that was previously small-scale farming and now has been converted to large-scale rice plantations. B) Field observations, observing the size of teak tree leaves. C) Field observations and narrative walks with a farmer that shows small-scale rice field expansion to the protected Ramsar area. D) Field observations and narrative walk with forest ranger that shows illegal charcoal production, and expansion of small-scale farming in the protected mountain forest.

Participatory art workshops

Participatory art was used as a means to engage local farmers, fishermen, and pastoralists in the co-production of knowledge about socio-environmental change. The narratives from the focus group discussions and interviews formed the foundation for two participatory art workshops, one held in the area close to the rice farm of Kilombero Plantations Ltd., and one close to the teak plantations of Kilombero Valley Teak Company. The village, natural resources, and natural resource use were depicted as paintings, representing the past, present and future (Figure 10). A Tanzanian artist, Joseph Mwalyombo, instructed the participants how to paint the Tanzanian art-style tinga-tinga, which often represents people and animals in different environments.

Figure 10. Participatory art workshop. A) Sketching the main features and locations of rivers, mountains, settlements, farmland. B) Instructing participants how to mix colors, make broad stroaks with the brush, and build the background of the painting. C) Adding details to the painting, a participant fills in color between the lines of what will visualize a modern house with concrete walls and tin roof. D) One of the participants add more layers to the painting, here adding tin and grass roofs to the houses.

Paper IV: Remote sensing and socio-environmental change

As there is a lack of historical quantitative data and maps of the Kilombero Valley, it is difficult to evaluate how experienced socio-environmental changes relate to actual changes in the environment. The lack of baseline data made me curious to explore if

local perceptions of change could be observed and analysed from space with remote sensing. I also wanted to make a land cover change detection based on local concerns and land cover categories developed in consultancy with people on the ground (i.e. forests, shrubland, grassland, wetland, farmland, and water).

Remote sensing and land cover classification

Satellite data were used to quantify land use and land cover changes for one of the fieldwork sites in Kilombero Valley, surrounding the area where the agribusiness KPL grow rice. Satellite images were collected from Landsat (Table 2) and analysed for two different years: 2004 and 2014, which represent the periods just before land was acquired, and the state of the area during approximate time of fieldwork (Figure 11).

Table 2. Information about the satellite images used in dissertation work.

Product ID	Acquisition date	Satellite	Instrument
LC81680662014194LGN00	2014-07-13	LANDSAT 8	OLI TIRS
LT51680662004199JSA00	2004-07-17	LANDSAT 5	TM

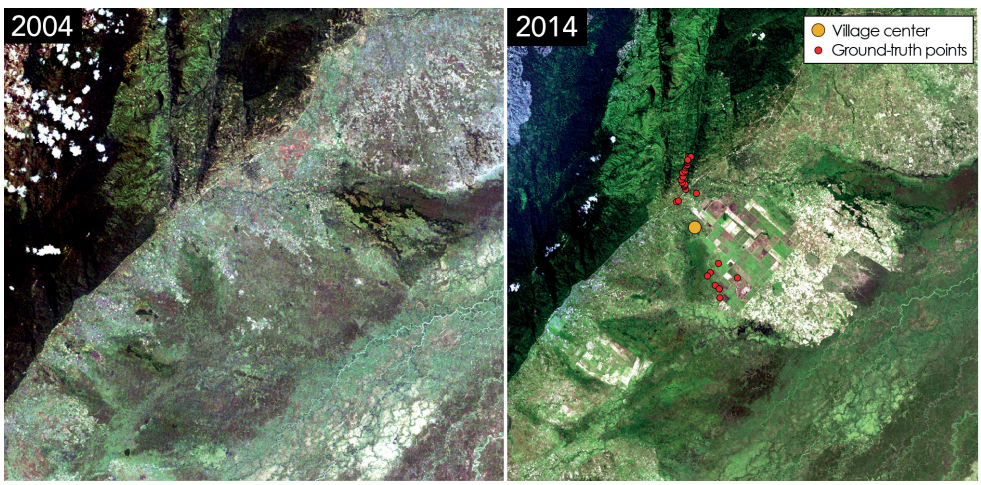

Figure 11. Satellite images used for supervised classification. The two time-slices (2004 and 2014) represent the time before the arrival of the agribussiness (Kilombero Plantations Limited), and the current state during fieldwork. The yellow dot represents where the participatory art workshop was held for Paper III, and the red dots show areas where the (36) ground-truth points were collected for classifying past and current land cover.

Landsat is of great value for land change detection since it is the longest continuously running program for capturing satellite images of the Earth's surface (Landsat 2018). The first satellite was launched in 1972, and since then eight different satellites with upgraded instruments have captured millions of satellite images. All images are freely available and can be viewed and downloaded through the U.S. Geological Survey

(USGS) "earth explorer" website. Each image is 185x185 km in spatial extent, and has a temporal resolution of 16 days. Landsat 8 is the most recent satellite in the Landsat program, and each image contains multiple spectral bands of non-visible and visible wavelengths ranging from 15 to 100 meters spatial resolution (Table 3).

Table 3. The 11 bands of Landsat 8 and their spectral and spatial resolution. The bands that are also recorded by Landsat 5 are highlighted in grey.

Band	Description	Wavelength (micrometers)	Resolution (meters)	Bands used in analysis in Paper IV
Band 1	Coastal Aerosol	0.43-0.45	30	
Band 2	Blue	0.45-0.51	30	x
Band 3	Green	0.53-0.59	30	x
Band 4	Red	0.64-0.67	30	x
Band 5	Near Infrared (NIR)	0.85-0.88	30	x
Band 6	SWIR 1	1.57-1.65	30	x
Band 7	SWIR 2	2.11-2.29	30	x
Band 8	Panchromatic	0.50-0.68	15	
Band 9	Cirrus	1.36-1.38	30	
Band 10	Thermal Infrared (TIRS) 1	10.60-11.19	100	
Band 11	Thermal Infrared (TIRS) 2	11.50-12.51	100	

In *Paper IV*, two satellite images were used to perform supervised land cover classifications of the study area for year 2004 and 2014, using six land cover categories established by participants during fieldwork (i.e. wetland, farmland, forest, grassland, water, shrubland).

A supervised classification means that the researcher specifies training sites (i.e. polygons that contain spectral signatures that represent a certain land cover class) in order to classify the whole image (Humboldt State University 2018; McCoy 2005). Ground truth points are normally collected in field in order to define training sites, but in this case the ground truth points were limited to 36 geo-referenced locations (locating areas that have changed, and remained the same, between 2004 and 2014), which is not sufficient for classification and validation. There are also no ground truth points for year 2004 since no fieldwork was done at that time. Therefore, training sites and 60 validation points for each class were identified in satellite images (Bagan et al. 2010), mainly from high-resolution imagery available through Google Earth (from year 2012 and 2013), as well as the Landsat images themselves by combining different spectral bands to distinguish between land cover classes. Both false-colour composites and vegetation indices were used to observe and distinguish different land cover classes in the Landsat images.

The combination of different spectral bands has facilitated global change research, particularly within the fields of agriculture, geology, forestry, and mapping (Landsat 2018). For example by analysing vegetation "greenness" by combining non-visible infrared bands, with visible green, and blue bands, which creates an image that for example enhances the presence of vegetation in different shades of red (Jackson et al.

2004). This type of false-colour composite was particularly valuable for delineating forests, shrubland, and farmland areas.

Another benefit of pixel-based spectral information is the possibility to create different indices for identifying and separating different land cover types. The Normalized Difference Vegetation Index (NDVI) is the difference between near-infrared (850 – 880 nm) and red (640 – 670 nm) surface reflectance divided by their sum, and captures the spectral signature of live green vegetation (Rouse et al. 1973). Normalized Difference Water Index (NDWI) is the difference between green (530 – 590 nm) and near infrared (850 – 880 nm) surface reflectance divided by their sum, and captures plant water content. NDVI and NDWI were used to distinguish between different types of vegetation and land cover classes, for example farmland and wetland pixels.

The land cover classification was performed in the open source software R, using the *RandomForest* (Liaw & Wiener 2002) and *Caret* (Kuhn 2008) packages, and further analysed in QGIS, an open source software for geographic information systems. The supervised classifications for the two time-slices were then compared to each other in a cross-tabulation in order investigate how the different land covers have changed over time. Thereafter, the quantified land cover changes were compared with perceptions of socio-environmental change described in *Paper III*.

Results and discussion

This chapter summarizes some of the main insights about socio-environmental drivers, impacts, and feedbacks in the context of large-scale land acquisitions that were obtained at the different scales of analysis. An initial overview is presented in Table 4, followed by summaries of, and discussions about, land system change for each paper. The final section adds some perspectives and reflections on scale and space, and different modes of knowledge production.

Table 4. Identified drivers, impacts, and feedbacks of socio-environmental change for the four papers of this dissertation.

Paper	Drivers	Impacts	Feedbacks
I	Country-to-country relations/connections (in this context investors are represented by their country of origin).	1) Countries susceptible to rapid and vast land cover changes. 2) Countries where there is a shift in land ownership. 3) The land acquisition network is vulnerable to shocks, since a few key actors act as hubs for either importing or exporting land.	1) The global trade of land might lead to conflicts over land and water resources. 2) Abrupt social (e.g. political, economic) or environmental (e.g. droughts, floods) changes in these key nodes would affect many other nodes in the network.
II	Large-scale land acquisitions in operation in Africa (mainly for forestry and biofuel purposes).	1) Crops grown on acquired land require more water than traditional crops. 2) Use of irrigation systems increase the use of water from blue water sources (e.g. rivers, dams, groundwater). 2) Crop choice has bigger incluence over total water use than the water-use efficiency of different irrigation systems.	1) High levels of blue water use might lead to conflicts over water. 3) It is not possible to analyse how changes in water use affect people on the ground at this scale and level of analysis.
III	1) Large-scale land acquisitions for rice, and teak production (KPL and KVTC). 2) Population growth. 3) Conservation areas.	1) Large-scale land acquisition expands on small-scale farmland and wetland. In turn, small-scale farmland shifts to, and expands over protected parts of the wetland and mountain forest. 2) Large-scale land acquisition expands over highland forests, replacing natural forests with teak. Also here, small-scale farming expanded towards the protected wetland due to population growth.	1) Deforestation - drying out of rivers - decrease in fish stocks. 2) Use of fertilization and pesticides - lower water quality - negative health impacts. 3) lower land availability - intensified agriculture - lower soil fertility - lower agricultural yields. 4) expansion of small-scale farming + influx of pastoraist groups - negative effects on wildlife and biodiversity.
IV	1) Large-scale land acquisition for rice production (KPL). 2) Population growth.	1) Alignment in exerienced and quantified change regarding farmland expansion to the wetland. 2) Divergence between local perceptions of deforestation and quantified changes in forest cover.	1) It is not possible to analyse socio-environmental feedacks with the remote sensing approach in isolation, feedbacks are obtained from Paper III.

Paper I: Land acquisitions as a telecoupled system

Paper I aimed to investigate the geographical pattern and distant relationships between countries that engage in large-scale land acquisitions, and analyse land acquisitions as a telecoupled system. We found that 126 countries participate in the land trade network, but only a few of these account for the majority of land acquisitions (i.e. they have a high degree centrality) and play a disproportionately central role in providing network connectivity; the main importers of land are China, the US, and the UK, and the main exporters of land are Ethiopia, Philippines, and Madagascar.

Three countries, China, the US, and the UK, have high normalized betweenness centrality values, with the shortest trading path between any two countries traversing one of these countries over a third of the time. These three countries are therefore particularly important for providing network connectivity, as these hubs act as a bridge between many other countries in the network. This uneven network structure is prone to propagate risks, as many other countries become vulnerable to political, economic, and environmental changes in these key countries (Barabasi 2002). The local clustering coefficient was used to identify land trade submarkets in the global land-acquisition network, representing countries with tight land trading relationships. High clustering could provide a buffer against global geopolitical and environmental disturbances since countries with high clustering coefficients might be less dependent on global land trade. Overall, the land trade network displayed a low incidence of clustering, except a few distinct submarkets like Finland, Sudan and China, or Swaziland, the UK, and South Africa. The clustering coefficient could be explored further in order to analyse if land-trade relations are shaped by pre-established historical, political, and colonial ties. The average nearest neighbour degree indicates that the land trade network is slightly dissassortative, meaning that countries with a low number of export partners tend to trade land with countries with a high number of import partners, and vice versa. For example, Cameroon exports land to six countries, which in turn import land from 17.8 countries on average. The dissassortative pattern of the global network implies that low-income countries tend to have many export partnerships with high-income countries, but import little land themselves.

Network theory made it possible to understand land acquisitions as a telecoupled system (Friis et al. 2015), where distant places are connected and affect each other in terms of resource use, risks, and vulnerability. Research at the country-level of analysis can indicate how the structure of the network is prone to propagate socio-environmental risks and vulnerability for both importers and exporters of land. For example if there are crop failures due to extreme weather events like droughts and floods, countries that acquire land are likely to also be affected by these distant

environmental changes. This is highly relevant since droughts and floods are expected to occur more often in the future due to effects on temperature and precipitation from climate change (IPCC 2014; Kotir 2011). There are also risks that countries where land is acquired will end up with unsatisfactory infrastructure development and job opportunities if investors stop production due to global market changes, which has partly been seen in the global biofuel market (Ahmed et al. 2017).

Paper II: Land acquisitions and water conflicts

Paper II was developed in order to investigate risks of water scarcity and conflicts in areas of large-scale land acquisitions in Africa. The continental-scale analysis made it possible to add details about water requirements on a sub-national level, while still being able to map large-scale patterns of hydrologic change (Figure 12). *Paper II* reveals that crops grown on acquired land require more water than traditional food crops, and that blue water demand mainly depends on crop type, and irrigation efficiency (as opposed to climate, which determines green water demand). The type of crops grown on acquired land is therefore a dominant driver of change in water use. The ratio between blue and green water demand for each land acquisition in production highlights 'blue water hotspots', which we define as areas where more than half of the total water demand needs to be extracted from blue water sources to obtain maximum yields. We found that 29-53 out of 134 land acquisitions are blue water hotspots, depending on the irrigation efficiency of the land acquisition. Even with the most water efficient irrigation system, 18% of the land acquisitions would still be blue water hotspots and considered as high-risk areas for water conflicts.

Linking back to the concept of telecoupling, the hotspot areas can be used to analyse how sub-national water budgets change due to distant demands of agricultural products. The hotspots can also be used to identify areas of socio-environmental change, where people and the environment might face severe water-related challenges due to increased pressures on water resources.

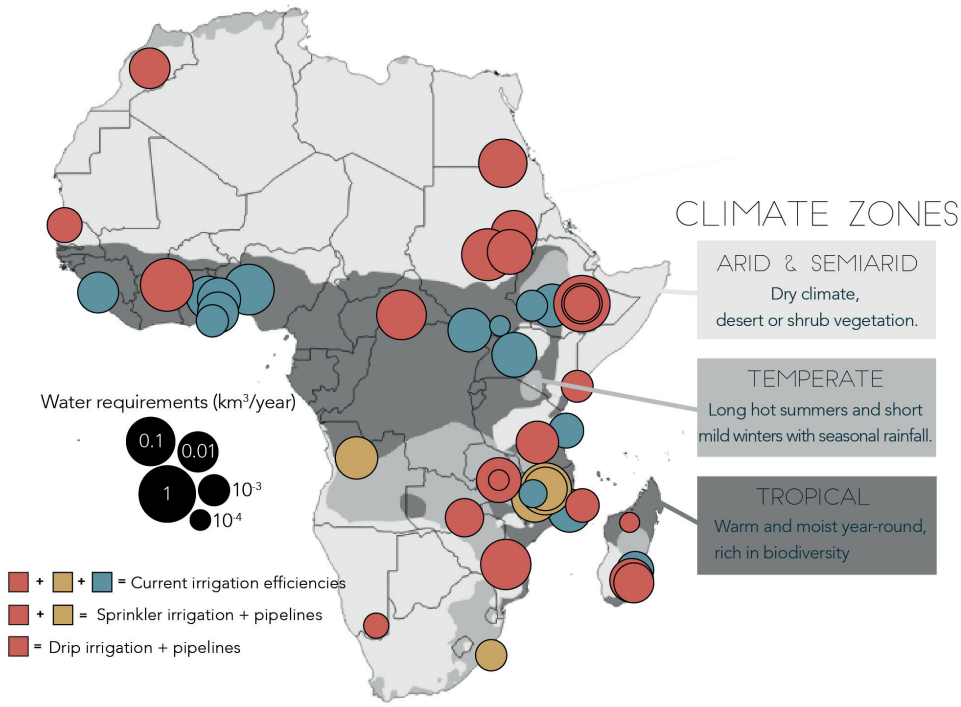

Figure 12. Blue water hotspots for land acquisitions (in operation) in Africa. The map shows land acquisitions where more than half of the water needs to be extracted from blue water sources in order to obtain maximum yields. The blue water extractions depend on the efficiency of the irrigation system, here represented by the color of the dots (pink, yellow, blue). The size of the dots represents the total water requirement of crops grown. The map shows that blue water hotspots appear in all types of climate zones, which indicates that the crop type is the dominant driver of water use, since blue water hotspots also appear in water rich areas.

Paper III: Socio-environmental drivers, impacts, and feedbacks

Paper III is a concrete example of how effects of the telecoupled land acquisition system are experienced on the ground, as well as how land system change contributes to changes at other nearby sites, using Kilombero Valley in Tanzania as the study site. As such, it is the only paper in this dissertation that manages to fully capture the complex interaction between socio-environmental drivers, impacts, and feedbacks. The dominant narratives of socio-environmental change point to large-scale transformation and expansion of farmland (both from the establishments of foreign agribusinesses, as well as expansion of small-scale farms) towards the protected wetland and forest. The rapid farmland expansion is partly due to that the two agribusinesses have not offered any substantial options for employment, and local

farmers remain in poverty and need to continue small-scale farming on more marginal land. Other observed environmental changes relate to rivers that dry out completely during dry seasons, as opposed to in the past when there was an annual flow. Lower water levels (explained as a consequence of irrigation and planting of water demanding trees like teak), coupled with overfishing has led to a reduced amount of fish in the rivers, and more difficult conditions for fishermen. Participants also report that the wildlife, in particular elephants, has disappeared from the area. They trace this change to disturbances in the landscape caused by large-scale farms, as well as rapid increase of pastoralists and cattle to the area.

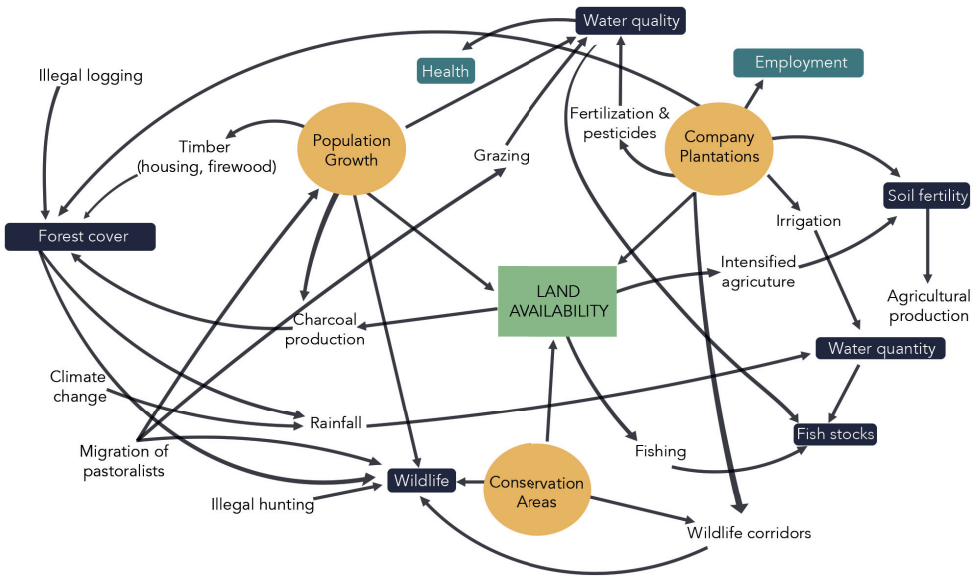

Figure 13. Causal loop diagram that represents the main drivers, impacts, and feedbacks of socio-environmental change in Kilombero Valley.

Key findings indicate that there are multiple drivers of socio-environmental change in Kilombero Valley that are internal (e.g. population growth) and external (e.g. large-scale land acquisitions, conservation areas). To fully understand socio-environmental impacts of land use and land cover change, researchers cannot only look at land acquisitions in isolation, but also need to include effects from population growth, migration patterns, initiatives for nature conservation, and infrastructure development projects, since they all play a big role in land system change, and natural resource use.

The participatory painting process added value to the research process as a whole, as it created a natural platform to stay in the fieldwork area for a longer time (8 weeks in total) and get familiar with people and the environment, as well as to give the participants a sense of ownership over their contribution to research. This is

important since many researchers make very short field visits (e.g. a few hours, or a day), extract information, and rarely report back to the community how their information was used. In this case, I re-visited the villages in 2016 in order to disseminate copies of the paintings, to share the article, and to invite village leaders to participate in an exhibition of the paintings at the National Museum and House of Culture in Dar-Es Salaam.

Paper IV: Mixed approaches to study socio-environmental change

Paper IV shows that qualitative and quantitative research approaches can be combined in order to explore drivers, impacts, and feedbacks of socio-environmental change. Fusing two different research approaches can reveal aligning and diverging perspectives on environmental change. For example, alignment was found in perceptions and mapping of large-scale and small-scale farmland expansion towards the wetland. There was however divergence in the outcomes about farmland expansion to the mountain forest area, where local perceptions of rapid deforestation could not be corroborated with remote sensing techniques. Similar mismatches have been identified by other researchers (Fairhead & Leach 1995; Wainwright et al. 2013), who discuss that there are persistent discourses in e.g. science, education, and policy making, that claim that indigenous land use practices (e.g. slash-and-burn) create environmental crises like deforestation (King 2014). Fairhead and Leach (1995) however claim that these discourses are rooted in a misrepresentation of the actual drivers of socio-environmental change, which in turn have led to flawed development policies in the Global South. The researchers therefore stress the need for multiple methods for a deeper understanding of drivers, impacts, and feedbacks of socio-environmental change.

By adding remote sensing and land cover classification to the local perceptions of change, it is possible to understand convergence and divergence of results, and discuss strengths and limitations of what can be known by using different research approaches. In the case of Kilombero Valley, occurrence of rapid deforestation might not have been identified if only using remote sensing analysis, due to difficulties to see understory clearings, failure to classify forests and shrubland correctly, or mismatches in scale of analysis and interpretation. However, local perceptions of rapid deforestation might also be based on skewed memories of the past, persisting discourses of destructive indigenous land use practices and deforestation (as mentioned in Fairhead and Leach (1995)). This is something that needs to be investigated further in order to better support decision-making in the region. In the two proceeding sections, I add some perspectives on challenges that emerged from

using different scales of analysis, and highlight the importance to reflect on how social (e.g. economic and political) processes can construct and manipulate knowledge about space, nature, and scales when wanting to understand and describe socio-environmental change.

Reflections on scale and space

Scale is important for observing and explaining socio-environmental change, and is deeply embedded in land system science. According to Verburg et al. (2015) "Land system changes are the direct result of human decision making at multiple scales ranging from local land owners decisions to national scale land use planning and global trade agreements" (p. 4). The spatial scale of analysis, and choice of actors of a system, determines what type of socio-economic or environmental processes that can be identified. It is therefore important to acknowledge that scales construct certain kinds of relationships and knowledge (Manson 2008). In this dissertation, I use scale as different analytical entry points, and reflect on *what can be known* at the various scales of analysis, considering trade-offs between realism, precision, and generality (Chowdhury 2013; Levins 1966). Overall, there is an inverted relationship between generality and precision (e.g. global scale analysis tend to be general, local scales tend to be detailed and nuanced), which has motivated me to continuously shift scales of analysis. The limitations of each research approach opened up for new research questions, which led to the development of the papers in this dissertation in their specific order, which is presented in the following paragraph.

Paper I is global in its scope, analysing large-scale land acquisitions at the country-level. Aggregating individual land deals to the country level, however, limits the level of detail of system components, as it masks information about investors, crops planted, purpose of production, and how much land is in production. Nonetheless, the relational and geographical pattern can point to actors and areas of interest, where it is important to zoom in and add more layers of complexity (e.g. groups of countries that have strong ties, or geographical regions with many land acquisitions). By scaling down the analysis from the global to continental scale in *Paper II*, it was possible to add layers of detail to the data analysis of site-specific blue and green water requirements, while still being able to map continental-scale changes on a sub-national level for each individual deal. This study did not include any demographic data (e.g. population, income, livelihood) when defining blue water hotspots, which renders the high-risk areas of conflict somewhat hypothetical. Understanding actual experiences of socio-environmental change in relation to water use would provide an important foundation for understanding what kind of water-related challenges that are important for people in place (e.g. is it all about quantity, or is quality and accessibility of bigger importance?), which requires ground-based fieldwork. The need

to explore local experiences of socio-environmental change led to the development of *Paper III*, which provides a detailed understanding of local experiences, observations, and opinions. Fieldwork allowed for examining societal and environmental complexities and interactions with people in place, for example by identifying direct, and indirect socio-environmental impacts and feedbacks caused by local and non-local drivers, like farmland expansion of agribusinesses, as well as shifts, and expansions of farmland by small-scale farmers. *Paper IV* also operates at the local scale, and adds a quantitative estimate of change in land cover categories established by people in field. This paper is however more focussed on knowledge production (which will be discussed in the next section). Even though many land acquisition areas seem to experience similar socio-environmental effects (D'Odorico et al. 2017), the local impacts and feedbacks are site-specific and cannot be directly generalized to the continental or global scale. It is however possible to identify general socio-environmental trends by drawing on similarities between multiple case studies.

The following paragraphs add some reflections on specific challenges that emerged from using spatial scales as an entry point to observe and analyse large-scale land acquisitions. A first challenge was to find an appropriate level of representation for the actors that have increasing influence on land systems through large-scale land acquisitions, as investors range from individuals, multi-national corporations, banks, and governments (and therefore have a wide range in spatial representation). Some of these actors currently have more economic power than nations, as the 10 biggest corporations (topped by Walmart) are wealthier than all countries in the world combined (Global Justice Now 2016). As these somewhat spatially untied actors have direct and indirect impacts on specific spaces and places, it is increasingly important to address for how these powerful economic actors, their activities, and accompanied flows across sites are embedded within land system change, as how this embeddedness challenges the notion of space and spatial relationships (Munroe et al. 2014). In *Paper I*, the challenge was to represent two different types of actors/entities of the land acquisition system: one that represent spatially wide-ranging multinational firms and businesses (although the investors have a country, or multiple countries, of origin), and one that represents the geographical locations where land is acquired and the direct impacts of land system change are experienced. The network approach however made it possible to de-construct and re-construct the notion of space from spatial to relational, which is particularly useful when a given object is simultaneously local, regional, or global in terms of its connections to other phenomena (Bergmann & O'Sullivan 2018; Manson 2008). The critique of space also questions one of the core laws in geography, that "everything is related to everything else, but near things are more related than distant things" (Tobler 1970). The shift from geographical space to relational space highlights that relationships between countries are likely to be an effect of historical, colonial, linguistic, and political ties (though this was difficult to demonstrate with the clustering coefficient), rather than geographical space, which

has also been highlighted by Schoeman (2011). For example, Swedish investment in Tanzania are likely to be related to existing relationships built on a long history of aid and cooperation (McGillivray et al. 2016). Likewise, Belgian investments in the Democratic Republic of Congo are likely to relate to linguistic and colonial ties. This implies that classical geographical definitions of spatial extent, resolution, and Tobler's first law, may not be as important for understanding drivers, impacts and feedbacks of large-scale land acquisitions as the socio-economic relationships between actors and places. Similar discussions about reformulating proximities in Cartesian space to similarities in relational space have been outlined in (Bergmann & O'Sullivan 2018).

Another persistent challenge when writing this dissertation has been to distinguish between drivers, impacts and feedbacks of socio-environmental change. For example when developing the causal loop diagram in *Paper III* (Figure 13), it was difficult to distinguish what is a driver and what is an impact, since it depends on the scale of analytical entry. This was particularly the case for describing processes of deforestation, which is directly driven by people engaged in small-scale farming (who expand their farmland to forested areas due to increasing pressures on land), and charcoal production (which is an illegal activity, yet has a high demand and big market in Tanzania). The local drivers of deforestation are however an outcome (or impact) of larger global economic structures and actions that manifest themselves as large-scale land leases to powerful foreign agribusinesses, which in turn pushes small-scale farmers (economically less powerful people) to protected land areas due to the lack of alternative livelihoods. So, instead of thinking about the local as site specific, and the global as a separate site of generality, it is important to acknowledge that the global is embedded in the local (Munroe et al. 2014), and that local drivers of change are an outcome of a globally unjust economic system.

Reflections on knowledge production

In this section, I want to add some perspectives on knowledge-production in the context of large-scale land acquisitions, and how knowledge can be co-produced in order to integrate science and society to facilitate the development of sustainable land use practices. Participation of people outside of academia can help the researcher to develop research questions that are of actual concern for society, which in turn is important for bridging science and society for sustainable policy development and future decision-making.

The four papers of this dissertation were developed through an iterative process of gaining knowledge in fieldwork, while also exploring and analysing large datasets. The constant engagement with qualitative and quantitative research approaches led to

reflections about how knowledge is produced, using a top-down research approach (i.e. developing the research based on a pre-determined interest in a specific area of focus), as opposed to a bottom-up approach (i.e. developing the research based on local knowledge and concerns). For example, the local concerns about farmland expansion to the wetland and forest that were outlined in *Paper III* became a key focus of analysis *Paper IV*. Just as the concepts of scales and space can be discussed as social constructs (Manson 2008), so can the production of knowledge (Haraway 1989), meaning that all knowledge and understanding is subjective and situated, and connected to where, how, and by whom it is produced. All research methods therefore offer different opportunities for interpretation, understanding, and representation of 'reality' (Nightingale 2016). By applying different research approaches it is possible to provide different pieces of the puzzle and help build a clearer picture of drivers, impacts, and feedbacks of socio-environmental change.

Paper II is a good example of how a top-down approach can be useful for focussing on a specific socio-environmental challenge (i.e. increased blue water extractions and conflicts) but fails to link the observed changes to actual water-related challenges on the ground. Actual challenges might not only be linked to changes in water quantity, but rather to issues of water quality and accessibility, which can only be known through bottom-up approaches and engagement with people in the field. Even so, actual challenges on the ground might not even be related to water. The following example from Egypt highlights the need for local knowledge when discussing water conflicts and blue water hotspots (see Figure 14). In the middle of the desert, an investor is growing wheat, alfalfa, and potato with centre pivot irrigation systems (circular fields in the middle image). Satellite images show that water is provided from Lake Nasser, which is connected to the Nile (image to the right). The satellite image to the left in Figure 14 shows that no people lived in this area before, so it is not likely that the land acquisition has produced any local conflicts over water in this case. Blue water extractions might however impact people and ecosystems downstream, which highlight the need to observe and evaluate real socio-environmental and hydrological changes, impacts, and feedbacks at local to regional scales.

In the case of Kilombero Valley, decisions by non-local actors affect the local population who have little power to control the changes in the environment. Participatory research is a bottom-up approach that aims to co-produce knowledge with non-academic actors, e.g. marginalized groups, in order to develop research based on local concerns (Fraser et al. 2006). This is why I chose to include local small-scale farmers, fishermen, and pastoralists in the knowledge production in *Paper III*, since people with these livelihoods are directly affected by the socio-environmental changes in the region, yet excluded from the debates and decision-making about large-scale land acquisitions. I was interested to understand if, and how, people in the water-rich wetland areas of Kilombero Valley experience water-related challenges or conflicts (as suggested in *Paper II*), and if water really is the most

important challenge according to the participants. In this way, the research focus was not entirely pre-determined before going to the field, and knowledge could be co-produced with people in place. However, conflicting ideas and interests between local and non-local stakeholders make it difficult to navigate between the different actors in place, and it is therefore difficult to find the truth about what socio-environmental changes that are taking place. The confusion caused by conflicting ideas and interests was one of the reasons for developing *Paper IV*, partly in order to compare local perceptions with changes that can be observed in satellite images, but also to complement socio-environmental narratives from the ground with quantitative estimates of change, and maps of where the land cover changes occur. Important for this analysis was that land cover categories should be based on local categorizations of land cover classes, and bridge local concerns to a scientific understanding of change. Even though local people were not participating in the remote sensing analysis, the co-production of knowledge lies in that the analysis was developed from, and based on, local experiences and observations of change.

Figure 14. Example of a fully irrigated large-scale land acquisition. Images from Google Earth shows the previous land cover (desert) in 2007 to the left, and the current land use in the middle with wheat, alfalfa, potato irrigated with center pivot systems. Zooming out shows the digging of canals for irrigation purposes in the image to the right.

Conclusions

To sum up, I have investigated four key challenges that relate to contemporary trends in global land use, accounting for distal connections of land system change in the context of large-scale land acquisitions. Findings related to each challenge are summarised in the box below.

Challenge 1: Global shift in land ownership: what are the relationships between distant places?

Objective 1: *To map countries involved in the virtual trade of land through large-scale land acquisitions, and to describe their connectivity (global level).*

Findings: Land acquisitions are a telecoupled system where distal actors cause land system change elsewhere.

- 126 countries participate in the land trade network.
- The network is highly skewed, and a few countries dominate land trade. Main land 'importers' from the UK, USA, China, and land 'exporters' are Ethiopia, Madagascar, Philippines.
- The land acquisition network is prone to propagate crisis as changes in a few key countries can influence many other countries in the network.

Challenge 2: Risks of water conflict: how do land acquisitions affect blue and green water sources in Africa?

Objective 2: *To calculate water requirements of land acquisitions currently in production in Africa, and analyse how water demand has changed across a range of irrigation scenarios (continental level).*

Findings: Crops on acquired land require more water than traditional crops, and distant actors might contribute to water conflicts.

- Most crops grown on acquired land are not edible, but mainly for forestry and biofuel purposes.
- Water requirements primarily depend on crop type, but also on irrigation efficiency.
- 29-53 of 134 land deals are blue water hotspots, meaning that >50% water are from blue water sources, and are at high risk for water conflicts.

Challenge 3: Local perceptions of socio-environmental change: what socio-environmental changes and challenges do local farmers, fishermen, and pastoralists experience?

Objective 3: *To document perceptions of socio-environmental change, and to visualize the narratives as paintings (local level).*

Findings: Participants describe socio-environmental changes and challenges as complex interactions between cross-scale drivers, impacts, and feedbacks.

- Not only land acquisitions are causing socio-environmental change, but also population growth, and conservation areas contribute to increased pressures on land and water resources.
- Both case-study areas describe farmland explansion to the (protected) wetland area as a coupled effect of large-scale land acquisitions and population growth (more people on less land).

Challenge 4: Different ways of understanding socio-environmental change: How do local perceptions compare to quantifications of land cover change?

Objective 4: *To quantify land cover categories established in field with remote sensing, and compare with local perceptions of change (local level).*

Findings: The use of mixed methods point to aligning and diverging environmental changes.

- Farmland expansion to the wetland area can be identified (though with low accuracy) in the land cover classification, but the narratives of deforestation can not be strengthened by the remote sensing analysis.
- Mixing participatory methods and land cover classification points to aligning and diverging patterns of environmental change, which highlights the need for co-production of knowledge and use of mixed methods for future decision-making.

The *main empirical contributions* of this dissertation relate to the growing current competition for land and water resources, and how distal land connections cause socio-environmental impacts, and feedbacks elsewhere. They respond to key research gaps in land system science, which have been outlined by several authors in Seto and Reenberg (2014). *Firstly*, network analysis at the global scale made it possible to analyse land acquisitions as a telecoupled system, which is useful for identifying key players of the system, and how vulnerability and risk can spread between different countries. *Secondly*, hydrological modelling at the continental scale made it possible to obtain a refined understanding of hydrological change due to land acquisitions, a knowledge gap identified by numerous researchers who discuss large-scale land acquisitions as water grabs (Dell'Angelo et al. 2018; Dell'Angelo et al. 2017; Mehta et al. 2012; Woodhouse & Ganho 2011; Woodhouse 2012). My contribution consists in calculating and mapping blue and green water requirements of land acquisitions based on site-specific crops, climate, and irrigation alternatives (which improves previous estimates by Rulli et al. (2013)). These patterns can be used to identify areas that are likely to experience challenges and conflicts over water quantity due to high levels of blue water use. *Thirdly*, participatory research made it possible to understand local experiences of distal land connections, as well as future aspirations for change, which is crucial for developing pathways for a more sustainable future.

The *main methodological contributions* of this dissertation relate to developing participatory art as a way to co-produce knowledge, and thereby link local concerns to the scientific agenda, which is essential for facilitating sustainable development (Clark & Dickson 2003; Jerneck et al. 2011; Kates et al. 2001; Pohl et al. 2010; Verburg et al. 2013). The mixed-methods approach provided insights about knowledge production regarding socio-environmental change, in particular concerning complex feedbacks between farmland expansion, and the degradation of wetlands and forests. Aligning and diverging results from using bottom-up participatory approaches, and top-down land change detection methods, highlight the need to find contrasting and complementary ways to represent cross-scale feedbacks between changes related to population growth, conservation initiatives, and rapid land system changes in the context of large-scale land acquisitions.

A fisherman that I interviewed in Kilombero Valley told me *"I doubt that there will be any benefits in the future, regarding the current trends and how decisions are made."* This quote can be used to summarise my own conclusion and opinion about large-scale land acquisitions. With this dissertation, I add my voice to the growing body of scientific literature that highlights harmful socio-environmental effects of large-scale land acquisitions, including water stress and conflicts over water resources (Chiarelli et al. 2016; Franco et al. 2013), and complex feedbacks that accelerate land degradation, biodiversity loss, deforestation, and other land system changes (Bluwstein et al. 2018). Further research is needed to account for actual water changes caused by land acquisitions, and to better connect those hydrological changes to

demographic data and lived experiences. Possible refinements relate to water management on acquired land, and other site-specific parameters, e.g. what irrigation systems are used? How was the land used before being acquired? What are the local socio-hydrological changes? There is also a need to design sustainable solutions, based on local needs and aspirations. Such solutions should be developed in collaboration with affected communities, and could for example be based on scenario building.

Existing recommendations to stakeholders are often within the socio-economic realm; for example the Food and Agriculture Organization (FAO) recommends that "land contracts must be structured so as to maximise the investment's contribution to sustainable development" (Cotula 2009). Linking back to contemporary and future challenges of population growth, unequal distribution of consumption and production, and requirements to meet the Global Sustainable Development Goals, I see limited scope for land acquisitions to benefit all, facilitate sustainable development, or protect the environment. With the four papers of this thesis, I would therefore like to add a few socio-environmental recommendations for stakeholders.

Since there are no signs that the trend of global land acquisitions are abating, I suggest that crops grown on acquired land should be edible, and primarily produced to satisfy local or domestic food demands, in particular if land is acquired in countries with high food insecurity. I also suggest that crops planted should be suitable for that local climate, and low in water requirements in order to avoid conflicts over water quantity. If agribusinesses use irrigation, the irrigation systems should be of highest water use efficiency, like drip irrigation with pipelines as opposed to sprinkler irrigation. Consequently, if land acquisitions are to be considered as investments, they must be at the forefront of exploring more sustainable pathways of farming, by accounting for local needs, improving environmental conditions, and applying the latest scientific knowledge, no matter the economic cost. For example through implementing agro-ecological farming and organic agriculture that is low in imported synthetic input and contribute to restoring soils rather than degrading them (Liu et al. 2013b). From the socio-economic point of view, I suggest that local people should have the opportunity for education and long-term employment contracts at the farms, as opposed to temporary employment that seems to have little effect on bringing people out of poverty (Oya 2013). There is also scope for designing the investments differently. For example, farmers in Kilombero Valley suggest that they can do the farming, and that the agribusiness can provide storage for the harvest, packaging facilities, and connection to markets. This is similar to already existing outgrower schemes, which are often developed in parallel with the large-scale farms. These arrangements, however, seem to generate more benefits for already land-rich farmers rather than the land-poor (Herrmann 2017). A final reflection, in line with Liu et al. (2013b), is that no matter what arrangement, it is important to combine the strengths of the investor (capital and technology) with those of local farmers (labour, traditional know-how and knowledge of the local conditions).

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