The Impacts of Biofuel Expansion on the Resilience of Social-Ecological Systems in Ethiopia

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Abstract

This thesis investigates biofuel expansion as a disturbance to the resilience of social-ecological systems. Examining this issue through a resilience framework illustrates the dynamics of such systems, identifying potential trade-offs and regime shifts. Additionally, this research highlights the differentiated impacts for actors across multiple scales, allowing power relations to be taken into account – the lack of which is a common criticism of resilience studies.

The thesis presents a systems analysis of sugarcane-ethanol expansion in Ethiopia at the current and planned levels of production, incorporating both the production and consumption sub-systems. To create an integrated systems analysis multiple methods were utilised between 2010 and 2012 to collect primary data – household surveys and interviews in multiple localities and interviews with key stakeholders, supplemented with documentary evidence. The production sub-system analysis incorporates food system impacts at the household scale and ecological impacts at the regional scale, whilst the consumption sub-system analysis investigates the impacts of ethanol adoption as a household fuel. The findings of these analyses are then synthesised in a resilience assessment at the national scale.

The results show that current levels of sugarcane and ethanol production have not surpassed the majority of potential critical thresholds that would induce regime shifts. Therefore, most of the sub-systems under study, and actors within them, are resilient to the perturbation of biofuel expansion to date. However, a detrimental regime shift is underway for pastoralists being relocated for sugarcane expansion. The planned expansion will replicate this regime shift across a much larger population. In addition, the larger scale of operation will more severely influence the ecological sub-system. The analysis of multiple nested scales using a resilience model demonstrates the need to examine all scales to highlight the winners and losers, as only examining one scale conceals the dynamic nature of interactions.

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1. Introduction

Biofuels have been an emerging issue since the turn of the century, with significant implications for social-ecological systems worldwide, and promoted as a 'silver bullet' with multiple benefits – the ability to mitigate greenhouse gas (GHG) emissions, a source of energy security, and the ability to create rural development opportunities (Bauen 2006; Demirbas 2009; Tilman et al. 2009; Ewing & Msangi 2009; Farrell et al. 2006; Farrell 2011). Their adoption was rapid, supported by the relatively minor adjustments required to existing engine technology and fuelling infrastructure (REN21 2013; Rajagopal et al. 2007). In essence, biofuels were attractive as they allow the transport sector to continue 'business as usual' and not require massive transformation in the face of climate change and decreasing fossil fuel availability.

The anticipation of such benefits led many governments to establish policy frameworks to promote the production and consumption of biofuels. Whilst initially in developed countries, who were creating mandates for use of liquid biofuels as a reaction to rising fossil fuel prices and increasing commitments to decrease GHG emissions, the trend was rapidly followed by governments in developing countries, where the rural development benefits such as job creation, poverty reduction and energy access were understandably attractive (REN21 2013; Ewing & Msangi 2009; Gallagher et al. 2008; Bekunda et al. 2009). Biofuels therefore became a powerful new driver of agricultural and energy systems across the world.

Whilst the expansion of biofuels has led to the substitution of food products for energy markets rather than food markets, it has also been associated with vast land use change. This is particularly detrimental when located within the land grabs phenomenon. Initial publications regarding the expansion of 'land grabs' for biofuel expansion discuss the relocation of rural smallholders and pastoralists to make way for foreign and government biofuel schemes (Friends of the Earth 2010; Cotula 2011; Vermeulen & Cotula 2010; Cotula et al. 2009; Borras Jr et al. 2011). Land grabs are of concern because of the rapid rate of allocation - between 2008 and 2009 forty million hectares of land was distributed worldwide (for all commodities, not just biofuel feedstocks), twenty times the average rate of land transfer for the preceding forty years (Arezki et al. 2011).

Whilst the majority of this is still speculative and not under production (Deininger et al. 2011), such a rapid driver to the global and regional social-ecological system opens the system up to new vulnerabilities. In particular there is a concern that such large-scale investments will reduce access to resources for local farming communities, reliant on the ecological sub-system for their livelihoods, whilst directing the agricultural outputs to export markets (De Schutter 2011). In addition, the rapidity of the introduction of land grab schemes may lack transparency or community dialogue whilst accelerating the market for land, and in countries where tenure rights are informal or lacking, there is little protection for the existing users against displacement (Wolford et al. 2013). Such loss of access invokes a loss of traditional livelihoods and can have major negative impacts on food security (Cotula et al. 2008; Anseeuw et al. 2012).

The evidence of impacts on food security has begun to emerge within the biofuels literature, and the rapid globalisation of biofuels has been accompanied by a dramatic change in discourse, from that of a 'silver bullet' to an environmentally damaging policy shift associated with massive negative implications for food security and access to land (Pimentel et al. 2009; Searchinger et al. 2008; Fargione et al. 2008; Von Braun 2008). Much of this discussion remains very high level and conceptual, and within the literature biofuel expansion has still not been routinely subjected to systematic analyses – the existing literature focuses on one impact at one scale, for example impacts on food prices, the ecological sub-system, or energy balances (Fischer et al. 2009; Rosillo-Calle & Johnson 2010; Rosegrant 2008; Mitchell 2008; Hill et al. 2006; Solomon 2010; Farrell 2011; Hammerschlag 2006; Koh & Wilcove 2008).

Although the sum of the literature shows that there are differentiated impacts of biofuel expansion, integrated analyses of biofuel expansion are lacking – particularly those that incorporate multiple scales in one social-ecological system and highlight the winners and losers within these scales. In addition, the few integrated studies that do exist focus on efficiency, for example cost-benefit analyses and life-cycle analyses. There are few studies addressing the resilience of systems to biofuel expansion – the magnitude of change a system can experience before shifting into an alternative state. This thesis adopts a resilience framework which allows an integrated study to be produced that focuses on the multiple scales biofuels influence, identifying potential thresholds and regime shifts.

Such integrated studies are critical within the global debate on biofuels and the wider land-use change literature, due to the integrated systems that biofuels will influence – energy, food and land. As pressure for resources increases with issues such as population growth, development, and climate change, an understanding of the impacts biofuel policies and markets have on social-ecological systems is critical to help prevent the replication of such negative impacts in other systems. Addressing biofuels within a resilience framework is particularly relevant given the adoption of resilience within the policy sphere and the implications for biofuel policy adoption worldwide. This thesis therefore provides evidence to such debates in both the research and policy spheres.

1.1. Research Objectives

This thesis therefore aims to contribute empirical evidence to the debate on biofuels, highlighting the winners and losers across scales and key dynamics via a systems analysis of biofuel expansion. Previous research, as reviewed in Chapter 2, has highlighted the expected differentiation of impacts but not provided evidence of such impacts. This thesis contributes timely and thorough empirical data to inform a debate lacking such evidence. It also contributes to the theoretical literature by operationalizing the resilience framework and incorporating power dynamics to satisfy previous criticisms of resilience theory.

The overall research questions are as follows:

1) How does the expansion of biofuels affect the resilience of actors within local food systems?

2) How does the expansion of biofuels affect the social-ecological resilience of the regional system?
3) How does the introduction of ethanol stoves affect the resilience of actors within the consumption sub-system?
4) How does the expansion of biofuels affect the resilience of social-ecological systems at different scales in Ethiopia, from household to national?

1.2. An Overview of the Thesis

This thesis is divided into eight chapters. The following chapter presents the conceptual framework of the thesis and the issue being studied, highlighting the research gaps existing in the literature and the research questions that therefore arise. A description of the research design, the system in which the issue is studied, and the methodology are presented in Chapter 3. Chapters 4, 5, 6 and 7 present the results of the research, each, respectively, addressing the key research questions. Chapter 8 concludes the thesis with a summary of the key findings and implications for research and policy. These chapters are outlined in more detail below.

Chapter 2 presents an overview of the academic literature in the fields of resilience of social-ecological systems, food systems and biofuels. Summarising the state of knowledge in these fields highlights the research gaps existing within the individual literatures and in their combination. The research questions outlined above reflect the main areas of impact highlighted within the biofuels literature. Chapter 2 concludes by examining each of these research questions in depth at the appropriate scale and presenting more specific research questions that each results chapter answers.

Chapter 3 outlines the research design and methods that are used within a resilience framework to answer the four main research questions presented in Chapter 2. This chapter therefore provides an overview of the research design applied, the system investigated in Ethiopia, further context regarding the case study sub-systems and an overview of the methodologies applied so to answer the research questions. Chapter 3 begins with an introduction to the system where biofuel expansion is studied (Ethiopia) and the justification of analysing this biofuels system. The investigation of the research questions within this system requires the use of multiple research methodologies, modified to fit the scale at which the research question applies. Therefore, the chapter then goes on to outline the different scales, from household to national, where impacts are expected. Within each scale, further specific research questions are outlined relevant to the impacts within this scale, as well as the key populations of interest within these scales, data collection methods and the data analysis methods that are utilised.

Chapter 4 presents the results of the food system analysis at the household scale, using household surveys data on the entitlements and other food security measures of the samples to examine access, availability and utilisation of food at the current level of biofuels production, and over a period to measure change due to the expansion of biofuels. Such issues are investigated in three samples – employees of the existing sugar estate, residents of a nearby town, and pastoralists undergoing relocation due to the establishment of a new sugar estate. The analysis allows inferences to be made concerning the social-ecological system resilience for these samples. The overall contribution of this chapter is to highlight that the expansion of biofuels has differentiated impacts on the actors within the local social-ecological system.

Chapter 5 complements the household scale analysis in the production sub-system by using secondary data from Metehara Sugar Factory to highlight the key ecological impacts of the current and expanded levels of sugarcane production at the regional scale. The overall research question is answered by addressing the four stages of production occurring at Metehara Sugar Factory (MSF) and Kesem Sugar Factory (KSF) – cultivation, harvesting, processing sugar and processing ethanol – within a life-cycle analysis (LCA). The chapter examines what interactions occur during each stage, and what the direction and severity of the impact is on the regional social-ecological system, both at the current and planned levels of production.

Chapter 6 examines the novel consumption system within Ethiopia – ethanol as a household fuel. To identify the impacts of the introduction of this new technology on the consumption sub-system, this chapter analyses data from two quantitative household surveys carried out with samples stratified by income. The chapter shows that the impacts of ethanol stove adoption are differentiated for households from different income stratifications, and also outlines the barriers to uptake within the current regime whilst examining the potential for uptake in the future.

Chapter 7 examines the expansion of biofuels through a resilience framework, using the adaptive cycle to investigate the dynamics of the social-ecological system, to highlight the winners and losers at each phase. To do this, the chapter synthesises the results presented in Chapters 4, 5 and 6 regarding the food, ecological and energy sub-systems, examining the dynamics at each scale before presenting an analysis of the overall impacts on resilience of the national social-ecological systems when perturbed by the current level of biofuels production. The chapter concludes by discussing the impacts and dynamics at the planned level of production, highlighting the potential thresholds and regime shifts within that system.

Chapter 8 summarises the main findings of the previous chapters. It discusses the implications for policies on biofuels, both within Ethiopia and at the global scale, and highlights the main contributions of this thesis to research, within the biofuels and resilience literatures. The chapter concludes by reflecting on the contribution of this thesis.

1.3. Conceptual Contribution of this Thesis

As discussed above, the rapid introduction of biofuel policies has resulted in a lack of empirical evidence of the differentiation of impacts for different scales and different actors. This thesis contributes evidence regarding the differentiation of impacts on social-ecological systems due to the expansion of biofuels. It also contributes to the conceptual literature by addressing biofuel expansion within a resilience framework. As emerging environmental and resource problems are framed as complex systems problems, integrative and interdisciplinary approaches are developed to address them. Berkes et al. (2003) argue that resilience has a place in this modern era of sciences as *"sustainability implies maintaining the capacity of ecological systems to support social and economic systems"*. By assuming change and explaining stability, rather than assuming stability and explaining change (Van der Leeuw 2000), resilience offers the required holistic method of analysing the dynamics of interrelations within complex social-ecological systems.

To address the dynamics within a system, the resilience framework utilises the adaptive cycle – a heuristic model of the cyclical changes within a social-ecological system, essentially that gradual change will be followed by rapid change, triggered by a disturbance and leading to a new state or the continuation of the present state (Folke 2006). Applying the adaptive cycle allows examples of regime shifts and transformation to be identified, whilst nesting adaptive cycles allows the cross-scale interactions and influences to be demonstrated (Berkes et al. 2003; Holling 1986; Folke et al. 2010; Holling & Gunderson 2002). This thesis tests the strength of the adaptive cycle in analysing the dynamics that the expansion of biofuels causes on multiple scales, and how these impacts are transferred between scales. This contributes evidence to the resilience literature regarding the usefulness of the adaptive cycle, particularly within social sub-systems. Addressing dynamics within the social sub-system is a critical contribution to the resilience literature as it is acknowledged that the resilience framework contains some theoretical weaknesses regarding the integration of power relations within social-ecological systems. Therefore, the thesis builds on the work of Beymer-Farris et al. (2012) by analysing power dynamics associated with the different phases.

Overall, this thesis contributes towards the operationalisation of resilience as a lens through which to analyse change in social-ecological systems. The strength of resilience theory is the acknowledgment of the dynamic nature of systems, and the cross-scale features. By analysing multiple nested scales using a resilience model and highlighting the power dynamics within these scales, this thesis demonstrates the need for such an integrated approach when studying land-use changes due to the differentiated influences across multiple temporal and spatial scales and the actors within those. Within the example of biofuels, the thesis highlights the dynamic nature of interactions between producers, consumers and those indirectly affected through biofuel expansion.

2. Resilience, Food Systems and Biofuels

This chapter presents an overview of the academic literature in the fields of resilience of social-ecological systems, food systems and biofuels. Summarising the state of knowledge in these fields highlights the research gaps in the literature. Whilst all three have large academic literatures, there are still areas to be investigated. In addition the combination of these fields provides a novel framing for examining the impacts of biofuel expansion. Based on the research gaps already existing within the fields and further produced by the framing through a resilience lens, this chapter presents the research questions this thesis will answer, highlighting the novelty of this thesis and the contribution to knowledge it will make.

2.1. Resilience and Social-Ecological Systems

Resilience is a systematic property that refers to the magnitude of change a system can experience before shifting into an alternative state – for example with different hydrological cycles, levels of primary productivity, social relations and economic prosperity (Walker et al. 2004). This section will outline the terminology of resilience and social-ecological systems, key aspects of resilience theory and key studies within the literature.

2.1.1. The Terminology of Resilience

The use of the term resilience emerged in the field of ecology in the 1960s, introduced as a measure of the disturbance that can be tolerated in a system whilst retaining the same structure and function (Holling 1973). As resilience declines, smaller changes (disturbances within resilience literature) will have a larger effect, and eventually a threshold will be crossed moving the system into a different region of state space and a different set of controls (Carpenter et al. 2001; Holling 1973; Walker et al. 2009). The key concept of stability domains, or basins of attraction, within a system is a product of the heterogeneity (or non-linearity) of temporal and spatial scales encompassed within a system (Holling 1973; Folke 2006). Focusing on heterogeneity represented a shift from the traditional dominant view within ecology that ecosystems were linear systems with a single equilibrium. The evolution of terminology between these two paradigms resulted in the following definition of social-ecological resilience which synthesises previous definitions into a concise summary:

1) The amount of disturbance a system can absorb and still remain in the same state.
2) The degree to which the system is capable of self-organisation.
3) The degree to which the system can build up and increase the capacity for learning and adaptation (Carpenter 2001).

By addressing dynamic and complex systems, Holling shifted attention to the variability rather than the stability of systems (Holling 1973). Whilst a system is resilient if it can adapt to remain in the same state, it is also resilient if it has a high enough capacity to transform into a different state if necessary. In comparison, a system that undergoes a regime shift unintentionally due to a lack of adaptive capacity is not resilient. Integrating these ideas of dynamics and intentionality is important when framing the behaviour of social-ecological systems.

2.1.2. Integrated Social-Ecological Systems

Social-ecological systems (SES) are integrated systems in which humans are part of nature and therefore cultural, political, social, economic, ecological and technological components interact (Resilience Alliance 2011; Resilience Alliance 2010a). For example, in many coastal fishing communities, marine resources are usually tightly integrated with the local economy, culture, and political dynamics (Resilience Alliance 2010a). The (normative view of the) function of an SES is to provide goods and services from the ecological components to the social components, but these interventions directly and indirectly modify ecosystem structure and function (Resilience Alliance 2007). These interacting components form a complex and dynamic entity, the analysis of which requires a holistic approach. The equal attention paid to the social and ecological components of a system, and the focus on the relationships between these components rather than their individual functions, is key within resilience theory (Berkes et al. 2003).

Work on the science of complexity led to a new understanding of systems and systems thinking, and fed into resilience literature – complex systems have a number of attributes not observed in simple, linear, systems such as non-linearity, uncertainty, emergence, scale and self-organisation (Berkes et al. 2003). These attributes are clearly reflected in the key features of social-ecological system structure and function, as defined by Holling (1996):

1) Dynamic, complex systems
2) Thresholds
3) Multiple stability domains
4) Non-linear spatial and temporal variability
5) Episodic change
6) Learning
7) Self-organisation
8) Cross-scale interactions
9) Infinite possible trajectories between stability domains
10) Instabilities are equally as important as stabilities

Having already discussed complex systems the remaining features will now be outlined. Figure 2.1 is a conceptual model of an SES and demonstrates the different ecological and social components within an SES and their interactions at multiple spatial and temporal scales. The conceptual model below shows that within a system there are many variables operating, and influencing each other. These influences can be internal or external to the focal system. Generally external influences that lead to regime shifts in the ecological component tend to be slow variables, whereas internal influences are faster-changing. In comparison, in the social component regime shifts can be caused by both fast and slow variables – for example, technological change is a fast variable whereas culture is a slow variable (Walker et al. 2006).

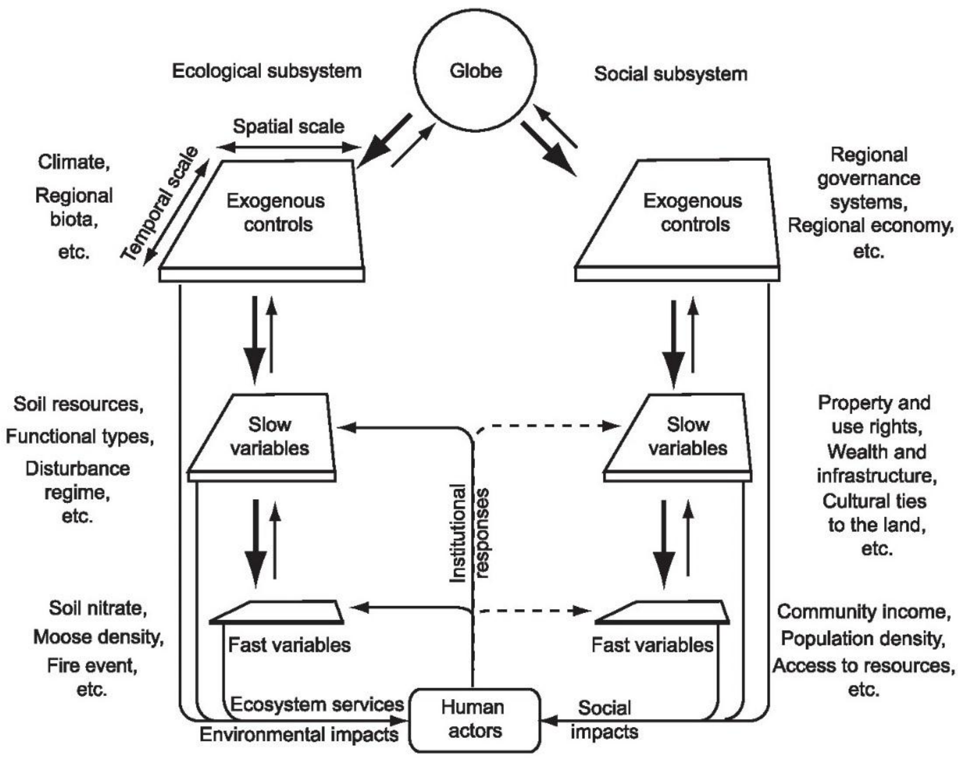


Figure 2.1. Conceptual model of integrated social-ecological system (F. S. Chapin et al. 2006).

Walker et al. (2006) go into further detail and conclude that slow variables can be of two types – a slow rate of change, or a slow frequency of change. Commonly, whichever type of slow variable, an external (and therefore slow) variable will influence internal variables which influence people i.e. the social component, more directly. The social component will then respond to such changes in the system through institutional mechanisms, creating feedback loops that affect environmental benefits and human well-being (Chapin et al., 2006). This feeds back into the final aspect of the definition of resilience; feedbacks either amplify change throughout the entire system, or have a stabilising effect, dependent on the capacity for self-organisation and learning. If the change is amplified, a threshold may be crossed that pushes the system into a new configuration.

2.1.3. Thresholds

Thresholds are a key aspect of resilience theory. Thresholds are the breakpoint between two regimes (or configurations) of a system and are integrated into the idea of multiple stability domains (Folke et al. 2010; Resilience Alliance 2011). The concept of multiple possible stability domains (also phrased as basins of attraction) within a system is a way of illustrating the different system regimes that result from heterogeneity (or non-linearity) of temporal and spatial scales encompassed within a system (Holling 1973; Folke 2006). A stability domain or basin of attraction is the *"portion of the state space of a dynamic system that contains one "attractor" toward which the state of the systems tends to go, and is therefore one region of the state space where the system would tend to remain in the absence of strong perturbations"* (Gallopin, 2006:297). The metaphor of basins of attraction in a stability landscape (Walker et al. 2004), is demonstrated in Figure 2.2.

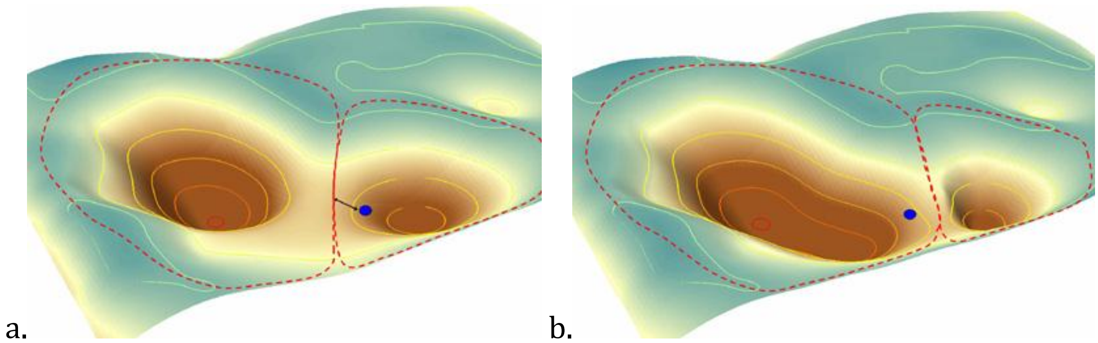


Figure 2.2. A 'ball in the basin' representation of resilience (B. H. Walker et al. 2004).

Figure 2.2 demonstrates how the SES can exist in multiple system configurations. The Resilience Alliance Workbook explains further (Resilience Alliance, 2007:15):

"Each configuration is actually a set of system states that has the same essential structure and function - and such a configuration (same structure and function) is termed a system "regime". As biophysical and social attributes of the system change, the positions of the attractors move around, and the various basins of attraction get smaller and larger, or appear and disappear… The state of this two dimensional system is the ball. The system can change regimes either by the state changing, or through changes in the shape of the basin (i.e. through changes in processes and system function), as shown in b."

The stability landscape is a useful metaphor to allow visualisation of alternate system regimes. Such alternate regimes are separated by thresholds, upon passing which the nature and extent of feedbacks changes, changing the function and therefore structure. A regime shift is an unintended transformation – *"a fundamental alteration of the nature of a system once the current ecological, social or economic conditions become untenable or undesirable"* (Nelson et al. 2007:297). When intentional, such change is referred to as a transformation. The changes between regimes can be large and sudden (i.e. episodic change – infrequent and discontinuous), or continuous and gradual (a cumulative and evolving change) (Weick & Quinn 1999). SESs have multiple thresholds, at different scales and in different components of the system, which interact and give rise to multiple alternate regimes. However, not all of these thresholds are possible due to cultural or ecological constraints, *"for example social values may constrain options for abating agricultural pollution from runoff whereas ecological states may preclude certain social configurations, e.g., threatened loss of endangered species may limit options for land-use changes"* (Walker et al., 2006:9).

2.1.4. Adaptive Cycle and Panarchy

As discussed above, social-ecological systems are dynamic – they are predisposed to change rather than equilibrium. A key contribution of resilience theory is the adaptive cycle, a heuristic model that outlines the four phases of cyclical change Holling proposed were characteristic of SES, taking into account fast (external) and slow (internal) dynamics (Berkes et al. 2003; Holling 1986). The four phases are described below and shown in Figure 2.3 (Holling & Gunderson 2002):

1. Rapid growth and exploitation (r): Periods of exponential change where resources are easily available and capital is accumulated
2. Conservation (K): Periods of growing rigidity where resources become increasingly unavailable
3. Collapse or release (Ω): Periods of readjustment and collapse characterised by the rapid loss of capital
4. Reorganisation or renewal (α): Periods of reorganisation and renewal where novelty succeeds

Essentially, gradual change will be followed by rapid change, triggered by a disturbance and leading to a new state or the continuation of the present state (Folke 2006).

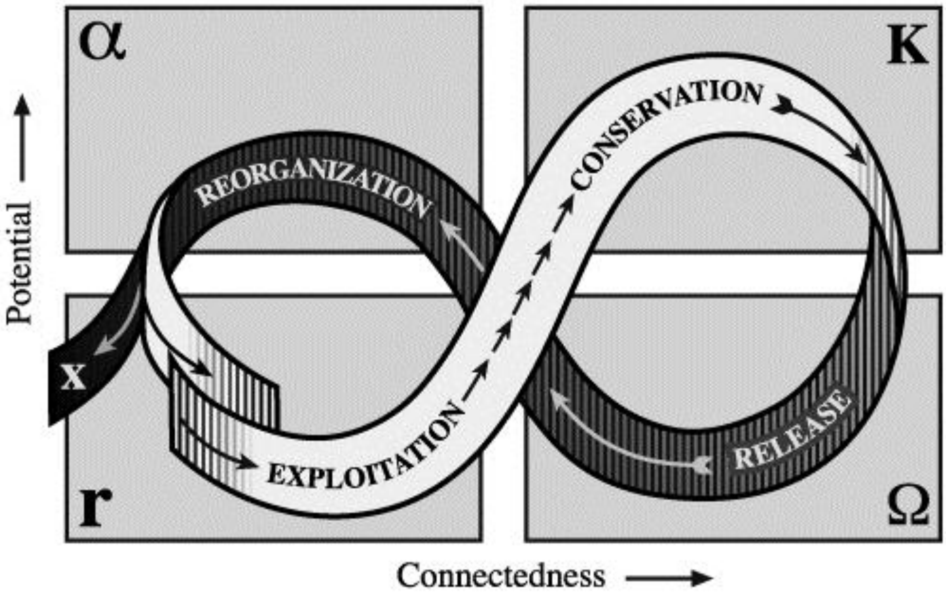


Figure 2.3. The adaptive cycle (Holling & Gunderson 2002).

The existence of multiple adaptive cycles within a system has led to the theory of panarchy – nested adaptive cycles emphasising cross scale interplay, as demonstrated in Figure 2.4 (Folke 2006).

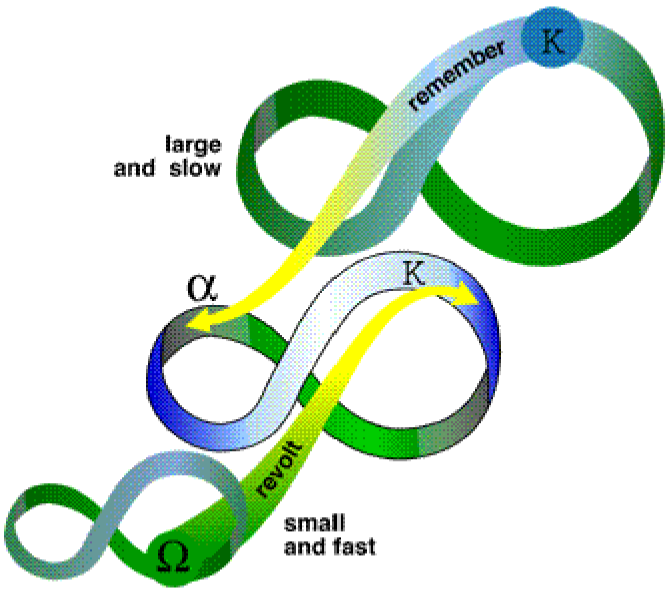


Figure 2.4. Panarchy, a heuristic model of nested adaptive renewal cycles emphasising cross scale interplay (Folke 2006).

Panarchy infiltrates resilience frameworks via the incorporation of coupled, interacting systems. In Figure 2.4 it can be seen that adaptive cycles at different spatial and temporal levels are linked by connections called 'revolt' and 'remember'. Revolt represents the translation of a disturbance from a smaller and faster cycle to a larger and slower cycle via a cascade of events (Folke 2006). Remember is the opposite – a connection that allows reorganisation and renewal by drawing on social-ecological memory accumulated in the larger cycles and passing it down to smaller cycles (Berkes et al. 2003). A neat summary of panarchy is provided by Berkes, Colding, & Folke, (2003:19):

"The panarchy is therefore both creative and conservative (Holling 2001) *through the dynamic balance between change and memory, and between disturbance and diversity."*

The term panarchy was chosen instead of hierarchy to emphasise the cross-scale and dynamic nature of the theory, as although hierarchies can be imagined between larger slow cycles and faster small cycles, the inclusion of dynamics within each adaptive cycle and the connections across levels via revolt and remember provide a non-traditional hierarchy (Bunnell 2002). However, the embedded nature of adaptive cycles within panarchy shows that scales do fit together. Panarchy creates an opportunity to examine the linkages and relationships between scales. As such it is possible that *"what may appear as linear change (e.g. growth) at one temporal scale may in fact be part of a cycle when viewed from a higher-order temporal cycle"* (Berkes, Colding, & Folke, 2003: 17).

With an understanding of panarchy, the potential for cascading thresholds through scales can be seen. As resilience declines, the size of disturbance required to trigger a regime shift becomes progressively smaller, because of the combination of interacting variables. Walker et al. (2009) discuss this using the case study of the Goulburn-Broken Catchment in Australia. Figure 2.5 outlines the identified slow variables and their interactions.

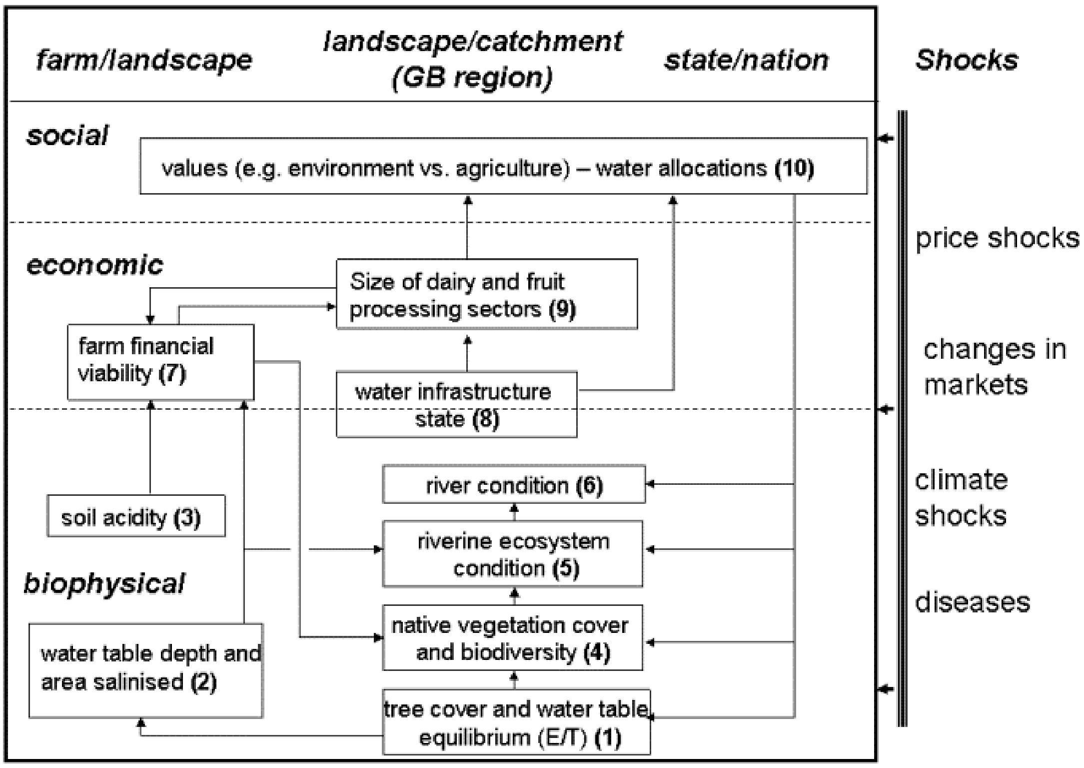


Figure 2.5. Ten slow variables with identified thresholds in the panarchy that constitutes the Goulburn-Broken Region (Walker et al. 2009).

2.1.5. Transformability and Adaptability

The capacity to undergo such fundamental change when thresholds are surpassed and transform into a fundamentally new system, as displayed in Figure 2.4 and Figure 2.5, is referred to as transformability (Walker et al. 2006). Figure 2.3 displays a transformation where one possible trajectory into another stability domain is demonstrated by the pathway labelled 'x'. A regime shift can occur at any point of the adaptive cycle, thus creating an infinite number of possible trajectories and an infinite number of regime shifts.

The infinite number of trajectories and basins of attraction are due to the multiple temporal and spatial scales involved in a SES. They allow the adaptive cycle to portray an organic and process-dependent system with a capacity for self-organisation, as included in the adopted definition of social-ecological resilience. However, human interactions in SES provide a different type of self-organisation to that which occurs in purely ecological systems because of foresight and deliberate action (Westley et al. 2002). Therefore, social capital and social memory are key aspects alongside adaptation and social learning, supporting the ability to persist when faced with disturbance. This introduces the concept of adaptability within resilience theory - the capacity of actors within the system to influence (or manage) resilience (Resilience Alliance 2011). Adaptability is then a component of adaptive capacity – the capacity to adapt and shape change (Resilience Alliance 2011).

The three components of resilience, adaptability and transformability interrelate across multiple scales, as whilst adaptability allows adjustment within the current regime, transformability allows change into other regimes (Walker et al. 2004). Folke et al. (2010) argue that transformational change at smaller scales enables resilience at larger scales as the crises leading to transformation are windows of opportunity for novelty and innovation. Empirical evidence of this is a key area for future research.

2.1.6. Variability and Disturbances

Given the dynamic nature of complex systems, variability is inherent and surprises are *"the rule, not the exception"* (Gunderson 2003:36). Therefore the role of instabilities is as important as the role of stabilities within an SES. Surprise, change, and crisis are all types of disturbance that result from either specific discontinuities or synergistic couplings and trigger reorganisation or renewal within a system (Folke et al. 2003; Nelson et al. 2007). A disturbance is an external shock or stress that disrupts ecosystems, communities or populations, and creates new opportunities for alternative regimes to become established (Resilience Alliance 2011). There are many examples in the resilience literature of disturbances, whether ecological disturbances such as forest fires and forest pest outbreaks or social disturbances such as within Native American societies but other examples not fully studied through a resilience framework yet include technological changes and economic disturbances such as recessions and innovations (Peterson 2002; Ludwig et al. 2002; Delcourt & Delcourt 2004; Schoon & Cox 2011).

That human interventions in SESs introduce new forms of variability, and hence disturbance, is commonly discussed within the literature and is thought to be *"generally harmful to social resilience and human welfare"* (Adger 2000:350). Such interactions can be divided into the following categories:

- Human actions driving environmental change.
- The impact of ecosystem state changes on the availability of ecosystem services to society.
- The interaction between ecological resilience and resilience of the whole SES (Adger & Brown 2009).

In a resilient SES, disturbance from either social or ecological components can lead to innovation and development, whereas in a vulnerable SES disturbances may have *"dramatic social consequences"* (Adger, 2006; Folke, 2006:253). These social consequences depend on the adaptability of the system which is mainly a function of the individuals and groups managing the SES, as their actions influence resilience, whether intentionally or unintentionally (Walker et al. 2006).

2.1.7. Desirability within Resilience Theory

In summary, variability is a fundamental aspect of any system, and can lead to disturbances that in turn can lead to regime shifts or transformations. More resilient SESs are able to absorb larger disturbances without changing in fundamental ways. However, if a regime shift is inevitable (as episodic change often leads to), resilient systems contain the components needed for renewal and reorganization (Folke et al. 2002). A resilient system should not aim to prevent shifts between regimes, but prepare for surprises and system renewal. The desirability of various states is a normative classification created by human society – from an analysis perspective the stable domain is no better than the previous stable state. Obviously regimes will have more and less desirable elements and alternatives when viewed by society. For example, poverty traps are a very resilient system but undesirable whereas technological regimes can differ in desirability depending on the temporal viewpoint – once an alternative is produced, the desirability of the previous regime decreases (Carpenter & Brock 2008; Dangerman & Schellnhuber 2013).

The evolution of the term resilience as it becomes operationalised has been accompanied by a more malleable notion of resilience, from the original, ecological, concept of the ability of a system to absorb change towards a more normative concept related to sustainability – i.e. the maintenance of natural capital in the long-run (Brand & Jax 2007). The difference is that utilising this concept allows resilience to be a systemic property, whilst applying the latter normative concept makes resilience more of a boundary object – a tool for communicating through disciplinary borders (Brand & Jax 2007). Whilst this allows scientists from different fields to engage for management purposes, it prevents a scientific robustness within the literature due to the ambivalence within the term. Therefore this thesis applies the extended social-ecological concept as outlined in section 2.1.1, ignoring any perspectives of desirability related to the resilience of the system, and instead integrating such issues into the power dynamics analysis, expanded on below in section 2.1.9.

In summary, regime shifts can (and will) occur whether desirable or not, due to multiple reasons – for example, policy failures, resource crises, shifts in social values – and the pathways through regime shifts are usually poorly understood. Walker et al. (2006) outline four system attributes that enable transformative change:

- Cross-scale awareness and reactivity, including networking within the social-ecological system and between the system and other systems;
- Incentives to change (vs. not to change, especially subsidies);
- A willingness to experiment; and
- Reserves and highly convertible assets in human, natural, and built capital.

Whether the transformation is planned or an unintentional regime shift will influence which of these four attributes are focused on within management, or happen to occur naturally to allow change. When regime shifts do occur, the system shifts into a new stability domain with a different structure and function and different impacts at the scales above and below the focal system, as represented by panarchy.

2.1.8. Assessing Resilience

Resilience is a conceptual framework – the theory of panarchy and adaptive cycles is heuristic. Rapoport summarises neatly that *"conceptual frameworks are neither models not theories... Models describe how things work, whereas theories explain phenomena. Conceptual frameworks do neither; rather they help to think about phenomena, to order material, revealing patterns- and pattern recognition typically leads to models and theories"* (Rapoport 1986:256). Therefore, by using resilience as a framework the dynamics within the studied systems can be investigated thoroughly to identify possible alternate states, thresholds and trajectories.

Berkes & Folke (1998) point out that as a conceptual framework, there is no explicit methodology for a resilience assessment, rather an interdisciplinary case-study approach is required so to *"identify relevant characteristics of the ecosystem, people and technology, local knowledge, and property rights institutions that characterise the case study"* (Berkes & Folke 1998:15). The Resilience Alliance has created a series of workbooks for both practitioners and scientists which outline the broad steps of a resilience assessment, so all key theoretical aspects of the systems are discussed – as listed above, this includes the system boundaries, key drivers, fast and slow variables and thresholds (Resilience Alliance 2010a; Resilience Alliance 2007).

There are still relatively few examples in the literature of studies empirically analysing social-ecological systems through a resilience lens. The majority of publications analyse a regime shift within the ecological system. Classic case studies include the sudden blooms of toxic algae in freshwater lakes (Carpenter et al. 1999), emergence of shrubs in semi-arid grasslands (Walker et al. 1981) and shifts in species dominance in freshwater wetlands (Davis 1994). However, all these are examples of ecological regime shifts, only involving the social component when actors in the social component of the SES (who have a role in resource management) cause the disturbance. The Goulburn-Broken Catchment case study incorporates the social system to a greater degree, as it assesses the resilience of the regional system so to identify the key slow variables with identified thresholds, allowing management recommendations to be made

(Walker et al. 2009). More recent studies include the study by Dangerman & Schellnhuber (2013) examining barriers to energy system transformation.

Therefore, the resilience literature is still lacking empirical studies regarding the analysis of changes in social sub-systems as a result of ecological change, particularly concerning actors in SES at lower scales than the scale of management. There are studies published investigating social-focused systems, and some utilising the adaptive cycle heuristic. These studies address, but are limited to, the impacts of environmental change on livelihoods (Goulden et al. 2013), collapses of civilisations (Dugmore et al. 2009) and land-use change (Rasmussen & Reenberg 2012; Gronenborn et al. 2013). However, there is still a knowledge gap within the literature regarding empirical evidence of the dynamics within social-ecological systems, primarily those where evidence collected focuses on social rather than ecological regime shifts.

2.1.9. Power and Equity within a Resilience Framework

As the emerging environmental and resource problems are framed as complex systems problems, integrative and interdisciplinary approaches are developed to address them - for example, sustainability science and ecological economics (Costanza et al. 1997). Berkes et al. (2003:2) argue that resilience has a place in this modern era of sciences as *“sustainability implies maintaining the capacity of ecological systems to support social and economic systems”*. By assuming change and explaining stability, rather than assuming stability and explaining change (van der Leeuw 2000), resilience offers the required holistic method of analysing the dynamics of interrelations within complex social-ecological systems. However, it is acknowledged that the resilience framework contains some theoretical weaknesses. Jerneck & Olsson (2008) assess poverty-relevant adaptation using three discourses (development, resilience and transition theory) and conclude that resilience does not recognize that social change mainly implies transitions to renewed forms of production, consumption and distribution that are accompanied by new combinations of organizational, institutional and technological structure. They conclude that transition theory is therefore the most appropriate for an analysis of multi-level changes in complex systems. Amongst others, Hornborg (2009) highlights that resilience theory has been poor in elaborating the power dynamics of social-ecological change and acknowledging the asymmetrical distribution of resources and power in social systems. The weakness regarding power dynamics was further highlighted by Davidson (2010:1135) who summarised that whilst resilience theory was a *"compelling source of theoretical insight"* it was not readily applicable to social systems as agency required further exploration.

These points are accepted by resilience scholars and addressed, for example in Leach (2008). In contrast with claims made by the above critics, the literature of Elinor Ostrom and colleagues have traditionally utilised the concepts of institutions and governance (Anderies et al. 2004; Ostrom 2007; Ostrom 2011). However, there has been a recent response within resilience theory to further integrate power and agency dynamics by integrating ideas such as social-ecological memory, social networks and governance (Barthel et al. 2010; Andersson et al. 2007; Bodin et al. 2006; Ernstson & Barthel 2010; Janssen et al. 2006).

When discussing the desirability of SESs, the state of knowledge within the literature can be contributed to still further by differentiating power dynamics and differentiated impacts on all the actors within an SES. Commonly, resilience literature examines SES with a single manager or at least the desirability from their viewpoint. By highlighting the complex nature of actors as well as the ecological complexity a full analysis of dynamics can be presented. The integration of power dynamics requires utilising other frameworks that analyse differentiated impacts on actors within a resilience framework. Beymer-Farris et al. (2012:283) applied a political ecology approach with a resilience approach to consider *"whose needs are being met from the goods and services and the politics of their distribution and management"* and highlighted the inequitable outcomes due to power imbalances of competing resource users, who have different visions of desirable states.

The use of political ecology is a specific application of the 'winners and losers' context as described in O'Brien & Leichenko (2003). This paper highlights the dynamic context of impacts from events at a range of possible scales, all of which fits easily with the context of social-ecological systems and resilience theory as outlined above. There are various ways of defining winners and losers, for example whether actors engage by choice or without full knowledge of the system, whether wins or loses are absolute or relative and whether self-identification is a factor (O'Brien & Leichenko 2003). However the 'winning' or 'losing' is defined, it can be within an economic or ecological context and O'Brien & Leichenko (2003) posit that this is what determines the typology required to interpret winners and losers, as shown in Table 2.1.

Table 2.1. A typology for interpretations of winners and losers (O'Brien & Leichenko 2003).

	Winners and losers are natural, inevitable and evolutionary (NIE)	Winners and losers are socially and politically generated (SPG)
Ecological interpretations	Social Darwinism Environmental determinism	Political ecology
Economic interpretations	Neoclassical economics	Marxian political economy

Recognition of the different perspectives is important so to account for different attitudes in identifying winners and losers. However, within the context of change in SES and the differentiated impacts, political ecology is the most appropriate framework through which to investigate winners and losers. Political ecology *"combines the concerns of ecology and a broadly defined political economy. Together this encompasses the constantly shifting dialectic between society and land-based resources, and also within classes and groups within society itself"* (Blaikie & Brookfield 1987:17). As with a resilience framework, acknowledging that changes in the environment do not affect society in a homogenous way allows political ecology to incorporate knowledge, power and practice alongside justice, governance and ecological democracy (Peet & Watts 2004). Beymer-Farris et al. (2012) present these power dynamics by annotating an adaptive cycle (Gunderson & Holling 2001) with the details of the impacts within the phases.

In summary, resilience is difficult to apply due to the theoretical nature of its heuristic adaptive cycles, but it allows the dynamics of social-ecological systems to be fully investigated, including the linkages within and between scales.

Incorporating power issues will complement the dynamics already highlighted by the resilience framework leading to a thorough systemic analysis of change in social-ecological systems. There is also an added novelty in using a resilience framework as resilience assessments addressing integrated social-ecological systems are currently not well represented in the academic literature – the majority of examples present purely ecological accounts.

2.2. Food Systems

The assessment of food systems through a resilience framework has rarely been studied in the literature and therefore this section addresses food systems as the social-ecological system of choice that will be analysed in this thesis. The term food system refers to the entire chain of activities from production to consumption i.e. growing, harvesting, processing, packaging, transportation, marketing, consumption and disposal of food and food-related items (Ericksen 2008a). By addressing food systems as opposed to farming systems, the entire population can be integrated into the study, not just those involved in agriculture. Figure 2.6 outlines a food system diagrammatically, and encompasses all aspects of food systems, demonstrating the features of a social-ecological system it contains and hence the suitability of a resilience framework. For example, Figure 2.6 demonstrates that food systems incorporate multiple ecological, social and economic drivers which influence food security. The conceptual model of food security contains three elements: food availability, access and utilisation (Ericksen 2008a). The definition of food security has evolved over time and now includes these three elements whereas originally only the availability of food was considered. The most recent FAO definition of food security (published in the 2002 State of Food Insecurity Report) continued to build focus on access of vulnerable people to food:

"Food security [is] a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (Food and Agriculture Organisation of the United Nations 2002)

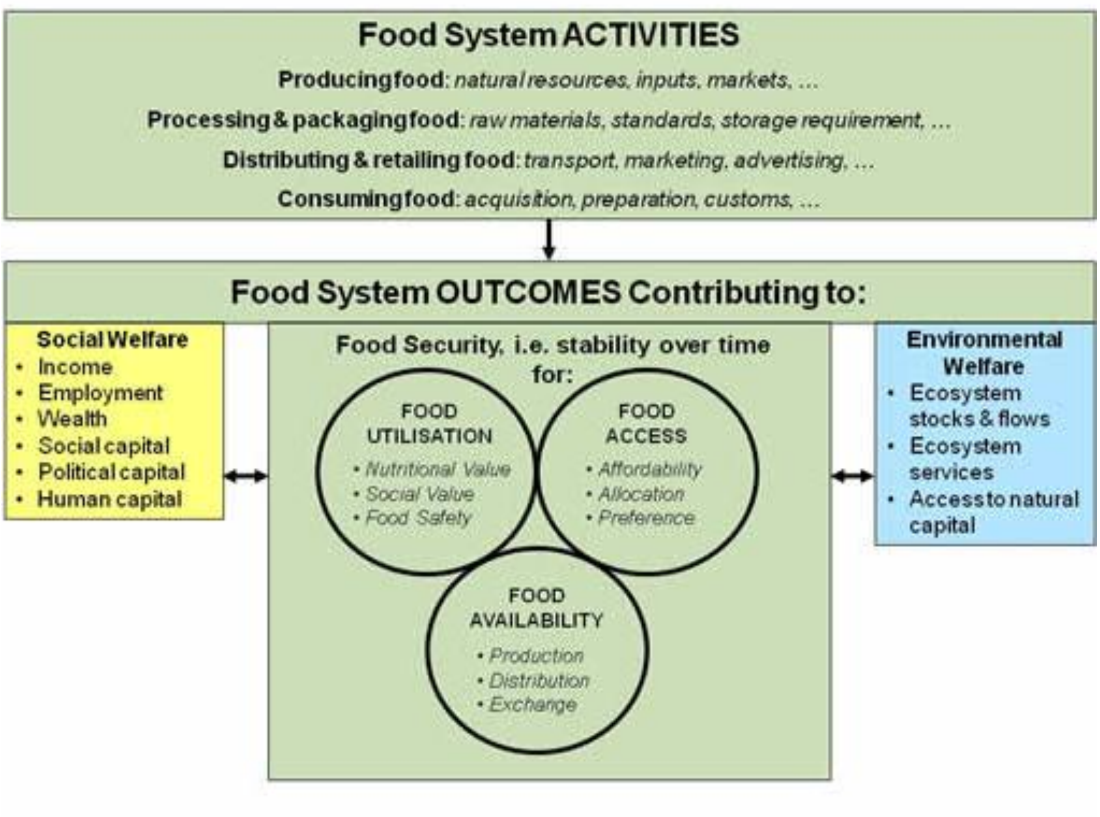


Figure 2.6. Components of food systems (Ericksen 2008a).

2.2.1. Food Systems as Social-Ecological Systems

After the introduction of food systems as integrated social-ecological systems above, it is clear that food systems can be portrayed as such as they *"incorporate multiple and complex environmental, social, political and economic determinants encompassing availability, access and utilisation"* and involve varying spatial, temporal, and institutional scales (Ericksen 2008a:234). For example, at a household level, developing world households dependent on agricultural livelihoods often live in complex, diverse, and risk-prone settings, with inherent seasonal instability (Chambers 1991). The conceptualisation of modern food systems as a chain of activities from production to consumption allows the couplings to be identified (Ericksen 2008a) which itself allows chains of activities to be seen as cross-scale processes that incorporate nested cycles.

Food systems can also be seen to include all ten key features of social-ecological system structure and function referred to above in section 2.1.2. For example, the modern trade system highlights the cross-scale interactions – from imports and exports at national levels down to food prices for the individual consumer.

Rapid changes in food prices seen in the past decade are associated with high levels of complexity and uncertainty. Ericksen (2008) also points out that there is a reciprocal effect where food systems affect the environment, as the human domination of ecosystems combines with global environmental change leads to higher uncertainty regarding production.

2.2.2. Traditional Frameworks for Food Systems Analysis

Within the academic and grey literature, the focus of analysis is on food security rather than food systems. Food security can be analysed at all levels from global down to individual. However, at no level can a single indicator measure the range of food security. Therefore, many different combinations of indicators are applied by different actors with different outcomes in mind. When discussing food security at the national or regional level, a commonly used measure is the Global Hunger Index (GHI). The GHI value combines the proportion of undernourished in a population, the prevalence of underweight children under 5 and the mortality rate of children under 5 to create an empirical measure of food security (Von Grebmer et al. 2008). Also used is the proportion of undernourished itself, as applied by the FAO in their Prevalence of Hunger maps which gives an indication of health and nutrition (Food and Agriculture Organisation of the United Nations 2013a). Another, less anthropometric indicator, of food security is the agricultural potential of a region, as agriculture has a much greater impact on reducing poverty and improving food security than do other sectors of the economy (Yu et al. 2010). The rate of urbanisation can also be applied as a proxy for distribution of food within a country.

When investigating food security at the household level more detailed empirical data can be collected on food availability regarding production, as well as food budgets and expenditure to indicate access. Also used as a measure of access as well as utilisation is the dietary diversity – the quantity and quality of food consumed over a set period of time, weighted for nutritional benefit. In addition, the actual nutrient intake levels can also be measured. Three measures of nutrient intake are taken into account – calories, protein and fat intake, as a balanced diet cannot be reflected by one of these alone. Finally a key measure of access is the employment of household coping-measures in times of food insecurity.

An alternative to the concept of food security is the entitlements approach, established in Sen's seminal work 'Poverty and Famines'. The entitlements approach has become the conceptual basis of aid agencies' and researchers' approaches to assessing food security. Entitlements are defined by Sen (1984:497) as "*the set of alternative commodity bundles that a person can command in a society using the totality of rights and opportunities that she or he faces*". Therefore an 'entitlement set' is the full range of goods and services an individual can obtain by converting 'endowments' (assets, resources) through 'exchange entitlement mapping' (Devereux 2001). Sen describes four entitlement categories (Sen 1981):

- Production based entitlements – food that an individual grows
- Trade-based entitlements – food that an individual acquires by trading something
- Own-labour entitlements – food that an individual is entitled to due to labour power
- Inheritance and transfer entitlement – food that an individual inherits from or is given by another who owned them legally

The four entitlement categories describe all 'legal' sources of food (Sen 1981). Sen summarises that starvation occurs when an individual's entitlement set fails to provide adequate food (Sen 1981). Such inadequacies can arise from either 'exchange entitlement decline' (obtain less food through trade) or 'direct entitlement decline' (produce less food for consumption) (Sen 1981). Such declines cause a decrease in the value of the endowment bundle or an unfavourable shift in exchange entitlement mapping. Therefore, although Sen acknowledges famines can be caused by decreases in production (for example, as a result of natural disasters), the majority of entitlement categories are to do with access to food, irrespective of sufficient food availability, as now reflected in the definition of food security highlighted above.

As informative as all these methods are, by solely addressing food security or entitlements, the focus is removed from the food system activities creating the level of food security, as well as the other social and environmental outcomes. Therefore, a systematic approach is necessary, as argued for by Ericksen (2008).

2.2.3. Entitlements through a Resilience Lens

This section discusses how entitlements can be addressed within a resilience framework. Devereux (2001:248) discusses how *"identifying the trigger does not explain the famine, which requires a more complex analysis of conjunctural triggers and structural or underlying causes to be fully explained"*. The failures of entitlements, whether direct or exchange, can be seen as releases within the adaptive cycle. From such a release we have established in section 2.1.4 that reorganisation and renewal follows. Depending on the resilience of the SES, it is feasible for the SES to pass a threshold which causes a transformation to a basin of attraction characterised by famine. The infinite number of trajectories between stable states makes it very difficult to predict transformations in advance, although in retrospect such factors can be identified (Folke et al. 2002).

Transformations could be a result of fast or slow dynamics. As direct entitlement failures, i.e. a reduction in production, are caused by environmental factors, these can be hypothesised to mostly represent the slow or internal dynamics within the system – for example results of environmental degradation: soil erosion, insufficient water for irrigation, nutrient mining. However, natural disasters could also cause direct entitlement failure and would therefore be classed as a fast or external dynamic. Other possible external dynamics could include agricultural policy decisions, market collapses, or conflict, i.e. societal influences. These would all be responsible for exchange entitlement failures as opposed to direct entitlement failure.

Recapping the four types of entitlement (production, trade, own-labour and transfer) - the latter three entitlement categories refer to access to food, irrespective of food availability. Sen argued that 'exchange entitlement declines' are most important. It can be argued that within modern food systems, trade-based entitlements are the key category, as the majority of people in the world rely on trade for a significant proportion, if not all, of their supplies of food.

However, before discussing the causes of transformation, a step backwards must be made to examine where the thresholds for transformation lie. As de Waal (1990) discusses, Sen's definitions of starvation and famine are never clearly fixed, and therefore there is some ambiguity over where the threshold between hunger and famine lies. The definition of famine is shown to vary between countries, dependent on experience of famines. de Waal (1990) attempts to identify famines within the categories general poverty, dearth, severe death, excess death, and frank starvation. He estimates that whereas an English diagnosis of famine would begin at severe death but only be defined at frank starvation, an African diagnosis would occur at dearth and be defined at excess deaths. This tells us that famines may not be distinct events due to a gradient of starvation. Therefore thresholds are difficult to predict - as discussed within resilience literature. There is also an added complication with identifying thresholds prior to famine, for example into food insecurity.

de Waal (1990) examines this within a discussion on coping strategies employed by some. The most severe coping strategy is to skip meals, but by lowering food consumption voluntarily it has been shown that capital can instead be diverted to maintaining livestock, buying seed or hiring labour i.e. preserving assets and enhancing entitlements for future years. The ownership of assets or the entitlements set can be divided into investments, stores or claims on other individuals. The exchange of entitlements can erode resilience in the long term, whereas maintenance of them will not enhance resilience in the short term, but may maintain resilience in the long run. When smallholders sell assets during times of dearth, they lose the assets that are critical to the future entitlements set, and can become locked into poverty – as discussed above a resilient regime difficult to transform out of. By spending money on preserving assets, they maintain their entitlements (and resilience) for after the period of dearth. However, there is obviously a judgement made about the risk of death – as de Waal (1990:476) bluntly says *"someone who chooses to starve* *will be forfeiting his or her future entitlements because he or she will be unable to claim them through being dead"*. Ravallion more clearly explains the rationale as *"discounting a risk of imminent mortality against the necessity of preserving productive assets for the future"* (Ravallion 1987; de Waal 1990:476).

However, the sale of assets is mostly applicable to rural smallholders. Landless labourers with no assets may not be able to employ such a coping strategy. An alternative is to substitute foods for free food stuffs i.e. those provided by aid programmes or wild. An alternative coping strategy is to move to urban areas with more reliable grain markets. Community cohesion is important and affects labour and asset markets. All such coping methods rely on memory within the system and the capacity for self-organisation.

Access to food is dependent on the legal, political, economic and social characteristics of the society in question, and the individual's position in it (Rubin 2009; Sen 1981). Cross-scale (hierarchical and geographical) linkages are very important for maintaining resilience, and an understanding and building of such linkages could lead to an increased understanding of diversity within the system, as diversity is an important aspect of both resilience theory and food systems. There are multiple types of diversity within food systems:

1. Biological diversity: provides the capacity for renewal and reorganisation following a disturbance, acting as insurance.
2. Agricultural diversity: an example of biological diversity. The number of species cultivated to feed humans has reduced massively from 7000 to 150 since the Industrial Revolution (Esquinas-alcázar 2005). This genetic erosion creates increased vulnerabilities to pests, diseases and changes in climate, reducing resilience and can lead to famine via direct entitlement loss as a fast variable in SES, possibly causing a transformation into a different, and less desirable, stable state. Market and institutional decisions regarding crop production can lead to changes in prices, and an increased variability in prices as the production becomes more volatile, leading to exchange entitlement failure.

3. Nutritional diversity: a side effect of globalisation and its impacts on modern agricultural diversity. Evidence has shown that a decline in food varieties adversely affects nutrition (Thrupp 2000), because 'modern' cereals are introduced, and replace native, diverse, more nutritious species of legume, pulses and grains. Decreasing nutritional diversity will lead to micronutrient deficiencies, reducing the productivity of individuals, and decreasing their resilience.
4. Cultural diversity: a side-effect of the loss of native species. Local landscapes, knowledge and traditions are lost as uniform agriculture predominates and erodes the ability to renew and reorganise as learning becomes less a part of the culture.
5. Response diversity: *"The variability in responses... within functional groups to environmental change"* (Elmqvist et al. 2003:488). As above, a decrease in this reduces the resilience of the SES as there are fewer coping strategies to deal with entitlement failures.
6. Functional diversity: functionally dissimilar species co-exist and complement each other, increasing the productivity of the ecosystems as a whole (Elmqvist et al. 2003).
7. Institutional diversity: results in increased legal sources of food i.e. local networks, unemployment benefits which in turn reduces the risk of entitlement failures and increases resilience.
8. Diversity in income sources: decreases the likelihood of exchange entitlement failure, and therefore another source of resilience.

In summary, *"although extensive diversity may not be necessary for humans to satisfy basic nutritional needs, within a socio-cultural context traditional biodiversity use is a powerful vehicle for maintaining and enhancing health-positive behaviours"* (Johns & Sthapit, 2004:144). Diversity is responsible for income generation and socio-cultural traditions and allows the maintenance of positive practices and sustainable development. Therefore, diversity should create resilience so that systems (and actors within the systems) can renew and reorganise from any transformations whilst maintaining the function of the system.

2.2.4. Disturbances within Food Systems

Although not usually discussed within resilience language, there are many examples within the agricultural literature of disturbances within food systems, usually framed as the factors driving change and creating uncertainty in world agriculture. As with any SES, such disturbances can be slow or fast, external or internal. The majority of highlighted disturbances are environmental fast variables, such as:

Pests - A fast variable that impacts food production are pests and diseases. One of the most well researched examples of this is the Irish Potato Famine, 1845-1850, when a pest (a fungal pathogen, *Phytophthora infestans*) caused crop failures for 4 years out of 5 and led to 1.5 million deaths (Holdren & Ehrlich 1974). Other examples are the wheat rust epidemic in the USA in the 1960s and a tungo virus epidemic in Indonesian rice crops in 1970 (Thrupp 2000).

Drought - Although not as immediate as extreme weather events such as floods, drought can be categorised as a fast variable due to being a weather condition rather than a climate condition. The impacts of drought on food security are well-represented in the literature, particularly the persistent drought in East Africa which caused a continuing deterioration of food production. The Ethiopian famine in the 1980s was triggered by a drought and led to the deaths of 590,000-1,000,000 people (Devereux 2000). Even in developed countries drought has a large impact - the 1988 Midwest drought *"led to a 30% reduction in U.S. corn production and cost taxpayers $3 billion in direct relief payments to farmers"* (Rosenzweig et al. 2001:90), whilst the classic example is the 1930s 'Dust Bowl' in the Southern Plains of the US. Here drought caused 200,000 farm bankruptcies and yields of wheat and corn were reduced by as much as 50% (Warrick 1984).

Since the introduction of entitlements theory, more economic and political disturbances have also been included in the literature, for example:

Imperfect markets - Famine can also be viewed as a product of imperfect markets, for example the failure of 'spatial arbitrage' leads to segmented markets, whilst speculative and precautionary hoarding, or failures in 'temporal arbitrage', increases food prices to unaffordable levels (Devereux 2001). von Braun et al. (1998) demonstrated econometrically that such market segmentation also played a role in the Ethiopian famine of the 1980s.

Political powerlessness - The *"near total lack of rights or political muscle within the institutions of the... state"* (Keen 1994:211) and outlines that causality of famines can be assigned to national and international institutions as opposed to the victims. The influence of the political system on famine has also been discussed in relation to the Ethiopian famine in 1984, where it is suggested food aid was used as a political weapon and withheld by the US in the hope of undermining the current regime (Sheperd 1993).

Examining these case studies, particularly with the example of the Ethiopian famine, it can be seen that no event is caused by one disturbance alone but by a combination of variables and thresholds within a system. The general consensus is that social, economic and political forces create a more vulnerable system so that if environmental disturbances occur their impact is much greater. Therefore, a political ecology framework is again proved useful when clarifying that research on all aspects of the food system is required to investigate particular disturbances within a resilience framework.

The more recent focus on entitlements and access as opposed to availability has led to a larger literature on economic and political variables. For example, returning to the Irish Potato Famine case study, in older literature it was viewed either as a Malthusian apocalypse (Daly 1986) or the result of British trade policies (Woodham-Smith 1962). However, when analysed via through an entitlements lens, more insightful results are gained that highlight the multiple variables that allowed the event to have such vast impacts (Fraser 2003; Fraser 2006). When discussing the Ethiopian drought and famine, it can be seen that as with other weather events, drought decreases food production, but in combination with the social, economic and political drivers, the impacts are worse due to institutional weakness and a lack of donor trust, all of which slowly erodes the adaptive capacity of agricultural households.

2.2.5. Food Systems Through a Resilience Lens

What these case studies exemplify is that when researching disturbances in food systems, analysis cannot simply focus on the environmental trigger but must give equal weight to the social-ecological settings of the system prior to the occurrence of the disturbance and the differentiated impacts afterwards.

By applying the entitlements framework within a resilience framework that also incorporates a political ecology emphasis on the actors, all potential dynamics will be investigated. There is only one example in the literature of such an application – Fraser (2003), where the entitlements framework provides insight into the characteristics of the affected communities, whilst the resilience framework allows the thresholds to change to be examined within a system. However, as Fraser is limited to historical data and limited in empirical analysis there is a large gap remaining in the literature, i.e. the empirical analysis of changes in entitlements due to disturbances within food systems, particularly non-famine events, through a resilience lens.

Bringing the resilience lens to the fore is critical in that it allows the dynamics of food systems to be focused on, rather than the traditional perspective of equilibrium-centred views. Multiple sources are now arguing for such an integrated approach to human-environment interactions for food systems in the face of current global economic and environmental change (Ericksen 2008b; Thompson & Scoones 2009). A rapid and large disturbance to food systems in recent years has been land use change as a result of the expansion of biofuels.

2.3. Biofuels

Having outlined the resilience framework, highlighted the impacts of disturbances within food systems, and determined the importance of an entitlements lens to investigate such impacts, this review now focuses on the chosen disturbance to a social-ecological system incorporating a food system – the introduction and expansion of biofuels. Biofuels are fuels made from biological materials rather than fossil fuels such as oil, gas and coal. There are two categories:

1. Bioethanol - produced by the fermentation of plants high in sugar or starch – for example maize and other grains, sugar cane, and sugar beet – which can then either be used neat in special engines or blended with petroleum and used in standard vehicles (Fulton et al. 2004).
2. Biodiesel – produced from crops rich in natural oils (rapeseed, soybean, Jatropha), which are extracted, undergo transesterification and can then be blended with diesel, creating biodiesel (Fulton et al. 2004).

Both these methods come under the title of first-generation biofuels if they use traditional food-stuff commodities such as sugarcane, maize, and oil seeds as well as conventional methods. Second-generation biofuels are produced from non-food crops (e.g. switchgrass, miscanthus, crop residues), although the focus within the literature has been on biofuels produced from cellulosic biomass (Rajagopal et al. 2007). Although the Intergovernmental Panel for Climate Change (IPCC) considers second generation biofuels to be a key mitigation technology for the transportation sector, they also estimate that they will not be commercially available until 2030 (Intergovernmental Panel on Climate Change 2007). Therefore, the imminent focus of governments, businesses and researchers remains on first-generation biofuels.

2.3.1. Biofuel Policies, Production and Consumption

Such focus arose due to rising fossil fuel prices and increasing commitments to decrease greenhouse gas (GHG) emissions. Biofuels were seen as a 'silver bullet' with multiple benefits – potential GHG savings, a source of additional fuel security as an alternative to fossil fuels, and the ability to create rural development opportunities. Also, the ease of blending due to their chemical and physical properties means relatively minor adjustments were required to existing engine technology and fuelling infrastructure (Rajagopal et al. 2007). Hence, policies were quickly introduced in developed countries creating mandates for use of liquid biofuels.

Such mandates have been enacted in 72 countries, provinces or states in at least 19 countries, including 10 EU countries and 4 developing countries (REN21 2012). The majority of mandates require blending 10–15 per cent bioethanol with gasoline or blending 2–5 per cent biodiesel with diesel fuel. An example of such a mandate is the Renewable Transport Fuels Obligation (RTFO) introduced in 2003 in the UK which *"requires 2.5% (by volume) of transport fuel to be delivered from renewable sources by 2008/09 rising to 5% by 2010/11"* (Gallagher et al. 2008:17).

The latest (2012) Renewables Global Status Report estimates that production of liquid biofuels exceeded 107 billion litres in 2011, of which 86 billion litres were ethanol – a 17% increase from 2009 but 0.4% decrease from 2010 (REN21 2009; REN21 2012). 2011 was the first year where global production of ethanol decreased in the modern era of biofuel production. Traditionally, there are three main biofuel producing countries, production from whom is outlined in Table 2.2:

- USA, producing maize bioethanol,
- Brazil, producing sugarcane bioethanol,
- And Germany, producing rapeseed biodiesel.

Table 2.2. Ethanol and biodiesel production by the largest producing countries in 2011 (REN21 2012).

Rank	Country	Ethanol (million litres)	Biodiesel (million litres)	Total (million litres)
1	United States	54.2	3.2	57.4
2	Brazil	21.0	2.7	23.7
3	Germany	0.8	3.2	3.9
4	Argentina	0.2	2.8	3.0
5	France	1.1	1.6	2.7
6	China	2.1	0.2	2.3
7	Canada	1.8	0.2	2.0
8	Indonesia	0.0	1.4	1.4
9	Spain	0.5	0.7	1.2
10	Thailand	0.5	0.6	1.1
World Total		86.1	21.4	107.0

Although Asian and African countries represented a small share of annual production in 2010, countries here saw continued rapid growth. The global proportions of biofuel production are also reflected in the literature, as most peer-reviewed research refers to maize bioethanol in the USA, sugarcane bioethanol in Brazil, and palm oil biodiesel in Indonesia. Studies examining

Jatropha curcas in Sub-Saharan Africa and India are increasing but still proportionally low.

As the above discussion on policies alludes to, traditionally policies were initiated to produce biofuels that could be used domestically within transport blends, reducing the reliance on oil products of that country and resulting greenhouse gas emissions. As of 2011, worldwide mandates created the demand for 220 billion litres of ethanol by 2022, with expected demand driven primarily by Brazil, China, the EU and the USA (REN21 2012). However, new demands are being introduced to biofuel markets, particularly in light of the disjuncture between the prevalence of households reliant on biomass for cooking and lighting in the developing world and the low car-ownership. For example, highlighted as a hypothetical consumption for biofuels in the literature (Ewing & Msangi 2008; Ewing & Msangi 2009; Johnson 2013; REN21 2012; The Network of African Science Academies 2010; Practical Action 2010) schemes are now investigating replacing charcoal or biomass cookstoves with ethanol stoves (Novozymes 2011; Project Gaia 2013; Rajvanshi et al. 2007; Sesan et al. 2013) or biodiesel stoves (Kapilan et al. 2008; Wagutu et al. 2010; Dare et al. 2011).

2.3.2. Biofuels in the Literature

The majority of the earliest biofuels literature examined energy balances of biofuels – whether biofuels achieved the desired net effect of lowering carbon dioxide emissions compared to fossil fuels. Such studies used Net Energy Balances (measuring the biofuel energy content output compared to the fossil fuel energy inputs) or Energy Return on Investment (EROI), the ratio of energy obtained from an energy activity compared to the energy taken to generate that activity (Hill et al. 2006; B. D. Solomon 2010). Key early papers included Pimentel (2003), who reported the energy balances of biofuels were favourable until land conversion and carbon debts were incorporated. This debate led to a period where, overall, the literature was very critical of the majority of biofuels, because of the poor return of energy for the inputs required.

The main reason for such poor energy balances was land use change during land preparation, which involves deforestation or other such vegetation clearing. Such removal releases the organic carbon incorporated within that vegetation and soil via burning or fermentation (Fargione et al. 2008). Land-use change emissions combined with the emissions associated with inputs of fossil energy during the production and processing periods i.e. fertilisers, fuel use during transport, creates a 'carbon debt' – i.e. the amount of carbon dioxide released during the first 50 years after land conversion (Fargione et al. 2008). However, ameliorating this carbon debt are the avoided emissions from fossil fuel consumption due to substitution, because the biofuels themselves are carbon neutral as the emissions of carbon dioxide released during combustion are equal to the carbon dioxide absorbed during growth of the plants. Various reviews of EROI studies have found that for corn ethanol the EROI ranges between 1.1:1 to 1.65:1 (Farrell et al. 2006; Hill et al. 2006; Hammerschlag 2006) – a positive ratio if not a particularly high one. Corn bioethanol has widely been shown to be one of the least efficient biofuels, whereas cellulosic bioethanol and sugarcane bioethanol have much higher EROI ratios – 6.1<11.1 and 3.1<10.1 respectively (Farrell et al. 2006; Oliveira et al. 2005). Sugarcane is one of the most efficient biofuel feedstocks due to better growing conditions in tropical climates and fewer steps in the refining process (Goldemberg et al. 2008). However, the issue of land use change is still key in determining the energy balance as Fargione et al. (2008) demonstrate in Figure 2.7.

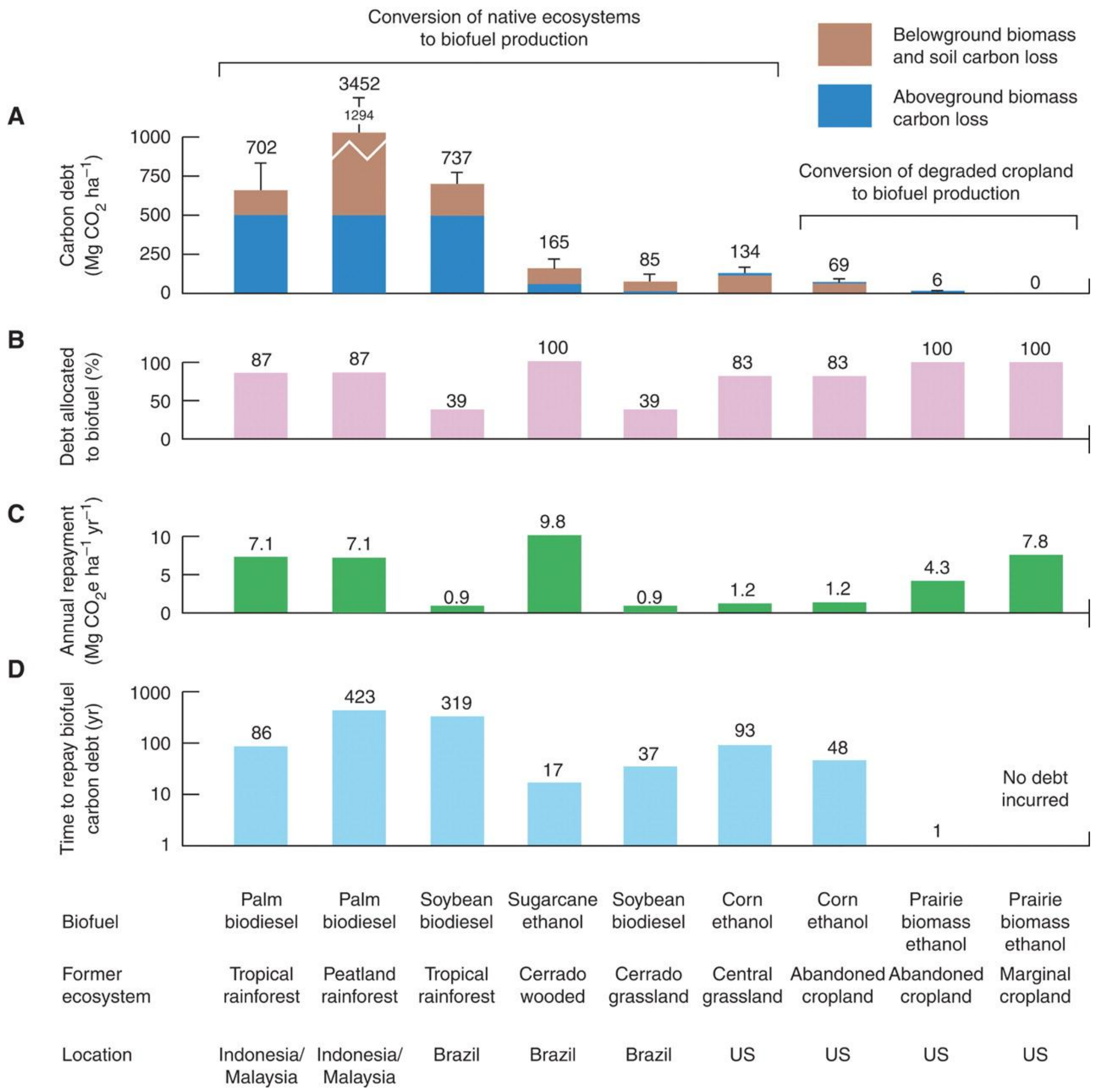


Figure 2.7. Carbon debt, biofuel carbon debt allocation, annual carbon repayment rate and year to repay carbon debt for nine biofuel scenarios (Fargione et al. 2008).

The focus on land use change led to a shift in the literature to Life Cycle Analyses (LCA) as the environmental impacts of biofuel expansion were realised and incorporated into energy balance studies. LCAs incorporate issues such as *"potential carbon debt, soil erosion, nitrate and phosphate nutrient losses, decreased ground and surface water quality, mixed effects on air quality, large water demand, and biodiversity loss"* (Solomon 2010:128). Practically there have been many issues with doing this in a systematic and robust manner in terms of energy or emissions.

LCA is defined as *"a cradle-to-grave approach that evaluates all stages of a product's life, from raw material acquisition to waste disposal, identifying, quantifying and evaluating the cumulative environmental impacts resulting from all stages in a product life-cycle"* (Pereira & Ortega 2010:78). In a practical sense it means *"a comprehensive environmental assessment of an industrial system, that considers both upstream and downstream inputs and outputs involved in the delivery of a unit of functionality"*, in this case a litre of ethanol or a hectare of feedstock land (von Blottnitz & Curran 2007:608). LCA studies focused on either the net energy balance, or net greenhouse gas emissions – especially carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). There are various tools available and examples in the literature of such analyses (Ofgem 2013; de Figueiredo et al. 2010; de Figueiredo & La Scala 2011; García et al. 2011; Panichelli et al. 2008; Wang et al. 2008).

The majority of studies show GHG emission savings – Solomon (2010:128) summarises the results of various review papers with the statement *"corn-based ethanol, biodiesel, sugarcane or cellulosic ethanol [net emissions] are lower by 10-20%, 40-50%, and 85-90% respectively"*. Again, this shows that sugarcane bioethanol is the most efficient and corn bioethanol the least. These results are not universal, with Pimentel & Patzek (2005) and Tilman et al. (2006) showing higher emissions, due to uncertainty over assumptions for prior land use, crop yields, nitrous oxide emissions and co-product energy content.

Von Blottnitz & Curran (2007) published a thorough review of 47 LCA assessments of bioethanol, highlighting the differences in methodologies and assumptions, and concluded that bioethanol in place or as an additive to conventional fuels leads to a net gain. Crop and climate productivity and the nature of the feedstock were the key variables, and so tropical sugar and cellulosic bioethanol were reported as the most promising feedstocks but the least analysed (von Blottnitz & Curran 2007). The paper also points out that analysis of other environmental impacts, for example acidification and ecological toxicity, are lacking in LCA studies (von Blottnitz & Curran 2007).

More recent literature has moved onto Embodied Energy Analysis Method or Emergy Analysis which *"considers the energy from petroleum necessary to prepare the industrial inputs used in a transformation process"* (Pereira & Ortega 2010:77). It analyses all the inputs necessary to drive a process, splitting them into two categories – nature's contributions and the inputs from the human economy (Pereira & Ortega 2010). Pereira & Ortega (2010) carry out an integrated life-cycle and emergy analysis for large-scale ethanol production from sugarcane in Brazil, analysing the energy balance and the associated environmental impacts. Their results indicated that for every 1 litre of ethanol produced, 1.82 kilograms of topsoil was eroded, 18.4 litres of water and 1.52 square metres of land are needed, and 0.28 kilograms of CO_2 is released (Pereira & Ortega 2010).

However, the majority of all such energy balance studies examine first generation biofuels in temperate countries. Whilst understandable, as the majority of biofuels produced currently today are first generation and were introduced by developed countries in temperate zones (i.e. US, Germany), the literature is lacking the increasing area of first and second generation biofuels in tropical areas – for example bioethanol from molasses (a waste product of sugarcane) in Southern Africa. One example is an LCA of sugarcane bioethanol production in Mexico, comparing five scenarios of feedstock (direct juice, B and C molasses) and fuel type (fuel oil or bagasse) (García et al. 2011). The LCA covered five phases – direct land use change, crop production, biomass transport to mill, industrial processing and ethanol transport, and incorporated fertilisation rates, field burning, fossil fuel consumption and co-product emissions. All five scenarios had positive energy balance ratios, with three above 4:1 (direct juice and B molasses); however, emissions due to land use change are the main contributor to total emissions, particularly when replacing tropical rain forests (García et al. 2011). The lack of data available in developing countries is also a factor in their lack of representation in the literature and may constrain the types of analysis possible.

2.3.3. The Ecological Impacts of Biofuels

As introduced in the above discussion, a large area within the biofuels literature is the ecological impacts of biofuel introduction or expansion - those that cannot be analysed fully within an energy balance. Again, Solomon (2010) highlights the main disturbances to the ecological sub-system:

- Biodiversity decreases due to land use change, which leads to habitat fragmentation and expansion of monocultures
- Soil salinisation due to intensive irrigation
- Soil erosion due to intensive irrigation and field clearance
- Reduced fertility of soils due to intensive production
- Water pollution due to run-off from farm inputs of chemical herbicides, pesticides and fertilisers
- Wastewater generation from processing that is released into water bodies and contains a high Biological Oxygen Demand (BOD)
- Large fresh water demands for irrigation and processing
- Air pollution from field burning during cultivation and also from increased VOC emissions from bioethanol-petrol blends

The majority of studies on ecological impacts are Brazilian bioethanol case studies cultivating sugarcane, due to the longevity of the biofuels industry in this country. They conclude that the main negative impacts are on biodiversity, soils and water quality. The deforestation and destruction of virgin high-biodiversity rain forest is irreversible, and causes the extinction of species along with a loss of ecosystem services (Goldemberg et al. 2008). Oil palm plantations have also been shown to have a large negative impact on biodiversity, as 55-59% of oil palm plantations in Malaysia occurred at the expense of primary forest (Koh & Wilcove 2008).

Sugarcane may actually reduce soil erosion, if burnt and harvested manually and residues are left on the surface, due to its long growing lifetime (5-7 years), but usually has a high erosion potential, as do other crops (for example soybeans) which also have negative soil nutrient effects (Smeets et al. 2008; Gasparatos et al. 2011). In order of decreasing soil erosion hazard, de Vries et al.

(2010) ranks common feedstocks in decreasing soil erosion hazard as: cassava, soybean, sugarcane, corn, sugar beet, winter wheat, oil palm, winter rapeseed. Alternatively, the trend for production on marginal land, for example with *Jatropha curcas*, can improve soil quality and control erosion if managed properly (Achten et al. 2008). The constant cultivation of monocultures reduces the soil fertility and increases the demand for fertilisers to keep production constant. Continual irrigation can also lead to salinisation of soils, decreasing yields.

Water availability is a key issue related to the sustainability of biofuels, especially in the face of climate change. Sugarcane has a very high water requirement, but within Brazil the climate is suited and cultivation is mostly rainfed, whereas in Africa and the US, irrigation is required for sugarcane and corn cultivation (Goldemberg et al. 2008; Gasparatos et al. 2011). Currently however, the total water requirement for biofuels is modest when compared to food production (de Fraiture et al. 2008). However, biofuel cultivation and processing and expansion will result in increased demand which could be an issue in countries under water stress and who experience increasingly unpredictable monsoons and droughts (Agoramoorthy et al. 2009). The processing of ethanol (and particularly sugarcane to ethanol) has a large water footprint – 21 m^3 per ton of cane in Brazil (Goldemberg et al. 2008). Water pollution is also a concern – irrigation and industrial use result in organic and inorganic pollutants that can leach into freshwater supplies and damage biodiversity of water bodies, for example in the Gulf of Mexico where 'dead zones' are attributed to nutrient runoff from increased corn and soybean cultivation (Donner & Kucharik 2008).

Impacts on air quality are mixed - there are studies showing benefits to urban air quality due to ethanol and biodiesel blending due to a decrease in sulphur emissions, lead ambient emissions, and aromatic hydrocarbons (i.e. benzene) (Goldemberg et al. 2008). However, the cultivation of feedstocks (particularly sugarcane) can have negative impacts on air quality due to fertiliser use, land-clearing by fire, sugar-cane burning, and volatile organic compound (VOC) emissions from oil palm (Gasparatos et al. 2011). The burning of sugarcane whilst in the field introduces a negative health impact due to inhalation of particulate matter (PM) in the resulting smoke. Particulates of concern include $PM_{2.5}$ (fine particulate matter) and polycyclic aromatic hydrocarbons (PAH) which are associated with various cancers (Cristale et al. 2012), crystalline silica polymorphs (Le Blond et al. 2010), and total suspended particles (TSP) which have been proven to have an acute effect on asthma admissions in Brazil (Arbex et al. 2007).

The literature concludes that large-scale biofuel feedstock cultivation produces mostly negative ecological impacts, as with any large-scale monoculture. However, depending on the feedstock, cultivation methods and scale, negative impacts can be reduced or even made positive. The majority of empirical studies address Brazil and not the more recent expansion of biofuel feedstocks due to the limited time during which data could have been collected and analysed.

2.3.4. The Social Impacts of Biofuels

A major criticism of the expansion of biofuel feedstock cultivation was the substitution of food crops and the impact this had on food prices. First generation biofuels are based on staple crops (corn and wheat), vegetable oils (palm) and key components of the food industry (sugarcane and soybeans), leading to direct competition with food production as well as indirectly via competition for land and labour. 'Food vs. Fuel' formed the first area of discussion within the literature on the social impacts of biofuels.

Fischer et al. (2009) calculated that 1.6% of cultivated land was used for biofuels in 2007, and that if 2030 targets are to be met, biofuel feedstock cultivation will reach 4-10% of total cultivated land (65-150 million hectares), a level of production that will significantly disrupt food production. Coinciding with the rapid introduction of biofuel policies discussed above, prices of basic agricultural commodities increased rapidly after 2006. An early section of the biofuels literature attempted to calculate what proportion of the increase can be attributed to the increased demand for biofuels from developed countries during this same period (Rosillo-Calle & Johnson 2010). Rosegrant (2008) estimated biofuels were responsible for 30% of the increase in weighted average grain prices, whereas Mitchell (2008) estimated 65%. The FAO simply concluded that biofuels were partly responsible, as were weather-related production shortfalls, historically low stock levels and increasing fuel costs (Food and Agriculture Organisation of the United Nations 2008). Whatever the proportion, the diversion of grain to bioethanol impacted on food security, particularly for poor rural smallholders who are net purchasers of food (Ewing & Msangi 2009; Zilberman et al. 2013).

Poor rural smallholders are also focussed on within the other large area of discussion within the social impacts of biofuels literature – that of direct competition with food production, and so biofuel production leading to indirect competition for land and labour (Cotula et al. 2008). The expansion of 'land grabs' for biofuel expansion resulting in the relocation of rural smallholders and pastoralists to make way for foreign and government biofuel schemes is an extension of this issue (Friends of the Earth 2010; Cotula 2011; Vermeulen & Cotula 2010; Cotula et al. 2009; Borras Jr et al. 2011).

Although an increasingly common example, biofuels are just one land-use driving the land grab phenomenon. Others include food production, plantation forestry, adaptation purchases to meet climate change and associated sea level rise, nature reserves and ecotourism to protect biodiversity, special economic zones, infrastructure, mining of precious minerals and metals, residential migration, access to water or hydropower, and land purchases by migrants in their countries of origin (Zoomers 2010; Zoomers 2011). Land grabs are of concern because of the rapid rate of allocation. Between 2008 and 2009 forty million hectares of land was distributed worldwide – twenty times the average rate of land transfer for the preceding forty years (Arezki et al. 2011). Whilst the majority of this is still speculative and not under production (Deininger et al. 2011), such a rapid driver to the global and regional social-ecological system opens the system up to new vulnerabilities. Therefore, there is concern that such large-scale investments will reduce access to resources for local farming communities, reliant on the ecological sub-system for their livelihoods, whilst directing the agricultural outputs to export markets (De Schutter 2011). In addition, the rapidity of the introduction of land grab schemes may lack transparency or community dialogue whilst accelerating the market for land, and in countries where tenure rights are informal or lacking, there is little protection for the existing users against displacement (Wolford et al. 2013). Such loss of access invokes a loss of traditional livelihoods and can have major negative impacts on food security (Cotula et al. 2008; Anseeuw et al. 2012).

The negative impact on food security resulting from substitution has been commonly reported in the literature, whether via a direct or indirect mechanism. Direct substitution of food crops for biofuel feedstocks has been reported as leading to decreased food self-sufficiency and hence security for smallholders and those involved in out-grower schemes (Ariza-Montobbio & Lele 2010; Schut et al. 2011; Ariza-Montobbio et al. 2010; Hunsberger 2010; German et al. 2011; Borras Jr et al. 2011; German et al. 2010; Schoneveld et al. 2011). However, German et al. (2011) found increased food production resulted from biofuel expansion as conversion was countered by the opening up of new land, whilst Skutsch et al. (2011) found that households only substituted cash crops for biofuel feedstocks, and Dyer et al. (2012) found that there was no substitution of food crops for *Jatropha curcas* in Malawi. Indirect impacts also resulted in reduced food security, via decreased fodder production leading to decreased animal husbandry (Findlater & Kandlikar 2011) or via collapses of the feedstock market resulting in a loss of income (Hought et al. 2012).

However, biofuel policies in developing countries often focus on the opportunity to create rural development opportunities, so to benefit these small rural smallholders, specifically via job and income creation (Ewing & Msangi 2009; Bekunda et al. 2008). In this respect, biofuels can contribute to human wellbeing and be an agent of poverty alleviation by creating formal job opportunities where traditionally large proportions of the population are not in formal employment (Cotula et al. 2008; Borzoni 2011). There were few empirical studies of the impacts on rural development until recently, of which the majority relate to involvement in out-grower schemes.

Goldemberg et al. (2008) however do analyse the employment within the sugarcane industry in Brazil and conclude that the system is characterised by large-scale producers employing non-specialised workers (700,000 for every 300 million tons of sugarcane produced), and that wages tend to be higher than for other agricultural jobs. Other studies highlight the ratio of employment during different stages of introduction, and that the majority of employees are required solely during plant construction, after which skilled employees are required and there will be few opportunities for surrounding unskilled workers, limiting rural development opportunities (Solomon 2010). There may however also be indirect job creation in the surrounding areas due to financial leakage (Solomon 2008). A study of Indonesian palm oil corroborated this as it calculated that in 2001, whilst only 1,000 people were directly employed, up to 4.5 million Indonesians depended on the palm oil industry due to downstream processing, associated services, and family dependents (Cassman & Liska 2007).

More recent empirical data within the literature reports that large-scale biofuel production has resulted in labour opportunities and new economic activities and across crops, scales of production and geographies. For sugarcane, the potential for job creation was dependent on mechanisation (Borras Jr et al. 2011) whilst the expansion of palm oil had increased wage labour opportunities for some farmers, while marginalising others (McCarthy 2010; Obidzinski et al. 2012). Despite low employment on soy plantations, soy was considered synonymous with income generation due to the arrival of urban services such as access to schools, health care and professional development services (Lima et al. 2011).

Conversely, although the theoretical literature regarding job creation in out-grower schemes reports that greater benefits could be produced in out-grower schemes due to the generation of livelihood opportunities, land rents being appropriated by smallholders rather than estate owners and the increased access to technologies and knowledge (Beall 2012), this has not be found in the empirical literature. Instead it is widely reported that involvement in biofuels, particularly those cultivating *Jatropha curcas* in out-grower schemes in Africa and Asia, has led to issues such as reduced household income, increased social disparity, poor contract conditions and reduced access to land (Lima et al. 2011; Obidzinski et al. 2012; McCarthy 2010; Ariza-Montobbio & Lele 2010; Schoneveld et al. 2011; Findlater & Kandlikar 2011). Such negative implications for smallholders are likely to be due to the nature of the biofuels industry, which allows the better resourced and connected agri-business actors to capitalise on the opportunities from increased demand for biofuels (Cotula et al. 2008; Tomei & Upham 2009).

There is still the potential for smallholders to benefit, particularly for smallholders selling directly to the market who can add value to their products (Ejigu 2008). However, such benefits will be easier to realise if the value-added stages, i.e. processing and refining, take place at the site of cultivation (Mol 2007). If this is achieved, Arndt et al. (2008) found that for Mozambique, the positive effect on GDP would be greater with decentralised out-grower units than large-scale estates, and could then contribute up to 0.6% of GDP, decreasing poverty by 6% over a 12 year period.

The expansion of biofuels also has implications for health. For example, if the use of biofuels was diverted towards household energy – reducing the use of biomass as the Total Primary Energy Supply (TPES) – the expansion of biofuels could have huge welfare benefits for the rural and urban poor. The use of biofuels in the agricultural, industrial and residential energy sectors could allow a range of applications including off-grid electrification, household energy, small machinery power, irrigation pumping and food production equipment (Ewing & Msangi 2009). The FAO has said that sustainable pro-poor bioenergy development could represent an *"answer to the needs of the 1.6 billion people who lack access to electricity and could also improve the lives of 2.4 billion who rely on traditional biomass"* (Brittaine & Lutaladio 2010:10).

Substitution is key as the use of biomass (i.e. wood fuel, charcoal) within the household for open fires and cooking stoves is not only inefficient, but is a source of air pollution and responsible for the high rates of health issues such as acute respiratory infections (ARIs) in developing countries (Robinson 2006). ARIs are thought to be responsible for the death of over two million children under five worldwide (Smith et al. 2000). Consequently, the substitution of traditional biomass for biofuels could have significant health benefits, particularly for women and children who traditionally suffer more from ARIs because they are based within the home. Substitution would also reduce deforestation in the immediate area or increase the proportion of agricultural residues returned to agricultural land, whilst allowing households to move up the energy ladder. There would also be time savings for women, who traditionally collect biomass fuels, who instead could carry out other income-earning activities, education, or simply have leisure time.

To synthesise the above discussions regarding the social impacts of biofuels, Hodbod & Tomei (2013) present a systematic review of the peer-reviewed literature presenting empirical data regarding social impacts of biofuel expansion at the local (household and community) scale. The review identified just seventeen empirical research papers out of 582 referencing social impacts, and three issues emerged as especially important at the local level, as reflected in this chapter: reduced food security, reduced household incomes and reduced access to ecosystem services (Hodbod & Tomei 2013).

The discussions above show that the costs and benefits of biofuel production are unevenly differentiated within and between communities, with consequences for the ways in which social, economic and environmental impacts are experienced. The small number of empirical studies as shown in Hodbod & Tomei (2013) confirms a knowledge gap remains regarding the impacts of biofuels on social-ecological systems at the local level. More evidence is needed to further investigate the dynamics of this complex issue and stimulate a more nuanced understanding of the winners and losers of this commodity. The above discussion outlines that biofuels may actually have the potential to provide benefits to social-ecological systems. However, the literature is lacking studies that empirically examine such social and ecological impacts, whether they are positive or negative. Also lacking are multi-scale, integrated assessments of the impacts of biofuel expansion on the environment, economy and social systems.

2.4. Biofuels and Food Systems through a Resilience Lens

In summary, the above discussions outline the multiple impacts biofuel introduction and expansion will have on social-ecological systems, specifically those with a food system component. Biofuel expansion will influence both fast and slow variables, for example systematic land use change will impact the availability of food at larger scales whilst creating ecological disturbances, as well as access to food, due to indirect impacts on food prices, job creation and welfare impacts at smaller scales. Whilst there are some publications that attempt to address either bioenergy and the adaptive cycle (Grundmann et al. 2012), biofuels and scalar dynamics (Schut et al. 2013), transformation in energy systems (Smith & Stirling 2010; Geels 2002; Dangerman & Schellnhuber 2013; Turnheim & Geels 2012) or food systems and resilience (Fraser 2007) there are no combinations examining a whole biofuel system and its resulting disturbances through a social-ecological resilience lens. There are therefore many literature gaps, highlighted in this chapter, that can be filled by such a study and these are summarised below:

- The majority of systems analysed through a resilience framework examine the impacts of social change on ecological systems. There is a lack of empirical data regarding the impacts of changes in human management on ecological systems and then resultantly on the social system.
- Food systems have rarely been addressed through a resilience perspective and there is again, a lack of empirical data in such studies.
- The food security literature focuses on food emergencies such as famines, both of human and natural causes. There is a knowledge gap when examining the impact of slow variables on levels of food security, particularly regarding empirical food system entitlements data.
- The biofuels literature focuses on the energy efficiency of large-scale first generation biofuels, usually in temperate zones, i.e. US maize-bioethanol, not tropical, second generation, biofuels.
- Within the biofuels impacts literature there is very little empirical data on both the social and ecological impacts of biofuel production and there

are very few multi-scale, integrated assessments of biofuel expansion incorporating both production and consumption.

- There is a geographical bias towards the sugarcane biofuel system in Brazil and recently *Jatropha curcas* systems in Asia and Africa.

This study therefore aims to presents a systems analysis of a biofuel system undergoing expansion through a resilience lens. The study will investigate disturbances to the social-ecological system at multiple scales as well as disturbances to the consumption system, allowing the impacts on social-ecological resilience that emerge to be identified. The multiple scales perspective is critical in creating a thorough analysis, due to the cross-scale interactions as discussed above. These interacting scales are depicted in Figure 2.8, which outlines the main scales where impacts occur.

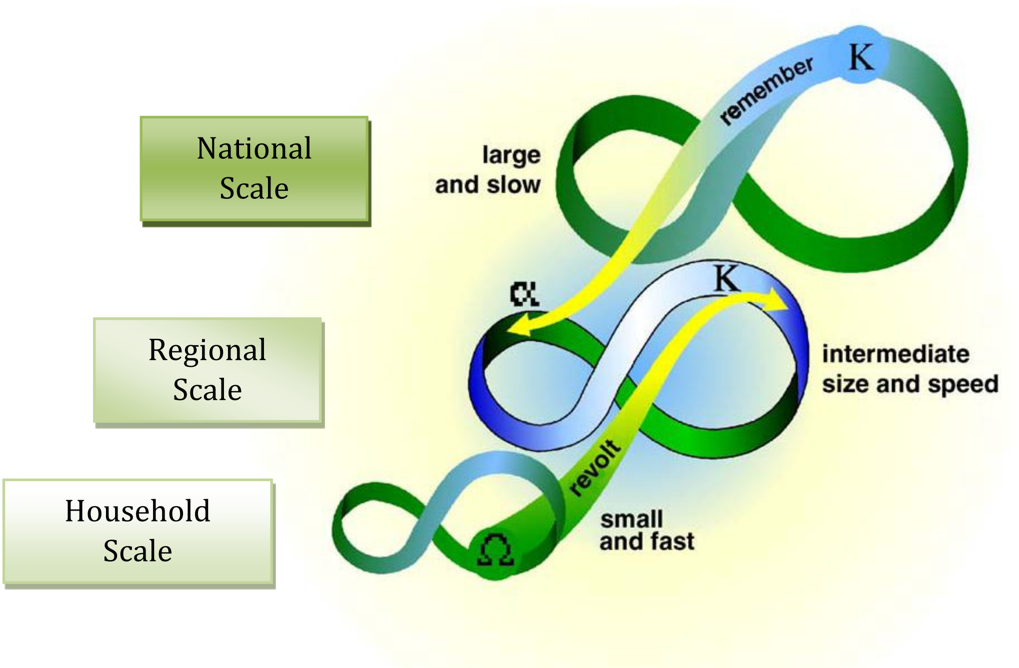


Figure 2.8. The panarchy underlying this study (adapted from Holling & Gunderson, 2002).

2.5. Research Questions Emerging from the Literature

There are three main hypotheses when investigating the impact of biofuel expansion on SES at a broad scale:

- That biofuel feedstock expansion will reduce the access to food for consumers within food systems.

- That decreasing food production will have negative impacts on access to foodstuffs in the market.
- That the expansion of large-scale agriculture will have negative ecological impacts on the surrounding land and water.

When combined with the highlighted literature gaps above, these hypotheses allow the research questions to be formed at the appropriate scale of interest.

Household Scale (Production) - "How does the expansion of biofuels affect the social-ecological resilience of food systems?"

By studying the roles of production, consumption, income and access in a household the diversity of entitlements and other measures of food security can be compared across multiple groups at a household level. Key actors discussed in the literature include farming households involved in the production of biofuel feedstocks as smallholders or estate workers; non-farming households involved in the production of biofuels; or those entirely separate from the entire biofuels production chain. It is hypothesised that the production of biofuels will compete for land with food crops, leading to a reduction in food production – either at a large scale by removing smallholders from their land, or at a small scale as smallholders alter their crop production to access attractive markets, either of which could lead to a 'direct entitlement decline'. Alternatively, the reduction in food production will lead to increased competition for the crops that are produced and higher food prices. Increased food prices will lead to 'exchange entitlement decline' as consumers can afford less food per unit of money than prior to biofuel expansion. The analysis based on this research question will present the results of the food system analysis, applying an entitlements framework to examine access to food with the current level of biofuels production as well as other complementary methods to build up a thorough analysis of a complex system. The chapter will address these issues over a period of time to measure change due to the expansion of biofuels. Therefore, these specific research questions will be addressed:

- What is the current aggregate level of entitlements for those populations hypothesised to be affected by the expansion of biofuels?

- What is the current diversity of entitlements for those populations hypothesised to be affected by the expansion of biofuels?
- How has the aggregate level and diversity of entitlements changed since expansion of biofuels began in the area four years ago?
- Do other measures of food security concur with the results of the entitlements assessment?
- What are the key mechanisms that have influenced entitlements and food security?
- What are the resilience implications from the measured levels of change in food security?

Regional Scale (Production) - "How does the expansion of biofuels affect the resilience of the regional social-ecological system?"

It is hypothesised that expansion of biofuel feedstock estates will erode the resilience of the regional landscape due to:

- Decreased diversity as proportion under biofuel feedstock increases
- Soil nutrient mining and increased reliance on fertilisers
- Increased soil erosion and compaction
- Chemical run-off into water bodies
- Increased water footprint

To answer this research question, empirical data regarding the ecological disturbances resulting from biofuel production will be collected to create a life-cycle analysis. Additionally a carbon balance will be created, and where the data allows, conclusions as from an emergy study will be made – i.e. the water footprint of the ethanol, as the literature shows these are the best available data proxies for ecological impacts. Therefore, the thesis will address this specific research question:

- What are the impacts on the ecological sub-system from
    - Cultivation;
    - Harvesting;
    - Processing sugar;

- And processing ethanol?

Household Scale (Consumption) - "How does the use of ethanol as a household fuel affect the resilience of a household?"

The use of biofuel as a household fuel is being promoted as a substitute for both biomass and kerosene in lower income households and natural gas and electricity in higher income households. Substitution will be treated as a disturbance to the system at the household scale, from which the impacts on the resilience of the household will be measured. It is hypothesised that substitution may enhance the resilience of a household due to the environmental, health, and time benefits of replacing biomass fuels. Alternatively, if the biofuel is priced too highly, substitution will erode the resilience of the household by increasing the proportion of disposable income spent on fuel. Therefore, these specific research questions will be addressed:

- Are the hypothesised beneficial impacts of biofuel stove uptake realised?
- What are uptake rates of biofuel stoves?
- What are the barriers to uptake?
- What is the potential market for biofuel stoves?

National Scale - "How does the expansion of biofuels affect the resilience of the national social-ecological system?"

Analysis at the national level will synthesise the data presented from both the production and consumption systems at smaller scales with primary interview data and secondary data to examine the impacts on resilience of affected SES when disturbed by the expansion of biofuels, requiring analysis at multiple scales to conclude with an investigation of the dynamics at the national scale. By synthesising these smaller scales adaptive cycles can be created displaying the dynamics from the household up to the national scale. At each scale the differentiated impacts on actors can also be highlighted within the dynamics of the adaptive cycle. Therefore these specific research questions will be addressed:

- How have the dynamics of the SES changed with the expansion of biofuels?
- Has the expansion of biofuels caused any thresholds within each the sub-systems to be exceeded? If so, have any regime shifts occurred?
- What are the differentiated impacts on actors within the system under study?

The remainder of this thesis will answer these research questions.

3. Research Design, Study Area Selection and Methodology

This study aims to contribute empirical and analytical knowledge about the impacts of biofuel expansion on social-ecological systems at multiple scales in Ethiopia. The investigation of the research questions outlined in the previous chapter requires the use of multiple research methodologies, modified to fit the scale at which the research question applies. This chapter provides an overview of the research design applied, the system investigated in Ethiopia, further context regarding the case study sub-systems and an overview of the methodologies applied so to answer the research questions.

The overall research questions are as follows:

1) How does the expansion of biofuels affect the resilience of actors within local food systems?
2) How does the expansion of biofuels affect the social-ecological resilience of the regional system?
3) How does the introduction of ethanol stoves affect the resilience of actors within the consumption sub-system?
4) How does the expansion of biofuels affect the resilience of social-ecological systems at different scales in Ethiopia, from household to national?

3.1. Research Design

To answer these research questions requires four different empirical areas of study that in combination create a logical research design:

1) Examining the diversity of entitlements and other measures of food security at a household scale for populations surrounding an expanding sugar estate, using a quantitative survey;
2) A life cycle analysis of the interactions of the sugar estate with the ecological sub-system at the regional scale, synthesised via a carbon balance;
3) A quantitative survey investigating the impacts of the adoption of ethanol as a household fuel, barriers to uptake and its potential given the current urban energy regime;

4) The impacts of biofuel production and consumption on the national social-ecological system at the current scale of operation and the planned scale of operation, synthesising the quantitative data presented in the above three studies and supplementing it with primary data from interviews and analysis of secondary data.

This interdisciplinary methodological approach, applying both quantitative and qualitative methods, is required due to the range of research questions to be studied and allows the synthesis of analysis of the social and ecological sub-systems to highlight the major impacts on the resilience of the system. The assessment framework created by the Resilience Alliance forms the basis of the research design (Resilience Alliance 2010a). The research questions lend themselves to the study of one particular example of biofuel expansion, with disturbances at multiple scales. The process of selecting the biofuel system under study is outlined below.

3.1.1. Biofuels in the Global Context to Inform Choice of Study Area

To select a biofuels system in which to address the research questions, various countries producing biofuels were initially considered. It was decided to address the research questions in a developing country that has recently begun to produce or expand its biofuel production. As the study aims to address a biofuels system that included the novel consumption of biofuels as a household fuel, the potential for this was a key factor. Countries with a high proportion of biomass within the Total Primary Energy Supply (TPES), resulting in deforestation and burden of disease due to wood-smoke inhalation, were identified. Those where biofuels were a viable household fuel – judged via experience of such technology in the country – are Brazil, Ethiopia, India, Kenya, Malawi, Mali, Mozambique, Nigeria, Senegal, South Africa, Sri Lanka, Tanzania and Zimbabwe (Jumbe et al. 2009; Rajvanshi et al. 2004; Novozymes 2011; Robinson 2006; Bizzo et al. 2004; Project Gaia 2013; Jackson 2012; Utria 2004). Multiple key variables of nations producing biofuels were plotted to further compare the countries:

- Primary or secondary biofuel production?

- Are the biofuels for export or for domestic use?
- Does production require direct land use change or substitution from existing agricultural land?
- Is the production subsidy or market driven?
- Is the intended end use the transport or household fuel sector?

Figure 3.1 presents the distribution of these countries within the variables presented above.

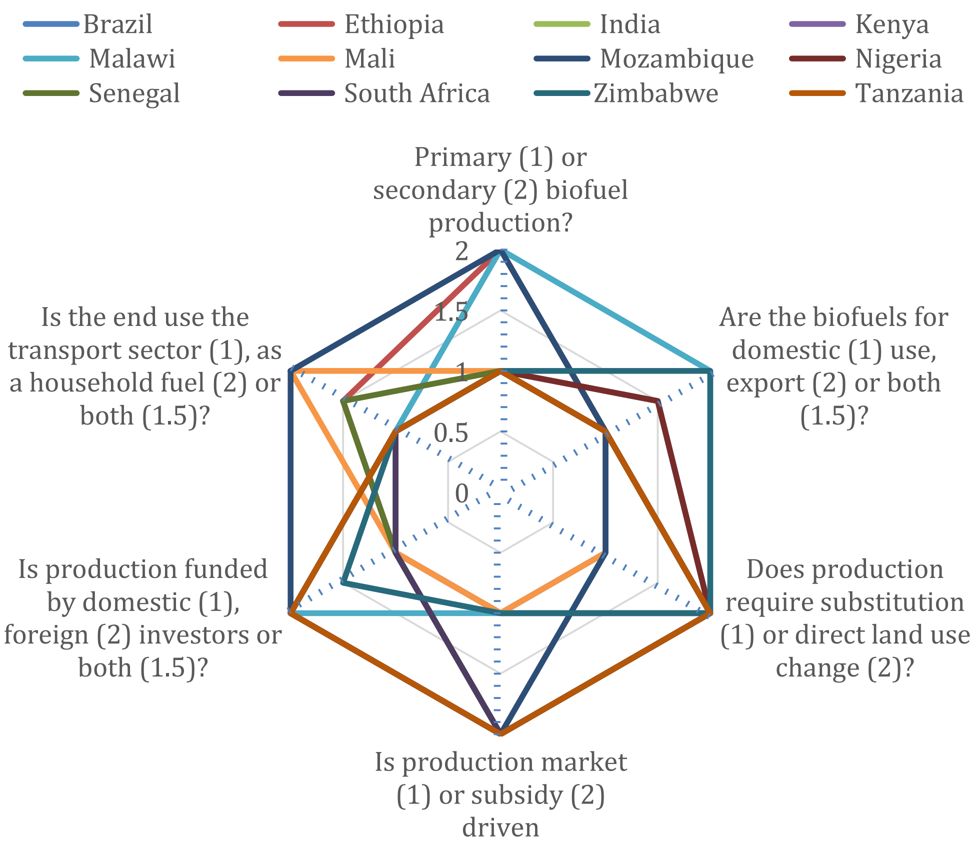


Figure 3.1. The distribution of biofuel systems across key variables for a range of developing countries.

Ethiopia is a unique example of a biofuels system, particularly in Africa. Its production and consumption has a domestic focus – funded and managed by the Ethiopian Government for consumption within Ethiopia so to reduce foreign exchange on oil products. However, its production system is different to those with a similar consumption regime – i.e. Brazil, as shown in Figure 3.2 - as the biofuel is a secondary biofuel (ethanol from molasses not sugarcane directly) but large areas of land are being converted for its cultivation. In addition, Ethiopia was chosen because its familiarity with ethanol (its main biofuel output) as a household fuel was at a national governance level – Ethiopia's biofuel policy mandates utilisation in both transport and domestic energy. At the time of selection (2010) this contrasted with other Africa countries familiar with household energy, such as Mozambique, who did not have a policy dictating such, but were focusing on ethanol as a household fuel funded by foreign investors because of the market benefits.

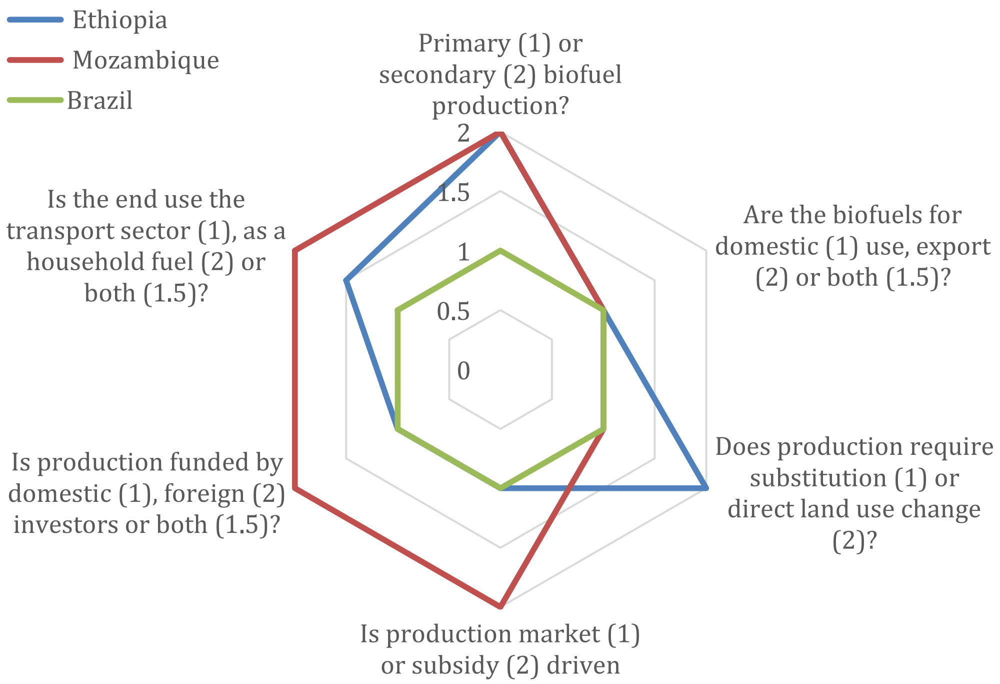


Figure 3.2. The distribution of Ethiopia, Mozambique and Brazil across the key variables concludes that Ethiopia is different as it has a biofuel system that has few external disturbances, is domestically funded and diverts its output for domestic consumption.

Therefore, this thesis will investigate the expansion of biofuels in Ethiopia, a landlocked country with a rapidly growing population and therefore an increasing demand for energy. The Federal Democratic Republic of Ethiopia has an estimated population of 94 million distributed across 1.1 million square kilometres, with a population growth rate of 2.9% (Central Intelligence Agency 2013). The second most populous country in Africa, data from the last census reported that 84% of the population resides in rural areas and derives their livelihoods from agriculture, resulting in agriculture accounting for 47% of GDP (which totals $103 billion) and 84% of exports (Central Intelligence Agency, 2013). Imports and exports are estimated to be $10.6 billion and $3.2 billion respectively in 2012 (Central Intelligence Agency, 2013). Key agricultural products include cereals, pulses, coffee, oilseed, cotton, sugarcane, khat, cut flowers and livestock products. Although GDP growth has remained high (7% real growth rate in 2012), per capita income is among the lowest in the world and 29% of the population are below the poverty line (Central Intelligence Agency, 2013).

3.2. Biofuels in Ethiopia

The Ethiopian Government has promoted biofuels as a key aspect of its economic development plans and introduced the 'Biofuel Development and Utilisation Strategy of Ethiopia' in 2007, the goal of which is to *"produce adequate biofuel energy from domestic resources for substituting imported petroleum products and to export excess products"* (Ministry of Mines and Energy, 2007:9). The Ethiopian policy is an unusual example of a biofuels policy as it not only outlines that the biofuels produced are primarily for use within Ethiopia and only for export secondarily but also dictates their use as a household fuel – as a substitute for the kerosene and biomass fuels still relied on by the majority of the population.

Ethiopia is 100% reliant on oil and petroleum imports, spending $0.9 billion on oil imports in 2011 – 8% of its total import bill and a figure which will only increase with increasing prices of oil products and an increasingly mobile population (Ethiopian Petroleum Enterprise, 2011b; Central Intelligence Authority, 2013).

It is also familiar with biofuel technologies, as ethanol has been produced from molasses within Ethiopia since 1999, as a secondary biofuel following the production of sugar from sugarcane. In 2009/10 Finchaa Sugar Factory produced 7.1 million litres of ethanol, 89% of its full capacity. The immediate demand was for the continuation and expansion of the mandated transport blend. The 2007 policy formalised this mandate whilst dictating a much larger expansion of biofuels for domestic transport use, from 8 million litres per annum to 128 million litres in 2012/13 (Ministry of Mines and Energy 2007). The planned expansion will be realised by constructing more sugar estates with ethanol mills attached, as well as constructing ethanol mills at the two sugar estates without them.

The first of these estates to undergo expansion is Metehara Sugar Factory (MSF) in the south east of Ethiopia. Prior to expansion in 2010, MSF cultivated 10,000 hectares of sugarcane. Expansion will occur at a neighbouring site (Kesem) so to increase cultivation to 30,000 hectares by 2012/13 and the construction of an ethanol mill in 2010/11 will produce 10 million litres of ethanol. The expansion will create another 10,000 jobs across both sites.

3.2.1. Current Governance of Biofuels in Ethiopia

The Ethiopian Government published the 'Biofuel Development and Utilisation Strategy of Ethiopia' in September 2007, through the Ministry of Mines and Energy (Ministry of Mines and Energy 2007). As stated above, the overall goal of the Strategy is to *"produce adequate biofuel energy from domestic resource for substituting imported petroleum products and to export excess products"* (Ministry of Mines and Energy, 2007:9). The general objectives of the Strategy are to:

- *"Substitute mineral fuels by locally produced biofuels, in order to save and earn foreign exchange;*
- *Contributing to rural development through agricultural based growth by creating jobs in feedstock production, biofuel manufacturing, and in transporting and distribution of feedstocks and products;*
- *Reduction of environmental pollution by harmful pollutants from vehicle exhausts (GHG emissions)" (Ministry of Mines and Energy, 2007:10).*

The objectives of the Biofuel Strategy therefore reflect the first three objectives of the Growth and Transformation Plan of Ethiopia, which has seven key pillars:

- *"Sustaining faster and equitable economic growth*
- *Maintaining agriculture as a major source of economic growth*

- *Creating favorable conditions for the industry to play key role in the economy*
- *Enhancing expansion and quality of infrastructure development*
- *Enhancing expansion and quality of social development*
- *Building capacity and deepen good governance*
- *Promote women and youth empowerment and equitable benefit" (Ministry of Finance and Economic Development 2010:22).*

The Growth and Transformation Plan is a medium term (2010/11–2014/15) development plan published by the Ethiopian Government as a strategy for the overall development of the country. It replaces the Plan for Accelerated and Sustained Development to End Poverty (PASDEP), which was judged by the Ethiopian Government to be highly successful and responsible for large scale economic and social development. PASDEP strategies resulted in attaining the minimum goals and targets set by the Millennium Development Goals in addition to strong economic growth, as displayed in Table 3.1.

Table 3.1. Growth targets for the main sectors of the Ethiopian economy. The growth targets outlined in the PASDEP were exceeded in all sectors but industry (Ministry of Finance and Economic Development 2010a).

Sector	Average growth targets (2005/06 - 2009/10)		Average growth achieved (2005/06 - 2009/10)
	Base case scenario	High case scenario	
GDP (%)	7.0	10.0	11.0
Agriculture and allied activities	6.0	6.4	8.0
Industry	11.0	18.0	10.0
Service	7.0	10.3	14.6

Due to the success of PASDEP, the GTP targets are set even higher – to maintain at least an average real GDP growth rate of 11% per year and meet all the Millennium Development Goals – so that continued growth will contribute to Ethiopia's goal of becoming a middle-income economy by 2020–2023 (Ministry of Finance and Economic Development 2010a). Achieving these targets, however, will require very large productivity growth and huge amounts of financial resources anticipated to be sourced from increased domestic saving mobilization, foreign direct investment, and foreign borrowing.

The ordering of the objectives within the Biofuels Strategy is atypical from that of the majority of countries producing biofuels, although not surprising for a developing country – foreign exchange is the primary focus rather than benefits regarding climate change. The Strategy describes how Ethiopia has a large labour force, land potential and a suitable climate for the development of biofuels and therefore has the potential to supply the international market, strengthening its international finance and technical cooperation (Ministry of Mines and Energy 2007). However, the Strategy recognises the shortcomings of biofuel production as outlined in the literature and Chapter 2 and addresses them within the seven principles for the implementation of the Strategy:

- *"Food security should be supported;*
- *The land and water rights of farmers and pastoralists should not be subject to negative effects, and economic development, environmental and cultural values should be maintained;*
- *Farmers and pastoralists should participate and share the benefits*
- *Environmental sustainability should be maintained- i.e. soil fertility, water quality and biodiversity;*
- *By-products of biofuels should be utilised to provide economic benefits;*
- *Ethiopia's economic resource development should be maintained;*
- *The development of biofuels should conform to the international effort on the mitigation of greenhouse gas emissions" (Ministry of Mines and Energy, 2007:10).*

The Strategy outlines both the expansion of ethanol and biodiesel. Whereas ethanol feedstocks are limited to sugarcane, the proposed biodiesel feedstocks include jatropha, castor and palm. The production of biodiesel has not been realised yet in Ethiopia, with some foreign investors beginning cultivation but none reached the processing stage before stopping their operations. Due to the lack of biodiesel operations currently active in Ethiopia, this study only investigates ethanol. Specifically relevant to ethanol, section 7.3.1 of the Biofuels Strategy outlines the objectives of the policy as:

- *"To commence low level mix of ethanol with benzene for use by vehicles and to increase the share of ethanol in the mix.*
- *To ensure that government establishments play a leading role in the use of ethanol.*
- *To ensure that benzene driven imported vehicles are fit for mixed fuel of which ethanol has a relatively higher level of share. To devise incentives to encourage the import of Flex Fuel Vehicles (FFV) and to issue and enforce directive accordingly.*
- *To substitute ethanol for domestic fuel. Study and create favourable conditions for the domestic manufacturing, efficiency improvement and use of these bio-ethanol stoves and equipments.*
- *To facilitate export market for ethanol production when the national need is satisfied" (Ministry of Mines and Energy, 2007:11).*

To achieve these objectives the Government has initiated ethanol production via the nationalised sugar estates, as described below.

3.2.2. Sugarcane Ethanol Governance in Ethiopia

Sugarcane has been cultivated commercially in Ethiopia since the 1950s, when Handels vereniging Amsterdam (HVA, a Dutch company) established the sugar estates of Wonji-Shoa and Metehara in 1954 and 1968, respectively. There have been two governance shifts of sugarcane due to changes at the national level – the initial Dutch managers (HVA) were removed and the estates shifted under the control of the nationalised Sugar Corporation following the collapse of socialism and establishment of the Mengistu Government in 1975. In the early 1990s the nation transitioned from the Mengistu Government to rule by the Ethiopian People's Revolutionary Democratic Front (EPRDF) which resulted in the liquidation of the Sugar Corporation in 1992. After this the individual estates became autonomous public enterprises, although federally managed via the Ethiopian Sugar Development Agency (ESDA). Finchaa Sugar Factory was constructed by the ESDA in 1998. The main objectives of the ESDA were to implement government sugar development policies whilst making the public sugar enterprises efficient, modern and competitive (Ethiopian Sugar Development Agency 2010).

In 1979 the Sugar Corporation initiated discussions about the production of ethanol from molasses to be used as a gasoline additive. The other actors involved were the Ministry of Industry and UNIDO, who paid for a feasibility study to be carried out by the State Alcohol Monopoly of Finland Ltd. (Fessehaie 2009). Further to this, another feasibility study was carried out in 1984 by SOFRECO (a French consultancy) but again was not acted upon. A Technical Committee was set up in 1999, bringing together all the relevant actors to address successful commercialisation of alcohol fuel and as a result, the construction of Finchaa included an ethanol mill from which production began in 1999 (Fessehaie 2009).

In 2000, as a result of the Technical Committee's findings, the Federal Government's Council of Ministers issued the 'Council of Ministers Directive on the Production, Distribution and Control of Ethanol-Gasoline Blended Fuel'. The Directive outlined the blending of up to 10% ethanol with gasoline as a transport fuel. The regulation was not enforced until October 2007 due to *"unsettled problems with the oil companies"* (Bayissa, 2008:225). A further feasibility study in 2004, also carried out by SOFRECO, concluded that the expansion of Finchaa Sugar Factory was economically viable, but did not appear to appease the oil companies.

In 2010 the ESDA reverted back to the name the Sugar Corporation (Council of Ministers 2010) and announced massive expansion of sugarcane cultivation, sugar and ethanol production within Ethiopia, as outlined in the Growth and Transformation Plan and discussed below in section 3.2.3. In summary, the sugar estates producing ethanol run autonomously but receive capital from the Government-run Sugar Corporation and sell their sugar and ethanol through the same institution, which is directly under the Prime Minister's Office i.e. not within the Ministries for agriculture or energy. There are other government ministries linked to biofuels, but they have very little to do with ethanol production and are mostly linked to foreign direct investment for biofuels:

- Biofuels Development Directorate - now based in the Ministry of Water and Energy. Prior to 2011, the Ministry of Mines and Energy was responsible for biofuels, within which the Ethiopian Rural Energy Development and Promotion Center (EREDPC) was the office where the Biofuels Development Co-ordinator was based
- Ethiopian Investment Agency
- Ministry of Agriculture and Rural Development
- Ethiopian Petroleum Enterprise
- Ministry of Transport and Communication,
- Ministry of Finance
- Environmental Protection Authority (Heckett & Aklilu 2008).

3.2.3. Sugarcane and Ethanol Production

As noted above, there are currently three sugar estates operational in Ethiopia. Outputs prior to expansion are shown in Table 3.2.

Table 3.2. Annual sugar and ethanol capacity in Ethiopia in 2010, prior to expansion as a result of the Growth and Transformation Plan (Sugar Corporation 2013c; MSF Management 2011; Ethiopian Sugar Development Agency 2011).

		Wonji-Shoa	Metehara	Finchaa	Total
2008/ 2009	Land under sugarcane (ha)	4,200	10,300	9,200	**23,700**
	Sugar production (tonnes)	75,000	137,000	110,000	**322,000**
	Ethanol production (litres)			8,000,000	**8,000,000**

The sugar produced is 'plantation sugar', which is not as refined as white sugar in European markets. Ethanol at Finchaa is produced from molasses and is therefore classed as a secondary biofuel as the molasses are a waste product of sugar processing. In the 2000s there were, on average, 51,000 tonnes of molasses produced per year from sugar production and were used as a road covering, fed to livestock, or dumped in rivers. The lack of available molasses has occasionally limited ethanol production – the last disruption to production was in 2010-11.

The Growth and Transformation Plan (GTP) (2010<2015) outlines the expansion of sugarcane and ethanol production in line with the 'Green Development' Strategy and couples this with the expansion of medium and large scale irrigation from 2.5% of land coverage in 2010 to 15.6% in 2015 (Ministry of Finance and Economic Development 2010a). This expansion translates to an additional ten sugar estates in Ethiopia during the 2010-2015 period (Davidson 2011). The total capacity of the expanded production totals 2.3 million tonnes of sugar and 304 million litres of ethanol, but estimates of production range between 2.3<3.4 million tonnes of sugar (Sugar Corporation 2013c; Ministry of Mines and Energy 2007; Ministry of Finance and Economic Development 2010a). Such a massive increase in scale potentially produces a different balance of winners and losers due to the different disturbances with the national social-ecological system.

The Sugar Corporation's expansion plan to meet GTP aims included expanding cultivation where possible at the existing estates (in addition to adding the capacity to produce ethanol at Wonji-Shoa and Metehara) as well as constructing new estates. Cultivation at Wonji-Shoa will increase to 16,000 hectares and new sugar and ethanol mills will be constructed with a capacity of 174,000 tonnes of sugar and 10,300,000 litres of ethanol per year (Sugar Corporation 2013d). The cultivation at Finchaa will increase to 21,000 hectares, the sugar mill will be upgraded and an ethanol mill will be constructed, resulting in an annual production of 270,000 tonnes of sugar and 20 million litres of ethanol (Sugar Corporation 2013a). Expansion at these two sites began in 2013 and will be complete by 2015/16. Finally, expansion at Metehara Sugar Factory was limited to constructing an ethanol mill of 10 million litres per year capacity, which came online in 2011, and unable to expand cultivation on-site due to land limitations. Instead, the MSF management have been responsible for the construction of a new estate – Kesem Sugar Factory (KSF), fifty kilometres away from MSF.

Kesem was one of two new sites announced early in the GTP period, the other being Tendaho Sugar Factory. Both sugar estates are in the Awash River basin, as are Metehara and Wonji-Shoa. Tendaho will cultivate sugarcane over 50,000 hectares in the north of Ethiopia. The location is significant as it is the arid Afar region but is very close to the only port access Ethiopia has, the Port of Djibouti. It has been speculated that production from Tendaho will be directly exported (MSF Management 2011). Construction at Kesem began in 2010 and the estate should commence processing by 2013, although will not reach full capacity until 2015.

The remainder of the expansion will occur in the Omo River Basin in the south west of Ethiopia. The expansion will be managed as the Omo Kuraz Sugar Factories Project and will cultivate 175,000 hectares of sugarcane, supplying five sugar mills and producing 60% of the overall planned national ethanol output (Sugar Corporation 2013b). This estate is in the early stages of construction and was only formally announced in 2012 (Sugar Corporation 2013b). Two further estates were announced in 2012, Beles and Wolkaita, where construction is in the very early stages. The total planned outputs are displayed in Table 3.3 and are shown to now far exceed the originally published aims of the GTP and Biofuels Strategy of 2.3 million tonnes of sugar and 304 million litres of ethanol, and will result in 400 million litres of ethanol, a 47-fold increase from previous production levels.

Table 3.3. The planned capacity of the Ethiopian sugar and ethanol system.

Sugar estate	Sugarcane cultivated (hectares)	Number of sugar mills	Sugar capacity (tonnes)	Ethanol capacity (litres)
Wonji-Shoa	15,500	1	280,000	10,300,000
Metehara	10,300	1	137,000	10,000,000
Finchaa	20,600	1	270,000	20,000,000
Kesem	19,900	1	153,000	12,500,000
Tendaho	50,000	1	619,000	55,400,000
Omo Kuraz	175,000	5	1,900,000	183,000,000
Wolkaita	45,000	1	242,000	20,900,000
Beles	75,000	3	726,000	62,500,000
Total	**411,000**	**14**	**4,330,000**	**375,000,000**

The scale of expansion – an extra 400,000 hectares cultivated with sugarcane - obviously has a large impact on land-use within Ethiopia. Expansion is supported by the land tenure system in Ethiopia, as outlined in the following section.

3.2.4. Land Tenure within Ethiopia

The governance structure of the Ethiopian Constitution supports such a vast and rapid change in land-use. Article 40.3 of the Ethiopian Constitution states *"the right to ownership of rural and urban land, as well as of all natural resources, is exclusively vested in the State and in the peoples of Ethiopia. Land is a common property of the Nations, Nationalities and Peoples of Ethiopia and shall not be subject to sale or to other means of exchange"* (Federal Democratic Republic of Ethiopia, 1995). However, the rights to food, livelihood, development, and property are internationally protected human rights and to allow such rights, the use of land is protected in the Constitution – specifically for pastoralists. Article 40.5 states that *"Ethiopian pastoralists have the right to free land for grazing and cultivation as well as the right not to be displaced from their own lands. The implementation shall be specified by law."* The last clause is reflected in Article 44.2, which legally allows relocation as long as households are compensated - *"All persons who have been displaced or whose livelihoods have been adversely affected as a result of State programmes have the right to commensurate monetary or alternative means of compensation, including relocation with adequate State assistance."* (Federal Democratic Republic of Ethiopia 1995). In summary, the Ethiopian Government can relocate any resident but must compensate them.

Land tenure governance is relevant as the land highlighted for substitution to sugarcane by the Ethiopian Government is that which is judged to be 'un-used'. Estimates for 'irrigable suitable areas' for sugarcane range from 700,000 (Ministry of Mines and Energy 2007) to 1,390,000 hectares (Fessehaie 2009). Obviously such a large increase in land under sugarcane will have associated social and environmental impacts, particularly as Ethiopia's large pastoralist population commonly use large areas of the land highlighted as available.

The legal right to force relocation has provided the Ethiopian Government with many opportunities to change pastoralist households to sedentary agriculture or wage labour. The GTP states multiple times that to increase the growth rate of the Ethiopian economy through agriculture, productivity of smallholders and pastoralists will have to increase (Ministry of Finance and Economic Development 2010a). Whilst re-settlement is not the only method of increasing productivity outlined in the GTP (also included are: increasing availability of water resources, improved animal health services, establishment of markets and strengthening government support systems), quotes such as the following reflect the view within multiple levels of Government that pastoralism is 'inefficient', not 'civilised' and in need of 'modernisation':

"[A]t the end of the day we are not really appreciating pastoralists remaining as they are. We have to improve their livelihood by creating job opportunities. Pastoralism, as it is, is not sustainable. We want to change the environment."
Abera Deressa, previous Minister of State in the Ministry of Agriculture and Rural Development (Butler 2010)

"I promise you that, even though this area [Omo] is known as backward in terms of civilization, it will become an example of rapid development."
Meles Zenawi, Prime Minister (Oakland Institute 2011)

"[Afar] people move around – they need to settle and then mix in a civilised world."
Awash Fentale Woreda Authority (Interview, 2011)

The above shows that the pastoralist way of life, requiring access to large areas of land and year-round access to water, is not compatible with the Government's development plans, particularly for areas such as the Lower Omo, attractive for its water availability and 'land-availability' where the Government intend to use the land more intensively (Human Rights Watch 2012b). Therefore, legally supported, the expansion of sugarcane can be used to initiate resettlement programmes and has already been documented as doing so at the Kesem, Tendaho, Beles and Omo Kuraz projects (Sugar Corporation 2013c).

3.2.5. Ethanol Consumption in Ethiopia

The expansion plan outlined in Table 3.3 above creates a massive surplus in ethanol in Ethiopia. There are two consumers of ethanol in Ethiopia – the petroleum blend and the use of ethanol stoves. Between 2008 and 2012 13 million litres of ethanol (34% of that produced) were blended with 281 million litres of petroleum, originally at an E5 blend in Addis Ababa only, then rolled out to a national E5 blend, and (since March 2010) an E10 blend in Addis Ababa (Walta Information Centre 2012). The other demands for ethanol within Ethiopia will be as a bio-diesel processing feedstock in the oil esterification process, which is not currently operating, or as a household fuel.

It is projected that the petroleum blend (incorporating a 7% growth rate in petroleum demand and a potential increase to an E25 blend) may demand 30-40 million litres per year (Kassa 2009). If introduced, the biodiesel processing requires approximately 10 per cent ethanol by volume for biodiesel production, approximately 1.6 million litres initially and growing by 10 per cent per year (Kassa 2009). Neither would consume the majority of the ethanol produced in Ethiopia and the only other major consumer is the use of ethanol stoves in the home and refugee camps.

The introduction of ethanol stoves in Ethiopia is led by an non-government organisation (NGO) in partnership with an Ethiopian business - the Gaia Association and MakoBu Enterprises. The Gaia Association is the Ethiopian branch of an international NGO – Project Gaia. Initial activities of the Gaia Association were limited to three refugee camps in eastern Ethiopia (Kebribeyah, Awbere and Sheder) in partnership with the United Nations Refugee Agency, UNHCR (CEIHD & Gaia Association 2007). After a successful pilot study, all 1,780 families (17,000 people) in the Kebribeyah refugee camp were given ethanol stoves and a ration of 1 litre of ethanol per day (Debebe, 2008). This level of demand consumes approximately 650,000 litres of ethanol per year but there is the demand to increase this to 2.2 million litres (Stokes 2010; Debebe 2008b).

The Gaia Association judged their activities in Kebribeyah Refugee Camp to be a huge success, as substitution of woodfuel means women no longer had to leave the camp to collect it several times a week. Such trips last up to 8 hours and put women at risk of harassment, rape and other violence. The reliance on woodfuel of the extra population around Kebribeyah had led to severe environmental degradation and a previously well-wooded area becoming severely deforested, which increased tensions between local populations and refugees (Debebe, 2008). Introducing ethanol removed the pressure on local resources by substituting 3.7 tonnes per year of largely unsustainable fuelwood used per household in Kebribeyah, which in turn removed approximately 6.2 tonnes per year of CO_2 emissions (Debebe, 2008).

The stove used by the Gaia Association is the CleanCook stove, originally developed by Swedish company 'Dometic' for European and North American leisure markets. The stove consists of an ethanol canister (240x50mm) packed with a special refractory mineral fibre which adsorbs up to 1.2 litres of ethanol on its surfaces, surrounded by a stainless steel framework (Debebe 2008b). There are two versions of the stove, a single-burner (290x240x160mm) and a double-burner (580x240x160mm). The CleanCook stove was chosen above other varieties due to its high safety level – the canister is not pressurised, hence chances of explosions are minimised and the special fibre holds the ethanol so even if knocked over there will be no spillage. In addition the stove is durable - the materials and minimal moving parts means the stove has a lifetime of 5-10 years with everyday use, combined with simple operation, similar to kerosene stoves, a familiar technology.

With full market penetration with low and middle income households in Addis Ababa, the Gaia Association and MakoBu estimate that the consumption of ethanol as a household fuel at the planned production levels could soak up the excess production and supply over 200,000 households (Kassa 2007).

3.2.6. Selection of Biofuels System

The above discussion of biofuels in Ethiopia allows the specific selection of a biofuel system within Ethiopia. Due to the lack of institutional or market-driven support for biodiesel and the strong governmental support for ethanol, ethanol was selected as the biofuel to study. The only feedstock in commercial use is molasses, a by-product of sugar processing from sugarcane. The very recent nature of the expansion of sugarcane for ethanol production in Ethiopia limited the number of estates where research on the impacts of production could be investigated. At the beginning of this study (2010), ethanol was only produced (or about to be produced) at two sites – Finchaa and Metehara. Visits to both sites identified expansion only to be occurring at Metehara, under the Kesem project as Finchaa's expansion was delayed until 2013. In addition, the scoping study at MSF and KSF identified the disturbances to the social-ecological system highlighted in Chapter 2. Therefore, the linked system of Metehara Sugar Factory and Kesem Sugar Factory were selected as the biofuel production sub-system to study. The activities regarding ethanol stoves in Addis Ababa justified its selection as the consumption sub-system. Analysis will be based on the commercialisation activities of the Gaia Association and MakoBu Enterprises rather than the refugee camp utilisation due to the limited demand in refugee camps. A map of this field area is shown in Figure 3.3.

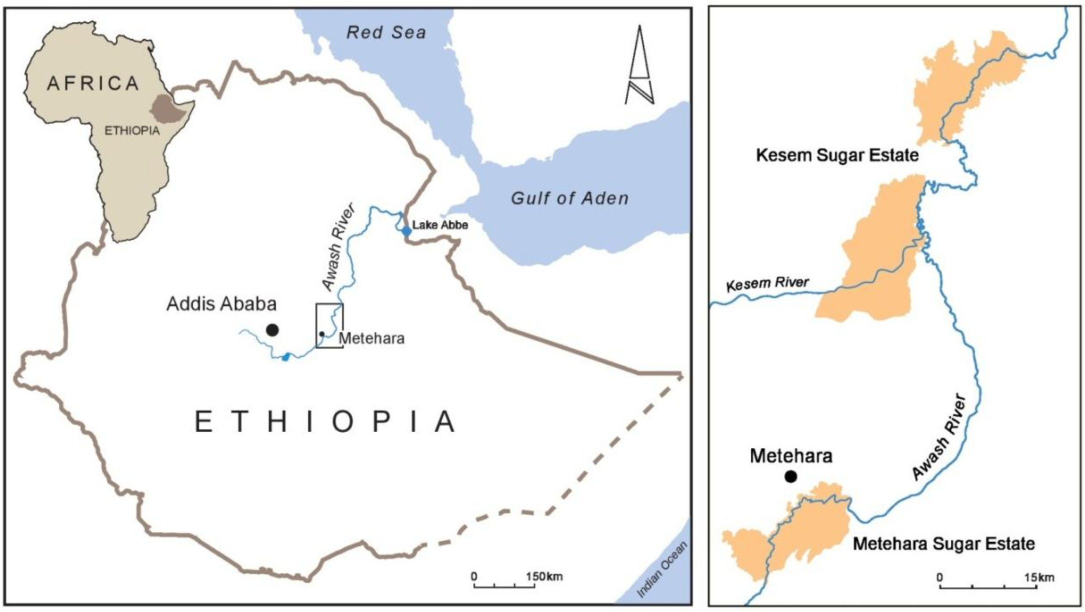


Figure 3.3. Key locations within the Ethiopian biofuels system.

The remainder of this chapter outlines how the research questions summarised at the end of Chapter 2 will be addressed within this biofuels system.

3.3. Household Food Systems in Metehara

This chapter investigates the impacts biofuel expansion has on the diversity of entitlements and other measures of food security at a household scale for populations surrounding an expanding sugar estate – Metehara and Kesem Sugar Factories – using a quantitative survey. It addresses these specific research questions:

- What is the current aggregate level of entitlements for those populations hypothesised to be affected by the expansion of biofuels?
- What is the current diversity of entitlements for those populations hypothesised to be affected by the expansion of biofuels?
- How has the aggregate level and diversity of entitlements changed since expansion of biofuels began in the area four years ago?
- Do other measures of food security (expenditure on food, dietary diversity and coping strategy analysis) concur with the results of the entitlements assessment?
- Of land use change, displacement and labour market shifts, which are the key mechanisms that have influenced entitlements and food security?
- What are the resilience implications from the measured levels of change in food security?

3.3.1. Populations of Interest

There are three populations hypothesised to be affected by biofuel production and expansion in the Metehara region:

- Employees of Metehara Sugar Factory: Labourers employed in large-scale schemes
- Residents of Metehara Town: Consumers influenced by changes in food prices
- Pastoralists of Kesem: Relocated populations or those shortly to be relocated

Therefore, these are the populations of interest, as there are no households participating in out-grower schemes in this case study. The location of the three populations is also a proxy for their engagement in biofuel production. An overview of each sample is presented below.

Employees of Metehara Sugar Factory: There are 7,000 employees of MSF, all of whom are provided with accommodation (for their entire families if a permanent worker) in villages within the estate, creating a population of approximately 27,000 distributed across 3,499 households (MSF Management 2011). This population is directly engaged in biofuel production.

Residents of Metehara Town: Metehara town includes the newer settlement of Addis Ketema town to form a population of 21,000 people distributed across 4,278 households and under one governance structure (Fentale Woreda 2011). The settlement is governed as the Addis Ketema Kebele (the smallest administrative unit of governance in Ethiopia) – the only urban Kebele within the wider Awash Fentale Woreda (the next administrative level) which covers a region of 13,340 square kilometres within the Oromo region (Fentale Woreda 2011). This population is not engaged in biofuel production, but is of interest due to potential indirect impacts on biofuel production, as discussed in the literature and summarised in Chapter 2.

Pastoralists of Kesem: The expansion site at Kesem is already home to approximately 600 Afar households – traditionally semi-nomadic pastoralists raising cows, camels and goats. This population is indirectly engaged with biofuel production as they are being relocated to new villages within the Kesem site. Whilst 288 households were relocated to a new village, Digdiga, in 2011, only 46 houses are currently occupied as the original villages (Wassero and Little Alveti) have not been destroyed and the residents have returned. There are multiple reasons for this – interviews reported a poor quality of construction in Digdiga alongside a lack of water resources and grazing land. The new village for the remaining 312 households is under construction and houses will be made of concrete rather than mud brick houses, with closer access to farmland. However, in the meantime the households are residing in their original village, Doho. This sample is therefore split into two sub-samples – those who have been relocated and those who have not yet.

A summary of the populations of interest and the sample sizes within these populations is found in Table 3.4. A stratified random sampling strategy was employed to ensure spatial representativeness throughout the populations.

Table 3.4. Population and sample sizes for the populations under study in the Metehara household food system study.

Sample	Employees	Residents	Pastoralists		Total
Sub-sample			Relocated	Not Relocated	
Population Size	3,499	4,278	288	312	8,377
Sample Size	235	170	53	38	496
Total Sample Size	235	170	91		496
Margin of Error (95% confidence level)	6.2%	7.4%	9.5%		4.3%

3.3.2. Data Collection Methods

To measure the impacts on entitlements and food security in the three populations, multiple sources of data were collected between April and July 2011, as demonstrated in Figure 3.4.

Research Question	Aggregate Level of Entitlements	Diversity of Entitlements	Change Over Time	Triangulation with Other Measures of Food Security
Data Collection Method	Household Survey			
			Interviews with key actors	
			Secondary Data	

Figure 3.4. Data sources for the different research questions. Household surveys and interviews with key actors provide the data to answer the research questions regarding the impacts of biofuel expansion on food security.

The household survey was comprised of three main sections – A) the household and housing unit, B) food and entitlements, and C) social networks. Whilst sections A and C collected data on dependent variables known to influence food security and entitlements, section B was framed to collect robust primary data on the household's food security via the following analyses, as also outlined above in Figure 3.4:

- Food access – past and present entitlements and food-related expenditure
- Food availability – production based entitlements
- Food consumption score – a weighted measure of dietary diversity

- Household food insecurity and coping strategies – past and present

Collecting such data allows multiple measures of food security to be calculated, to complement the entitlements analysis. Analysis via the entitlements framework can investigate the aggregate total of entitlements or the diversity of entitlements. The majority of studies analyse the aggregate level of entitlements, but with the impacts of biofuel expansion, the diversity of entitlements is likely to be affected even if the aggregate level of entitlements remains the same. Also, an aggregate analysis loses a layer of detail about the change between groups of actors. However, diversity of entitlements is strongly influenced by cultural norms. By investigating both in addition to alternate measures of food security for the populations of interest, any changes in the level of food security since biofuel expansion began should be reported, allowing conclusions to be made about which mechanisms of change, if any, are found at this scale as a result of biofuel production and expansion.

When addressing a disturbance, it is important to clarify the timescales involved. Therefore the Section B refers to the past 30 days to create a 'snapshot' of the current diversity of entitlements and food security, and also four years prior to the survey i.e. before the introduction of the Ethiopian Biofuels Policy in 2007 and expansion began at MSF. The surveys were collected over the short dry season within the Ethiopian calendar. Normally, this period would be a relatively productive time, where arable farmers plant a second, short harvest between the short rains in February and March and there is sufficient water and grazing land for pastoralists (belg) and long rains between July and October (meher). In 2010 the meher rains were poor and the 2011 belg rains preceding this season were also unusually low, initiating a period of drought and associated hunger further towards the south east and north of Ethiopia (Disaster Risk Management and Food Security Sector 2011). The Metehara region was affected but not as severely as other regions.

Practically, the survey was designed to be as simple as possible so to take no longer than 25 minutes in order to respect the time poverty of the respondents. Binary variables were developed so that questions could be answered with either 'yes' or 'no'. Where this was not possible multiple answers were suggested and the most appropriate answer was checked by the enumerator. Although this may be responsible for a decrease in the level of detail collected, it makes the delivery of the survey easier, as well as the analysis. The survey had a limited number of open questions for un-calibrated answers, but most could be closed in the process of piloting.

Three field assistants were hired as enumerators to carry out the surveys. The enumerators originated from Metehara and were fully conversant in both written and spoken Amharic and English, which allowed the survey to be printed in English to aid the coding process. The team was not gender-balanced (3 men) and was also skewed towards a younger age group (20-29). However, there were no issues found with this affecting the completion rates. Additional translators were hired when surveying with the Afar pastoralists due to the difference in primary language – Afar not Amharic. Prior to the undertaking of the survey, the team was trained in a workshop on the survey. The enumerator training contributed to tailoring the survey to the local area and rephrasing questions, to avoid redundant questions or those prone to misunderstandings. Prior to that occasion the surveys had been shared with the supervisory team, had been pre-tested and preliminarily coded. A pilot was carried out in one of the samples prior to the data collection period. As a result of the pilot minimal changes were made regarding specific language of food types and the entitlement categories were focused. Due to the minimal changes, the pilot data were included in the data analysis due to the limited access to this sample. Surveys were carried out throughout the day as the enumerators targeted the main female within the household, who is traditionally responsible for food acquisition and preparation, and the pilot found she was available throughout the day.

Prior to analysis, data checking was carried out on a daily basis. This allowed any bias from individual enumerators to be highlighted. Certain questions were disregarded from analysis due to repeated differences between enumerators, but the remainder of the survey data were then regarded with high confidence for analysis.

3.3.3. Data Analysis Methods

Analysis of the quantitative survey data were done using SPSS. Preliminary analysis involved correcting data entry errors and standardising entries of qualitative data. An initial exploratory analysis calculated the summary statistics and displayed them in table or graph form. Confirmatory analysis was then carried out, creating indices for the four key food security indicators, as listed above.

Analysing access and availability requires simple calculations with the reported data to create aggregate scores and then statistical descriptive analysis to calculate means, medians and frequencies. Entitlements scores are based on the locally specific types of entitlements as reported in pilot studies, allocated amongst the different classes of entitlements (Sen 1981).

To analyse dietary diversity a food consumption score (FCS) is calculated. FCS is an indicator of dietary diversity and nutritional content, based on dietary diversity (number of food groups consumed over reference period), food frequency (number of times), and the relative nutritional importance (weighted according to nutrient density). Frequency weightings are based on the categorical consumption rate – never, 0; every 1-3 days, 3; 4-15 times a month, 10; and 16-30 times a month, 24. The FCS used typical World Food Programme nutritional weightings, but per item rather than per group (World Food Programme 2010: Annex 11-3). The WFP weighted scores are translated into the following weightings as shown in Table 3.5. The contents of the dietary diversity section were tested in the pilot studies and adapted to include specific cultural foodstuffs such as gomen (a local cabbage species) and hoja (a coffee drink consumed by the Afar).

The coping strategy score is calculated using a similar method. Frequency weightings are as follows: 0, never; 1, once per month; 2, 2-10 times per month; and 3 for over 10 times per month. Severity weightings are based on published methodological literature, are related to how the strategy affects food consumption and are outlined in Table 3.6 (Coates et al. 2007; Hoddinott 1999).

Table 3.5. Nutritional weightings for the food stuffs included in the dietary diversity section of the survey.

Food Group	Food stuffs	Weighting
Cereals	Injera, bread, wheat, maize, tef, rice, sorghum, pasta.	2
Tubers	Sweet potato, irish potato, cassava.	2
Pulses	Beans	3
Fruit and vegetables	Tomatoes, onions, carrots, gomen, cabbage. Oranges, mangoes, papaya, avocado, bananas.	1
Animal products	Beef, chicken, sheep, goat and fish meat. Eggs Milk from all species.	4
Sugar		0.5
Miscellaneous	Salt, coffee, tea, hoja, balo.	0.5

Table 3.6. Severity weightings for the coping strategy score.

Coping Strategy	Weighting	Why?
Nothing	0	
Limited variety	1	Initial strategy
Borrow food	1	Allows food consumption to remain same
Sell labour power	1	Allows food consumption to remain same
Borrow cash	1	Allows food consumption to remain same
Food aid	1	Allows food consumption to remain same
Other	1	
Consume stored grains	2	Affects the future, so more severe than eating limited varieties but allows food consumption to remain similar
Sell livestock	2	Affects the future, but allows food consumption to remain similar
Sell domestic assets	2	Affects the future, but allows food consumption to remain similar
Reduce adult's quantity	3	Decreased food consumption
Reduce children's quantity	3	Decreased food consumption
Pledge land	3	Only considered if things very bad because would strongly affect the future in a negative way
Skip meals	4	Much decreased food consumption
Sell land	4	Strongly affects the future in a negative way

Upon calculation of the different measures of food security, the significant differences between samples are calculated and highlighted, using the appropriate statistical test for the data type and size of data set. Most commonly this was the non-parametric Kruskal-Wallis test to compare differences in means across all three samples and was applied at the 0.95 confidence level (Field, 2007).

3.4. The Ecological System in the Metehara Region

To answer the overall research question regarding the ecological impacts of biofuel production at Metehara Sugar Factory and their impact on the resilience of the regional social-ecological system, the interactions due to the four stages of production are framed as individual research questions:

- What are the impacts on the ecological sub-system from cultivation?
- What are the impacts on the ecological sub-system from harvesting?
- What are the impacts on the ecological sub-system from processing sugar?
- What are the impacts on the ecological sub-system from processing ethanol?

To synthesise the above disturbances at Metehara Sugar Factory, an additional research question is addressed regarding the carbon balance of ethanol production at MSF and its comparison with other examples in the literature. Finally, the chapter addresses the new interactions with the ecological sub-system occurring at Kesem Sugar Factory and whether these result in a different carbon balance.

3.4.1. Populations of Interest

Chapter 5 analyses the disturbances within the ecological sub-system at both the Metehara and Kesem Sugar Factories and addresses them as separate social-ecological systems.

Metehara Sugar Factory (MSF): as described above, MSF cultivates sugarcane over 10,300 hectares, producing 137,000 tonnes of white plantation sugar annually. Expansion at MSF was limited to the construction of an ethanol mill with a capacity of 10 million litres per year (which came online in 2011). Limits due to other land users in the area prevented the expansion of cultivation at MSF. Instead, the MSF management have been responsible for the construction of a new estate – Kesem Sugar Factory (KSF), fifty kilometres away from MSF.

Kesem Sugar Factory (KSF): Construction at Kesem began in 2010 and the estate should commence processing by 2013, although will not reach full capacity until 2015. Cultivation will total 20,000 hectares and allow the annual production of 153,000 tonnes of sugar and 12.5 million litres of ethanol.

3.4.2. Data Collection Methods

Investigating the above hypotheses required multiple sources of data, as demonstrated in Figure 3.5.

<table>
<tr><th>Research Question</th><th>Cultivation</th><th>Harvesting</th><th>Processing Sugar</th><th>Processing Ethanol</th><th>Kesem Expansion</th></tr>
<tr><td rowspan="3">Data Source</td><td colspan="4">Secondary quantitative data from MSF</td><td>Secondary quantitative data from KSF</td></tr>
<tr><td colspan="5">Primary qualitative data from interviews with key actors</td></tr>
<tr><td colspan="5">Secondary data from the wider literature</td></tr>
</table>

Figure 3.5. Data sources for the different research questions. Secondary data collected from the Metehara Sugar Factory management, combined with interviews with key actors to triangulate data and secondary data from the wider literature provide the data with which to answer the research questions.

Secondary data and confirmation of the secondary data along with perceptions on the ecological impacts was collected via interview. Every department within MSF has a manager, who was targeted for interview. The departments within MSF are listed in Table 3.7, and interviews were conducted with all managers. Interviews were carried out in English due to the high level of English spoken by managers, and this was not judged to affect the data collected. The data were collected in a scoping trip during October 2010 and between March and July 2011. To protect those who did not wish to be cited directly, all primary and secondary data provided by MSF managers is cited as MSF Management (2011). The data collected from MSF came either for the entire seasons 2004/5 to 2009/10, or monthly for the 2010/11 season up to the month of June. Therefore, if only monthly 2010/11 data were available it was scaled up to represent the entire season and adjusted compared to output of the 2010/11 season so to compare with the 2009/10 season data. If data from multiple seasons was available, the mean value was applied in calculations. The data collected from MSF is considered to be of high accuracy as it is directly from the managers responsible for that sector.

Table 3.7. The departments of MSF and their responsabilties. Data were collected from and interviews carried out with the manager of each department.

Department	Role
General Manager	Oversees all operations and deals with the Sugar Corporation.
Agricultural Operations	Oversees all field-based operations – cultivation, harvesting and irrigation.
Cultivation and Harvesting	Responsible for the application of compost and pesticides, field checks and harvesting.
Civil Engineering	Responsible for irrigation infrastructure.
Irrigation	Responsible for distribution of irrigation water.
Field Equipment Services	Responsible for the maintenance of field vehicles.
Sugar Processing	Responsible for the maintenance of and production from the sugar mill.
Ethanol Processing	Responsible for the maintenance of and production from the ethanol mill.
Research Centre	Carries out research on sugarcane and sugar yields and possible improvements.
Quality Management	Responsible for meeting various quality control regulations and the achievement of ISO international standards.
Human Resources	Responsible for hiring staff and distributing their housing, wages and other benefits.
Kesem Project	Responsible for the establishment of Kesem sugar factory.

3.4.3. Data Analysis Methods

The data collected is presented in Chapter 5 as a life-cycle analysis – production is outlined step-by-step as it occurs at the estate, highlighting any interactions with the ecological sub-system and if so the severity of this interaction. These use basic calculations using average seasonal data.

As shown in Chapter 2, a carbon balance acts as the best available data proxy for ecological impacts on the regional ecological sub-system, by tracing carbon through the life-cycle of the biofuel. Where suitable, after the discussion of an interaction within the ecological sub-system, the data are transformed into a measure of carbon dioxide equivalence. Summing the carbon emissions or sinks during the different phases of activity produces a carbon balance, reporting the relative carbon emissions of the full life-cycle of molasses-ethanol in this social-ecological system.

Cultivation data are converted where possible to carbon dioxide equivalence (CO_2e) using the IPCC methodologies for national greenhouse gas inventories – specifically Chapter 2 (Generic methodologies applicable to multiple land-use categories), Chapter 4 (Farming), Chapter 5 (Cropland), Chapter 6 (Grassland), Chapter 11 (N_2O emissions from managed soils and CO_2 emissions from urea application) and Appendix 2 (Flooded lands) (Intergovernmental Panel on Climate Change 2006). The global warming potentials (GWP) of different GHG applied in this chapter and used in similar analyses of biofuel systems (de Figueiredo et al. 2010; de Figueiredo & La Scala 2011) are the latest estimates by the IPCC (Forster et al. 2007). In addition, the MSF data are run through the UK Carbon Calculator to triangulate the analysis (Ofgem 2013).

The carbon balance only incorporates emissions within the bounded scale – i.e. the individual sugar estates – and does not reflect embedded emissions, for example related to the manufacturing of pesticides or distribution of ethanol after it leaves MSF.

Interview data were transcribed, or translated from short hand if consent was not provided for recording. The open nature of the interviews allowed interview data to be used to give depth and nuance to the quantitative data also collected from the managers, via the provision of quotes where appropriate.

3.5. Household Energy Systems in Addis Ababa

Complementing the household level analysis of the production sub-system, focusing on entitlements and food security, Chapter 6 presents a household level analysis of the impacts of ethanol stove uptake on the consumption sub-system. Such an analysis fills a knowledge gap created by the lack of previous expansion on such a large scale, as previously the stoves have only been used with specific groups i.e. refugee camps. The chapter addresses the following specific research questions:

- Are the hypothesised beneficial impacts of ethanol stove uptake (health benefits, increased time availability, reduced expenditure on fuel, and enhanced safety) realised?
- What are uptake rates of ethanol stoves?
  - Are there other more suitable stoves that are being adopted in their place?
- What are the barriers to uptake?
  - Is this differentiated amongst income groups?
- What is the potential market for ethanol stoves?
  - Is this differentiated amongst income groups?

Synthesising the answers to the above research questions allows changes in system resilience to be measured at a larger scale.

3.5.1. Populations of Interest

As the above discussion of ethanol stoves in Ethiopia outlined, the Gaia Association believe they could soak up all excess ethanol produced via consumption in the household energy market. Their initial commercialisation plan published in 2008 targeted residents of the newly constructed condominiums, as they are forbidden from using solid (and also traditional) energy sources like wood and charcoal, but also kerosene within the buildings due to the smoke damage and risk of accidental fire (Debebe 2008b; Addis Ababa City Housing Construction Project Office 2011). Via the Integrated Housing Development Plan, the Ethiopian Government is currently undergoing a massive expansion of its 'affordable housing stock' so to overcome the housing shortage whilst replacing what it calls 'slum and below standard housing' (Addis Ababa City Housing Construction Project Office 2012). The initial target was to construct 360,000 residential condominium units (studio to 3 bedroom apartments in large complexes) in Addis Ababa by 2010 (Addis Ababa City Housing Construction Project Office 2011; UN-Habitat 2010). In 2011, approximately 80,000 units had been constructed and handed over to the residents (Addis Ababa City Housing Construction Project Office 2011).

In 2009, eight of the original condominiums across different sub-cities in Addis Ababa were actively targeted with an advertising strategy where an ethanol stove was given to one household per block at each site and along with a weekly ethanol ration, *"in the hope that the household would demonstrate the stove and its benefits to their neighbours"* (Tadele 2012). Table 3.8 shows the distribution of stoves. The decreased ethanol production in 2010-11 meant that ethanol was diverted solely to the petroleum blend. When ethanol supply restarted in the summer of 2011, these condominiums were then re-targeted for stove sales, with the stoves for sale at their full imported cost of 1,740 Birr (double burner) or 1,050 Birr (single burner) (16.9 Birr per $ or 27 Birr per £ in 2011). These eight condominiums form one population within this study.

Table 3.8. Ethanol stove distribution by the Gaia Association and MakoBu Enterprises during their pilot scheme in 2009.

Condominium	*Sub-City*	*Blocks*	*Households*	*Stoves distributed*
Police Club	Arada	3	120	5
Balcha Meda	Lideta	3	120	5
Dekemehari	Lideta	5	177	5
Amanuel	Addis Ketema	8	329	10
Meskel Flower	Kirkos	4	154	5
Amalgamated	Kirkos	7	220	5
Yeka 1	Yeka	3	120	5
Adwa Dildiyi	Yeka	6	190	5
SUM			***1430***	***60***

Other targets by the Gaia Association were low-income groups offered the stoves at subsidised rates. An initial arrangement was with a group of households supported by a Catholic organisation called the Good Shepherd Sisters (GSS), but households never received their stoves due to the pause in the ethanol supply. More recently an arrangement has been successfully fulfilled with the Former Fuelwood Carriers (FFC) – a local NGO creating alternative employment opportunities for women who previously made their livelihood by bringing eucalyptus wood into the city from the surrounding hills (Mengesha & Tadele 2006).

When ethanol supply re-started in summer 2011, the Gaia Association offered 200 single burner stoves to the FFC for purchase at a subsidised price of 300 Birr, with payment delayed until September 2012 (Tadele 2012). There are four branches of the Former Fuelwood Carriers, at one of which (the headquarters) the Gaia Association arranged for a 10,000 litre ethanol tank to be installed. FFC then arranges transportation of ethanol in 10 litre jerry cans to adopters in the other three branches once a week. In total, 190 stoves were distributed between 212 members and ethanol supplied at the price of 12 Birr per litre. Therefore, both the Good Shepherd Sisters and Former Fuelwood Carriers are populations of interest.

The final population of interest was those who have purchased a stove directly from MakoBu Enterprises at the full price – 1,740 Birr for a double burner, 1,050 Birr for a single burner. When discussing the stove adopters, MakoBu report that those who have purchased the stoves are generally within the social networks of their employees (a feature of a networked economy), are not condominium dwellers but the 'middle class', and either have a car so can drive to MakoBu to purchase ethanol or have it delivered by the associated employee (Kebede 2012).

In summary – there are three populations of interest, due to the three different mechanisms by which households within these populations came into possession of an ethanol stove:

- Condominium residents who were given a stove for free by the Gaia Association and MakoBu Enterprises in the 2009 original demonstration period, or who bought one as a result of the second wave of advertising in 2011.
- Purchased for a subsidised price from the Gaia Association because of their association with the Good Shepherd Sisters or Former Fuelwood Carriers.
- Purchased a stove at its full price from MakoBu Enterprises after summer 2011.

The samples listed above reflect different income groups, data regarding which is displayed in Figure 3.6 and Table 3.9 below. Whilst the data has large standard deviations, significant differences are found between the total household income of condominium dwellers and those supported by the GSS or FFC (tested via independent t-test). Whilst the size of the snowball sample of adopters limits its involvement in parametric comparisons of means, a non-parametric (Kruskal-Wallis) test concluded that there is a significant difference between the mean total household incomes for all samples from Survey 2. Observational data such as location of household and ownership of cars, and other wealth indicators analysed in the chapter allow me to robustly address this group as another income class.

The GNI per capita (Atlas method, current US$ (The World Bank 2013a)) for Ethiopia in 2011 was $400, assuming two wage earners per household this translates to 1,127 Birr per month per household (16.9 Birr per $, 2011). Using this as a basis for 'average household income', both the GGS and FFC households are below this level – on average they earn 61% of this. In comparison, the average condominium household earns five times more than the average Ethiopian household, whilst the stove adopters report an average income of 39 times the national average.

To confirm the inequality reported compared to the national average household income, the distribution of household income (for those who reported it in Survey 2) was plotted and Figure 3.6 shows the distribution is very unequal. The adopters, whilst only 7% of the total population, account for 41% of the total income, whilst the FFC represent 30% of the population and yet only 2% of the income. The green line on Figure 3.6 represents the distribution of the three samples – 0<2% represents the Former Fuelwood Carriers, 2<59% the condominium residents and 59<100% the adopters. By also showing the cumulative income for the whole population (blue line), the GINI index (the degree of inequality, where 0 is income distributed with perfect equality and 100 with perfect inequality) can be calculated and is 70 – highly unequal.

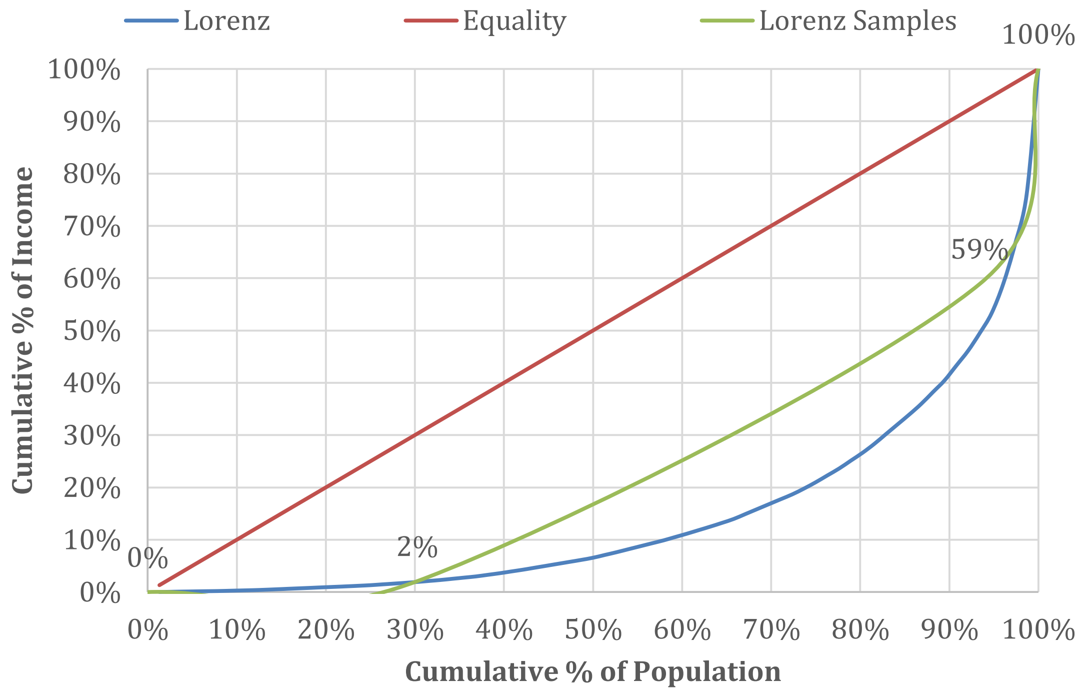


Figure 3.6. A Lorenz curve shows the distribution of wealth across the three samples is very unequal.

Therefore, whilst MakoBu staff referred to the ethanol adopters as 'middle income', in Chapter 6 they are referred to as the Very High Income sample, as they represent a minority with an exceptionally high income. Due to the order of magnitude difference between this sample and the condominium households, the condominium residents are not referred to as 'middle income' either, as they are still significantly above the average. Therefore they are referred to as the High Income sample and the remaining samples (GSS and FFC) as Low Income.

Knowing the samples are significantly different with regards to income allows their stratification to ease differentiation and in all further analysis they are referred to according to their income group. Table 3.9 outlines the renaming and resulting sample sizes from the surveys. Significant differences are found between the total household income of condominium dwellers and those supported by the GSS or FFC (tested via bivariate independent t-test). Whilst the size of the snowball sample of adopters limits its involvement in parametric comparisons of means, a multivariate non-parametric (Kruskal-Wallis) test concluded that there is a significant difference between the mean total household incomes for all samples from Survey 2.

Table 3.9. Income statistics across samples from both surveys (statistically significant differences tested by independent t-test and Kruskal-Wallis between samples in bold, p=0.05 or less).

Category	Statistic	Survey 1		Survey 2		
		Condo-miniums	Good Shepherd Sisters	Condo-miniums	Former Fuelwood Carriers	Stove adopters
N		174	70	83	33	6
Total Household Income (Birr/ month)	Mean	**4,544**	**885**	**6,294**	**481**	**43,700**
	Standard Deviation	*4,688*	*1,419*	*7,442*	*303*	*49,645*
Average household income as proportion of national mean		4.0	0.8	5.6	0.4	39
Labelled as		High Income	Low Income	High Income	Low Income	Very High Income

3.5.2. Data Collection Methods

To measure the impacts of ethanol substitution in samples stratified by income, multiple sources of data were collected and are reported in Figure 3.7.

Research Question	**Impacts of Adoption**	**Uptake Rates**	**Barriers to Uptake**	**Potential Market**
Data Source		Survey 1		Survey 1
	Survey 2	Survey 2	Survey 2	Survey 2
		Interviews with key actors	Interviews with key actors	Interviews with key actors
				Secondary Data

Figure 3.7. Data sources for the different research questions. Household surveys, interviews with key actors and secondary data provide the data to answer the research questions regarding the uptake and potential for ethanol stoves as a household fuel.

As shown in Table 3.9, two surveys were carried out during this study. Survey 1 was carried out between October and December 2010 with random samples from the 8 condominiums where stoves had been demonstrated (as these would be the initial targets of the commercialisation project) and the Good Shepherd Sisters households. Survey 1 collected data regarding household demographics, energy apparatus and fuel consumption as well as perceptions of health.

Building on the data in Table 3.8., Table 3.10 shows the sample sizes for Survey 1, adjusted during surveying due to the detection of business units. For both populations (applying a 95% confidence level) the margin of error is 7% for the condominiums and 11% for the GSS – slightly higher or equal to the proposed sample size margin of error.

Table 3.10. Sample sizes for Survey 1. The margin of error for the condominium and GSS samples is 6.9% and 11.1% respectively.

	Households (AAHDP)	Business Units (JH)	Residential Units (JH)	Completed Surveys	Sample (%)
Police Club	120	0	120	16	13.3%
Balcha Meda	120	0	120	16	13.3%
Dekemehari	177	12	178	23	12.9%
Amanuel	329	18	291	33	11.3%
Meskel Flower	154	28	119	19	16.0%
Amalgamated	220	18	202	25	12.4%
Yeka 1	120	16	70	18	25.7%
Adwa Dildiyi	190	0	190	24	12.6%
Condominiums	***1,430***	***92***	***1,290***	***174***	**13.5%**
Good Shepherd Sisters	***700***	***0***	***700***	***70***	**10.0%**

The aim of Survey 2 was to measure uptake rates, the impacts of uptake and the barriers to uptake. Therefore, Survey 2 was carried out across the two populations targeted for uptake via a random sample of FFC households and a random sample of those households in the condominiums already sampled for Survey 1, between April and June 2012. Follow-up surveying at GSS was not possible due to their removal from the stoves programme. Survey 2 was also carried out with a purposive sample of stove demonstrators in the condominiums and a snowball sample of stove purchasers outside the condominiums.

The final sample sizes for Survey 2 at a 95% confidence level resulted in a margin of error of 13% for the high income group and 16% for the low income group. The margin of error is very high for the demonstrator and adopter samples (19% and 40%) due to the small samples size so these samples will not be included independently in the parametric statistical comparisons, but used to provide an extra level of detail via non-parametric tests and observational data. The sample sizes for both surveys are summarised in Table 3.11.

Table 3.11. Sample sizes for both Survey 1 and 2. Samples are renamed according to income group and sample sizes.

Survey	Sample	Who included in this population?	Labelled as:	Population Size	Completed Surveys	Sample (%)
Survey 1	**Condominiums**	Random sample	High Income	1,290	174	14%
	Good Shepherd Sister Households	Random sample	Low income	700	70	10%
Survey 2	**Former Fuelwood Carriers Households**	Random sample of Adopters and non-adopters	Low income	212	33	16%
	Condominiums	Purposive sample of Original Demonstrators	High income	45	17	38%
		Purposive sample of Adopters and Non-adopters	High income	174	66	38%
	Other purchasers	Snowball sample of Adopters	Very High income	268	6	2%

Again, the surveys were designed to be as simple as possible so to take no longer than 25 minutes in order to minimise the time required of the respondents. Binary variables were developed so that questions could be answered with either ‘yes’ or ‘no’. Where this was not possible, multiple sensible answers were suggested and the most appropriate answer was checked by the enumerator. The data collection team for both surveys in Addis Ababa consisted of the same five enumerators – all of whom were Masters Students from the Faculty of Social Science at Addis Ababa University. The enumerators originated from Ethiopia and were fully conversant in both written and spoken Amharic and English, which allowed the survey to be printed in English to again aid the coding process. The team was gender-balanced (3 women and 2 men) but skewed towards a younger age group (20-29). However, there were no issues found with this affecting the completion rates. Prior to the actual undertaking of the survey, the team was trained in an afternoon workshop on the survey. The enumerator training contributed to sharpening the survey and rephrasing questions, to avoid redundant questions or those prone to misunderstandings. Prior to that occasion the surveys had been shared with local institutions (AAU, the Gaia Association) and the supervisory team, had been pre-tested and preliminarily coded. Pilot studies were carried out for Survey 1 in two of the samples prior to the beginning of the data collection period, with four of the five enumerators. The pilot resulted in the changing the format of the household members section of the survey and some specific language regarding stove types. The pilot data were not included in the data analysis due to these changes. Survey 2 was not piloted due to majority of content being the same as in Survey 1, and time constraints. The new ethanol uptake section was practiced amongst the enumerators, which was judged to be sufficient as no changes to format or language were required. The survey was targeted at the main female in the house, traditionally responsible for acquiring and using household fuels, although self-identification of this role was used in the introduction by the enumerator. Piloting also reported that surveying during the day resulted in low completion rates as the majority of residents were working away from the home. Therefore, surveying was carried out between 6 and 8.30pm to target households when the majority of members were at home.

Prior to analysis, data checking was carried out on a daily basis to highlight any biases from individual enumerators. If this was not corrected within the first few days of surveying, these questions were disregarding from analysis. There were very few issues with the energy survey data due to the familiarity of the enumerators to surveying.

3.5.3. Data Analysis Methods

The majority of the data analysis is based on Survey 2, but Survey 1 is used to provide change over time data where possible. To quantitatively analyse differences between samples and sub-samples in the survey data, the non-parametric Kruskal-Wallis test is applied to test whether the distribution of responses is different between three sub-samples (i.e. Low/High/Very High) due to there being three samples. A non-parametric test was applied because of the uneven sample sizes, multiple samples, and the fewer assumptions about the samples being normally distributed (Field, 2007). The significance of all results is assessed at the 0.95 confidence level. Where the size of the sample allowed and a normal distribution could be assumed, parametric tests are also applied, for example the independent t-test.

Survey 2 also asked a series of Likert-type questions to investigate perceptions of the stoves. It is accepted that Likert data can suffer from bias, for example central tendency bias and acquiesce bias. The survey presents such questions in a mixed manner so to try and avoid such biases. The Likert questions are scored from 1 to 5 indicating, respectively, strongly agree, agree, neither agree or disagree, disagree, strongly disagree. There is also a 'don't know' option. Initial analysis regarding the central tendency is presented using the mode. Comparative analysis of the Likert data are done using the non-parametric Mann-Whitney U test to compare adopter and non-adopter groups. In addition, the Kruskal-Wallis test is used to analyse differences between non-normal modal Likert data for the three samples stratified by income.

3.6. The National Scale Ethiopian Social-Ecological System

Examining the expansion of biofuels through a resilience framework allows the impacts on the resilience of the social-ecological system to be identified, by investigating the following specific research questions:

- How have the dynamics of the SES changed with the expansion of biofuels?
- Has the expansion of biofuels caused any thresholds within each the sub-systems to be exceeded? If so, have any regime shifts occurred?
- What are the differentiated impacts on actors within the system under study?

The synthesis of these elements for each scale disturbed by the expansion of biofuels and analysed in Chapters 4, 5 and 6 outlines the complex nature of these systems whilst allowing conclusions to be made about which actors are the most vulnerable to the potential regime shifts biofuel expansion has or will cause. The synthesis creates innovation in comparison to traditional resilience studies, which focus on one scale of a system to highlight the most desirable system for a particular stakeholder, which underplays the dynamic nature of interactions between actors.

3.6.1. Populations of Interest

Therefore, the investigation of these elements of resilience as well as the power relations is carried out for every sub-system analysed in the previous chapters – the production and consumption sub-systems at Metehara, Kesem and Addis Ababa. The conclusions from the various sub-systems are then synthesised to investigate the impacts on resilience at the national scale.

A new population of interest was included from the Metehara region – that of the Karayu Pastoralists relocated for the original construction of MSF in the 1960s. Twenty seven households from a population of approximately 285 households in the Gola Kebele answered the entitlements survey Chapter 4 is based on. The data from this sample is analysed to investigate the future impacts relocation may have on the pastoralist sample being relocated for the Kesem Sugar Factory.

3.6.2. Data Collection Methods

This chapter integrates the data analyses presented in Chapters 4, 5 and 6 based on the multiple sources of primary data regarding food security, land use and production of ethanol in Metehara and Kesem Sugar Factories, coupled with consumption in Addis Ababa. This primary data were collected through household surveys and interviews. The same three enumerators collected the entitlements survey data for the additional surveys in the Karayu sample but required additional translators due to the difference in primary language – Oromo not Amharic. In addition, all the key institutions in the multiple localities and at the national level were identified and all were targeted for interviews. In the local levels, all institutions in the area were targeted, whether involved in biofuel production or not, to gauge the influence (or lack of influence) of the sugarcane-sugar-ethanol system on all parts of the SES. At the national level, all government institutions related to the impacts highlighted at smaller spatial scales were targeted. For example, the Ministry of Water and Energy due to the possible impacts on water availability. NGOs were targeted if they had previously produced work on biofuels. Interview data were supplemented with documentary evidence. A summary of the data sources is presented in Figure 3.8. All data collection occurred between 2011 and 2012.

Research Question	Dynamics	Thresholds	Power relations
Data Source	Chapter 4		
	Chapter 5		
	Chapter 6		
	Interviews with key institutions		

Figure 3.8. Data sources for the different research questions. Chapter 7 synthesises the evidence presented in the previous results chapters with interview data from key institutions.

Interviews were carried out with a representative of all institutions operating in the Metehara region, a summary of which is presented in Table 3.12. The majority of these institutions are governmental.

Table 3.12. Institutions in the Metehara region. A representative of each was interviewed to provide primary data.

Institution	Role
Fentale Woreda Authority	Governmental office responsible for rural population near Metehara
Addis Ketema Kebele Authority	Governmental office responsible for urban population in Metehara and Addis Ketema
Ministry of Agriculture and Rural Development	Governmental office responsible for agricultural training and the Productive Safety Nets Programme in the local rural areas
Awash Basin Authority	Governmental office responsible for water administration from the Awash River and controlling Lake Beseka
Awash National Park	Governmental office responsible for management of the Awash National Park
Child Fund	Charitable non-governmental organisation focusing on orphan development

The interviewing strategy targeted the most senior member of the institution. In all interviews across all localities the same format was followed, asking about their perception of the impact of biofuel expansion on their own and other institutions. Again, the interviews were carried out in English due to the high level of English spoken by the individuals, and this was not judged to affect the data collected. The positionality of the interviewer (as a foreign female) was not judged to be a hindrance to interview data collection, in fact was judged to help with access to managers due to the international element.

Table 3.13 lists the institutions present in the Kesem region. Although there is a small settlement in the region called Sabure with a local Kebele office, no-one was available for interview at this institution. An interview was carried out at the Awash Fentale Woreda authority, as a representative of the governance of the Kesem region. A non-governmental institution, CARE Ethiopia, was operating in the area but had closed the office in Awash Arba and so the interview was carried out at the national office in Addis Ababa.

Table 3.13. Institutions in the Kesem region. All except the Sabure Kebele Authority were interviewed to provide primary data.

Institution	Role
Awash Fentale Woreda Authority	Governmental office responsible for rural population near Kesem
Sabure Kebele Authority	Governmental office responsible for urban population in Sabure
Awash National Park	Governmental office responsible for management of the Awash National Park
CARE Ethiopia	Non-governmental organisation focusing on female genital mutilation in Afar communities

Interviews were also carried out with the key governmental institutions at the national scale active in the biofuels system and are listed in Table 3.14. In addition, representatives of multiple non-governmental institutions were interviewed to collect a range of opinions on the impacts of biofuel expansion so far – these included environmental NGOs such as Forum For Environment, MELCA and the Horn of Africa Regional Environment Centre, consumer-based NGOs such as Ethioscope, and academics at Addis Ababa University. In both government and non-government institutions, the most senior representative was targeted for interview.

Table 3.14. Institutions at the national level. A representative of each was interviewed to provide primary data.

Key Government Institutions	Role
Sugar Corporation	Over-sees expansion of new sugar factories and sales of sugar and ethanol produced.
Ministry of Water and Energy (MOWE)	Manages irrigation infrastructure construction and allocation of water.
Biofuels Directorate	To co-ordinate all tasks, from nation to Woreda level.
Ethiopian Wildlife Conservation Authority (EWCA)	Responsible for management of national parks and related issues.
Environmental Protection Agency (EPA)	Manages environmental quality in Ethiopia.
Ministry of Agriculture and Rural Development (MOARD)	Responsible for educating small-farmers.
Food Security Directorate	Responsible for managing the Productive Safety Nets Programme.
Ethiopian Petroleum Enterprise (EPE)	Manages the import and domestic sales of oil products, including blending of ethanol
Ethiopian Investment Agency (EIA)	Allocates land to foreign and domestic investors and manages their permits.

3.6.3. Data Analysis Methods

The analysis of the resilience of the social-ecological systems at different scales was based on the framework published by the Resilience Alliance (Resilience Alliance 2010a). To analyse how the dynamics of the SES have changed with the expansion of biofuels, an adaptive cycle is produced, outlining the timescale of shifts between phases. The data presented in Chapters 4, 5 and 6 alongside the primary data from interviews is analysed qualitatively to identify these shifts.

To identify some thresholds between regimes, analysis of quantitative survey data were required and was carried out in SPSS. As there were only two samples being compared, independent t-tests were used to compare means, but confirmed with a Mann-Whitney U test where appropriate because of the small sample size of the Gola agro-pastoralists. In addition to the food security scores calculated above in section 3.3.3, this included a wealth index based on multiple socio-economic factors within the survey which were weighted equally as nominal variables and are listed in Table 3.15 (World Food Programme 2010).

Table 3.15. Factors within the wealth index.

Category	Factor
Demography	Literate head of household
	Children currently in education
Housing Unit	Permanent housing unit
	More than one room
	Kitchen separate from the main living area
Assets	Possess a television
	Possess a radio
	Possess a telephone
Environmental Health	Protected source of drinking water
	Non-biomass cooking source
	Non-biomass lighting source
	Electricity access

Interview data were transcribed where possible (consent was not given for all interviews to be recorded), or the interviewer's notes were changed from short hand. Due to the closed nature of the interviews, quotes were then extracted for the specific questions regarding perceptions of impacts on their own institution and on other institutions and attributed a 'positive', 'negative' or 'no impact' heading.

3.7. Overview of Data Collection Methods

Figure 3.9 summarises the systems under study, the scale of the systems and the relevant research questions, with the respective data collection methods employed in this thesis. Figure 3.9 emphasises that this thesis draws upon mixed methods and is a truly interdisciplinary study. The thesis utilises qualitative methods of inquiry at various stages, in addition to quantitative data which the bulk of the empirical analysis results from. The quantitative and qualitative data collection processes have been in communication throughout the research. To summarise, the quantitative data results from three household-level surveys and secondary data collected from the sugar estates under study. Qualitative research methodologies used are primarily key informant interviews alongside field observations to comprehensively analyse the formal survey material. In addition, secondary data from other institutions was used extensively, both to provide an initial position for the empirical analysis and to facilitate the overall analysis of the research findings. Important secondary data sources were national agencies such as the Ethiopian Centre for Statistical

Analysis, international agencies such as the World Bank, and work by other academics and NGOs based in the field areas.

<table>
<tr><th colspan="2">Scale and focus</th><th colspan="7">Research questions</th></tr>
<tr><td rowspan="4">Household – food sub-system</td><td>Chapter 4</td><td>Aggregate Level of Entitlements</td><td colspan="2">Diversity of Entitlements</td><td colspan="2">Change Over Time</td><td colspan="2">Triangulation with Other Measures of Food Security</td></tr>
<tr><td rowspan="3">Data sources</td><td colspan="7">Household Survey</td></tr>
<tr><td colspan="3"></td><td colspan="4">Interviews with key actors</td></tr>
<tr><td colspan="3"></td><td colspan="4">Secondary Data</td></tr>
<tr><td rowspan="4">Regional - ecological sub-system</td><td>Chapter 5</td><td colspan="3">MSF Life Cycle Analysis and Carbon balance</td><td colspan="4">KSF Life Cycle Analysis and Carbon balance</td></tr>
<tr><td rowspan="3">Data sources</td><td colspan="3">Secondary quantitative data from MSF</td><td colspan="4">Secondary quantitative data from KSF</td></tr>
<tr><td colspan="7">Interviews with key actors</td></tr>
<tr><td colspan="7">Secondary data from the wider literature</td></tr>
<tr><td rowspan="5">Household - energy sub-system</td><td>Chapter 6</td><td>Impacts of Adoption</td><td colspan="2">Uptake Rates</td><td colspan="3">Barriers to Uptake</td><td>Potential Market</td></tr>
<tr><td rowspan="4">Data sources</td><td></td><td colspan="2">Survey 1</td><td colspan="3"></td><td>Survey 1</td></tr>
<tr><td colspan="7">Survey 2</td></tr>
<tr><td></td><td colspan="6">Interviews with key actors</td></tr>
<tr><td></td><td colspan="2"></td><td colspan="3"></td><td>Secondary data</td></tr>
<tr><td rowspan="5">National - social-ecological system</td><td>Chapter 7</td><td colspan="2">Dynamics</td><td colspan="2">Thresholds</td><td colspan="3">Power relations</td></tr>
<tr><td rowspan="4">Data sources</td><td colspan="7">Chapter 4</td></tr>
<tr><td colspan="7">Chapter 5</td></tr>
<tr><td colspan="7">Chapter 6</td></tr>
<tr><td colspan="7">Interviews with key institutions</td></tr>
</table>

Figure 3.9. A synthesis of the key research questions and applicable data collection methods in this thesis.

3.8. Reflection on the Research Process

When carrying out any data collection, the methods employed and collection procedures have to be tailored to the context of the country. Therefore, the methodological field protocol was carefully developed, reflecting practical recommendations and insights from relevant existing literature with a particular focus on methodological experiences in Ethiopia, or more generally Africa (Torkelsson 2008; CSAE & IFPRI 2004; Dercon & Hoddinott 2004; Central

Statistical Agency 1994; Narayan 1998; The World Bank 2011; Corbera 2010;. Goulden 2010).

One key recommendation emerging in the literature was to tailor concepts so that they have local meaning and practical relevance. Therefore, when the survey was designed local terms were incorporated rather than the direct translations. For example, the phrase 'grid electricity' was removed as there was no association in Ethiopia with the 'grid'. In addition, specific names were used for example 'idir' for burial societies and 'gomen' for a local cabbage species. Links with the Gaia Association and Addis Ababa University were beneficial in that discussions with the staff at both institutions greatly influenced the specific focus on the research topic, as well as providing practical assistance in choosing – and entering – field sites.

Therefore, although during the period of data collection there were changes in the governance of the systems under study, available populations and rates of expansion, the adaptation of the research design allowed data collection to continue providing high quality data that allowed all the research questions to be answered. One such adaptation meant that the transportation sector was not addressed as a separate consumption-based SES and instead was addressed within the national SES. Whilst interviews were sought with individual oil companies, who in the past have been speculated to be losers associated with ethanol introduction (Bayissa, 2008:225), during the period of field work access to these companies could not be arranged. However, sufficient quantitative data were provided by the Ethiopian Petroleum Enterprise allowing the integration of the transportation sector within the national SES.

It is also acknowledged that the case study selection – that of Metehara Sugar Factory – influenced the findings of this study. During the scoping study, both Metehara and Finchaa Sugar Factories were visited as potential case studies. The decision was made to carry out the study at Metehara as it allowed all the research questions to be addressed. Expansion at Finchaa is occuring in an un-populated gorge, and so was judged to have fewer interactions with the social-ecological system. If the study had been carried out at Finchaa the conclusions regarding food security would have been different due to the lack of local populations (urban residents but particularly pastoralists), the latter of whom the MSF case study reported the main negative impacts on.

Reflection on the research design acknowledges that in selecting Ethiopia as a case study, the study could have been alternatively framed around sugar as the commodity driving change in the system, rather than biofuel production. However, the method of ethanol production as a by-product, creating a vast economic profit from minimal input costs (solely infrastructure construction) in addition to the global and Ethiopian discourse on biofuels at that point in time was judged in the scoping trip to be a sufficient driver to justify the expansion of sugarcane and hence sugar production, and therefore the study is framed with biofuels as the main driver.

3.9. Summary

The research design for this thesis is based on a full system analysis of the impacts of biofuel expansion on social-ecological systems. A system analysis requires addressing the impacts at the scales they occur and then synthesising the results to analyse the impacts on resilience at the national scale. Biofuel expansion is investigated in the Ethiopian context, where there is a rapid and vast increase in ethanol production based on molasses, originating from sugarcane. The data are collected via mixed methods, dependent on the data required to answer the specific research questions. The empirical data are provided by three quantitative surveys and interviews with key actors.

4. Impact of Biofuel Expansion on the Diversity of Entitlements

This chapter presents the results of the food system analysis, using the entitlements framework alongside other food security measures to examine access, availability and utilisation of food at the current level of biofuels production, and over a period to measure change due to the expansion of biofuels. The chapter concludes by discussing the implications for social-ecological resilience at the household scale, due to changes in the food sub-system. As discussed in Chapter 2, food systems include different actors accessing their food from different sources. Chapter 3 identified the general groups of actors hypothesised to be affected by biofuel expansion in this region, outlining the populations of interest for this study:

- Employees of Metehara Sugar Factory: Labourers employed in large-scale schemes
- Residents of Metehara Town: Consumers influenced by changes in food prices
- Pastoralists of Kesem: Relocated populations or those shortly to be relocated

The samples are outlined fully in Chapter 3 but Table 4.1 introduces the sample sizes and some key cultural characteristics for each sample. Whilst the majority of Employee households have migrated into this region from other regions further south (indicated by the prevalence of Protestant households), the Resident population is mostly composed of Amhara and Oromo households, traditional highland ethnic groups. In comparison, the Pastoralist sample is almost entirely Afar – the traditional lowland cultural group from the north of this region.

Table 4.1. Sample and sub-sample sizes for the populations under study, along with key characteristics of their sample.

Sample	MSF Employees	Metehara Residents	Pastoralists	
Sub-samples			Relocated	Not Relocated
Sub-sample size			53	38
Total sample size	235	170	91	
Ethnic diversity	Other (62%) Amhara (23%) Oromo (15%)	Amhara (36%) Oromo (32%) Other (32%)	Afar (99%) Oromo (1%)	
Religious diversity	Protestant (47%) Ethiopian Orthodox (41%) Other (12%)	Ethiopian Orthodox (55%) Muslim (23%) Other (22%)	Muslim (100%)	
Livelihood diversity	Field worker (63%) Mill worker (11%) Management (1%)	Merchant (30%) Wage labour (52%)	Pastoral agriculture (62%) Kesem Sugar Factory (17%)	

This chapter investigates the following specific research questions for the three samples:

- How is the current aggregate level of entitlements for these populations affected by the production of biofuels?
- How is the current diversity of entitlements for these populations affected by the production of biofuels?
- How has the aggregate level and diversity of entitlements changed since expansion of biofuels began in the area four years ago?
- Do other measures of food security concur with the results of the entitlements assessment?
- What are the key mechanisms that have influenced entitlements and food security?
- What are the resilience implications from the measured levels of change in food security?

Answering the above research questions allows changes in resilience for the populations of interest to be concluded, but also allows the system resilience to be measured at a greater scale (as analysed in Chapter 7). It is hypothesised that the major impact of biofuel production and expansion in the region is displacement of the Pastoralist sample, which will lead to reduced food production and a 'direct entitlement decline'.

This chapter therefore presents empirical and analytical knowledge about the impacts of biofuel expansion on the diversity of entitlements and other measures of food security at the household scale in Ethiopia. The expansion of sugarcane and ethanol production in this example has had a limited negative impact on the aggregate level of entitlements accessed by the proportion of the population directly engaged in production, and those not engaged at all. Pastoralist households who have been, or will be, relocated have experienced the main negative impacts. Around one quarter of these households diversified their entitlements and employed coping strategies compared to four years ago, prior to the biofuel expansion. Whilst this diversification can be viewed as an indication of their resilience, diversifying may actually be pushing these pastoralist households into a less resilient state, where a small change could push them into a more severe state of hunger. The overall contribution of this chapter is to highlight that the expansion of biofuels has differentiated impacts on the actors within the local social-ecological system. By examining the multiple pathways in production and consumption chains, the winners and losers are identified and changes in resilience at different scales assessed.

4.1. Context of Access and Entitlements in Metehara

As discussed in Chapter 2, food security is composed of three factors – availability, access and utilisation. Access is the key factor that defines whether people shift from a secure to insecure state as such shifts can occur irrespective of food availability (Sen 1981). An 'entitlement set' is the full range of goods and services an individual can obtain by converting 'endowments' (assets, resources) through 'exchange entitlement mapping' (Devereux 2001), and there are four main types of entitlements:

- Production based entitlements – food that an individual grows;
- Trade-based entitlements – food that an individual acquires by trading something;

- Own-labour entitlements – food that an individual is entitled to due to labour power;
- Inheritance and transfer entitlement – food that an individual inherits or is given by another who owned them legally.

An initial focus of the study is to identify the correct entitlements for the study area, so to tailor the food security section of the survey correctly. The relevant individual entitlements are displayed in Table 4.2 and expanded on below.

Table 4.2. The specific entitlements within each of the entitlements categories relevant to the Metehara region.

Sen's Entitlement Category	Individual Entitlements
Production	Raise animals for food Grow crops for food
Trade	Buy at market/shops Trade other goods for food
Own-labour	Work for food
Inheritance and transfer	Given by friends/family Given by assistance organisations Given by Metehara Sugar Factory
	Other

Production: Whilst there are few opportunities within Metehara Sugar Factory to grow crops due to the lack of available land, it is a traditional livelihood for the semi-Pastoralist households in Kesem, and a possibility for the Metehara town Residents. Livestock rearing is more commonly practiced and is an option in all populations. Within the sugar estate, small animals (chickens, goats, and sheep) are allowed within villages, whereas communal areas are provided on the outskirts of villages for cattle. Within Metehara Town there are no constraints, other than available land within the household plot. For the Pastoralists in Kesem, raising livestock (cattle, goats, sheep, and camels) is the traditional livelihood.

Trade: The main local market is in Addis Ketema (an extension of Metehara town). In addition to small shops and informal stalls in the Metehara Sugar Factory and Metehara town, this is the nearest source of foodstuffs for the Employee and Resident samples. The Pastoralist sample accessed this market or one in the nearby town of Awash Arba, as well as small shops and the cattle market in Sabure, their nearest non-Pastoralist settlement. Whilst it is most common to exchange goods for currency, some exchange of goods for goods goes on in the Pastoralist sample – i.e. livestock for other foodstuffs.

Own-labour: There is a national work-for-food programme in Ethiopia, the Productive Safety Nets Programme (PSNP). The PSNP aims to provide households with enough income (as both cash and food) to meet the food gap and therefore protect their assets from depletion. Income is provided via direct support to households without labour, and as payment for labour towards public works such as schools, roads, soil and water conservation, water development (The World Bank 2013b).

Inheritance and Transfer: It is relatively common across all samples to exchange foodstuffs within social networks in times of need, i.e. before payday. In addition, there are some NGOs active in the area, mostly working with pastoralist households. The Metehara Sugar Factory also gives its Employees a ration (eight kilograms) of sugar per month.

4.2. Current Aggregate of Entitlements

Based on the categorisation outlined in Table 4.2, the maximum possible aggregate entitlements score was nine. Figure 4.1 outlines the entitlements score per sample, and it can be seen that, on average, the Pastoralist households access a higher number of entitlements (2.8, sd = 1.3) than the Employee and Resident households, which access, on average, one entitlement only (standard deviation 0.5 and 0.8 respectively). There is a greater variation in the Pastoralist sample, as highlighted in Figure 4.1.

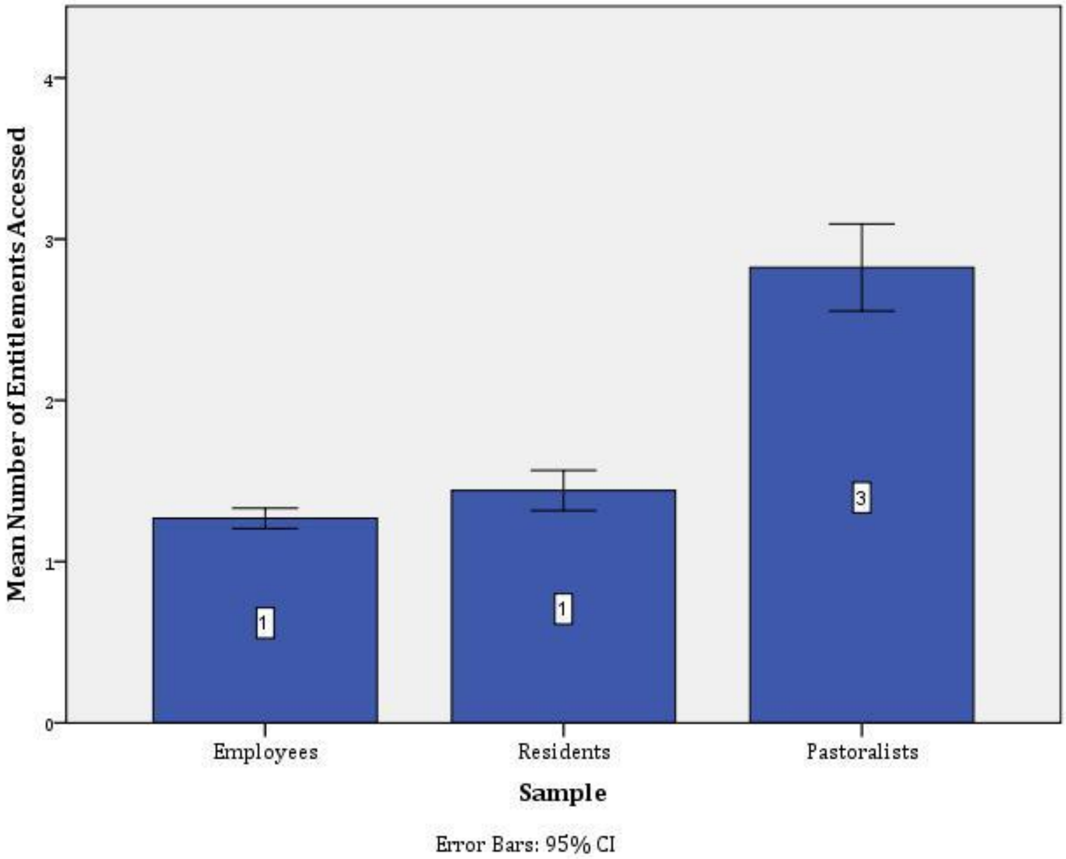


Figure 4.1. The mean number of entitlements accessed. Pastoralist households access a higher number of entitlement types than Employee or Resident households, but with a greater variation between households.

The maximum number of entitlements accessed was in the Pastoralist households, where one household accessed seven entitlements. The vast majority of households across all samples only accessed one entitlement – 75% of Employee households and 72% of Residents. However, only 15% of the relocated Pastoralist households and 3% of the unrelocated households relied on one entitlement, the largest proportions of these samples accessed two entitlement categories – 38% and 40% respectively. The range of entitlements access by these two sub-samples is displayed in Figure 4.2.

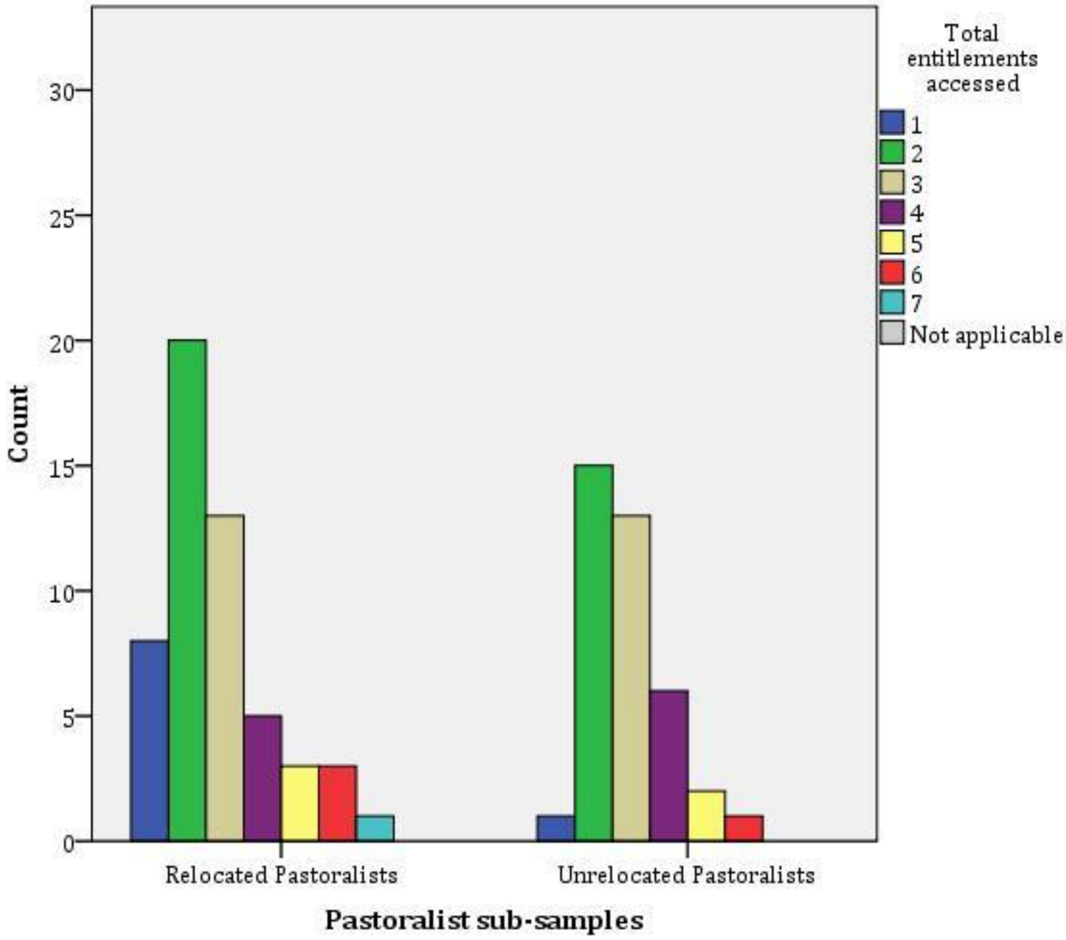


Figure 4.2. The range of entitlements accessed by Pastoralist sub-samples. The range is far greater in the Pastoralist sample, whereas in the Employee and Resident samples the majority of households only access one entitlement type.

4.3. Current Diversity of Entitlements

Coupling the analysis of the aggregate number of entitlements with the diversity of entitlements, i.e. the types of entitlements, creates a more robust investigation of the impacts of biofuel expansion on the food system. Table 4.3 displays whether the distribution of each sample is significantly different for each entitlement category using the Kruskal-Wallis test. The data shows a reliance on trade entitlements – nearly 100% of households in all samples rely on markets and shops to provide trade-based entitlements, the only entitlement for which the distribution is not significantly different between the three samples. Far fewer households rely on direct trade – 5% of Residents, but this increases to 30% for Pastoralist households.

Table 4.3. Access of individual entitlements across the three samples. The vast majority of households access trade entitlements by purchasing from shops and markets (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis test).

Entitlement Category	Entitlement Type	Employees (n=235)	Residents (n=175)	Pastoralists (n=91)
Production	Livestock	**21%**	**14%**	**75%**
	Crops	**6%**	**0%**	**3%**
Trade	Buy	100%	99%	99%
	Trade	**0%**	**5%**	**30%**
Own Labour	Work for food	**0%**	**3%**	**17%**
Transfer	Given by friends and family	**0%**	**12%**	**20%**
	Given by NGOs	**0%**	**9%**	**36%**
	Given by MSF	**0%**	**0%**	**2%**
Other	Other	0%	1%	1%

Production entitlements are the second most commonly accessed entitlement, most commonly via animal production consumption. Whilst logic would suggest that 100% of Pastoralist households would access production of livestock as an entitlement, only 75% of households reported doing so. The remaining 25% of Pastoralist households reported not having consumed meat or milk in the previous 30 days and attributed this to the lack of holy days in this period. However, 98% of the Pastoralist sample reported raising livestock, compounding the reliance on livestock as the primary livelihood within their cultural regime. The two households not raising animals were non-Afar traders in the newly constructed settlement where the Pastoralists will be relocated.

Table 4.4 presents data regarding livestock numbers in the different samples. The Pastoralist households raise a larger range of animal species in much larger herds – the average Pastoralist household reported 2 chickens, 37 goats, 19 sheep, 24 cattle, 1 donkey and 23 camels. In comparison, those Employee and Resident households keeping animals for food are more likely to keep 3-6 chickens or small numbers (1-6) of goats or sheep. The average town Resident keeps more animals and a larger range of animals that the Employee households, as there are fewer space restrictions. There is a large variation in this data for all the samples, reflected in the large standard deviations.

Table 4.4. Livestock ownership across the samples. Pastoralist households unsurprisingly reported raising much larger groups of animals.

Animal	Employees (n=57)		Residents (n=38)		Pastoralists (n=89)	
	Mean	*Standard deviation*	Mean	*Standard deviation*	Mean	*Standard deviation*
Chickens	3	*3.3*	6	*16.7*	2	*7*
Goats	0	*0.6*	6	*11.5*	37	*32.8*
Sheep	0	*1.0*	4	*6.8*	19	*22.7*
Cattle	1	*1.2*	2	*3.7*	24	*40.1*
Camels	0	*0.3*	0	*0.0*	23	*35.4*

As Table 4.3 shows, very few households across all samples reported cultivating arable crops for food. For the few who did, the species cultivated varied between the samples. Of the 15 Employee households cultivating arable crops, all reported cultivating fruit – most commonly 53% mango and 33% papaya. The prevalence of fruit crops reflects the high number of fruit trees in the settlements, a by-product of the original Dutch plantation, and the lack of available space on the estate for other crops. No Metehara Resident households reported cultivating crops for food. In the four Pastoralist households cultivating crops, three were growing onions and two tomatoes.

It can also be seen from Table 4.3 that the Pastoralist households, whether relocated or not, are more likely to access transfer and own-labour entitlements. In Ethiopia, 'work for food' indicates that household is a member of the Productive Safety Net Programme (PSNP), the Ethiopian Government's response to chronic food insecurity, which has traditionally been a feature of rural communities. The households already relocated report some support by MSF, but there is also a reliance on direct support from Non-Governmental Organisations (NGOs) active in the area, such as CARE Ethiopia. It is also possible however that due to a lack of coherence across surveyors, and that as the payment from the PSNP is delivered by NGOs, these households are actually reporting PSNP enrolment.

4.4. Change over Time and Impact of Biofuel Expansion

Examining the change over time in entitlements allows linkages to be established between the expansion of Kesem Sugar Factory and methods of food access.

4.4.1. Change in the Aggregate Entitlements Score between 2007 and 2011

The majority of households in all samples (98% Employees, 100% Residents, 78% Pastoralists) did not report a change in their aggregate sum of entitlements since expansion of Metehara Sugar Factory began four years earlier, as shown in Figure 4.3.

The lack of change indicates the operations of MSF and expansion at Kesem SF has not affected food access for the majority of households, even in the Pastoralist sample. However, as Figure 4.3 displays, the majority of households that have reported a change are in the Pastoralist sample, where across the whole sample 6% reported a decreased aggregate entitlement score, and 16% an increase. Examining this in greater depth, the effects were split evenly across the Pastoralist sub-samples – 23% of relocated Pastoralists and 21% of unrelocated Pastoralists reported change. Within these sub-samples, the majority reported an increase of one entitlement type – 15% and 10% of the relocated and unrelocated Pastoralists respectively, 2% and 6% an increase of two types, and 4% and 3% reported a decrease of one entitlement type. The following section expands on this by investigating the substitutions or additions of entitlement types.

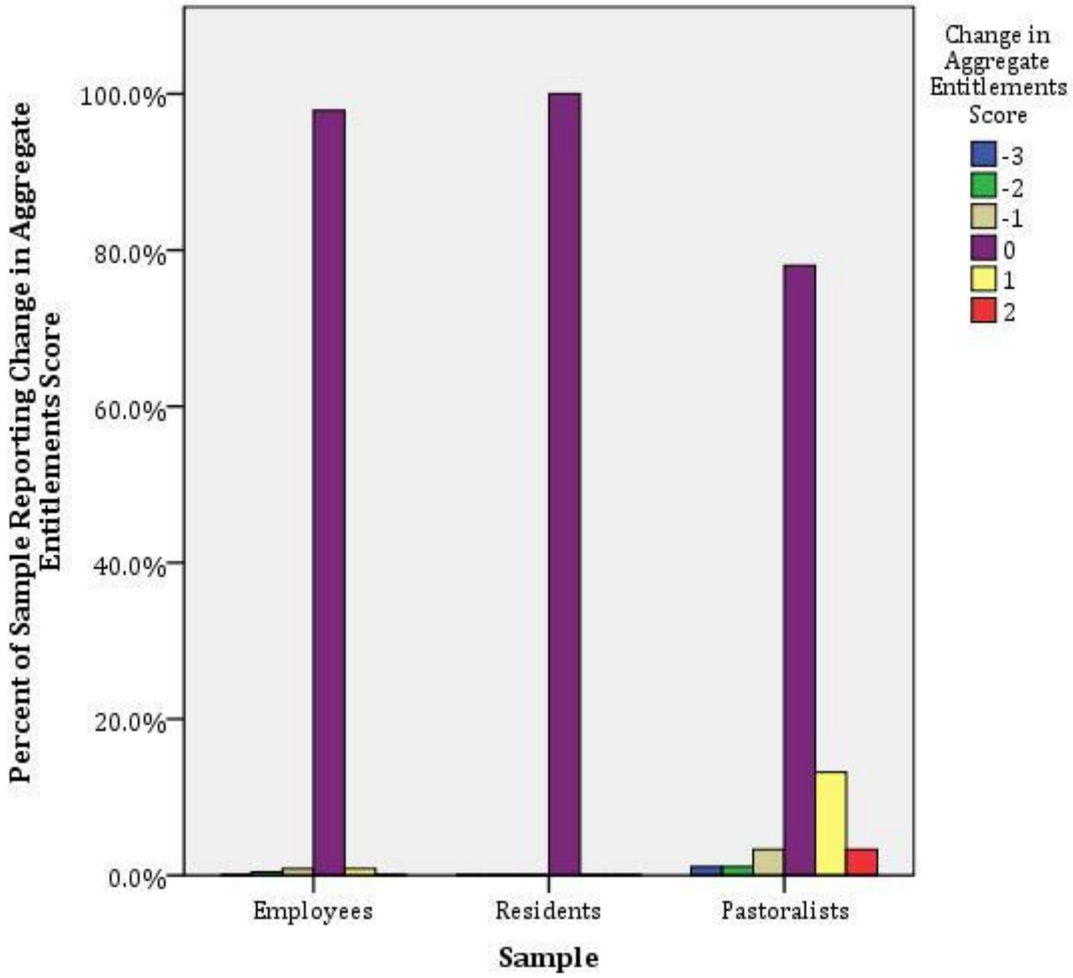


Figure 4.3. Change reported in entitlements. The majority of households reported no change in aggregate entitlements between 2007 and 2011 across all sub-samples, but those that do are mostly Pastoralist households and report an increase in the range of entitlements accessed.

4.4.2. Change in the Diversity of Entitlements Between 2007 and 2011

Households reported how their entitlement access had changed compared to four years ago. Figure 4.4 shows the change in frequency in each entitlement type for each sub-sample. Even with the small number (n=5) who reported change in the Employee sample, all households reported the same direction of change – for example, all households that reported a change in their livestock production reported adding that entitlement rather than losing it, whilst all lost access to crops. However, as these results reflect very small sample numbers they are not robust and no firm conclusions are attributed to these changes.

	Production		Trade		Own Labour	Transfer			
	Livestock	*Crops*	*Buy*	*Trade*	*Work*	*Friends/ Family*	*NGOs*	*MSF*	*Others*
Town Residents									
MSF Employees									
Pastoralists - Relocated	57:43	75:25		50:50	75:25				
Pastoralists - Not Relocated	22:78			20:80					

KEY	Removed	Added
100%		
51<99%		
No Change		

Figure 4.4. Change reported in the diversity of entitlements. Change per entitlement type for those households who reported a change in aggregate entitlement between 2007 and 2011 (if not 100% in one direction, the ratio is included in the box - households who removed this: households who added this).

Results that are more robust come from the Pastoralist households, where the main patterns, as seen above, are a decrease in production entitlements and increase in trade and transfer entitlements. Figure 4.5 shows that for all Pastoralist households, the option to cultivate arable crops is no longer available – 19% of all Pastoralist households reported this change. The addition of ‘buying food’ reflects a similar shift in the opposite direction (20% of all Pastoralist households), and therefore it is hypothesised that households who lost crop-based entitlements substituted for them by purchasing in the markets.

Another main shift is the addition of transfer entitlements within Pastoralist households, with up to 11% relying on NGOs where they did not 4 years previously. However, interestingly, half the relocated households reported a removal from the PSNP, whereas the majority of those not yet relocated reported joining the programme.

A final main trend is that a significant proportion of the relocated households have lost their livestock-based entitlements, whereas those not yet relocated have mostly added it. There were also a significant number of entitlements not described in the survey (answered with 'other') but reported as being lost.

	Production		Trade		Own Labour	Transfer			
	Livestock	Crops	Buy	Trade	Work	Friends / Family	NGOs	MSF	Others
Relocated	11%:8%	16%:5%	0%:16 %	5%:5%	8%:3%	0%:8%	0%:11%	8%:0%	21%:0%
Not Relocated	4%:13%	23%:0%	0%:25 %	2%:8%	0%:6%	0%:4%	0%:4%	13%:0%	26%:0%

% of Households	Added	Removed
<10%		
11<19%		
20%<		

Figure 4.5. Change reported in the diversity of entitlements for the Pastoralist sub-samples. Change per entitlement type for all pastoralist households between 2007 and 2011.

4.4.3. Perceptions of Change over Time

An interesting issue is whether a change in access to entitlements has resulted in a change in food security. As Sen (1987) concluded – access is a key issue in food security. However, if changes in the diversity of entitlements are adapted to by accessing other entitlements (i.e. the PSNP), or a larger dependence on one entitlement (i.e. trade), does this affect food security for these households?

Households were asked if in the past 30 days they had worried about whether their household would have enough food. Of the households who had previously reported changing their diversity of entitlements, 14% of Employee and 66% of Pastoralist households reported that they had worried. Across all samples, 8% of Employee households, 4% of Resident households and 49% of Pastoralist households reported that food security had been a worry in the past 30 days. When reporting whether during the past four years food security had been an issue, again the majority of households reported it had not. Those that did report an issue accounted for 4% of the Employee sample, 1% of the Resident sample and 32% of the Pastoralist sample.

To further quantify whether these perceptions of food security impacted food availability, the access data analysed above was triangulated with other measures of food security, so to provide more detail as to any impacts on food security from the expansion of Kesem and is presented below.

4.5. Triangulation with Other Measures of Food Security

As discussed above, Section B within the household survey was framed to collect robust data on the household's food security via multiple analyses:

1. Food access – past and present entitlements and food-related expenditure
2. Food availability – production based entitlements
3. Food consumption score – a weighted measure of dietary diversity
4. Household food insecurity and coping strategies – past and present

The analysis below presents the results of other measures of food security in the food system under study. Carrying out such complementary analyses to the entitlements analysis allows a more robust synthesis to be presented regarding mechanisms of change due to the biofuel expansion in the region.

4.5.1. Expenditure on Food

The majority of households across all samples reported the same weekly expenditure on food – between 100 and 199 Birr, approximately £3.70 - £7.37. As Table 4.5 shows, the range of reported food expenditures was greatest across the Pastoralist households.

Table 4.5. Expenditure on food in the three samples. The median expenditure on food was not significantly different across all samples (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

	Employees (n=233)	Residents (n=169)	Pastoralists (n=90)
Median	100-199 Birr	100-199 Birr	100-199 Birr
Percentage reporting median	46%	51%	47%
Range	0-99 Birr < 600-699 Birr	0-99 Birr < 700-799 Birr	0-99 Birr < Over 1200 Birr
Mean ratio of food: income	0.54	0.49	0.57
Standard deviation	*0.23*	*0.26*	*0.21*
Mean food expenditure per household member (Birr)	222	285	223
Standard deviation	*194*	*236*	*167*

It was hypothesised that the greater range of expenditures across the Pastoralist sample was due to a higher range of incomes. To test this, the ratio of food expenditure to total household income was calculated for each sample. Again, Table 4.5 shows the samples did not report a significantly different distribution of the mean ratio between the three samples (Kruskal-Wallis, p = 0.115). The lack of significant difference could be a factor of the data for both expenditure and income being categorical, which reduces the variance. In addition, some results were not included in these calculations due to underreporting of household income leading to discrepancies where the expenditure on food exceeded total household income. Therefore, expenditure on income does not give robust results on levels of food security and further triangulation is required.

4.5.2. Food Consumption Score

The food consumption score (FCS) is a weighted measure of dietary diversity, where foods are weighted depending on nutritional content and frequency of consumption and is outlined in Chapter 3. A higher score indicates a higher level of food utilisation (i.e. a varied diet) and therefore food security. A

Kruskal-Wallis test confirmed that the three samples have significantly different FCS values (p = 0.00), as Table 4.6 reports.

Table 4.6. Food consumption scores across the three samples. The mean FCSs are significantly different, attributed to different cultural preferences (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

	Employees (n=235)	Residents (n=170)	Pastoralists (n=91)
Mean Food Consumption Score	**514**	**728**	**420**
Standard deviation	*278*	*223*	*125*
Minimum FCS	48	236	112
Maximum FCS	1440	1440	858

However, whilst the FCS relate to food access and availability and is a good indicator for food security, cultural preferences are also a key factor in the foods people eat and can be responsible for differences in the scores. Analysis of cultural preferences is especially important when, as noted above, expenditure on food is similar across samples. To investigate this further, a more detailed analysis is required. Table 4.7 presents the proportion of that sample who did not consume that foodstuff in the past 30 days, and a Kruskal-Wallis test shows significantly different results across the samples.

Table 4.7. The % of households in each sample who did not consume a specific foodstuff in the past 30 days. All foodstuffs show a significantly different distribution across the three samples (p=0.000) indicating different cultural norms for the three samples (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

	Employees (n=235)	Residents (n=170)	Pastoralists (n=91)
Injera	**1%**	**0%**	**71%**
Maize	**18%**	**55%**	**2%**
Tomatoes	**1%**	**1%**	**41%**
Onions	**7%**	**0%**	**38%**
Gomen (spinach)	**20%**	**4%**	**89%**
Mangoes	**35%**	**14%**	**37%**
Bananas	**44%**	**28%**	**86%**
Avocadoes	**97%**	**65%**	**97%**
Beef	**40%**	**4%**	**28%**
Chicken	**49%**	**66%**	**94%**
Fish	**89%**	**65%**	**98%**
Milk	**28%**	**14%**	**1%**

Injera is the staple carbohydrate source in Ethiopia, but is not traditionally eaten by the Afar, who instead rely on maize as their staple – as reflected in the data. Within the Employee and Resident samples, 88% and 98% respectively consume injera at least every other day, whereas only 13% of the Pastoralist sample reported this regularity and 91% of the Pastoralist sample consumed maize products this frequently. Nutritionally, tef provides high levels of fibre and protein as well as essential minerals and a high calcium content (Condé Nast 2012). Employee and Resident households reported similar levels of vegetable consumption, particularly tomatoes and onions – base ingredients for the majority of dishes in the Oromo and Amhara cultures, from which the majority of the population hails, as shown in Table 4.1. These two vegetables were the most utilised vegetables in the Pastoralist households but by a lower proportion of households. The utilisation of vegetables is important for the provision of vitamins and key nutrients, and yet they are lacking from a traditional Pastoralist diet. Gomen, a local cabbage species similar to collard greens, is a key indicator of this – a key provider of vitamin K and iron (The George Mateljan Foundation 2013), gomen is used by the vast majority (96%) of Resident households and 80% of Employee households but only 11% of Pastoralist households.

The Pastoralist households did report a higher utilisation of fruits, commonly mangoes (63%) and oranges (33%), due to their cultivation on a state-farm in the area and common trade at local markets. The seasonal nature of the survey coincided with mango season and a high prevalence of them in the markets, therefore high utilisation was reported in all three samples, but consumption was significantly larger in the Resident sample than the Employee sample, even with the many fruit trees on the estate. A greater range of fruits was consumed in the Resident sample including avocadoes (35%) and bananas (72%).

Vegetarianism is a key feature of Ethiopian eating habits, commonly due to religious reasons such as the 250 fasting days within the Ethiopian Orthodox Church calendar (The Ethiopian Orthodox Tewahedo Church Faith and Order 2003). The main sources of protein during periods of fasting are pulses such as beans and lentils, and meat at other times of the year. The survey coincided with the period of fasting during Lent and the feasting of Easter for those in the Employee households. The other samples were not affected by this, and were collected during a period with no religious fasting days. The seasonality of the survey is reflected in the higher proportion of Employee households who had not consumed beef in the past 30 days (40%), but who had consumed chicken – the traditional meat consumed on Easter Sunday - once in the past 30 days (42% of the sample). The different cultural traditions of the Muslim Pastoralists during this period explain the very low levels of chicken consumption reported (6%), but far higher levels of beef consumption (72%), of which 49% of households reported consuming once or twice a week. The proximity to Lake Beseka provides the Resident sample with greater access to fish, which 35% of households consumed during the survey period. Finally, milk is confirmed to be a staple of the Pastoralist diet, with 98% of households consuming it at least every other day. However, it is a common component of the diets of households in the other samples too, although for a lower proportion of Employee households (72%).

Town Residents have greater access to a range of foods due to their proximity to larger markets, and therefore report a much higher dietary diversity, an indicator of greater food security. The distance from large markets (which are located in Metehara town, ten kilometres away) is proposed to limit the access to a greater variety of foods for the Employee households. However, the Pastoralists have a significantly lower FCS and a limited diet. Whilst this is a factor of distance from markets, the analysis in section 4.3 shows that the majority of Pastoralist households access markets frequently and therefore the limited dietary diversity is as much a factor of culture then as of limited access to other foods.

4.5.3. Coping Strategies Score

Coping strategies are employed when a household feels their food security is threatened, and are therefore an indicator of food insecurity. The household has options, it can adapt its food consumption or change other household practices, for example selling assets. The coping strategy score (CSS) construction is outlined in Chapter 3, and the results presented below in Table 4.8. There are three versions presented – the overall score combining both food and non-food coping strategies, weighted for severity and frequency (maximum score of 58), and those of the food and non-food coping strategies separately (maximum scores of 42 and 16 respectively). Analysing all three provides a detailed insight into households' perceptions of their food security.

Table 4.8. Various measures of the Coping Strategy Score. The Pastoralist sample reported the highest CSS due to a large proportion of the sample employing non-food related coping strategies (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

	Employees (n=235)	Residents (n=170)	Pastoralists (n=91)
Mean Coping Strategy Score	**1.3**	**0.6**	**5.6**
Standard deviation	*5.9*	*2.2*	*6.0*
Minimum CSS	0	0	0
Maximum CSS	39	20	24
Percentage of households employing coping strategies	5%	5%	86%
Percentage of households employing food related coping strategies	5%	2%	22%
Percentage of households employing non-food related coping strategies	3%	4%	83%
Mean Food CSS	**1.2**	**0.3**	**3.0**
Standard deviation	*5.6*	*2.1*	*6.1*
Mean Non-Food CSS	**0.1**	**0.3**	**2.6**
Standard deviation	*0.5*	*0.5*	*1.8*

A Kruskal-Wallis test reported the distribution of CSS, Food CSS and Non-Food CSS scores to be significantly different ($p = 0.000$) between the samples at the 0.95 confidence level. The Pastoralist sample was found to have the highest CSS, but the Employee population had the largest range of reported strategies enacted. The town Residents were found to have the lowest CSS, indicating the highest level of food security across the three samples. A similar proportion of the Employee sample was employing coping strategies, mostly by adjusting food consumption.

Table 4.8 shows that the majority of the Pastoralist sample (83%) reported employing non-food coping strategies. Due to the availability of livestock assets in Pastoralist households, the majority of those employing coping strategies did so by selling livestock (82%). The most common alternative was to sell their own labour – i.e. take paid work, changing their traditional livelihood, which was also reported in the Resident and Employee samples as the most common non-food coping strategy. Table 4.9 shows that, as seen above in the entitlements analysis, a large proportion of the Pastoralist sample also relied on food aid via the PSNP. A Kruskal-Wallis test reported there were multiple strategies that had significantly different distributions between the three samples.

Table 4.9. The percentage of households employing non-food coping strategies. The majority of Pastoralist households reacted to food insecurity by selling their livestock assets (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

Non-Food Related Coping Strategy	Employees (n=12)	Residents (n=9)	Pastoralists (n=76)	*p*
Selling labour power	**5%**	**20%**	**38%**	***0.000***
Short term migration	0%	0%	0%	*1.000*
Borrowing cash or grain	**4%**	**0%**	**0%**	***0.011***
Food aid	**0%**	**3%**	**30%**	***0.000***
Selling livestock	**0%**	**2%**	**82%**	***0.000***
Selling domestic assets	3%	0%	4%	*0.062*
Pledging land	**0%**	**0%**	**7%**	***0.000***
Selling land	0%	0%	0%	*1.000*
Other	0%	2%	0%	*0.100*

The households employing food-related coping strategies utilised a range of strategies of different severities, in all samples. Table 4.10 lists the coping strategies in order of severity. It would be expected that percentages would decrease as severity increases, depending on the severity of the food security event. What is reported is a mixture of strategies employed, including skipping meals – the most severe strategy that indicates high food insecurity. However, the small number of households reporting this data makes robust conclusions difficult. The majority of households reduced the range of foods they consumed and the quantity fed to adults. Very few households consumed grain, but this is an indication of the lack of arable farming households in the samples and hence grain as an asset. In the Employee sample, children were also served smaller quantities, a strategy that was avoided by the majority of households in the other samples. A Kruskal-Wallis test reported the distribution of each strategy between samples was significantly different for all strategies.

Table 4.10. The percentage of households employing food related coping strategies. Although sample numbers are small, households in all samples reported employing multiple food-related coping straetgies, of different severities (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

Food Related Coping Strategy	Employees (n=11)	Residents (n=4)	Pastoralists (n=21)	p
Eat a limited variety of foods	**91%**	**100%**	**100%**	***0.000***
Consume stored grain	**0%**	**25%**	**10%**	***0.000***
Borrow food	**82%**	**50%**	**90%**	***0.000***
Reduce quantity of food for adults	**91%**	**100%**	**95%**	***0.000***
Reduce quantity of food for children	**91%**	**0%**	**35%**	***0.000***
Skip meals	**82%**	**75%**	**85%**	***0.000***

When questioned about the main cause for the food insecurity in the households reporting employing coping strategies, all Employee households (100%) attributed the cause to increased food prices. In comparison, 25% of Resident households attributed it to a decrease in household income, but the majority (92%) also attributed insecurity to increasing food prices. The Pastoralist sample reported multiple causes for food insecurity, but no direct attribution to the expansion of biofuels. Instead, 99% reported increasing food prices, 46% decreased household income, and 41% a shortage of rain.

The vastly higher level of employment of coping strategies in the Pastoralist sample compared to the Resident and Employee samples indicates that relocation due to the expansion of Kesem Sugar Factory is having significant impacts on their food security, to a level where adaptation is necessary. Analysing the Pastoralist sample in detail, it can be seen that the mean CSS score is higher in the relocated sample – 6.0 (standard deviation 6.2) compared to 5.0 (standard deviation 5.7) in the unrelocated sample. However, the proportion of the two sub-samples employing coping strategies was not significantly different: 89% of the relocated Pastoralists and 82% of those still to be relocated. Therefore, whilst the changes in access to entitlements are affecting the majority of households within both Pastoralist sub-samples, relocation appears to have had a larger impact on food insecurity, requiring the employment of more severe coping strategies.

4.6. Mechanisms of Impacts from Biofuel Expansion

The hypothesis at the beginning of this chapter was that pastoralists, compared to other populations, would bear the costs of biofuel production and expansion in the region, due to their displacement leading to reduced food production and a 'direct entitlement decline'. The evidence presented here tests this hypothesis. All measures of food security analysed are consistent and complementary, and allow the overall effect on food security to be concluded so the hypothesis can be accepted or rejected. This section concludes with a summary of the impact on the different measures of food security for the different samples.

The current level of entitlements access was not significantly different between the Employee and Resident samples, indicating that direct engagement with biofuels production does not create any alternative access to entitlements for Employee households compared to Resident households as both rely on purchasing food rather than producing it. The access to entitlements of these two samples has not been affected by the expansion of biofuels in the area, as shown by the lack of change in access over the period of interest. The access to food is therefore relatively constant for the Employee and Resident samples. The reported expenditure on food was not significantly different, averaging 100-199 Birr per week, and consuming half of household income.

However, the food consumption scores were significantly different, with the Resident sample consuming a greater variety of food. Whilst cultural preferences may play a role in dietary diversity, the proximity of Resident households to markets, and therefore a greater range of foods to purchase on a daily basis, is suggested to be the main reason for the difference between the Resident and Employee samples. Both samples report a diverse diet that regularly includes all food groups and therefore a range of nutrients and indicates few issues with food insecurity. To test this further, coping strategies within the household were analysed. Both samples reported the same proportion of households employing coping strategies, but a very low proportion – 5%. The mean score was lower in the Resident sample, indicating more frequent or more severe issues for the few Employee households.

However, of those perceiving food insecurity and the necessity of coping strategies, none attributed this directly to the expansion of biofuels in the area, but to the increasing food prices in the markets.

Although this could be an indirect effect of biofuel expansion at a larger scale, there are no suggestions that biofuel expansion in the Metehara region has affected food prices and the perceived increase in food prices is more likely to be attributed to inflation and price control by the Ethiopian Government. Therefore, the level of food security is reported to be good for both the Resident and Employee samples, but slightly better for the Resident sample, which has greater access to a larger diversity of foods and employs less severe coping strategies. Table 4.11 summarises the levels of food security across the samples.

Table 4.11. A summary of the levels of food security across the three samples (✓ indicates a good level of food security, × a poor level of food security, and – a mixed response across the sample).

	Employee	Resident	Pastoralist
Change in the aggregate level of entitlements	✓	✓	-
Change in the diversity of entitlements	✓	✓	-
Expenditure on food	✓	✓	✓
Dietary diversity	✓	✓	×
Coping strategies	✓	✓	×

Table 4.11 also shows that, comparatively, the Pastoralist sample has lower food security than the other two samples. The aggregate level of entitlements was higher and, for the majority of Pastoralist households reporting change, an increased entitlements score was reported. Although this on its own does not indicate low food security, within the history of relocation this leads to a conclusion of adaptation to maintain food security, and a potential shift towards decreased food security.

One of the first actions of the management at the new Kesem SF site was to remove the access to arable land used by the Pastoralist households to grow staples and cash crops such as maize, onions and tomatoes. The loss of arable land is demonstrated in Figure 4.5 – only 3% of Pastoralist households reported cultivating crops for food (of which three were growing onions and two tomatoes), but up to 20% of the sample reported losing access to crop-based production entitlements. As part of the relocation package, households will receive one hectare of irrigated arable land per household, to be managed cooperatively by the head of the village. However, this has not yet been delivered, along with the promised grazing lands. The package also includes monetary recompense, allowing households to rely on markets and purchase more food. The receipt of this financial compensation is the most probable cause for the shift away from the PSNP scheme in relocated households and the substitution of production entitlements for trade entitlements. The other main trend is for the Pastoralist households not yet relocated to rely more heavily on transfer or own-labour based entitlements, an option possibly more easily accessed within Ethiopia, a country familiar with food insecurity and with national strategies already in place, for example the PSNP.

Therefore, the main response of Pastoralist households to the enforced or imminent displacement is the diversification of entitlements, consistent with theories of peasant household behaviour faced with disturbances and risk. The core of these theories is that smallholders will typically respond to risk by diversifying livelihoods, whether through necessity or as a choice – i.e. reactive or proactive (Ellis 1993; Ellis 2000). The same logic applies to the diversification of access to food when faced with a disturbance. However, differing from the livelihoods literature, diversification of entitlements is not necessarily an indication of present food insecurity having occurred; indeed resilience theory tells us that diversity is a key element of resilient systems. This is explored further in section 4.7.

Expenditure on food was not a clear indicator of food insecurity – the Pastoralist sample reported a similar expenditure to the other two samples whilst reporting lower scores for the other food security measures. It was predicted that a larger aggregate entitlements score would be reflected in reduced expenditure in markets for the Pastoralist sample, as the access to food was distributed across sources. The rejection of this hypothesis indicates the increased reliance of the Pastoralist sample on markets due to issues with access to the other entitlement sources. Again, the increased reliance on markets is not a clear indicator of food insecurity; if the level of food consumed is the same, does it matter where the food comes from? What this measure of food security highlights is the changing food system and cultural regime for these households.

The dietary diversity analysis presented reflects the strong cultural identity of the traditional Afar diet. Therefore, although the low food consumption score raises issues about the nutritional well-being of the diet, it again is not an indicator on its own of food insecurity. What does clearly indicate increasing food insecurity is the high level of coping strategies employed. Half the Pastoralist sample reported a perceived negative concern about food security, and although this was not directly attributed to the expansion of biofuels, the causes reported (99% reported increasing food prices, 46% decreased household income, and 41% a shortage of rain) can be linked to the expansion of biofuels and resulting displacement. For example, increasing food prices and decreasing household income has more of an effect in the present circumstances because of the increased reliance on trade entitlements and market, whereas previously the Pastoralists would have had more of a buffer between food prices and their food security due to their increased proportion of food accessed from production entitlements. Over 80% of Pastoralist households were employing coping strategies, mostly non-food strategies such as selling livestock assets. The high level of employment across the majority of the sample translated into a significantly higher mean coping strategy score compared to the other two samples, which indicates that the change due to displacement is having significant negative impacts on their food security, to a level where adaptation is necessary.

The overall balance of impacts is synthesised in Table 4.12 and shows no significant adverse or positive change in food security across all measures for the Employee and Resident households. The most significant impacts on food security caused by biofuel production and expansion in the region are negative impacts experienced by the Pastoralist households, whether relocated or still in the process of being relocated. The similar level of food expenditure to the other samples indicates that although access to food is changing, the diversification of entitlements is maintaining a level of food security for the Pastoralist households, although supplementation via coping strategies such as selling livestock is necessary.

Table 4.12. Synthesising change in food security measures for the different samples. This confirms that the majority of negative measures of food security (×) were reported by the Pastoralist sample (- indicates no change and ✓ a positive measure of food security).

	Employee	Resident	Pastoralist
Change in the aggregate level of entitlements	-	-	×
Change in the diversity of entitlements	-	-	×
Expenditure on food	-	-	✓
Dietary diversity	-	-	✓
Coping strategies	-	-	×

The results presented in Table 4.12 confirm the original hypothesis, that pastoralists bear the costs of biofuel production and expansion in the region, due to their displacement leading to reduced food production and a 'direct entitlement decline'. Therefore, the key mechanism influencing access to entitlements is displacement, due to land use change leading to the substitution of production entitlements for large-scale agriculture. Labour market shifts are not found to have a significant effect on the level of food security, as confirmed by the similar results for the Employee and Resident samples. In conclusion, the Sugar Factory has offered a fair compensation package for relocation, but the sluggishness with which it is delivering the agreed contents can be attributed as the cause of the main food security issues, reducing access to production entitlements and forcing greater reliance on markets where prices of staples are increasing.

4.7. Resilience Implications

The fields of entitlements and resilience are rarely applied together, but by viewing entitlements through a resilience lens new contributions can be made. Examining the framing of entitlements theory, it can be seen that key aspects can be addressed within resilience language. For example, Devereux (2001:248) discusses how *"identifying the trigger does not explain the famine, which requires* *a more complex analysis of conjunctural triggers and structural or underlying causes to be fully explained"*. Transformations to the extreme state of famine could be shown within a resilience framework to be a result of fast or slow dynamics passing a threshold, which causes a transformation. Therefore, failures of entitlements, which Sen (1981) defined as being direct (produce less food for consumption) or exchange (obtain less food through trade), can be seen as collapses in the adaptive cycle and hence the cause of transformations within the SES into a less resilient state. A disturbance such as the expansion of biofuels can be viewed as an external dynamic, causing both direct entitlement failure for the Pastoralist households by removing their arable and livestock entitlements, alongside exchange entitlement failure by reducing income and therefore weakening the household's purchasing power.

Chapter 2 explains that diversity is an important trait of resilient social-ecological systems, as sustaining diversity allows a system to cope with change, whether via adaptation or transformation by providing the resources for renewal and reorganisation. For example, biodiversity has been shown to increase resilience of desirable ecosystems, securing the production of essential ecosystem services (Elmqvist et al. 2003), but other types of diversity are important as well, for example response, cultural and institutional diversity. Within social systems, the importance of diversity is outlined by Johns & Sthapit (2004:144): *"although extensive diversity may not be necessary for humans to satisfy basic nutritional needs, within a socio-cultural context traditional biodiversity use is a powerful vehicle for maintaining and enhancing health-positive behaviours"*.

As stated above, that the main response of pastoralist households is the diversification of entitlements is consistent with theories of livelihood diversification, when faced with risk. Diversification in this form is not necessarily an indication of food insecurity but that pastoralist households are utilising their adaptive capacity and the response diversity within their food system to diversify their entitlements, hence indicating their resilience – they are maintaining the current system in the face of a shock. This is an unusual example, as the resilience of this system leads to diversity, whereas the resilience literature usually refers to diversity causing resilience. However, by adapting to maintain levels of food security the system can be pushed further towards a threshold and a potential shift into a less food secure system if a new disturbance occurs, as the response diversity and hence adaptive capacity is eroded. In a system where increasing food prices and decreasing household income have already been reported, this indicates further change could have a severe negative effect on households due to the increased reliance on trade entitlements and markets.

Whilst resilience in the present food system has desirable outcomes as it allows the households to maintain access to food, it is obviously not the desirable state for the pastoralists, whose culture revolves around production entitlements. It can also be seen that eroding adaptive capacity and response diversity could push the system into a trap – a resilient state that is difficult to adapt or transform out of. In this case, the proportion of food accessed from production entitlements acted as a buffer to changes in food prices. The removal of the buffer leaves pastoralist households locked-in to trade systems and closer to food security thresholds.

The results of this chapter also reflect cross-scale interactions across a panarchy of food systems. A relatively high proportion of households are already accessing food from the PSNP and NGOs, which indicates that, as discussed above, response diversity may have already been utilised. If, for example, a further food price shock occurred and market prices moved beyond their purchasing power, households would be limited in terms of new sources of accessing food. In addition, by maintaining their level of food security they may be reducing the level of resilience at a higher scale, i.e. the national scale from where the PSNP is managed. Currently, approximately 10% of the Ethiopian population is benefiting from the PSNP (The World Bank 2013b). A price shock as mentioned above would shift a larger proportion of the population into the 'chronic food security' state required for registering, increasing the burden on the national budget and reducing the national resilience to shocks. Therefore, the expansion of biofuels has differentiated impacts on resilience at different scales.

4.8. Conclusions

This chapter presents an analysis measuring the change in the diversity of entitlements alongside other food security measures and draws inference concerning the social-ecological system resilience. The expansion of biofuels in this specific Ethiopian example has had a limited impact on both the proportion of the population directly engaged in production (Employees) and those not engaged at all (Residents). Here, the potential benefits to actors involved in production do not appear to be realised, as their level of food security is comparable to the Resident sample. The only negative impacts are experienced by the Pastoralist households, at all stages of the relocation process. Around one quarter of these households diversified their entitlements and employed coping strategies compared to four years ago, prior to the biofuel expansion. Whilst this diversification reflects their current resilience, diversifying may actually be pushing these Pastoralist households towards a threshold, where a small change could push them into a more severe state of hunger due to the current utilisation of response diversity within the system and erosion of future coping strategies. In addition, diversification is pushing them towards a regime shift, where food security may remain satisfactory, but the traditional livelihood methods and diet will adjust to a more sedentary and market-based regime.

The results highlighted in this chapter confirm that the expansion of biofuels has differentiated impacts of on different actors within the local social-ecological system. By examining the multiple pathways in production and consumption chains, the winners and losers can be identified and changes in resilience at different scales assessed.

5. Environmental Impacts and Trade-offs

The previous chapter investigated the key interactions of biofuel expansion with household-scale food systems. It demonstrates the limited, but negative, impacts on household food security resulting from the production sub-system at Metehara Sugar Estate and the differentiated impacts on resilience at different scales. This chapter complements the household scale analysis in the production sub-system by highlighting the key ecological impacts of the current and expanded levels of sugarcane production so that the key research question "How does the expansion of biofuels affect the social-ecological resilience of the regional system?" can be explored. The research question is answered by independently addressing the four stages of production occurring at Metehara Sugar Factory (MSF) and Kesem Sugar Factory (KSF), framing each of those as specific research question - what are the impacts on the ecological sub-system from cultivation, harvesting, processing sugar and processing ethanol?

The overall hypothesis is that expansion of biofuel feedstock estates will erode the resilience of the regional landscape due to specific interactions with these variables:

- Biodiversity
    - Land use change leads to habitat fragmentation and expansion of monocultures and decreases biodiversity.
- Soil
    - Intensive irrigation increases soil salinization.
    - Intensive irrigation and field clearance increases soil erosion and decreases the fertility of soils.
- Water
    - Both run off from farm inputs (of chemical herbicides, pesticides and fertilisers) and wastewater generated by processing (containing a high Biological Oxygen Demand (BOD)) increases water pollution.
    - Irrigation and processing creates large demands for fresh water.
- Air
    - Field burning impacts air quality

During the investigation of the relevant stage, the above hypotheses are assessed to conclude a) what interactions have occurred during this stage, and b) what the direction and severity of the impact is on the regional social-ecological system. The life cycle analysis of the environmental impacts of both sugar estates requires a different focal level to that of the food security analysis – the regional extent of each sugar estate, as bounded by the limits of the geographical area they govern, as shown in Figure 5.1. The downstream impacts on social-ecological systems at larger scales are also considered.

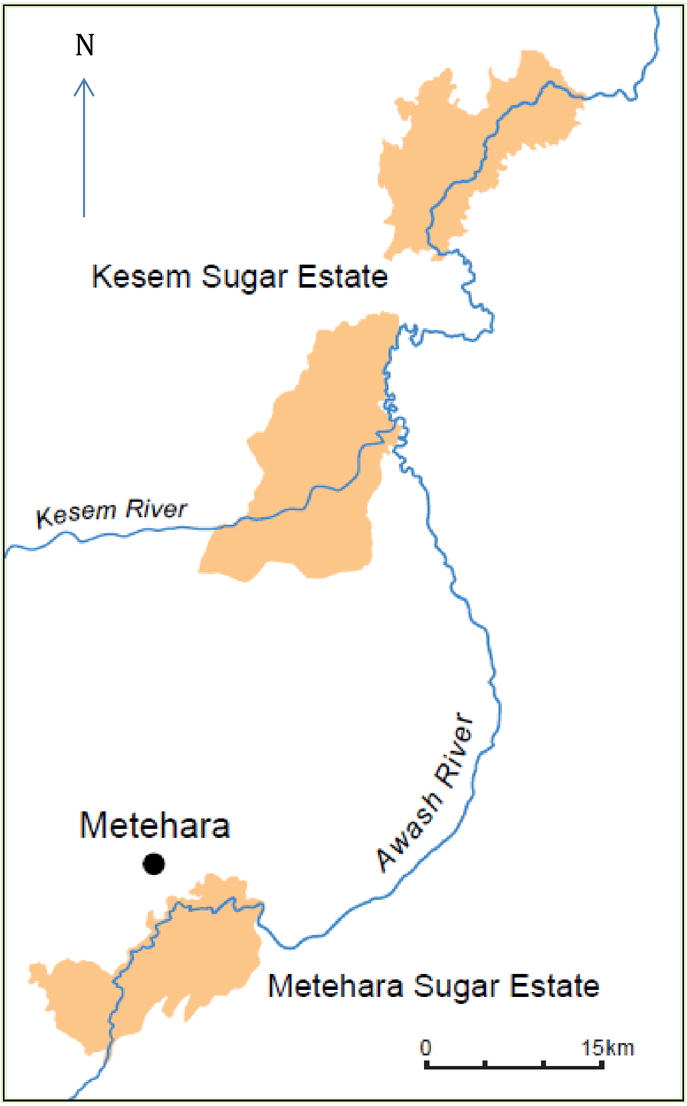


Figure 5.1. Boundaries of Metehara and Kesem Sugar Factories.

This chapter reports that the ethanol production system in the Metehara region does not appear to have breached any significant ecological thresholds for the set of quantifiable indicators analysed, but supports the hypotheses above. Such impacts could potentially lead to a loss of ecosystem services for future or downstream users and are not adequately considered by the management. The new production at KSF will repeat the majority of these disturbances with the ecological sub-system but also has a large associated carbon footprint driven by the significant land-use change and construction of a reservoir for irrigation.

5.1. Cultivation Inputs and Outputs

Metehara Sugar Factory cultivates sugarcane over 10,300 hectares, split into approximately 1,500 fields with an average size of 7 hectares, but ranging between 0.5<30 hectares (MSF Management 2011). The land on which MSF lies is a volcanic cambic soil, which is typically potassium-rich (MSF Management 2011). Ten commercial varieties of sugarcane are grown, of which four varieties cover the majority of the land. Species choice is dependent on soil and moisture conditions for a specific field.

Sugarcane is a perennial crop that has a life cycle of 4-8 years at Metehara. It consists of a 'stool' or common root system from which 8-9 canes grow. The first harvest occurs roughly 18 months after planting the seed-cane, by cutting the cane stalks above the soil line. New canes then re-grow from the same stool, known as ratoon-cane. Whilst the ratoon cycle depends on soil type and the variety of cane, in the MSF fields it takes 12-13 months to reach maturity again (i.e. maximum sucrose content) and there is a minimum of 3 ratoons and a maximum of 7 (MSF Management 2011). After the final ratoon is harvested the ratoon-cane is up-rooted, the field cleared, and the cycle begins again. The complete cultivation cycle is outlined below, highlighting the interactions with the ecological system and resulting impacts.

5.1.1. Organic Fertiliser

After clearing, the fields are mechanically harrowed and ploughed, both on the surface and at a depth of 70cm to break up soil clods and allow maximum possible root penetration. The field is then levelled and a compost layer composed of filter-cake and vinasse (waste products of the processing discussed further below) is applied mechanically at a rate of 4 tonnes per hectare. After the application of compost, the furrows, ditches through which irrigation water is supplied, are constructed. The choice of furrow irrigation demands the levelling discussed above as uneven topography impedes flow through the furrows. Level fields are therefore required to prevent water pooling. In MSF, furrows are 100m long and spaced 1.45m apart, totalling 70 per hectare. Seed-cane is planted on the mounds between furrows at metre intervals. The field is then irrigated to prepare the optimum moisture for planting and as well as germinate weed seeds, which are then removed manually.

The average seasonal compost application is estimated to be 5,200 tonnes, calculated by multiplying the application rate by the mean hectares of newly planted land per season (MSF Management 2011). However, the previous (manual) application rate was 10 tonnes per hectare and as managers reported that the current level is not sufficient and will be increased in future seasons, this study uses the higher application rate and estimates that annual application is 13,000 tonnes, as reflected in the calculations below. MSF has the capacity to produce up to 42,000 tonnes of compost per year; hence, lack of compost has never been a barrier to production.

The utilisation of waste products within the production system is both sustainable and economically favourable. Compost utilisation enhances the soil structure by adding organic matter, supplies nitrogen to the soils, makes the soil more suited to receiving irrigation water and also aids yield by increasing soil micro-organisms concentrations (Bot & Benites 2005). The use of vinasse as a compost prevents its purposeful release into watercourses, where it is classed as a pollutant due to its high Biological Oxygen Demand (BOD) and low pH (4-5) (Goldemberg et al. 2008). However, the threat of leaching into water bodies remains. Goldemberg et al. (2008) suggest that, for the Brazilian sugarcane system, the threshold for leaching from vinasse application is 30,000 m^3 per km^2, below which there should be no significant damaging impacts. The MSF application translates to 180 m^3 per km^2 and therefore, although in a different ecosystem, is so far under the threshold that leaching is thought not to be an issue.

Thus, the overall impact of the organic compost is dependent on the application rate and whether the benefits of increasing soil quality and yield are cancelled out by the negative environmental impacts due to leaching. In this system, the application is beneficial and has limited negative impacts on water bodies.

5.1.2. Inorganic Fertiliser

Six to eight weeks after the final compost application, the field is fertilised manually with urea ($CO(NH_2)_2$), containing 46% nitrogen. The urea is applied as solid granules when the soil moisture is judged to be at an optimum dryness at both a 30 and 60 cm depth. The urea is volatile and so can produce a lack of uniformity in growth, which is rectified via a second application if necessary, but is not mandatory. Application on seed-cane is 117 or 213 kilograms per hectare dependent on the soil classification. Future applications occur after harvest, and the application on ratoon-cane increases to 219 or 317 kilograms per hectare. In 2009/10, the total application of urea was 2,800 tonnes per year, including the extra application and research quota. Using the total area of sugarcane cultivated, the application rate is 0.3 tonnes per hectare, shown in Table 5.1. The urea application is average compared to other countries, although extreme applications of 400 to 750 kilograms of Nitrogen per hectare per year occur in India and China (Robinson 2006). No phosphorous or potassium fertilisers are applied, minimising chemical inputs compared to sugarcane cultivation in other countries, for example Cuba and Thailand where phosphorous rates range from 50<55 kilograms per hectare and potassium 65<87 kilogram per hectare (Food and Agriculture Organisation of the United Nations 2007).

The application of both organic and inorganic nitrogen via compost and urea leads to the release of nitrous oxide (N_2O), a greenhouse gas (GHG) with a global warming potential (GWP) of 298 (over a 100 year time horizon) (Forster et al. 2007). Although the precise nitrogen content of the MSF compost is unknown, this study uses 0.368 kilograms N per m^3 for vinasse and 1.4% dry mass for filtercake, as used in de Figueiredo & La Scala (2011), a paper analysing a sugarcane-based social-ecological system in Brazil. As the MSF data are for combined vinasse and filtercake, the 1.4% dry mass value is applied due to its higher value (0.368 kilograms N per m^3 translates to 0.01% N). To calculate the emissions of N_2O the study applied the default IPCC emission factors (EF). For direct emissions the EF is 1.25%, as it is for indirect emissions, taking into account the volatisation of 90% of the organic and 80% of the inorganic fertilisers (Mosier & Kroeze 2006). Finally, the IPCC also apply a 30% leaching fraction, of which 0.75% of the remaining N is emitted as N_2O (Mosier & Kroeze 2006). Summing the N_2O emissions via all three mechanisms, the calculated N_2O emissions are 33 tonnes from inorganic fertiliser and 4.5 tonnes from organic fertiliser, as shown in Table 5.1. This is 2.6% of applied nitrogen and 0.24% of applied mass. The summed N_2O emissions are then converted to CO_2e emissions, totalling 11,026 tonnes. Due to their removal during field burning in the harvesting process N_2O emissions from sugarcane residues, although discussed in the literature and IPCC AR4, are not calculated here.

Urea application also leads to direct CO_2 emissions, by releasing the carbon that was fixed during its production process. As the urea breaks down, it forms bicarbonate (HCO_3) and evolves into CO_2 and water. As the Ethiopia specific emission factor is not available, the default IPCC emission factor of 0.20 (the carbon content of urea (Mosier & Kroeze, 2006:32) is applied to the seasonal urea application at MSF, 2,800 tonnes producing 560 tonnes of CO_2.

Table 5.1. Fertiliser inputs to the cultivation phase. During an average season these inputs result in large outputs of N_2O, which has a high global warming potential.

	Input	Tonnes per season	Tonnes per hectare	Associated output	Tonnes per season
Organic fertiliser	Compost	12,900	1.3	N_2O	4.5
				CO_2e	1,340
Inorganic fertiliser	Urea	2,780	0.3	N_2O	33
				CO_2e	9,690
				CO_2	557
	$FeSO_4$	134	0.01		

Field inspections monitor cane quality and further fertiliser requirements. Ferrous sulphate is the final fertiliser used at MSF but is only applied when necessary in fields showing leaf discolouration, a symptom of iron deficiency. This can be dependent on the cane variety, but is found on no more than 5% of the total area under cultivation, more commonly in the marginal fields that have not been cultivated for some time. Total application in an average season is 134 tonnes, reflecting the limited use compared to urea. As ferrous sulphate is not discussed in the literature as contributing to the carbon balance, it is not included in the calculations.

The combined inorganic fertiliser application at MSF is considerably lower than that reported in most other large producer countries due to the lack of phosphorous and potassium fertilisers applied. Of the countries within the FertiStat database (with data from the last 10 years), only Argentina has a lower application rate, as shown in Table 5.2. This leads to a reduced economic cost for the estate and fewer impacts on the environment.

Table 5.2. Seasonal inorganic fertiliser application across the main producer countries. The Ethiopian rate of application for sugarcane is less than in other countries (Food and Agriculture Organisation of the United Nations 2007).

Country	Rate N (kg/ha)	Rate P (kg/ha)	Rate K (kg/ha)	Rank in world production
Ethiopia	**98**	**0**	**0**	**42**
Brazil	55	51	110	1
India	125	44	38	2
Thailand	70	55	65	4
Pakistan	125	56	0	5
Argentina	80	2	0	10
Cuba	63	50	87	16
Indonesia	90	35	30	11
Mean of these countries	*88*	*37*	*41*	

Economically, utilising compost from waste products is beneficial to MSF as the estate can supply its own needs, even at the higher manual application rate (10 tonnes per hectare), and need not rely on local markets. Although no phosphorous or potassium are applied currently, field managers are urging phosphorous application in certain fields, due to falling natural concentrations (MSF Management 2011). Such decreases are assumed to be due to continued monoculture over a sustained period, with minimal time left fallow. The decreases have a negative effect at the mill level due to the role of phosphorous concentration in juice clarification, decreasing sucrose yield. Economically therefore the introduction of phosphorous fertilisers may be justified by the increased sugar yields. The focussed method of fertiliser application following field inspections allows the most efficient rate of application, and for managers to notice such field-by-field issues as this.

5.1.3. Inorganic Pesticides

Pesticide application is also reactive, depending on the specific issue. Field managers decide on the need for manual weeding or the use of a suitable herbicides and pesticides on a field-by-field basis. The main pests in this ecological sub-system include black beetles and termites. For black beetle infections, commonly between late February and May when soil temperatures increase, Ethiozenon and Basudin are applied at 3 l/ha. This is mandatory on seed-cane but only applied if observed on ratoon-cane. If termites are found, more commonly around irrigation canals, Dursupan is applied. For weeds, 2,4D-amine and Gesapax are applied in combinations of 4 – 8 litres per hectare. Finally, Round Up (a broad spectrum, low toxicity herbicide) is applied on all bare areas, but not fields due to its non-selective nature (MSF Management 2011; Séralini et al. 2012). MSF provided data regarding consumption data of 2,4D-amine, Ethiozionon and Gesapax, of which Gesapax is the most applied, as shown in Table 5.3. Teepol is a detergent that MSF use as a wetting agent to ease application of the other chemicals. Table 5.3 also contains the overall application rates, taking into account the entire area under sugarcane cultivation (10,300 hectares).

Pesticides have embedded GHG emissions due to their production from fossil fuels. However, this carbon balance analysis only includes emissions directly related to the cultivation to processing stages. The main interaction of pesticides with the ecological sub-system is via water contamination and toxicity. 2,4D-amine has a short half-life (7 days) and therefore a low persistence under normal conditions, minimising any environmental health effects (Environmental Protection Agency 2005a; Mergel 2010). In comparison, Round-Up has a half-life of 47 days and is therefore classed as 'moderately persistent' and has been linked to water contaminations (S. Foley 2009). The active ingredient of Gesapax is ametryn, which has been used to control broadleaf weeds in sugarcane fields for over 40 years but poses some chronic risk to birds and mammals (Environmental Protection Agency 2005b).

Data are unavailable to assess the run-off and contamination level in the water bodies of MSF and was not raised as an issue by any manager during interviews. However, the toxicity of the pesticides was raised as a potential negative impact and one of the motives to field-by-field application rather than blanket coverage. As a result, MSF implement mandatory training in chemical application for field workers and only treat fields if necessary. Cost was another motive behind this decision. Overall, estate managers did not perceive pesticides to have a negative impact on the wider ecosystem, solely a positive impact on yield.

Table 5.3. Seasonal pesticide inputs to the cultivation phase.

	Input	Litres per season	Litres per hectare
Inorganic pesticides	2.4D-Amine	19,800	1.9
	Ethiozinon	12,800	1.2
	Gesapax	25,800	2.5
	Teepol	3,100	0.3
Total		61,500	6.0

5.1.4. Water Consumption and Outputs

As discussed above, fields are irrigated within the fertilisation sequence, and then regularly afterwards at 6-15 day intervals, the frequency of which is determined by the soil type in the field. The process is variable due to the large man-power, meaning fields are inspected daily to measure soil moisture and determine when irrigation is required, and when deemed appropriate one hectare receives 800<1000 m^3 of irrigation water (MSF Management 2011). Over a season, this amounts to a huge water requirement, as shown in Table 5.4. Water intake throughout the season (October<June) is consistent, as shown in Figure 5.2.

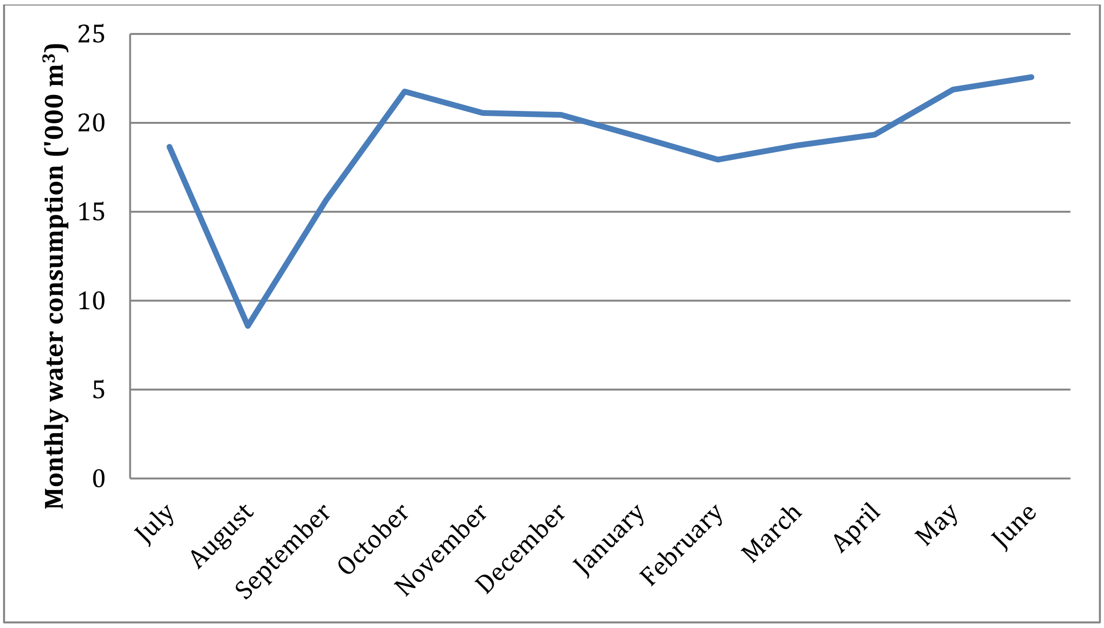


Figure 5.2. Average monthly water consumption at Metehara Sugar Factory (2007-2010). Consumption is relatively consistent across the season (October – June).

Water is sourced from the Awash River at MSF via two intakes, with a maximum intake of 947,000 m^3 per day (MSF Management 2011). Once on-site, the water travels through a canal network totalling 1,000 kilometres into one of the 27 reservoirs (total capacity 1,430,000 m^3). Gates are opened before dawn to irrigate the necessary field, delivered via furrow irrigation. Of this, 84% is gravity-powered and 16% (1,700 hectares) is powered by pumps, due to the topography. There are three pumps, powered by diesel generators during the season months. The average total diesel consumption for pumping is shown in Table 5.4 above, and is responsible for 107,000 kilograms of CO_2e emissions, using the conversion rate of 2.7 kilograms CO_2 per litre of diesel (Environmental Protection Agency 2011).

Table 5.4. The seasonal irrigation inputs of Metehara Sugar Factory. This is a large water footprint.

Activity	Inputs	Average Season	CO_2e (kg)
Irrigation	Water ('000,000 litres)	262,000	n/a
	Diesel (litres)	39,800	107,000

This water consumption is also used during processing in the sugar and ethanol factories, not solely for cultivation, and the proportion used for processing is discussed below in sections 5.3.2 and 5.4.2.

Once fed into the furrows, the majority percolates into the soils and becomes ground water, flowing back to the Awash River by groundwater transport. There is some surface flow discharge, but MSF attempt to minimise this by irrigating field-by-field with workers assigned to monitor progress rather than automating the system. Tumebo (2008) calculates the consumption rate of MSF as 80%, indicating 20% of intake travels back to the Awash as return flow. Water that is discharged (whether from directly, from the fields or from the factories) travels via 168 kilometres of drainage channels. Water from the factories is treated prior to release into these channels, as outlined below. The drainage channels then flow back into the Awash River.

Whilst MSF is reliant on the Awash River, and therefore susceptible to natural variance in river flow such as floods and droughts, the managers do not see this as a negative. In contrast, interviewed managers outlined that the environment had no influence on production at MSF due to the Awash River. Such a reliance on irrigation creates a threshold where productivity of the estate can be transformed below a certain water availability; however, it does not appear this threshold has been reached. There are, however, plans in place for prioritising certain fields when river levels decrease, initially those with the lowest water-holding capacity and therefore lowest water requirement.

The reliance on irrigation also has an impact on the ecological sub-system. Furrow irrigation recharges the groundwater due to the direct contact with the soil; managers estimate 40% is lost to groundwater (MSF Management, 2011). As the groundwater is recharged it rises closer to the soil surface, and the resulting capillary action increases the salt content of the soils. Therefore increasing soil salinity is an issue at MSF and will decrease yields due to prohibition of root growth. However, irrigation is not the only cause of salinity in the system and the estate managers' report the expansion of Lake Beseka to be a larger disturbance, as discussed in section 5.9.1.

5.1.5. Fuel Use in Field Machinery

As well as the consumption of diesel within the generators, petroleum fuels are consumed in the field machinery. There are 310 vehicles within MSF, ranging from tractors to motorcycles. The total fuel consumption is shown in Table 5.5.

Table 5.5. Fuel consumption in field machinery over a season. The majority of fuel consumed is diesel.

Activity	Inputs	2010/11	Coefficient (kg CO_2e/ litre consumed)	CO_2e (kg)
Machinery	Diesel Use (litres)	13,800,000	2.7	37,200,000
	Petroleum Use (litres)	1,610,000	2.3	3,700,000

Again, using the CO_2 emission rates from the Environmental Protection Agency (2011), the fuel consumption is translated into carbon emissions to feed into the carbon balance. The secondary data collected at MSF does not allow the fuel consumption to be split between the cultivation and harvesting phases, so is shown entirely within the cultivation phase.

5.1.6. Biodiversity

Metehara Sugar Factory is an established monoculture, therefore in essence a managed ecosystem of low biodiversity. However, observational data indicates that the estate supports wildlife including insects, birds, primates and other mammals. One manager hypothesised this to be a result of the proximity of the Awash National Park and ease of mobility between the two areas (MSF Management 2011). Such biodiversity is also a result of the large number of trees planted in MSF – introduced by the original Dutch managers of the estate for aesthetic reasons in the settlements, but primarily to act as a wind break and prevent wind felling the sugarcane (MSF Management 2011). The majority of trees in the fields are 10-15 year old Royal Poinciana (*Delonix regia*), whereas in the settlements there are also mango (*Mangifera indica*), papaya (*Carica papaya*), lemon (*Citrus limon*) and avocado (*Persea americana*) trees. As discussed in Chapter 4, whilst providing insect and bird habitat these trees are also an important source of fresh fruit for the MSF households. The onsite nursery cultivates 1 million trees per year, to continually replace those that fall in the wind. There is also a 190 hectare commercial fruit farm on-site, producing different species of mangoes, papaya and lemons for sale in regional and national markets.

A final impact on biodiversity, not related to cultivation but to the processing of sugar and ethanol is the utilisation of molasses in ethanol production, which aids biodiversity. Previously if the molasses were not sold (as cattle feed or to a perfume producer in France) they were used to cover roads or were disposed of in the Awash River (MSF Management 2011; Tadele 2012). Local NGOs allege such disposal to have a large negative impact on biodiversity as the molasses coated the river bed, reducing the concentration of organisms, although no primary or secondary data exists to quantify such impacts (Tadele 2012).

Therefore, whilst the initial transformation to a sugarcane plantation would have reduced biodiversity from the original acacia shrubland ecosystem to essentially a monoculture, the choices made by MSF management have aided biodiversity significantly, as shown in Table 5.6. The biodiversity impacts of the land-use transformation resulting from the construction of Kesem Sugar Factory are discussed in section 5.7.1.

Table 5.6. Impacts on biodiversity.

Activity	Inputs	Impact on Biodiversity
Cultivation	Monoculture	↓
	Tree planting	↑
	Fruit farm	↑
Processing	Utilisation of molasses	↑

5.1.7. Soil Carbon Sequestration

As discussed in Chapter 2, the biological process of plant growth is carbon neutral, until other inputs such as fertilisers and land use change are involved. The biological neutrality is because the plants being cultivated are cycling carbon already in the atmosphere, rather than fossil carbon. Sugarcane has a high carbon sequestration rate during growth due to the C4 photosynthetic pathway it employs – Moundzeo et al. (2011) report 30 < 70 tonnes/ha in the Niari Valley, Congo, depending on climate and species. Indeed, sugarcane results in higher sequestration rates than some forests (Goldemberg et al. 2008;

Rhoades et al. 2000). As for any crop, the carbon contained in the sugarcane is released again on decomposition or burning, cancelling out the carbon savings and making the process carbon neutral.

However, some carbon is sequestered permanently due to the production of silica phytoliths or 'plantstone carbon'– microscopic grains of silica in plant leaves that are highly resistant against decomposition and hence remove CO_2 from the atmosphere for up to 8,000 years (Parr et al. 2009). Sugarcane is particularly efficient at incorporating carbon into such silica phytoliths (Parr & Sullivan 2005). Parr et al. (2009) reported phytolith production amounting to 1.3<2.6% of the original sugarcane plant mass, resulting in the sequestration of 0.12<0.36 tonnes CO_2e per hectare per year. Although using different sugarcane species to those found in Metehara Sugar Factory, a similar rate of sequestration (0.24 tonnes CO_2e per hectare per year) would result in 2,500 tonnes of CO_2e sequestered per year.

Other carbon is sequestered into the soil as organic carbon – however, this is not counted in a carbon balance due to its temporary status in agricultural soils. However, the regular harvesting of sugarcane depletes soil carbon levels compared to the initial ecosystem, hence why conversion of land to cropland results in a 'carbon debt'. Conversion releases CO_2 via burning or microbial decomposition, whilst this is rapid initially (released from fine roots and leaves), it is prolonged over a 50 year period as thicker roots and wood products decay (Fargione et al. 2008). As MSF has been operating for over 50 years, it is assumed this loss of soil carbon has occurred and is not counted within the carbon balance. However, it must be included in the Kesem Sugar Factory carbon balance where land conversion is recent.

The burning of the sugarcane prior to harvesting also results in much lower organic carbon sequestration – de Figueiredo et al. (2010) show that if green harvesting (i.e. un-burnt sugarcane using machinery) was practiced rather than burning, an additional 7.2 tons of CO_2e per hectare per year would be sequestered. Within the carbon balance, (as in de Figueiredo et al. (2010)) CO (which rapidly transforms to CO_2 in the atmosphere) and CO_2 emissions from burning are not included as these emissions are simply compensating the season's temporary sequestration of atmospheric CO_2. However, products from incomplete combustion, such as methane (CH_4) should be included, and are discussed fully in section 5.2.1 below.

5.2. Harvesting Inputs and Outputs

After a sufficient period for the cane to mature, the fields are 'dried out', i.e. managers halt irrigation, increasing the sucrose content of the cane. 'Drying out' lasts between 1.5 and 2.5 months, depending on the cane variety and whether the soil has a low or high water-holding capacity. Once core samples at various depths report the field is dried, the field is burnt. As Chapter 2 outlines, burning has negative impacts on air quality and is being phased out in other producer countries such as Brazil (Gasparatos et al. 2011). However, Sugar Corporation regulations require manual harvesting and prohibit mechanical sugarcane harvesting to maintain job creation, therefore MSF still employ field burning (MSF Management 2011). Burning the field eases manual harvesting by removing the sharp outer leaves.

As the cane is cut, the remaining tops and stalks are left in the field and MSF residents and local people are welcome to collect the vegetation to use as fuelwood or animal feed. Within a couple of days the field will be 'cleaned' - i.e. the remaining vegetation is removed and burnt. The process of harvesting is highly adjustable with timing based upon daily field observations, mill capacity and backlog, and planned maintenance. The late decision allows the harvest schedules to be finalised the day prior to harvesting. In the 2009/10 season (consisting of 278 days), a total area of 7,400 hectares was harvested.

5.2.1. Field Burning

When a field is burnt, fires are set at each corner of the field between four and six am. The field burns in 35 to 40 minutes without the addition of fuel, and cools sufficiently by sunrise for cutting to begin that day. To cut a field approximately 30 day-labourers are required, and are paid by the furrow.

When quantifying emissions from field burning the embedded CO_2 and CO emissions are not included, as the emissions during combustion are equal to the CO_2 absorbed during growth of the plants. However, due to incomplete combustion during the field burning there are other emissions that do require inclusion in the carbon balance – methane (CH_4, 100 year GWP is 25), non-methane volatile organic compounds (NMVOC, GWPs range between 0.5<5.5 depending on species), nitrous oxide (N_2O, 100 year GWP is 298) and NOx (nitrogen oxides, GWP uncertain) (Forster et al. 2007). Due to the uncertain global warming potentials, NMVOCs and NOx products are not included in this carbon balance.

The IPCC emission accounting methodology was applied to this case study, to calculate the emissions of CH_4 and N_2O from field burning (Mosier & Kroeze 2006). For each gas, the area burnt was multiplied by the mass of fuel available for combustion (a residue per yield ratio of 0.205, as used in de Figueiredo et al. (2010) as such data were not available from MSF), the default combustion factor (0.80), and the default emission factors – 2.7 for CH_4 and 0.07 for N_2O. With 7,400 hectares burnt in an average season, 533 tonnes of CH_4 and 14 tonnes of N_2O are emitted, translating to 17,400 tonnes of CO_2e, as shown in Table 5.7.

Table 5.7. Seasonal emissions from field burning. Field burning is responsible for large greenhouse gas emissions due to methane and nitrous oxide emissions during incomplete combustion.

Output	Emissions per Season (tonnes)	Global Warming Potential (100 Year)	CO_2e emissions per season (tonnes)
CH_4	533	25	13,300
N_2O	14	298	4,120
Total			**17,400**

The emission of GHG during field burning reduces the positive carbon balance of the ethanol (as referred to above, if green harvesting was practiced an additional 7 tons of CO_2e per hectare per year would be sequestered).

The pre-harvest burning of fields is shown in the literature to have many other negative environmental impacts such as the reduction in nutrient and organic matter retention in the soil, which leads to greater fertiliser and water requirements in future seasons (Mitchell et al. 2000). Although there are relatively low levels of soil erosion in sugarcane land due to its semi-perennial nature (Macedo 2007), this reduction in organic matter leads to increased soil erosion when the land is not under sugarcane (Moundzeo et al. 2011). The deposition of nitric acid (formed as NO_2 released during burning reacts with hydroxyl radicals) contributes towards acidification of natural ecosystems as well as eutrophication in standing water, both of which are detrimental to productivity (Oppenheimer et al. 2004). However, the limited data available from MSF means it is not possible to confirm these impacts in this case study. Interviews conducted with the managers of the sugar estate questioned the environmental impacts of the estate they perceived to be key, but whilst issues such as salinization of soils and phosphorous deficiency were raised, soil erosion and organic carbon loss was not. In summary, the expected direction of ecological impacts from the pre-harvest burning of fields is highlighted in Table 5.8.

Table 5.8. The environmental impacts of field burning. All four are likely to be negative but cannot be quantified specifically for MSF.

Activity	Impacts	Impact on ecological system
Field burning	Greenhouse gas emissions	×
	Nutrient retention in soil	×
	Soil erosion	×
	Acidification	×

The most discussed impact of this ecological disturbance focussed on in the literature is the negative health impact due to inhalation of particulate matter (PM) in the resulting smoke. Particulates of concern include $PM_{2.5}$ (fine particulate matter) and polycyclic aromatic hydrocarbons (PAH) which are associated with various cancers (Cristale et al. 2012); crystalline silica polymorphs which are also carcinogen and cause silicosis (Le Blond et al. 2010); and total suspended particles (TSP) which have been associated with hospital admissions due to respiratory disease (Arbex et al. 2007; Cançado et al. 2006). No primary or secondary data were available regarding particulate levels in the Metehara area post-burning.

Observational data reported that high levels of smoke were produced during burning, but dissipated within a few hours. Households surveyed regarding their food security levels were also asked about their perceptions of air quality in the area. The majority of employee households residing on the sugar estates, and therefore closest to the burning fields, reported a 'good' air quality (54%) but 36% did report a 'poor' air quality. Of these households, only 8% specified field burning emissions to be the cause – other causes were attributed to be the lack of sanitation, vegetation and precipitation creating odours and dust. In the wider sample, residents in the nearby town had more favourable perceptions of the air quality, as only 9% reported it to be 'poor'. The pastoralist households were the most critical of the air quality – 41% reported it to be 'poor'. However, 56% of those households linked the poor air quality to high levels of dust in the area, and 28% to the high temperature – no household referred directly to field burning. These perceptions are indicative of the highly arid and hot climate in the Rift Valley, where the sugar estates are located - average rainfall in this area is 501mm/year (MSF Management, 2011). When asked about levels of respiratory disease in the household, 42% of pastoralist households who perceived poor air quality reported a high (more than 3 times a year) frequency of respiratory disease, compared to 36% of Metehara residents and 20% of MSF employees. Therefore, whilst it is acknowledged that field burning emits particulates that create respiratory disease and will be having an impact on the populations close to the sugar estate, particularly the employee households, the majority of households did not associate field burning with poor air quality and illness. The reliance on solid biomass fuels in the area (sugarcane leaves, charcoal and woodfuel) would also be a major contributor to levels of respiratory disease.

5.2.2. Sugarcane Output

As outlined above, in the 2009/10 season MSF harvested a total area of 7,400 hectares, producing 1,200,000 tonnes of sugarcane, an average of 162 tonnes per hectare and supplying an average 5,000 tonnes of sugarcane to the mill per day (MSF Management 2011). This yield is significantly higher than in Brazil and other top sugarcane producing countries, as shown in Table 5.9. Although Ethiopia has the highest yield in the world within the FAOSTAT dataset, the MSF yield is significantly higher than the national average (133 tonnes per hectare). The national yield is lowered by the inclusion of household level production of sugarcane in FAOSTAT, which reports lower yields. Metehara Sugar Factory has a high level of adaptive capacity and the attention paid to individual fields on a daily basis allows any pest or fertility issues to be dealt with quickly and in a focused manner, in addition to the supply of irrigation only when necessary. All this allows the estate to respond quickly to change, adding to the efficiency of the estate, but is only possible due to the huge labour force of MSF.

Table 5.9. Sugarcane yields across producer countries. It can be seen that Ethiopia's yield ranks first worldwide (Food and Agriculture Organisation of the United Nations 2013b).

Country	Annual Production (tonnes)	Production Rank	Yield (tonnes/ hectare)	Yield Rank
Brazil	685,000,000	1	80	22
India	309,000,000	2	68	36
China	118,000,000	3	68	35
Thailand	70,000,000	4	71	33
Pakistan	54,000,000	5	51	60
Mexico	50,000,000	6	73	32
Colombia	38,500,000	7	101	9
Philippines	33,500,000	8	87	17
Australia	31,500,000	9	80	21
Argentina	25,800,000	10	73	30
Ethiopia	2,430,000	51	133	1
Peru	9,660,000	27	131	2
Egypt	15,900,000	24	118	3
Senegal	841,000	65	116	4
Malawi	2,500,000	48	109	5
Metehara Sugar Factory	*1,200,000*		*162*	

5.3. Sugar Processing Inputs and Outputs

The sugar mill at Metehara has a crushing capacity of 5,000 tonnes per day, or the harvested equivalent of 31 hectares. As described in Chapter 3, MSF process the cane initially to produce sugar, and then utilise the waste product from sugar processing (molasses) to produce ethanol. Within the sugar mill the sugarcane is crushed, clarified, boiled, seeded and centrifuged to extract sugar crystals, which total 12% of sugar cane mass (MSF Management 2011). In an average season, MSF produces 120,000 tonnes of Plantation White Sugar.

Processing sugar produces large amounts of waste and has large water requirements, leading to multiple interactions with the ecological system, as discussed below. Some of these feed into a carbon balance and their contributions are shown below.

5.3.1. Furnace Oil

The sugar mill is powered by bagasse – the fibrous residues leftover from crushing the sugarcane to separate the juice from the fibre – reducing the fossil fuel requirement and therefore aiding the carbon neutrality of the operation. However, some furnace oil is required to begin processing after the mill has paused operations. During an average season, 1,900 tonnes of furnace oil are consumed (MSF Management 2011). Applying an emission rate of 3.12 kilograms CO_2 per kilogram of fuel consumed (Hocking 2006), the related CO_2 emissions per season are 6 million kilograms, as displayed in Table 5.10.

Table 5.10. Seasonal furnace oil consumption. Furnace oil is consumed when bagasse is not available.

Input	Consumption per season (kg)	kg CO_2 per kg fuel consumed	CO_2 emissions (kg)
Furnace Oil	1,910,000	3.12	5,970,000

5.3.2. Water

The sugar and ethanol mills are jointly supplied with 112,000 m^3 per day, 12% of the annual water requirement (MSF Management 2011). As the ethanol mill only consumes a comparatively low amount, 740 m^3 per day, the majority (99%) of the water is supplied to the sugar mill – 112,000 m^3 per day. Table 5.11 displays the average seasonal consumption of both mills and the relative footprints, given an average of 224 operating days per season. It can be seen that water intake for processing is small (10%) compared to that made available for irrigation (90%).

Table 5.11. Water consumption per season at MSF. The water footprint of the sugar mill is far larger than that of the ethanol mill.

Input	Consumption per day (m^3)	Consumption per season (m^3)	Percentage of total
Sugar mill	112,000	25,000,000	99%
Ethanol mill	740	166,000	1%
Mill total	**112,000**	**25,200,000**	**100%**
Total Intake	947,000	262,000,000	

Multiple processing phases consume water in the sugar mill (MSF Management 2011). The initial phase is the washing of the sugarcane prior to its crushing, to remove soot residues deposited during burning. This wastewater then exits the mill via the treatment ponds. Water is also supplied to the boilers to produce steam that powers the machinery within the mill, for example the shredding blades and compressors. Occasionally some water is expelled from the boilers to avoid the concentration of impurities – this wastewater therefore contains high levels of phosphates and dissolved solids. Imbibition water is supplied to the system as the cane is squeezed, aiding the maximum removal of cane juice from the fibrous content by displacing it. To concentrate the juice, it is passed through evaporation cells, using more water from the boilers to produce steam. Once the mixture reaches the evaporators, a final steam input is required to remove the vapour from the sugar mixture. This water vapour is cooled and discharged to the treatment plant, as it can contain sugar if the fluids are over-loaded, before being returned to the Awash River. Throughout the processing phase water is used to cool the equipment.

Wastewater from washing is produced at multiple areas within the sugar mill and will commonly contain oils, detergents, and sugar. The system is also washed frequently with caustic soda to de-scale the evaporators, vacuum system and boilers (total consumption is 98,000 kilograms per season). This wastewater is stored in a holding tank with that from the boilers, and is re-used when concentrations are low enough to allow recovery, or alternatively added slowly with the final effluent in the treatment ponds.

The final effluent referred to above is a product of the clarifier system within the sugar mill, as the addition of lime and sulphur causes the solid impurities to precipitate out, purifying the sugar mixture. The mixture of impurities removed (referred to as press mud, containing calcium carbonate and calcium sulphide) still contains some sugar (<15%) and is processed for a final time to reduce the sugar content to 2% by adding bagasse and passing through a vacuum system. These outputs are summarised in Table 5.12. Their lack of inclusion in carbon balance analyses in the literature justifies their lack of inclusion in the carbon balance for MSF.

Table 5.12. Inputs of sugar processing that result in outputs to water. Wastewater outputs include calcium sulphide and calcium oxide.

Input	Consumption per season (kg)	Output	CO_2e emissions (kg)
Caustic soda	98,000		n/a
Lime	1,610,000	Lime, calcium oxide	n/a
Sulphur	419,000	Calcium sulphide	n/a
		Press mud and filter cake	Included above

These final wastewaters generally have very high biological oxygen demand (BOD) and total suspended solids (TSS), due to the high nutrient content. Therefore, the non-sucrose impurities are composted with bagasse from the final processing stage to produce a mixture called filter-cake, which can then be used as an organic fertiliser due to its high calcium, nitrogen and phosphorous content, as described above in the cultivation section.

However, if the wastewaters leach into irrigation canals or directly into the Awash River without processing, the high BOD may result in depleted oxygen supplies within the water and hence eutrophication. Additionally, deposition of the TSS on the river bed will decrease productivity of the species within the river. Secondary data from MSF is not available confirming the BOD and TSS of the wastewaters directly discharged from the sugar mill. Secondary data does exist however regarding water quality of various water channels within the estate, and is displayed in Table 5.13. Comparing the intake and outlet water qualities allows changes to be identified due to mill outputs or leaching from the fields. The results show that there is some natural variation in the intake water quality parameters, of which turbidity (a measure of the suspended solids in the liquid) has the largest variation. The legal limit values for discharges to water from the manufacturing of sugar are displayed in Table 5.14 and it can be seen that very few of the parameters are actually measured in Table 5.13. The only parameter directly measured, pH, is within the legal limits upon return to the Awash River, although slightly higher at one site.

Table 5.13. Water quality indicators from different locations on the MSF estate. Water quality upon output to the Awash River does not differ significantly from the original water quality of Awash River intake.

	Awash River (intake)		Field Drainage System (outlet)	Awash River (outlet)	
Location	Dam		Main drain to Awash	Awash River	
Year	2007	2009	2009	2007	2009
Appearance	Muddy	Cloudy	Cloudy	Muddy	Muddy
Odour	Odourless	Odourless	Odourless	Odourless	Unpleasant smell
Settleable solids	Present	Present	Present	Present	Present
Floating solids	Absent	Absent	Absent	Absent	Absent
Suspended solids	Present	Present	Present	Present	Present
Turbidity	239.0	16.98	14.37	85.0	77.0
Filterable residue at 180°C	206.0	178.0	190.0	216.0	184.0
Electrical conductivity at 25°C	287.6	285.0	309.0	301.1	270.0
pH at 20°C	7.96	7.93	7.87	8.75	8.53
Total hardness as $CaCO_3$	100.0	72.0	80.0	76.0	60.0
Silica, total SiO_2	28.2	19.51	29.27	28.0	23.41

Table 5.14. The legal limit values for discharges to water from the manufacturing of sugar (EPA FDRE 2005).

Parameter	Limit Value
Temperature	40 °C
pH	6 – 9
BOD5 at 20°C	90% removal or 60 mg/l, whichever is less
COD	90% removal or 250 mg/l, whichever is less
Suspended solids	50 mg/l
Total ammonia (as N)	15 mg/l
Total nitrogen (as N)	80% removal or 40 mg/l, whichever is less
Total phosphorus (as P)	80% removal or 5 mg/l , whichever is less
Oils, fats, and grease	15 mg/l
Mineral oils at the oil trap or interceptor	20 mg/l

Older secondary data supports these findings (Abejuhu 2005). This study compared quality parameters of Awash intake and 'factory used' water (FUW) for their irrigation potential. It concluded that the pH of both sources was satisfactory. The Awash intake ranged from 7.9<8.4 whilst FUW measured slightly lower – 7.4<7.7, both within the limit values outlined in Table 5.14. Abejuhu (2005) also measured ionic contents, and found there to be no significant differences between the two sources regarding ionic forms of elements such as calcium, sodium, sulphur and chlorine. In addition, both sources were found to contain relatively low concentrations of such ions and therefore not pose a toxicity hazard to the sugarcane. The only water quality issue acknowledged was that the electrical conductivity (EC) and sodium adsorption ratio (SAR) values of both samples may affect the structure of soils negatively, depending on the calcium status of the soil to be irrigated.

The lack of data makes it difficult to attribute any of the water quality parameters in the outlet samples to the operations within the sugar estate, but it can be seen that parameters do not vary significantly from the intake and therefore it is presumed that the treatment system within MSF is operating satisfactorily.

5.3.3. Air Emissions

Similar legal limits exist regarding air emissions from sugar manufacturing, as shown in Table 5.15 (EPA FDRE 2005). However, these limits, dictated by law, were rarely observed to be enforced and as a result, there is no monitoring of air quality parameters at MSF and no datasets to analyse.

Table 5.15. The legal limit values for emissions to air from the manufacturing of sugar (EPA FDRE 2005).

Substance	Limit value
Total particulates (at a mass flow of 0.5 kg/h or above)	100 mg/Nm^3
Hydrogen chloride (as HCl) (at a mass flow of 0.3 kg/h or more)	30 mg/Nm^3

Observational data confirmed that the sugar mill emits large amounts of odorous smoke during the milling season, which also contains a high concentration of particulate matter (by-products of bagasse consumption in the boilers) that is deposited in the surrounding area. Interview data attributed variations in smoke emissions to whether furnace oil or bagasse was being consumed (MSF Management 2011), but the high baseline level of emissions is indicative of poor filtering in the chimney system of the mill. Ash emissions could also be a result of incomplete combustion in the aged boiler system, leading to the emission of other GHGs, such as CO and N_2O. However, as this cannot be quantified, such emissions are not included in the carbon balance.

Other air emissions related to the sugar processing include emissions from electricity use within the mill and wider estate i.e. in the housing stock. The embedded electricity emissions are included within the carbon balance of the sugar estate as a necessary precursor to the operations. Whilst 73% of the electricity consumed with the wider estate is produced onsite via bagasse consumption and presumed to be carbon neutral, 27% is purchased from the Ethiopian Electric Power Corporation (EEPCo) (MSF Management 2011). In an average season, this totals 10 million kWh, of which 255,000 kWh is consumed within the mills.

The installed capacity of Ethiopian electricity generation is split between hydroelectric (1803 MW), geothermal (7.3 MW) and diesel (193 MW), with 90% of the installed capacity produced by large-scale hydroelectric power (EEPCo 2009). Not including embedded emissions resulting from their construction, large-scale hydroelectric operations emit little CO_2 after construction, other than methane emissions from reservoir surfaces (Parliamentary Office of Science and Technology 2006). The Ethiopian hydroelectric dams in proximity to Metehara are 'run-of-the-river' dams with no reservoirs, resulting in minimal methane emissions and the lowest carbon footprints of all electricity generation technologies – 5 grams CO_2e per kWh (Parliamentary Office of Science and Technology 2006). Combining this with the emission factors for diesel (778 grams of CO_2e per kWh) and geothermal (38 kilograms of CO_2e per kWh) (Sovacool 2008) gives an emission factor of 80g CO_2e per kWh for Ethiopian grid electricity. Applying this emission factor to the total grid electricity consumption produces the total CO_2e emissions for the estate in an average season, as shown in Table 5.16.

Table 5.16. Seasonal electricity consumption at MSF. Emissions from the grid electricity consumed within MSF are comparatively small due to the large proportion of hydropower within the Ethiopian electricity mix.

Inputs	Consumption per season (kWh)	Emission Factor (kg CO_2e per kWh)	CO_2e emissions per season (kg)
Grid electricity	10,100,000	0.080	800,000

5.3.4. Chemicals

Multiple chemicals are consumed within the sugar mill, as shown in Table 5.17.

Table 5.17. Chemical inputs required for processing sugarcane.

Inputs	Consumption per season
Lime (tonnes)	1,610
Sulphur mixed juice (kg)	356,000
Sulphur syrup (kg)	63,000
Sulphur total (kg)	419,000
Caustic soda total (kg)	98,000
Tri-sodium phosphate (kg)	3,870
Anti-spumin (litres)	0
Separan (kg)	2,110
Alcohol (litres)	2,930
Ammonium bi-fluoride (kg)	1,410
Triple Superphosphate (kg)	0
Sewing yarn total (spools)	1,310
Bag marking ink (litres)	117

Chemical consumption leads to the possibility of leakages into water bodies but was not reported in the interviews and is not supported by secondary data.

5.4. Ethanol Processing Inputs and Outputs

Ethanol is produced by fermenting the molasses (containing 45% weight fermentable sugars) and distilling the resulting 'wash' to increase the percentage of alcohol from 8% to 98.5%. A final dehydration stage increases the ethanol concentration to 99.85% ethanol (0.15% water). The 'spent wash' that is produced contains the removed water and any solid residues that remain – also referred to vinasse. During the 2010/11 season the ethanol mill produced 7,127,895 litres of ethanol, 29% under the planned 10 million litres (MSF Management 2011). The following season, the planned volume to be produced was adjusted downwards to 8,152,600 litres – this is the value to which the carbon balance refers as it is judged by MSF to be the most accurate seasonal output. The anticipated rate of production is 268 litres of ethanol per tonne of molasses. Processing ethanol produces large amounts of vinasse and requires large amounts of water, but has few other interactions with the ecological system.

5.4.1. Solid Emissions

When the ethanol plant is operating at full capacity, it produces 568 m^3 of vinasse per day, which is dehydrated to halve the volume prior to leaving the mill (310 m^3, containing 22% solids). The vinasse is transported to a lagoon (capacity 90,000 m^3, or approximately 30 days capacity) where it is sequentially removed to be mixed with the filter-cake and composted. As discussed above, vinasse is a strongly deoxygenating product that has highly negative impacts on water bodies. However, as the analyses in Sections 5.1.1 and 5.3.2 showed, there is no evidence of leaching at Metehara Sugar Factory.

5.4.2. Chemicals

There is a large chemical input to the ethanol mill, for two processes – fermentation and water treatment. The chemical inputs over an average season (224 operating days) are listed in Table 5.18 and (by mass) are mostly consumed during the treatment of water, as expanded on in section 5.4.3 below.

Table 5.18. Chemical inputs required for ethanol processing. Inputs to the ethanol mill are mostly consumed during the treatment of water.

Chemicals	Fermentation	Water treatment	Season Total
Urea	72 kg/day	42 kg/day	32,200 kg
DAP	30 kg/day	24 kg/day	12,100 kg
Magnesium sulphate	12 kg/day		2,700kg
Sodium meta by sulphate	18 kg/day		4,000 kg
Turkish red oil	50 litres/day		11,200 litres
Aluminium sulphate		6 kg/day	1,340 kg
Sodium hydrochloride		12 kg/day	2,690 kg
Caustic soda	80 kg/day	135 kg/day	48,200 kg
Sodium chloride		250 kg/day	56,000 kg
Decomp A for Bio-composting		10 kg/day	2,240 kg
Sulphuric acid	nil		0 litres

5.4.3. Water

When operating at maximum capacity, raw water inputs directed to the ethanol mill total 740 m^3, per season (224 operating days) this totals 166,000 m^3. Upon entry, the input divides between the three types of water used in the mill:

1. Soft water for the distillation, fermentation, and evaporation processes, of which 400 m^3 per day are produced;
2. Process water for fermentation, 290 m^3 which is then coupled with 310 m^3 of recycled process water;
3. Washing water processed with chlorine to remove any microorganisms present that would reduce the activity of the yeast, totalling 50 m^3 per day.

Table 5.19 displays the mass balance of inputs and outputs of water for the ethanol mill. Not all raw water is consumed on a daily basis - total water consumption is 866 m^3 per day, of which 459 m^3 per day are new water inputs, the rest is recycled. Outputs total slightly less (421 m^3 per day), a small part of which is due to the water inclusion in the final ethanol product (1.5>0.5% water) and the remainder is attributed to a lack of accounting. However, even with recycling within the mill, this is still a substantial water footprint per tonne of ethanol – 11 tonnes of water per tonne of ethanol solely for processing, not incorporating the previous water use for cultivation. The total water footprint of the ethanol is calculated below in section 5.6.

Table 5.19. Daily inputs to the ethanol mill. If working at full capacity, the mill can process 206 tonnes of molasses per day but doing so consumes a large amount of water - 11 tonnes of water per tonne of ethanol produced.

Inputs	Tonnes per day	Outputs	Tonnes per day
Molasses	206	Ethanol	40
Evaporation vapours	97	Evaporation vapours	97
Steam	144	Steam condensate	144
New Process water	290	Reject process condensate and spent lees	35
Soft water	26	Concentrated spent wash	242
Recycled process water	311	Recycled process water	311

The ethanol mill cannot discharge the water outputs directly because of their highly polluting nature. For example, the condensers produce 242 m^3 of concentrated spent wash produced per day, which has a pH of approximately 3.5 and high biological and chemical oxygen demand (BOD and COD) levels. The outputs are therefore treated with the chemicals listed above in Table 5.18, such as caustic soda and sodium chloride to raise the pH, before being released to the treatment ponds where anaerobic processes and filtering reduce the BOD and COD levels by up to 80% and adjust the colour.

The limited data available at MSF regarding the physical and chemical analysis of water is discussed in Section 5.3.2, and highlights that it is not possible to separate the effects on water quality parameters by different stages of production. However, as the analysis above shows, parameters do not vary significantly in the intake and output samples, and therefore it is presumed that the treatment system within MSF is operating satisfactorily and there are minimal emissions to water.

5.4.4. Air

The mass balance for the ethanol mill reports 40 tonnes of CO_2 is released per day of operation. These CO_2 emissions are a result of the chemical reaction within the fermentation process and Table 5.20 presents the seasonal output. There are no datasets regarding other air emissions related to the ethanol mill, as for the sugar mill. Observational data reported steam emissions and a pungent odour from the ethanol mill. In addition, the ethanol mill consumes 800 kWh of the electricity mix, the related emissions of which are accounted for above in Section 5.3.3.

Table 5.20. Carbon dioxide emissions resulting from ethanol processing.

Sector	Daily Output	Season Days	Season Output
Ethanol processing	40 tonnes	224	8,690 tonnes

5.5. Carbon Balance for Metehara Sugar Factory

The issues discussed above that contribute to the carbon balance of ethanol produced at MSF are summarised in Table 5.21, which shows that the largest number of sources are within the cultivation phase. The cultivation phase also contains the only GHG sink – the sequestration of carbon within silica phytoliths.

Table 5.21. The activities that result in GHG emissions, by sector.

Sector	Emissions Source
Cultivation	Direct and indirect N_2O emissions from managed soils, due to organic and inorganic fertiliser application
	CO_2 emissions from urea application
	Fuel use in irrigation pumping
Cultivation and Harvesting	Fuel use in farm vehicles
Harvesting	N_2O and CH_4 emissions from field burning
Sugar processing	Electricity consumption
	Furnace oil consumption
Ethanol processing	Electricity consumption
	CO_2 production within fermentation process
Estate management	Electricity consumption

Table 5.22 shows the complete carbon balance for MSF. It confirms that the cultivation phase is responsible for the majority (60%) of GHG emissions within the estate, whereas harvesting accounts for 21% and processing 19%. Fossil fuel and electricity consumption are the largest contributors to the carbon balance. Emissions from harvesting would be greatly reduced if field burning was substituted for green harvesting, however diesel consumption would then have to increase to fuel mechanical harvesting. Emissions due to electricity consumption are comparatively low due to the bias of hydropower within the Ethiopian electricity mix, but could be reduced if biogas was captured during vinasse treatment to use as a power source. It would be difficult to lower the other emissions as fertiliser rates are already low compared to other countries. One option would be to capture the CO_2 created during the fermentation process rather than release it.

Table 5.22. The carbon balance for Metehara Sugar Factory. The data shows that the cultivation phase is responsible for the majority of emissions.

Phase	Activity producing GHG	Seasonal output	Unit	Coefficient to transform into kg CO_2e	CO_2e emissions (kg)	Sum
Culti-vation	Sequestration	-2,470,000	kg CO_2e	1	-2,470,000	50,100,000
	Organic fertilisers	4,500	kg N_2O	298	1,340,000	
	Inorganic fertilisers	32,500	kg N_2O	298	9,690,000	
		557,000	kg CO_2	1	557,000	
	Diesel consumption	13,800,000	litre diesel	2.7	37,300,000	
	Petrol consumption	1,610,000	litre petrol	2.3	3,710,000	
Harve-sting	Burning emissions	533,000	kg CH_4	25	13,300,000	17,400,000
		13,800	kg N_2O	298	4,120,000	
Proces-sing	Furnace Oil	1,912,000	litre furnace oil	3.1	5,970,000	15,500,000
	Electricity emissions	10,100,000	kWh	0.8	800,000	
	Fermentation of ethanol	8,960,000	kg CO_2	1	8,960,000	
Total CO_2e Emissions					**83,000,000**	

The overall emission factor for MSF ethanol is 10 kilograms of CO_2e per litre of ethanol, as Table 5.23 shows. Comparing this to the emission from a litre of petroleum (2.3kg CO_2e per litre (Environmental Protection Agency 2011)) , the ethanol increases the emissions 4-fold, not resulting in carbon savings but additional carbon output.

Table 5.23. Emission factors based on the carbon balance and MSF outputs. A litre of ethanol is responsible for the emission of 10 kg of CO_2e.

	Product	Seasonal output	Unit	kg CO_2e per unit
CO_2e emission factors	Land cultivated	10,300	ha	8,090
	Sugarcane harvested	1,203,000	tonne	69
	Sugar	120,000,000	kg	0.69
	Ethanol	8,153,000	litre	10
		191,000,000	MJ	0.43

However, MSF emissions per hectare are lower than the carbon debts presented in Fargione et al. (2008) (Figure 2.7 and reiterated in Table 5.24), except for prairie biomass ethanol. As processing adds another 19% onto the MSF carbon balance, it is expected that the overall carbon balances for feedstocks presented in Fargione et al. (2008) feedstocks will be higher for the entire life-cycle. Other examples show that Brazilian sugar has a carbon footprint 349 times higher than MSF sugar, due to the combination of burning, increased fertiliser use and increased diesel consumption (de Figueiredo et al. 2010). Other examples are contained in Table 5.24.

Table 5.24. Carbon balance results from the literature.

Reference	Geographical area	Feedstock	Carbon balance
Fargione et al. (2008)	Brazil	Sugarcane juice	165,000 kg of CO_2e per hectare
	US	Corn	134,000 kg of CO_2e per hectare
	Indonesia	Palm oil (biodiesel)	702,000 kg of CO_2e per hectare
	US	Biomass	6,000 kg of CO_2e per hectare
de Figueiredo et al. (2010)	Brazil	Sugarcane juice	241 kg of CO_2e per ton of sugar produced
Pereira & Ortega (2010)	Brazil	Sugarcane juice	0.28 kg CO_2e per litre of ethanol
Feng et al. (2008)	US	Corn	1.99 kg CO_2e per litre of ethanol
Andreoli et al. (2012)	US	Corn	0.046 kg CO_2e per MJ
García et al. (2011)	Mexico	Sugarcane	0.04 kg CO_2e per MJ

The remainder of the examples within Table 5.24 are all at least one order of magnitude lower than the MSF carbon balance, and are similar to the results of a triangulation carried out with the UK Carbon Calculator (Ofgem 2013). Removing the transport and fuel blending stages to match the life cycle analysed above – only the cultivation and processing phases – and adapting with available MSF data, the Calculator attributes 0.04 kilograms of CO_2e per litre of ethanol – significantly lower than this life cycle analysis calculated. The default values of the Carbon Calculator for bioethanol from molasses in Malawi (the most similar social-ecological system to Ethiopia within their dataset) totals 1.29 kilograms CO_2e per litre ethanol, with 27.3% GHG savings, still an order of magnitude lower than this chapter concludes.

Whilst in a relative sense this and the results of Table 5.24 confirm that the MSF emissions are low compared to some other biofuel systems, the MSF results are also significantly higher than other examples and do not provide a carbon benefit when compared to petroleum. In some literatures, particularly those focusing on land-use change, MSF presents favourable carbon balance results for sugar and ethanol production, due to the lack of land-use change within the system. However, for other analyses, the MSF emissions appear high. This is attributable to those studies not factoring in some of the emissions included in the above MSF analysis. Therefore, this analysis can only conclude that the carbon balance for MSF places it within the middle of a range of results from the literature, and is favourable compared to some literatures whilst not compared to others, but does not report carbon savings due to the embedded emissions.

The data provided by MSF limited the analysis that could be carried out – for example, an emergy analysis could not be completed due to the lack of data regarding soil erosion. A large proportion of the LCA literature utilises energy balances, but that data were also not available directly. However, although the carbon balance relies on many coefficients from the literature the results are presented within confidence as they are shown to be within the range of results in the literature.

One possible reason for the difference in the carbon balance for this study compared to the lower results in the literature may be that 100% of emissions are attributed to ethanol in this case study. This is justified by the same attribution in other studies (de Figueiredo et al. 2010) and the logic that without sugarcane cultivation and sugar production, ethanol production would not be possible. However, other studies may attribute some emissions to the sugar production, therefore diminishing the emissions attributed to ethanol, but this is not clarified in the associated literature (Ofgem, 2013).

5.6. Water Footprint of Metehara Sugar Factory

Whilst the carbon balance is at the lower range of possible results, the water footprint of MSF is very high and removes a large amount of this resource from the regional ecological sub-system, as summarised in Table 5.25. The overall water consumption for MSF ethanol breaks down to 32 m^3 water per litre of ethanol.

Table 5.25. Total seasonal water consumption of MSF. The seasonal water footprint is large, and the cultivation phase is responsible for the majority of consumption.

Phase	Activity consuming water	Water input (m^3)	Proportion
Cultivation	Irrigation	237,000,000	90.4%
Processing	Sugar	25,000,000	9.5%
	Ethanol	166,000	0.1%
Total		**262,000,000**	

The MSF footprint is therefore significantly higher than the equivalent water footprint for a sugarcane-ethanol system in Brazil – 21 m^3 per ton of cane (Goldemberg et al. 2008). The MSF equivalent is 198 m^3 per ton of cane. However, this is the maximum possible usage due to the lack of data about water returned to the Awash, and therefore the water footprint is probably lower. Such results allow conclusions to be made as in an emergy study (Pereira & Ortega 2010), as shown in Table 5.26, although no data are available regarding soil erosion.

Table 5.26. System requirements for one litre of ethanol at MSF.

	Variable		Unit
Per litre of ethanol…	Land required	0.013	ha
	Sugarcane required	0.15	tonne
	Carbon emitted	10	kg
	Water required	32	m^3

5.7. Additional Interactions of Kesem Sugar Factory within the Ecological Sub-System

When complete, Kesem Sugar Factory (KSF) will cover 20,000 hectares, supplying a sugar mill with a crushing capacity of 10,000 tonnes per day, a 30 MW co-generation facility and an ethanol mill with an annual capacity of 12,500,000 litres. During the period of fieldwork, 800 hectares of sugarcane had been planted, and both mills were under construction although not operational until May 2014. Such construction was creating novel interactions with the ecological system that were not occurring at MSF. They are investigated below.

5.7.1. Land Use Change for Cultivation

The land MSF farms has been utilised for sugarcane since 1968, and therefore, within the context of this study, is not classed as undergoing land-use change. However, at Kesem the land has recently undergone change or still has to undergo preparation for sugarcane planting. Table 5.27 contains the schedule for planting across the two sites (shown in Figure 5.1 – Kesem is the southern area and Bolhano the northern) that will both be under KSF management upon completion.

Whilst undergoing the same process as outlined above prior to planting (harrowing, ploughing and levelling), an extra stage is required – vegetation clearance. In Kesem, this has involved removing the traditional vegetation cover – acacia shrubland. The removal of vegetation also has an implication for the carbon footprint of the ethanol produced at KSF, as carbon is released from stocks such as biomass, dead organic matter and soils. The carbon lost from these stocks must be calculated and included in the carbon balance for KSF.

Table 5.27. The schedule for planting at Kesem Sugar Factory, differentiated by site.

Cane to be planted by...	Kesem (hectares)	Bolhano (hectares)	Cumulative total (hectares)
June 2011	970		970
June 2012	1,030		2,000
June 2013	6,436	150	8,586
June 2014	4,564	2,050	15,200
June 2015		4,800	20,000
Total	*13,000*	*7,000*	*20,000*

The carbon losses from land use change are calculated over the 5-year period, during which the entire 20,000 hectares is converted. Table 5.28 shows that this change results in a large carbon debt – 555,500,000 kilograms of carbon over the 5-year period of change. This is a massive introduction to the carbon balance for KSF and changes the carbon balance per litre of ethanol by orders of magnitude.

Table 5.28. Carbon emissions from land use change for cultivation. Changing from a tropical dry grassland to a cultivated land results in a large carbon debt.

Year	Newly converted (ha)	Annual change in carbon stocks in biomass (tonnes C)	Annual change in carbon stocks in mineral soils (tonnes C)	Annual carbon loss from cultivated organic soils (tonnes C)	Total Annual change (tonnes C)
2011	970	- 4,220	- 3,320	- 19,400	- 26,900
2012	1,030	- 4,490	- 3,530	- 20,600	- 28,600
2013	6,590	- 28,700	- 22,600	- 132,000	- 183,000
2014	6,610	- 28,800	- 22,700	- 132,000	- 184,000
2015	4,800	- 20,900	- 16,400	- 96,000	- 133,000
Total	*20,000*	- *87,000*	- *68,500*	- *400,000*	- *556,000*

Indirect land-use change is not quantified within this carbon balance due to the lack of quantitative data about change occurring in the surrounding area – i.e. expansion into the Awash National Park. However, it is acknowledged that there will be indirect land use change as a result of the expansion at Kesem, as the pastoralists move into other lands to graze their livestock.

5.7.2. Dam Construction

As quantified above, sugarcane estates of this size have a large water requirement. The water for KSF required a weir to be constructed on the Kesem River, a tributary of the Awash River, from which the intake could be diverted. To regulate the water flow through the weir, the Kesem-Kebana rock-fill dam was also constructed, creating a 500 million cubic metres reservoir covering an area of 8,000 hectares. Construction was made more economically viable by including a 10-15 MW hydropower plant within the dam system. Construction was completed in 2012 (Tekleberhan 2012). The construction of the dam is associated with large carbon emissions due to the amounts of concrete required, but this is not included in the carbon balance for KSF, as the concrete is not produced within the bounds of the social-ecological system. However, the construction of the reservoir results in GHG emissions within the SES due to the decomposition of organic matter within it – methane, carbon dioxide and nitrous oxide. The diffusive emissions are estimated for the reservoir, based on the decomposition of the original organic matter during the first ten years of the reservoir lifetime. Multiplying the area of the reservoir by the median diffusive rate during ice-free periods for a dry tropical zone creates a total of 22 billion kilograms of CO_2e per year. As for the carbon debt from land use change, this has an overwhelming impact on the carbon balance for KSF, increasing the carbon debt of ethanol at this site.

5.7.3. Water Requirement

Using the ratios of water use per phase of operation at Metehara Sugar Factory, the water requirement for Kesem Sugar Factory is produced. The calculations shown in Table 5.29 below conclude that keeping the water footprint the same as for MSF (32 m^3 per litre of ethanol), KSF will require over 509 million cubic metres of water per season.

Table 5.29. The seasonal water footprint for Kesem Sugar Factory.

	KSF Output	MSF water footprint (m^3 per unit)	KSF water requirement (m^3)
Land cultivated (hectares)	20,000	23,000	460,000,000
Sugar (tonnes)	233,000	208	48,500,000
Ethanol (litres)	15,800,000	0.02	317,000
Total			*509,000,000*

The water for KSF will be taken from the Kesem River at the newly constructed dam, as discussed above. New sources of abstraction will change the downstream regime of the Kesem River and the Awash River for which it is a tributary, as KSF will become the largest upstream user. The implications of this are further discussed in Chapter 7.

5.7.4. Co-generation

As stated above, within the KSF capacity is a 30MW co-generation plant that will use bagasse to produce electricity that can then be used on-site and sold back to the grid. Cogeneration will reduce emissions from grid electricity compared to the MSF carbon balance because the electricity will be carbon neutral due to the locally grown feedstock. Substituting the grid electricity and its embedded emissions of 0.08 kilograms of CO_2e per kWh create a carbon saving of 2,387,700 kilograms of CO_2e.

5.7.5. Awash National Park

The Awash National Park (ANP) is located between the Metehara and Kesem Sugar Factories. An area of 756km^2, it is an arid and semi-arid woodland that contains major wildlife species such as the Beise Oryx, Greater Kudu, Lesser Kudu, Swayne's Hartebeest, Soemmering's Gazelle alongside a large number of bird species, including 5 endemics (EWCA 1993). Increasing anthropogenic pressure from the surrounding large-scale cultivation and local pastoralist populations (residing across both the Afar and Oromo boundaries) is increasing livestock encroachment from the peripheral areas, due to a reduction in grazing land resulting from the expansion of KSF. Encroachment is resulting in resource depletion and conflict within the ANP. Managers of the ANP express concern that the parks will be strongly affected as expansion progresses due to increased settlement, grazing of animals, and charcoal production and such changes will negatively affect the biodiversity of the park. For example, as wildlife habitats decrease in size there is a scarcity of prey population and predators such as lion and leopard are forced out of the park to surrounding villages, where they feed on livestock (ANP, 2011). Such movements lead to conflict with the residents who kill the large predators or poach them. The settlement will also negatively affect the cultural values embedded within the ANP and resulting tourism opportunities.

5.8. Carbon Balance for Kesem Sugar Factory

The cultivation, sugar processing and ethanol processing phases are presumed to be comparable from MSF to KSF due to the same management and methods, and are adjusted for the increased production at KSF (194% more cultivation and processing of sugar, 10 million litres of ethanol). An extra phase is included to represent the land preparation at KSF, including the carbon debt due to land-use change and diffusive emissions from the Kesem reservoir. Finally, the altered emissions from co-generation are included in the processing phase. The overall KSF carbon balance is shown in Table 5.30.

Table 5.30. The carbon balance for Kesem Sugar Factory. The land preparation phase is responsible for the majority of emissions.

	Activity producing GHG	Seasonal output	Unit	Coefficient to transform into kg CO_2e	CO_2e emissions (kg)	Sum
Land preparation	Carbon debt	111,000,000	kg CO_2e	1	111,000,000	-22,400,000,000
	Reservoir diffusive emission	22,300,000,000	kg CO_2e	1	22,300,000,000	
Cultivation	Sequestration	-4,800,000	kg CO_2e	1	-4,800,000	97,200,000
	Organic fertilisers	8,730	kg N_2O	298	2,600,000	
	Inorganic fertilisers	63,100	kg N_2O	298	18,800,000	
		1,080,000	kg CO_2	1	1,080,000	
	Diesel consumption	26,800,000	litre diesel	2.7	72,300,000	
	Petrol consumption	3,130,000	litre petrol	2.3	7,200,000	
Harves-ting	Burning emissions	1,030,000	kg CH_4	25	25,900,000	33,900,000
		26,825	kg N_2O	298	7,993,848	
Processing	Furnace Oil	3,710,000	litre fur-nace oil	3.1	11,600,000	19,200,000
	Electricity emissions	-30,000,000	kWh	0.8	-2,390,000	
	Fermentation of ethanol	10,000,000	kg CO_2	1	10,000,000	
Total CO_2e Emissions					**22,500,000,000**	

The overall emission factor for KSF ethanol is 2,253 kilograms of CO_2e per litre of ethanol, as Table 5.31 shows. This is 221-fold increase compared to the MSF ethanol carbon footprint, illustrating the huge difference land use change makes in the carbon balance. Comparing this to the emission from a litre of petroleum (2.3kg CO_2e per litre (Environmental Protection Agency 2011)), ethanol would result in nearly 1000-fold increase in emissions. The KSF carbon balance also exceeds all other examples of biofuel systems incorporating land use change included in Table 5.24, even that of palm oil substitution for tropical rainforest (Fargione et al. 2008).

Table 5.31. Emission factors based on the carbon balance and KSF outputs. A litre of ethanol is responsible for the emission of 2,253 kg of CO_2e.

	Product	Seasonal output	Unit	Kg CO_2e per unit of product:
CO_2e emission factors	Land cultivated	20,000	ha	1,126,669
	Sugarcane harvested	2,336,406	tonne	9,644
	Sugar	233,009,709	kg	97
	Ethanol	10,000,000	litre	2,253

5.9. Other Ecological Drivers in the Metehara Region

Whilst the sugar estates exert the majority of disturbances on the regional ecological system, there are other external disturbances – both slow and fast drivers – whose impacts are felt within the sugar estate and affect its productivity. These are outlined below, but are all related to the Metehara Sugar Factory rather than the Kesem Sugar Factory, due to the established history at MSF and awareness of such issues.

5.9.1. Soil Salinity

The volcanic activity in the region is a slow driver of the ecological system, causing groundwater recharge and the expansion of Lake Beseka (discussed in section 5.9.2 below). Groundwater recharge raises the water table and is responsible for flooding some MSF fields and rending them unproductive, whilst increasing the salinity of the surrounding fields – affecting 5-6% of MSF land under sugarcane.

Abejuhu (2005) reports that in most sugarcane fields, groundwater was observed at a shallow depth (40<100m) throughout the year, but that in fields in the north of the estate, affected by Lake Beseka, the groundwater sits at the surface level. The groundwater in this region has negative impacts on the physical properties due to its high salt content – EC measured 4000<35,000µS per metre. Abejuhu (2005) also studied drainage water from the fields and found that drains in the north of the estate reported higher EC values, due to the irrigation return flows from salt-affected sugarcane fields in this area of the estate.

High levels of salt negatively affect the physical structure of the soil and decreases infiltration of water, reducing the irrigation efficiency whilst also causing the sugarcane to mature more quickly. Increasing salinity can reduce the yield to 90 tonnes per hectare, nearly half the average yield at MSF. Saline soils are treated with increased compost application to increase water-holding capacity. However, continued groundwater recharge via irrigation, as discussed in section 5.1.4, will cause further long-term decreases to sugarcane productivity in the region.

5.9.2. Lake Beseka

Lake Beseka is a rapidly expanding lake resulting from the volcanism in this area (part of the Rift Valley), hence a comparatively fast driver resulting from slow mechanisms. The lake water is strongly basic (pH is over 9.6) and contains high concentrations of salt – EC values measure between 7,000 to 7,800 µS per metre and result in high concentrations of Na^+ ions (Abejuhu 2005). The measured samples also contain a high Boron concentration. All of the above decreases sugarcane yield enormously when fields are inundated with Beseka water. In the past 35 years Lake Beseka has expanded from 3km^2 to 40km^2 (Belay 2009) and as a result has encroached upon 178 hectares of MSF fields, 414 hectares in total (2009/10 season, (MSF Management 2011)). Encroachment of Beseka renders these fields un-useable due to the change in pH and metal content. However, yield also decreases in surrounding fields due to the increasing ground-water salinity. Although MSF management is involved as a stakeholder in Beseka management projects, including alternative diversion of irrigation water into the Awash River and new channel construction, continued expansion will have a large economic impact on the productivity of MSF.

5.9.3. Flooding and Drought

Fast drivers include impacts due to the variability of the Awash River. Floods are acknowledged to have more of a negative impact on productivity at MSF than droughts, although this was limited to fields near the Awash River boundaries, as the increased water held in the Awash can surmount the dykes protecting the fields in rainy periods. Whilst mature sugarcane is very successful at retaining the soil around its roots, young cane can be uncovered and eroded badly (MSF Management 2011)

One manager reflected that whilst there is no regular drought effect on MSF, the local pastoralist populations were strongly affected, and in times of drought were more frequently found on MSF grounds grazing their animals and collecting cane tops for fuelwood (MSF Management 2011). Increased pastoralist activity in MSF leads to conflict with the residents of MSF settlements who are also reliant on the same resources, and led to fatal discords in April 2011. There are new systems in place, since the 2011 conflicts, to mediate between the two populations and ensure equal access to resources.

When discussing future water availability in the Awash River, managers anticipate that *"water will be scarce in the future"*, and attribute this to increased irrigated agriculture within the river basin rather than climate change (MSF Management 2011). However, as water is a crucial resource for the productivity of the estate, research into alternative irrigation systems has been ongoing since 2005, and MSF began switching to a hydroflume system in 2006. Hydroflume systems consist of rubber tubes that lie in the furrows, decreasing water loss via soil percolation and therefore increasing overall utilisation, but also costs (MSF Management 2011). That MSF managers judge it to be worth the long-term investment is an indication of their awareness of a potential vulnerability regarding water availability.

5.9.4. Pests

Another fast driver affecting output at the sugar estates is the occurrence of pests. Sugarcane is a *"resilient crop"* (MSF Management 2011) due to its large size and thick leaf coverage. However, it is susceptible to 'smut' – a fungal disease that cannot be treated; the entire plant must be uprooted and buried. MSF spends 1 million Birr per year controlling smut, but limits the impact smut can have by choosing sugarcane species that are not affected (only 3/10 species planted are liable), although this can still affect up to 10% of the land under sugarcane.

5.10. Main Disturbances with the Ecological Sub-System due to Biofuel Production

Synthesising the above data for MSF, production is relatively efficient and the cultivation process appears to be very reactive for a large-scale monoculture. However, the data presented above does support the hypotheses that interactions do occur during all stages of production, but with varying levels of severity on the regional ecological sub-system, as outlined in Table 5.32.

Table 5.32. The hypotheses regarding ecological impacts and the results.

Hypothesis	Result	Severity
Land use change leads to decreased biodiversity	Yes	Historically this has been a severe impact at MSF, but MSF activities are minimising reductions. However, at KSF the land use change is ongoing and having severe impacts on the Awash National Park.
Intensive irrigation leads to increased soil salinity	Yes	In some areas, but salinization is also occurring due to volcanism in the area and therefore is not solely due to MSF activities.
Intensive irrigation and field clearance leads to increased soil erosion	No	Soil erosion is only reported during flood events and there is no other data to support the hypothesis. The perennial nature of the crop means there is minimal time where soil is left uncovered, also a feature of the large workforce and adaptive management.
Intensive agriculture leads to decreased soil fertility	Yes	In some fields phosphorous availability is becoming an issue but is not severe enough currently to require management.
Run-off of chemical inputs and wastewater from processing lead to increased water pollution	No	Existing data does not support the hypothesis. Treatment ponds appear to be successful, whilst vinasse application on fields reduces direct emissions to water, whilst being under the threshold for negative impacts on water quality. However, there is minimal data available from which to draw conclusions.
Irrigation and processing lead to a large water demand	Yes	MSF has a large water footprint, and this creates a vulnerability in times of drought, but is mostly managed adequately.
Field burning leads to increased air pollution	Yes	Field burning contributes to the carbon balance and also causes high particulate levels, but there is no data available to confirm this and negative impacts on health were not reported by the majority of surveys.

These findings support the hypotheses based on the literature within Chapter 2, that the main environmental impacts the four stages of biofuel production have are on biodiversity, soil, water and air quality, all of which can potentially lead to a loss of ecosystem services for future or downstream users. Addressing the interactions by phase, the data confirms that whilst cultivation affects levels of biodiversity, soil and water quality, harvesting only interacts with air quality and processing (of both the sugar and ethanol) with the water and air systems.

The new production at KSF will repeat the majority of these disturbances with the ecological sub-system but will also have a large interaction with the carbon cycle, as it responsible for large CO_2e emissions, increasing the carbon balance by a factor of 221.

5.11. Overall Resilience of the Ethanol Production Sub-System in Ethiopia

In summary, the ethanol production system in the Metehara region does not appear to have breached any significant ecological thresholds. The reactive management of cultivation and processing allows a rapid response to disturbances to the system such as pests and nutrient deficiencies. However, neither sugar estate appears to consider the down-stream impacts their operations have, which could be particularly detrimental regarding water availability, as operations could be pushing the ecological system closer to a threshold of water availability.

The production model of MSF is replicated across the other three existing sugar estates in Ethiopia, and is expected to be so in the ten new sugar estates under construction. The high yields reported at MSF, and across Ethiopia generally (Table 5.9) are attributable to the reactive method of management within MSF. Although field burning is a significant environmental impact being phased out in Brazil due to its impacts on air quality, the enforcement of manual harvesting requires a larger workforce than on sugar estates in other countries. This large work force therefore allows a highly adjustable method of field management, where daily checks are feasible. In turn, this allows reduced fertiliser and pesticide application because such chemical applications are limited to the required fields. Additionally, daily field checks allow harvesting at the optimum time when sucrose content is higher, which increases sugar yields. Due to its established nature and this reactive form of management, MSF has does not appear to have breached any major thresholds within the ecological sub-system.

However, that is not to say there are no negative impacts – MSF and KSF cause multiple trade-offs with the ecological sub-system. The lack of monitoring of environmental quality is hypothesised to mask the impacts of production on water and air quality, which are noted in the literature for other sugar estates. KSF will be responsible for large contributions to the Ethiopian national GHG emissions, attributed to the carbon debt associated with land use change and the construction of a reservoir for irrigation. In addition, the establishment of KSF is responsible for indirect encroachment into Awash National Park, resulting in large negative impacts on biodiversity. Finally, both estates have large water requirements, which create a vulnerability to changes in water availability from the Awash River in the future. These trade-offs are discussed in further detail in Chapter 7.

To summarise, Table 5.33 displays the impacts of MSF on the ecological sub-system, compared to case studies from the literature in other biofuel production sub-systems, adapted from von Blottnitz & Curran (2007).

Table 5.33. A comparison of the findings for MSF with other cases in the literature (↓ indicates a decreased impact from bio-ethanol production, ↑ an increase, - not reported and NA that the disturbance was not applicable or studied).

	Waste Feedstocks			Agricul-tural Feedstock	*Waste feedstock*	
Reference	Kadam, 2002	Sheehan, 2004	Tan & Culuba, 2002	Hu, 2004	***Metehara Sugar Factory***	***Kesem Sugar Factory***
Feedstock	Waste bagasse	Corn stover	Cellulosic waste	Cassava	***Molasses***	***Molasses***
Country	India	USA	Phillipines	China	***Ethiopia***	***Ethiopia***
Fossil fuel resource depletion	↓	↓	↓	↓	***↓***	***↓***
Global warming	↓	NA	↓	NA	***↓***	***↑***
CO_2	NA	NA	NA	↓	***↓***	***↑***
Acidification	↓	↑	↑	NA	-	-
SOx	NA	NA	NA	NA	***NA***	***NA***
NOx	NA	NA	NA	↑	***NA***	***NA***
Eutrophication	↓	NA	↑	NA	-	-
Human toxicity	↓	NA	↑	NA	***NA***	***NA***
CO	NA	NA	NA	↓	***NA***	***NA***
PM	NA	NA	NA	↓	***↑***	***↑***
Ecological toxicity	NA	NA	NA	NA	-	-
Photochemical smog	NA	↑	↓	NA	-	-
Solid waste	↓	NA	NA	NA	-	-
Land use	NA	-	NA	NA	***↑***	***↑***
Water use	-	NA	NA	NA	***↑***	***↑***
Odour	↓	NA	NA	NA	***↑***	***↑***

In conclusion, the analysis in this chapter shows that the existing sugarcane and ethanol production system at Metehara Sugar Factory has not breached any ecological thresholds for the set of quantifiable indicators analysed, though the dataset does not include a full analysis of the impacts on the water and air quality. In comparison, the newly constructed Kesem Sugar Factory has a large associated carbon footprint driven by the significant land-use change.

6. Ethanol Consumption for Household Energy: Potential and Uptake

The previous chapters demonstrate that the Ethiopian ethanol production sub-system creates few disturbances that approach thresholds in the social-ecological system. Negative food system impacts are limited to pastoralist households who are undergoing a social-ecological regime shift as they lose access to traditional livelihoods and food systems. The sugar estates utilise low chemical inputs and reactive management of cultivation and processing issues that allow a quick response to fast drivers. However, there are few considerations of down-stream impacts due to water and air quality impacts, and the newly constructed production sub-system at Kesem has a large associated carbon footprint due to the required land use change.

As the Ethiopian ethanol system incorporates consumption along with production, this chapter investigates the novel consumption sub-system within Ethiopia – ethanol as a household fuel. The usage of ethanol within the home could further differentiate the impacts on resilience of households within Ethiopia by enhancing the resilience of a household due to the environmental, health, and time benefits of replacing biomass fuels. Alternatively, if the ethanol is priced too highly, substitution will erode the resilience of the household by increasing the proportion of disposable income spent on fuel.

To identify the impacts of the introduction of this new technology on the consumption sub-system this chapter analyses data from the two quantitative surveys carried out with the samples highlighted in Chapter 3. The chapter reports that uptake rates have been very low and investigates the barriers to uptake within the current regime whilst examining the potential for uptake in the future.

6.1. Institutional Context

The introduction of ethanol stoves into the Ethiopian ethanol system is a result of the activities of a local branch of an international NGO – the Gaia Association. After the success of the ethanol stoves in the refugee camps, as introduced in

Chapter 2, the Gaia Association moved into a commercialisation phase with their business partner, MakoBu Enterprises, with the aim of selling the stoves in Addis Ababa. Pilot studies investigating household fuel use found a high prevalence of charcoal and woodfuel, the substitution of which would have direct positive impacts on air quality within the home. Tests have shown that using a litre of ethanol via the CleanCook stove can displace 5 kilograms of wood, 2 kilograms of charcoal or 0.9 litres of kerosene (Ethio Resource Group Pvt. Ltd. 2007; Kebede 2012; Murren & Debebe 2006). Common stove types and the ethanol stove are shown in Figure 6.1.

Figure 6.1. Common stoves in Ethiopia. From left to right, a traditional (biomass burning) injera stove, an improved charcoal stove, a kerosene stove and an ethanol stove.

Pilot studies also found a reliance on kerosene across different income groups, the substitution of which creates the potential for household expenditure savings with a substitution for ethanol (Murren & Debebe 2006). Commercialisation is supported within the political landscape via the inclusion of ethanol as a household fuel in the 'Biofuel Development and Utilisation Strategy of Ethiopia', which highlights the future use of ethanol stoves. It is hypothesised that the inclusion can be attributed to the Government's familiarity with the success of ethanol stoves in refugee camp settings, as well as reported briefings to the Prime Minister of Ethiopia on the potential of ethanol stoves for lower income households across the country (Takama et al. 2011). Whilst household consumption will not be the primary use of ethanol in Ethiopia (prior to expansion 88% of the ethanol produced was diverted to the

E5 transport blend and the remainder satisfied demand for the refugee camps) the expansion of ethanol will create a large excess that could further substitute alternative petroleum products – i.e. kerosene - reducing foreign expenditure, whilst increasing well-being.

The 'Biofuel Development and Utilisation Strategy of Ethiopia' was unique upon its publication in September 2007 as it specified the use of biofuels as household fuel as well as a transportation fuel (Ministry of Mines and Energy 2007). The main goal of the Strategy is to *"produce adequate bio-fuel energy from domestic resources for substituting imported petroleum products and to export excess products."* (Ministry of Mines and Energy, 2007:9). Within the Strategy is a specific aim to *"substitute ethanol for domestic fuel. Study and create favorable conditions for the domestic manufacturing, efficiency improvement and use of these bio-ethanol stoves and equipments"* (Ministry of Mines and Energy, 2007:12). The Strategy also includes a similar aim for biodiesel: *"To substitute bio-diesel for domestic cooking and lighting fuel, to study biodiesel stove, lamps and other equipments, and create favorable condition for their domestic manufacturing efficiency improvement and use"* (Ministry of Mines and Energy, 2007:13). No further detail is provided on ethanol as a household fuel – for example the reasoning behind its inclusion, time scales for roll-out or projections for uptake.

The Growth and Transformation Plan (the Ethiopian Government's roadmap for development) and Climate Resilient Green Economy Strategy also reflect this lack of transparency as neither contain references to the use of ethanol within the household. The focus instead relates to ethanol's use as a transport fuel, and is justified due to the resulting substitution of petroleum, potential as an export product and job creation (Ministry of Finance and Economic Development 2010a; Federal Democratic Republic of Ethiopia 2011). However, the GTP does promote alternative energy technologies which minimize deforestation, reduce indoor air-pollution and save working time of women and children – the same benefits outlined by the Gaia Association. In addition, the CRGE discusses the emissions from off-grid fossil fuel, which are projected to increase solely due to kerosene and gas consumption in the home. Coupled with the aim to decrease fuelwood consumption and decrease deforestation, the CRGE assumes that fuelwood-efficient, LPG, biogas and electric stoves will be key abatement initiatives, but does not refer to ethanol stoves.

The inclusion of ethanol stoves in the Biofuel Strategy indicates that the Government must consider them to create substantial benefits, presumably for livelihoods, health and energy security. However these benefits are not specifically linked to ethanol stoves in any key policy documents. Given these conclusions, it is not surprising that there has been little Government interaction with consumption of ethanol as a household fuel thus far. Currently the Government of Ethiopia is only active in the production of ethanol and its blending with transport fuels. The sales are being led by the Gaia Association's commercial partner, MakoBu Enterprises, who are selling imported CleanCook stoves (outlined in Chapter 3) for 1,050 Birr (single burner) and 1,740 Birr (double burner) (Kebede 2012), whilst the Gaia Association deals with the refugee camps and is investigating the potential for micro-distilleries.

6.2. Impacts of Uptake

The hypothesised benefits of ethanol stove adoption outlined in Chapter 2 relate to health, time savings, household economics and safety and are summarised as:

- Reduced particulate matter emissions from burning i.e. no smoke, reducing frequency of respiratory disease;
- Quicker cooking times compared to biomass and charcoal, creating time savings for women;
- Does not require time consuming fuel collection, also creating time savings for women;
- Reduced price compared to kerosene or gas per equivalent unit, creating monetary savings for these substituting these fuels;
- Reduced risk due to safer technology, reducing the frequency of burns and accidental fires (Debebe 2008a).

Therefore, for those households who have adopted stoves (whether a purchased stove or one provided for free), analysis of Survey 2 is presented so to confirm whether the adopters reported these benefits or not. Uptake rates are discussed in more detail in section 6.3, but as a brief introduction:

- Within the Low Income sample (n=33), 15 households possessed an ethanol stove and 14 were actively using it;
- Within the High Income sample (n=78 (previously surveyed and demonstrator samples)), 14 households possessed an ethanol stove and 11 were actively using it.
- Within the Very High Income sample (n=6), 6 households possessed an ethanol stove and all were actively using it.

Therefore, 35 of the total 117 households (30%) who completed Survey 2 possessed ethanol stoves, and their data were analysed to investigate the impacts of adoption.

6.2.1. Health

Table 6.1 displays the analysis of this data for the entire adopter sample alongside stratification by income.

Table 6.1. Modal Likert data reporting perception of smoke emissions from different fuels. The data reflects favourably on ethanol stoves, which are perceived to emit less smoke than kerosene, charcoal and gas stoves (statistically significant differences in bold, p=0.05 or less, Kruskal-Wallis).

Ethanol stoves produce…		Less smoke than kerosene stoves	Less smoke than charcoal stoves	Less smoke than gas stoves	Less smoke than electric stoves
Ethanol Adopters (n=35)		1 Strongly agree	1 Strongly agree	1 Strongly agree	2_a Agree
Ethanol adopters stratified by income	Low Income (n=15)	1 Strongly agree	1 Strongly agree	1 Strongly agree	2 Agree
	High Income (n=14)	2 Agree	2 Agree	2 Agree	4 Disagree
	Very High Income (n=6)	1 Strongly agree	1 Strongly agree	1_a Strongly agree	5 Strongly Disagree

a – Multiple modes exist. The smallest value is shown.

For the entire adopter sample, the consistency of the modal responses clearly reports a perception that the ethanol stoves produce less smoke than kerosene, charcoal and gas, but there is no consistent finding when comparing with electricity. When examining the difference in distributions of a particular statement when the samples are stratified by income, a Kruskal-Wallis test reported no significant differences regarding the perceptions of smoke emissions between the income groups.

The perceived reduction in smoke for ethanol stoves supports the findings from monitoring studies that substituting woodfuel, kerosene and charcoal for ethanol reduces particulate matter and carbon monoxide emissions (Pennise et al. 2009; Bizzo et al. 2004; Murren & Debebe 2006). There is no such noted health benefit for substituting gas and electricity. Therefore, the differing opinion of the Low Income sample regarding emissions compared to electricity is likely to be an indication of their lack of familiarity with electric stoves.

The associated benefit of lower smoke emissions within the home is a decrease in respiratory disease in women and children (Bruce et al. 1998; A. Singh et al. 2012; Smith et al. 2000). The survey confirmed both are commonly found to do the cooking or be present when cooking occurs. In 100% of the households surveyed across all income groups (no stratification for adopter/non-adopter) women did the cooking, as the sole cook in 94% of these households. Survey 2 also found that in up to 33% of Low and High Income households the female cook would be accompanied by others, both children and adults, whereas in the Very High Income households only adults were present when cooking occurred. Their prevalence confirms that women and children stand to benefit from substitution to ethanol.

However, collecting health data were a culturally sensitive issue, and so severity of respiratory issues may be under-reported by the participants. When asked (prior to discussions about smoke emissions so not to bias the answers) about the frequency of respiratory issues, the vast majority of households responded with 'can't remember the last time' (89%) or 'once a year' (9%). Within the small group who did report respiratory issues, 89% of adopters reported no change in the frequency of respiratory illness. Three adopter households reported a decrease in frequency, one household from the Low Income sample who had previously reported a frequent occurrence of respiratory illness, and two from the High Income sample, who had not. Therefore, the data does not report the burden of disease as reported in the literature and as such does not show a significant trend for health benefits upon substitution.

However, 46% of the adopter sample reported the production of smoke, as did 54% of the total surveyed sample (n=117) – the majority of which were from the Low Income sample (n=33), of whom 29 (88%) reported smoke emissions and 91% reported no venting of this smoke. The perception of smoke can be used as an indicator of respiratory disease and therefore the data in Table 6.1 supports the hypothesis that substitution to ethanol results in lower smoke emissions with resulting health benefits.

In summary, although the perceptions of health benefits are not directly reported within the results, reduced smoke emissions were and further study confirming the perceived reductions in particulate matter emissions may confirm that there are health benefits to ethanol stoves, particularly for low-income households who rely on fuels with high emissions.

6.2.2. Time Savings

The hypothesised time savings due to ethanol stove substitution result from two mechanisms: a) the decreased time cooking due to the increased efficiency, b) the decreased time sourcing fuel. Initially, time savings were judged to be a benefit of substitution of woodfuel for ethanol by the Gaia Association due to the second mechanism, which in turn removed the women collecting woodfuel from personal security threats. However, the reliance on woodfuel is less in urban areas and particularly so for the higher income households the Gaia Association are targeting. This analysis outlines whether there are any time savings from either mechanism within Addis Ababa and whether the Gaia Association can therefore advertise time savings as a benefit of ethanol stoves.

Survey 2 did not directly measure changes in cooking time upon substitution due to time constraints for the surveying period but perceptions of efficiency were reported, as presented below. A set of statements were posed to adopters regarding perceptions of efficiency, again compared to kerosene, charcoal, gas and electric stoves, and the results are displayed in Table 6.2.

Table 6.2. Modal Likert data comparing the efficiency of different stoves. Ethanol stoves are perceived to be more efficient across all samples (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

Ethanol stoves are…		Quicker than kerosene stoves	Quicker than charcoal stoves	Quicker than gas stoves	Quicker than electric stoves
Ethanol Adopters (n=35)		2 Agree	2 Agree	1 Strongly Agree	2[a] Agree
Ethanol adopters stratified by income	Low Income (n=15)	1 Strongly agree	1 Strongly agree	3 Don't agree or disagree	3 Don't agree or disagree
	High Income (n=14)	2 Agree	2 Agree	2 Agree	2 Agree
	Very High Income (n=6)	1 Strongly agree	1 Strongly agree	1 Strongly agree	1[a] Strongly agree

a – Multiple modes exist. The smallest value is shown.

As with the perceptions of smoke emissions, the samples reported ethanol stoves compare favourably to other stoves, including gas and electric. A Kruskal-Wallis test reported no significant difference in perceptions between the stratified samples for each statement and it is hypothesised that the Low Income sample's lack of familiarity with gas and electric stoves leads their responses to be non-directional. Very High Income households use more expensive, larger gas and electric stoves (analysed further in section 6.4.3) and therefore it is presumed that these households research stove selection in greater depth, leading to stronger opinions regarding efficiency.

Data collected via Survey 2 shows that majority of adopter households in all income groups use their ethanol stoves for 31<60 minutes per day. The usage varies across samples and the High Income sample report the highest use of ethanol stoves – the majority of the sample use the stove for 61<90 minutes per day, as shown in Table 6.3. However, the range of responses increases as income increases, as shown in Figure 6.2.

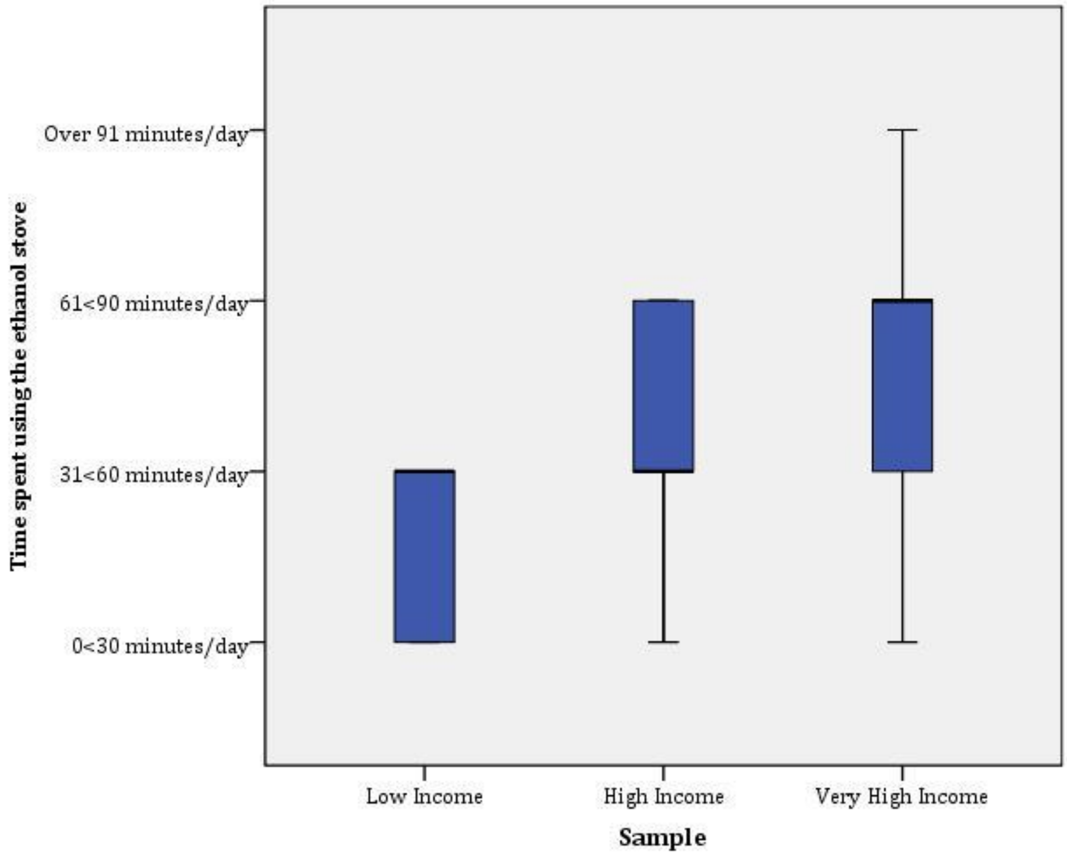


Figure 6.2. Ethanol stove usage. Data reporting the time adopter households use their ethanol stoves per day shows a mode of 31<60 minutes per day, but with greater variation in the higher income groups.

All but one of the households reporting the use of an ethanol stove also report using other stoves. The modal data shown in Table 6.3 reports that other stoves are used for the same or longer periods of time as the ethanol stove. The use of multiple stoves indicates that for the average adopter household in all samples, the combined usage of other stoves exceeds that of the ethanol stove. Therefore, although ethanol stoves are perceived to be more efficient than the alternatives (indicating a shorter cooking time), without data specifically measuring time savings this chapter has to conclude that no sample gains time savings due to substitution, as all report greater total usage of other stoves. There were no significant differences between stove use for each stove between the three income-stratified samples.

Table 6.3. Modal usage of different stoves by adopter households. The majority of adopters reported a total greater usage of other stoves, indicating that ethanol stove adoption has not led to time savings overall (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

	Stove usage	Electric stove	Electric injera stove	Gas stove	Kerosene stove	Charcoal stove	Wood-fuel stove	*Eth-anol stove*
	Ethanol adopters (n=35)	31<60 minutes per day	31<60 minutes per day	31<60 minutes per day	31<60 minutes per day	31<60 minutes per day	Over 91 minutes per day	*31<60 minutes per day*
stratified by income	**Low Income (n=15)**		0<31 minutes per day		31<60 minutes per day[a]	31<60 minutes per day	Over 91 minutes per day	*31<60 minutes per day*
stratified by income	**High Income (n=14)**	31<60 minutes per day	31<60 minutes per day		31<60 minutes per day[a]	0<31 minutes per day[a]		*61<90 minutes per day*
stratified by income	**Very High Income (n=6)**	0<31 minutes per day[a]	31<60 minutes per day	31<60 minutes per day[a]		31<60 minutes per day		*31<60 minutes per day[a]*

a – Multiple modes exist. The smallest value is shown.

No High or Very High Income households use woodfuel, the only fuel for which time savings are hypothesised by the Gaia Association. Data collected in Survey 2 regarding sources for all fuels shows that time spent acquiring fuels differed across income classes, due to differing ease of access to certain fuels. Table 6.4 displays the mean time spent acquiring each fuel type for each sample, calculated by multiplying the frequency of acquisition (per 30 days)*time per trip (minutes). The data shows that Low Income households spend less time acquiring ethanol than kerosene, due to its delivery to a central point in their neighbourhood whereas kerosene has to be purchased from petrol stations. However, the High and Very High households purchase ethanol from the MakoBu office and this increases the acquisition time. For all income groups, acquiring ethanol took longer than charcoal, due to the proximity of charcoal sellers near to residential centres. Too few data points were provided for gas to draw any robust conclusions from, but it is hypothesised that as gas is only available from a few sellers across Addis Ababa it would require a longer time investment, possibly similar to ethanol. Therefore, there is no clear conclusion regarding time savings due to ethanol substitution for charcoal and kerosene across all income groups, but it is clear that the only group who would find time savings would be the Low Income households substituting kerosene.

Table 6.4. Time spent acquiring fuels for cooking. For the majority of households in all income groups, kerosene and ethanol require the largest time period for acquisition, but both are exceeded by fuelwood if it is utilised.

	Minutes spent acquiring fuel per 30 days				
	Kerosene	Charcoal	Gas	Fuelwood	Ethanol
Low Income	440	117	n/a	848	296
High Income	414	517	n/a	0	635
Very High Income	0	137	n/a	0	150

Conversely, it can be seen in Table 6.4 that the Low Income households spend a large period of time per month acquiring fuelwood. The Low Income sample is more reliant on fuelwood – data collected within Survey 2 shows that 45% (n=33) of households in this sample utilise fuelwood, on average as the second most important fuel to the household. However, the majority of these households purchase fuelwood from traders within the city and therefore time spent acquiring fuel is similar to other fuels (mean 11.1 minutes per trip, 165 minutes per month). The average monthly time expenditure listed above (848 minutes) is biased as a small proportion of the sample (9.1%) collect their own fuelwood and spend, on average, 180 minutes per trip every four days or 1260 minutes per month. Therefore, time savings will only be felt for those collecting their own fuelwood, but these would be very significant savings.

Therefore, this study finds little evidence to support either mechanism of time saving due to substitution, mainly due to the urban setting and the decreased use of fuelwood, and instead finds that the limited access to ethanol may increase the time spent sourcing fuel for urban households. The lack of time savings could be reversed if there was greater access to ethanol in Addis Ababa – i.e. via petrol stations as for kerosene or if High Income samples utilised the service offered by MakoBu to deliver to the condominiums. This hypothesis is analysed further in section 6.4.4 but in the present access regime, there is no evidence to support the Gaia Association's claim that time savings are a benefit of ethanol stoves when used in urban areas.

6.2.3. Household Economics

The Gaia Association claims that households switching to ethanol from gas and kerosene will reduce their total expenditure on fuel. Survey 2 asked adopters whether, ignoring the initial cost of the stove, their monthly expenditure on fuel had changed. Across the entire adopter sample who responded (n=28) the answers were mixed, with 25% of households reporting an increase, 36% reporting a decrease, and 39% reporting no change. Incorporating income stratification shows a difference between samples, as shown in Figure 6.3, but not a significant one (p=0.62) – i.e. no Very High Income households reported an increase in expenditure, but the Low and High Income samples were split across all three options.

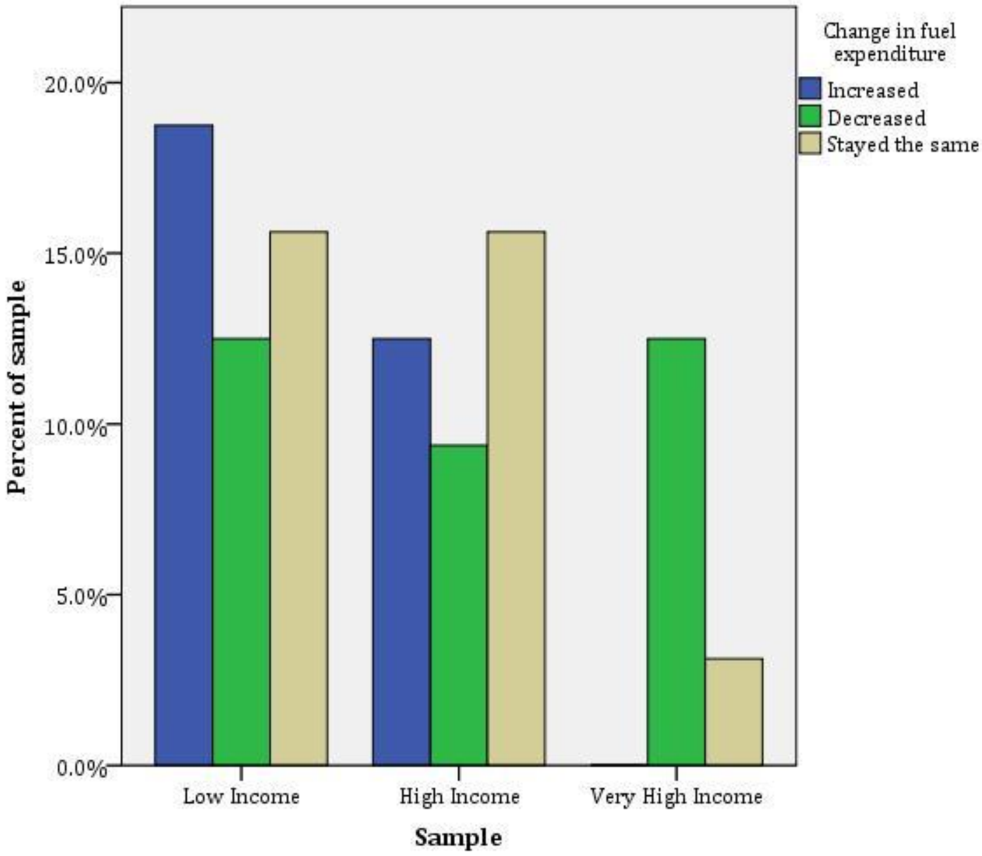


Figure 6.3. Change in fuel expenditure. Samples reported both increases and decreases in fuel expenditure following ethanol stove adoption.

To investigate this further, Table 6.5 presents data regarding expenditure on the different fuel types. Multiple questions were asked to triangulate this data – first a categorical measure of expenditure over 7 days (split into 10 Birr categories), then itemised data per fuel. Both of the above were translated into monthly (30 day) measures. Households tended to under-report their fuel expenditure in the initial categorised question, as when the averages for spending on all household fuels were calculated per sample the itemised measure always exceeded the categorised measure.

Table 6.5. Mean expenditure on all household fuels for adopters stratified by income is used to calculate the change since substitution, which matches the perceived change in expenditure since adoption.

		Low Income (n=15)	High Income (n=14)	Very High Income (n=6)
Mean Expenditure (Birr per 30 days) (Itemised)	Gas			500
	Kerosene	50	180	
	Charcoal	81	126	55
	Ethanol	107	168	232
	Fuelwood	17		
	Total	181	251	387
Fuel Expenditure (Birr/30 days) (Categorised)		80<116	120<156	280<316
Used to Spend (Birr/30 days)		87	186	1188
Change in Expenditure since Adoption (Birr)		+94	+65	-801

The higher value was then substituted from the mean reported "spending prior to ethanol stove adoption" to give an indication of expenditure change since ethanol adoption. For the Low and High Income samples, increases in expenditure were reported – most significantly for the Low Income households whose mean expenditure doubled. However, the Very High Income sample on average decreased their expenditure on fuel by 67%. The changes in expenditure match the perceptions of increases in expenditure across the samples shown in Figure 6.3. Within the Very High Income sample, four out of six (67%) reported substituting gas stoves for ethanol but two households of have continued to use some gas, whereas the household that substituted kerosene for ethanol has substituted it entirely. Therefore, it is concluded that substituting gas for ethanol, whether partially or totally, results in significant expenditure savings, but this expenditure saving is limited to a small group of households in Addis Ababa.

6.2.4. Enhanced Safety

Finally, the perception of safety amongst ethanol stove adopters was investigated, as it is hypothesised that ethanol stoves are safer than kerosene and charcoal stoves particularly and therefore will result in fewer fires and accidents (Debebe 2008a; Kebede 2012). Households responded to statements comparing ethanol stoves to other common stove types – kerosene, charcoal, gas and electric – using the same scale of agreement as previously introduced. Participants had already answered which stove they had substituted for ethanol, and were giving their opinions based on their familiarity of this technology as well as their experience with other fuels. Table 6.6 outlines the results of the safety statements, highlighting the modal score and its value for the different income stratifications.

Table 6.6. Modal Likert data reporting perceptions of safety compared to other common fuels. The data reflects favourably on ethanol stoves (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

Ethanol stoves are…		Safer than kerosene stoves	Safer than charcoal stoves	Safer than gas stoves	Safer than electric stoves
Ethanol Adopters (n=35)		2 Agree	2 Agree	2 Agree	3 Don't agree or disagree
Ethanol adopters stratified by income	Low Income (n=15)	2 Agree	2 Agree	3 Don't agree or disagree	3 Don't agree or disagree
	High Income (n=14)	2 Agree	2 Agree	2 Agree	2 Agree
	Very High Income (n=6)	1_a Strongly agree	1_a Strongly agree	2 Agree	3 Don't agree or disagree

a – Multiple modes exist. The smallest value is shown.

Table 6.6 shows that opinions are not significantly different across income groups and furthermore are consistently favourable about the safety of ethanol stoves compared to kerosene, charcoal and gas. The Low Income response to gas and electricity may be a result of this group's unfamiliarity with both fuels, which are more expensive and therefore less common amongst this income group. The non-directional response to electric stoves indicates the Very High Income sample (all of whom use an electric stove) believe the two stoves to be equally safe.

6.3. Uptake Rates

Table 6.7 displays the sales figures for ethanol stoves up to April 2012, with total sales of 268 stoves. MakoBu report that sales have been steady over the 10 months since advertising began but have obviously not reached the intended sales target of 2,000 (Kebede 2012).

Table 6.7. Ethanol stove sales in April 2012.

	One-burner	Two-burner	Total
Sold	143	125	**268**
Remaining	357	1375	**1,732**
Total	**500**	**1,500**	**2,000**

MakoBu planned to produce stoves on a site just out of Addis Ababa, so reducing the cost to the purchaser whilst creating jobs within Ethiopia. Although MakoBu secured a factory site and an engineering firm had produced the dies required within the factory, by May 2012 full-scale production had not begun (although prototypes using different materials have been produced). The delay in production was partly due to the lack of sales of the imported stoves, partly due to a lack of capital to fund construction and partly due to a copyright issue with the original producers Dometic (discussed further in section 6.4.7) (Kebede 2012). Planned production levels were for 18,000 stoves per year, potentially reaching 162,000 stoves per year (Debebe, 2008).

6.3.1. Uptake within Samples and Most Common Mechanisms of Uptake

Table 6.8 presents the data regarding uptake of stoves, briefly introduced above. The data for the High Income sample (n=66) refers to those previously surveyed and does not include the purposive demonstrator sample. Of the seven condominium households who possessed an ethanol stove, six were part of the initial demonstration scheme in 2009 and one purchased a stove following the advertising campaign in June 2011. Ownership is very low across the High Income sample reflecting little interest for the stoves in the condominiums, reasons for which are investigated below. The Low Income sample had a higher uptake rate and a higher level of familiarity with the stoves due to the targeted strategy offering them subsidised price stoves. The Very High Income snowball sample obviously displays a 100% uptake rate, biased by the selection of the sample for that reasoning. In addition, the purposive High Income sample (n=12) targeting demonstrators of the ethanol stoves found another seven households possessing stoves, of which five were being utilised. The data also reports that across the income stratifications, the distribution of responses was significantly different for each variable – familiar, possess and the sub-categories of use.

Table 6.8. Uptake rates. Of the random samples, uptake of ethanol stoves was higher in the Low Income sample where the cost of the stoves was subsidised (statistically significant relationships in bold, p=0.05 or less, Kruskal-Wallis).

Category		Statistic	Low income (n=33)	High Income (n=66)	High Income Demon-strators (n=12)	Very High Income (n=6)
Familiar with ethanol stoves		Count	**22**	**15**	**12**	**6**
		%	67%	23%	100%	100%
Possess an ethanol stove		Count	**15**	**7**	**7**	**6**
		%	45%	11%	100%	100%
Of those who possess:	Bought at full price	Count	**0**	**1**	**0**	**6**
	Bought subsidised	Count	**15**	**0**	**0**	**0**
	Given free	Count	**0**	**6**	**7**	**0**
	Using	Count	**14**	**6**	**5**	**6**

6.3.2. Familiarity with Stoves

Survey 2 asked households about their familiarity with ethanol stoves, to which (as shown above in Table 6.8) 23% of High Income households responded they were familiar. Figure 6.4 displays the diverse sources of information leading to the familiarity with ethanol stoves within this sample. In comparison, the information transfer within the Low Income sample was more uniform, with 86% of households informed by the Gaia Association and the remainder through friends and family.

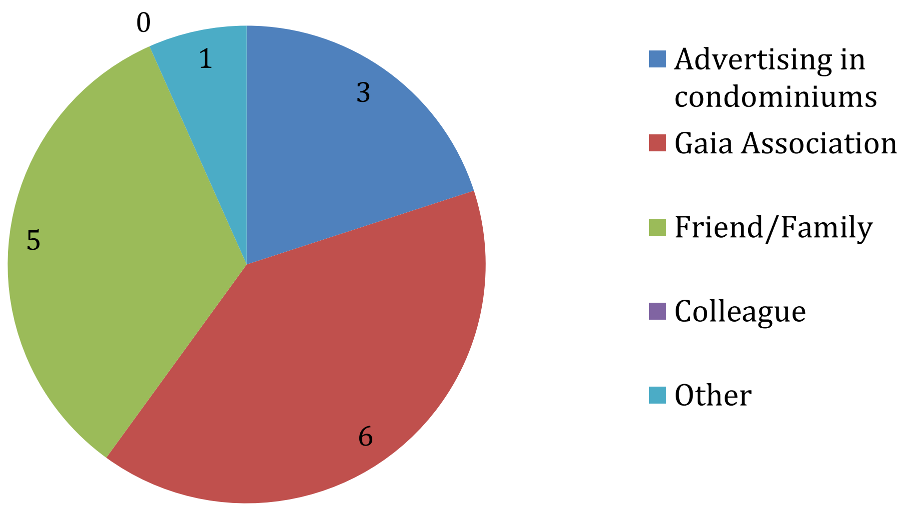


Figure 6.4. Sources of Information Regarding Ethanol Stoves in the Condominiums

The 'Gaia Association' legend in Figure 6.4 refers to information supplied to the original demonstrators. No household reported familiarity due to witnessing the original demonstrations and with the low rate of information transfer by the advertising campaign in June 2011 (a letter sent to every household) it seems that new advertising techniques are required. All households were asked about their reason for purchasing or not purchasing a stove – as discussed above, the majority were unfamiliar with the stoves and answered "No knowledge of stoves". Therefore the lack of information transfer is a major barrier to uptake. However, when households not familiar with ethanol stoves were given basic information about costs and access, and then asked to respond to the statement "The ethanol stove is not familiar, I wouldn't use it" the most common response, in both the Low (90%) and High (48%) Income samples, was "disagree". These results indicate that new technology is not a barrier to households' uptake of ethanol.

6.4. Barriers to Uptake

MakoBu's target of 2,000 stoves sales by January 2012 was obviously not achieved. During an interview, their representative Ato Hailu Kebede outlined what he believes to be the barriers to uptake (Kebede 2012):

- The ethanol stove price is very high – 1,050 Birr for single burner and 1,740 Birr for double.
- In comparison, the price of electricity is very low so a large proportion of the population use electric stoves (as reflected in the data from Survey 1 and 2).
- Ethanol supply is not constant – MakoBu will need more ethanol than Metehara SF can supply (as their priority is the petroleum blend) and the ethanol mills of Tendaho and Wonji-Shoa Sugar Factories are not online yet.

Of the households who are familiar with the stoves but do not own one (n=8 in the High Income sample), 50% attributed it to the lack of availability of ethanol fuel. Others highlighted the cost of the stove and cost of the ethanol to be prohibitive, concurring with Ato Hailu's opinions. Survey 2 collected data to test these hypotheses with non-adopter households and the results are presented below.

6.4.1. Ethanol Stove Cost

Analysis of the perceptions of ethanol stoves reports on two sub-samples – those familiar with ethanol stoves (n=55) and those not familiar (n=62). The same questions were asked to both groups but a little basic information was provided for those who were not familiar with the stoves i.e. the cost of the stoves, the cost of the fuel and where the fuel is available from. More questions were asked of those familiar with ethanol regarding usage cost, and compared to other stove types, safety and speed of cooking.

Samples reported on the cost of the stove and the response data are outlined in Table 6.9. A Mann-Whitney U test reports there is no significant difference for the three statements between those familiar with ethanol and not. A Kruskal-Wallis test concludes that there is significant difference ($p<0.05$) between the income-stratified samples when households are familiar with ethanol stoves, but not between the samples when not familiar with ethanol. Examining the income stratified sub-samples it can be seen that the Low and High Income samples have the opposite perception of the cost of ethanol stoves to the Very High Income sample, who think the stove cost is reasonable ($p=0.043$).

Table 6.9. Perceptions of stove cost. The majority of households, whether familiar with ethanol stoves or not, believe that the stoves are too expensive (statistically significant relationships in bold, p=0.05 or less, Mann-Whitney U (familiar Vs not familiar) and Kruskal-Wallis (income-stratified samples)).

		The cost of the ethanol stove is reasonable		The stoves are too expensive		If the stove cost 300 Birr I would consider purchasing one	
		Familiar (n=55)	**Not Familiar (n=62)**	**Familiar (n=55)**	**Not Familiar (n=62)**	**Familiar (n=55)**	**Not Familiar (n=62)**
Modal response		Strongly Disagree	Disagree	Strongly Agree	Strongly Agree	Agree	Agree
% Agree + Strongly Agree		33%	13%	71%	80%	61%	65%
Mode	**Low Income**	**Strongly Disagree**	Disagree	**Strongly Agree**	Strongly Agree	**Agree**	Disagree
	High Income	**Disagree**[a]	Strongly Disagree	**Agree**	Strongly Agree	**Agree**	Agree
	Very High Income	**Agree**	n/a	**Disagree**	n/a	**Neither Agree or Disagree**	n/a
% Agree + strongly agree	**Low Income**	**25%**	8%	**90%**	100%	**45%**	31%
	High Income	**28%**	15%	**68%**	31%	**80%**	73%
	Very High Income	**83%**	n/a	**17%**	n/a	**33%**	n/a

a – Multiple modes exist. The smallest value is shown.

The third question addresses the intended selling price of the stoves, once production has begun within Ethiopia. At this price (300 Birr, approximately £11, and the same price offered to the Low Income households currently) there was still a significant difference for the responses from the different samples (p=0.014). The majority of Low Income households not familiar with the technology indicated they would not purchase a stove, whilst 73<80% of both High Income samples indicated they would. For those who are familiar with the stoves to be willing to purchase it at this price indicates that education about the stoves and their benefits may be enough to convince Low Income households this is a worthwhile investment. However, at the current price the data supports the hypothesis that the price of the stoves is a barrier for all those but the Very High Income households.

6.4.2. Ethanol Fuel Cost

To investigate ethanol fuel cost, a similar series of statements were posed regarding the cost of ethanol, both independently and compared to other fuels. Those familiar with ethanol were asked about the usage cost compared to other fuels, leaving the households to apply their own judgements regarding the equivalent consumption rates. Those not familiar with ethanol responded to "the usage cost of ethanol would have to be less than x for me to consider buying one". Mann-Whitney U results displayed in Table 6.10 show that there is a significant difference (p=0.030) between the households familiar and not familiar with ethanol regarding their opinion of the price of ethanol fuel (13.5 Birr/litre). The distribution of households within the samples (analysed by Kruskal-Wallis test) is significantly different across income stratified samples, as the majority of Low Income households disagree with statement whether familiar (p=0.07) or not (p=0.03) with ethanol. The Low Income households familiar with ethanol had a more extreme reaction to the statement, and this is attributed to a further issue reported by 71% of the Low Income sample – that the ethanol "does not last too long" and "evaporates". Evaporation is not an issue reported in the Gaia Association's pilot study (Murren & Debebe 2006). Although the Gaia Association project the usage to be in a 1:1 ratio with kerosene, ethanol evaporates when stored and this potentially lowers the cooking time per litre of ethanol purchased. The Low Income sample obviously perceive to be an issue and potential barrier to adoption, especially as they purchase smaller volumes due to financial limitations.

Table 6.10 also presents the analysis for those households familiar with ethanol and finds that all samples agreed that the usage cost of ethanol was favourable compared to kerosene, but not for charcoal. A Kruskal-Wallis test reports a significant difference (p=0.002) regarding gas, due to the familiarity of the Very High Income sample with gas and their proven expenditure savings, as discussed above. Whilst reactions to the comparison with electricity were mixed, they were not significantly different but indicate that the majority of High and Very High Income households, those utilising electric stoves, believe electricity to have a lower usage cost. The same is shown for the households not familiar with ethanol, as shown in Table 6.11. For these households to adopt ethanol it would have to be cheaper than all other options of 'modern' fuels i.e. non-biomass fuels.

Table 6.10. There is a significant difference in the perception of the price of ethanol between those familiar with ethanol and not (statistically significant relationships in bold, p=0.05 or less, Mann-Whitney U (familiar Vs not familiar) and Kruskal-Wallis (income-stratified samples)).

		The cost of the ethanol fuel is reasonable		Familiar Households' Responses: "The usage cost is cheaper than..." (n=55)			
		Familiar (n=55)	**Not Familiar (n=62)**	**Kerosene**	**Charcoal**	**Gas**	**Electricity**
Modal response		**Strongly Disagree**	**Agree**	Agree	Disagree	Agree	Agree
% Agree + Strongly Agree		**45%**	**33%**	53%	25%	45%	39%
Mode	**Low Income**	**Strongly Disagree**	**Disagree**	Agree	Disagree	**Don't know**	Agree
	High Income	**Agree** a	**Disagree**	Agree	Disagree	**Agree**	Disagree
	Very High Income	**Strongly Agree** a	n/a	Strongly Agree	Neither Agree or Disagree	**Strongly Agree** a	Strongly Disagree
% Agree + strongly agree	**Low Income**	**25%**	**15%**	45%	15%	**25%**	35%
	High Income	**48%**	**41%**	56%	33%	**48%**	48%
	Very High Income	**100%**		67%	20%	**100%**	17%

a – Multiple modes exist. The smallest value is shown.

Table 6.11. Households not familiar with ethanol would only use it if it was cheaper than all other 'modern' fuels (statistically significant relationships in bold, p=0.05 or less, Kruskal-Wallis).

		Non-familiar Households' Responses: "The usage cost would have to be cheaper than... for me to consider buying one" (n=62)		
		Kerosene	**Gas**	**Electricity**
Modal response		Agree	Strongly Agree a	Agree
% Agree + Strongly Agree		87%	83%	80%
Mode	**Low Income**	Agree	Strongly Agree	Agree
	High Income	Agree	Agree	Agree
	Very High Income	n/a	n/a	n/a
% Agree + strongly agree	**Low Income**	100%	85%	77%
	High Income	82%	82%	78%
	Very High Income	n/a	n/a	n/a

a – Multiple modes exist. The smallest value is shown.

Therefore, the data shows that the price of ethanol should not be a barrier for High and Very High Income households substituting kerosene or gas, but information transfer is again a key factor in increasing the perceptions of those who are not familiar with ethanol.

6.4.3. Electricity Access

As the above section shows, those utilising electric stoves consider it to have a cheaper usage cost than ethanol. Electricity prices are controlled by the Government-run Ethiopian Electric Power Corporation (EEPCo), who charge domestic consumers a progressive rate varying from 0.27 to 0.69 Birr per kWh depending on usage.

There are two common types of electric stove – a hot plate (single or double) or a stove specifically produced for baking injera, the staple bread of Ethiopia (a biomass version of which is shown in Figure 6.1). Less common, other than in the highest-income houses, are electric ovens found routinely in developed countries – i.e. a wall unit with both a hob and oven. As seen in Table 6.12, all households in both samples have electricity access, even those in the Low Income sample where the housing unit is improvised (15%). However, expenditure on electricity is significantly different ($p<0.01$) for the two samples, and consumes double the proportion of income in the Low Income households than in the High Income households. No Low Income households use electric hot plates, but 21% use an injera stove, most commonly for 0<30 minutes per day (71% of users). In comparison, 85% of the High Income sample also reported using an injera stove, 89% of which for between 0<60 minutes per day. Of the 65 households in the High Income sample reporting using an electric hot plate, 54 of which also used an injera stove i.e. 69% of the sample.

Table 6.12. Electricity access and expenditure (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis)

Category	Statistic	Sample		
		Low Income (n=33)	High Income (n=78)	Very High Income (n=6)
Households with Electricity Access	%	100	100	100
Electricity Expenditure (Birr/Month)	Mean	**37**	**112**	**270**
	Standard Deviation	*32*	*65*	*111*
Mean Electricity Expenditure as Proportion of Mean Income	%	**10**	**4**	**2**
Electric Hot Plates	%	0	83	50
Electric Injera Stoves	%	21	85	17
Kerosene Stoves	%	27	17	0
Gas Stoves	%	0	10	33
Ethanol Stoves	%	46	15	100
Charcoal Stoves	%	**85**	**63**	**50**
Wood burning stoves	%	55	0	0
Number of Stoves Used	Mean	2.3	2.7	2.5
	Standard Deviation	*0.9*	*1.0*	*0.8*

Table 6.13. Cost of stoves. Electric hot plates are, on average, half the price of ethanol stoves (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis)

Mean Cost of stove (Birr)	Low Income (n=33)		High Income (n=78)		Very High Income (n=6)	
	Mean	*Standard Deviation*	Mean	*Standard Deviation*	Mean	*Standard Deviation*
Electric			616	*692*	550	*71*
Electric Injera	783	*893*	973	*724*		
Kerosene	**57**	***32***	**151**	***113***		
Gas			1,505	*1,120*	17,000	
Ethanol	**300**	***80***	**1,050**	***490***	**1,450**	***710***
Charcoal	**42**	***27***	**79**	***40***	**85**	***21***

Table 6.12 shows that it is very common for households in all income groups to utilise multiple stove types – the average household using two or three on a

weekly basis. Within the High Income sample, the mean number of stoves used has increased from 2.1 to 2.7, attributed to the addition of electric stoves rather than the substitution of another stove. Table 6.13 also reports that a Kruskal-Wallis test found the distribution of kerosene, ethanol and charcoal stoves prices to be significantly different between income-stratified samples.

The diversity in energy sources is an indication of the culture of cooking in Ethiopia but also reflects the different costs of fuels. This diversity of fuels makes households more resilient against shortages and price jumps (for example resulting from the removal of kerosene subsidies). In the condominiums, the AAHDP has banned solid fuels (biomass and charcoal) due to the associated smoke damage and accidental fire risk. However – 63% of households in the high income sample are still using charcoal, the majority solely for the traditional coffee ceremony (61%) but some still for cooking meals as well as coffee (39%). Sixty seven per cent of households in the Very High Income and 11% of Low Income samples use charcoal solely for coffee, but in the Low Income sample the majority use it for both meals and coffee (89%). The use of charcoal for meals is the only significantly different distribution (Kruskal-Wallis test) across the income stratified samples ($p<0.01$), but indicates the cultural importance of this fuel across all income groups.

The use of kerosene stoves in the Low Income sample shows some progression up the energy ladder but these households still mostly rely on traditional fuels such as fuelwood and charcoal. High Income households have taken a further step up the energy ladder by utilising gas and electric stoves, whereas the Very High Income households have progressed further as they no longer utilise kerosene. In contrast, a proportion of the Low Income households (21%) have skipped to the top of the energy ladder via their use of electric injera stoves, although this is still significantly less than the proportion of condominium households doing so. The increase in electric stoves discussed above partially supports the hypothesis that households are choosing electric stoves over ethanol stoves – but the data can only confidently conclude this for the High Income sample, where households were surveyed twice.

6.4.4. Ethanol Access

The Low Income sample has access to ethanol via a tanker at their headquarters in Entoto and weekly deliveries to the other centres. Similar delivery services are available from MakoBu to the condominiums (High Income sample) for an extra cost but the only other mechanism for purchasing ethanol is to go to the MakoBu Office in Lancha, Addis Ababa (Kebede 2012). Coupled with the limited purchasing mechanisms, there have been disruptions to the ethanol supply to MakoBu from Metehara Sugar Factory – namely between 2011-12 when ethanol production was minimal due to issues at the factory and what was produced was sold to petrol companies for the mandated blend rather than to MakoBu. To investigate the hypothesis that an inconsistent ethanol supply is affecting uptake rates, in Survey 2 statements were posed to the households regarding access. Table 6.14 displays the results.

Table 6.14. Modal Likert data reporting perceptions of access. The data reports a significant difference between income stratifications regarding their willingness to travel to the MakoBu office to purchase ethanol (statistically significant differences between samples in bold, p=0.05 or less, Mann-Whitney U (familiar Vs not familiar) and Kruskal-Wallis (income-stratified samples)).

		The availability of ethanol is constant and not a problem	I am happy to travel to Lancha to purchase ethanol		I would only purchase ethanol from within 1km of my house
		Familiar (n=55)	Familiar (n=55)	Not Familiar (n=62)	Not Familiar (n=62)
Modal response		Agree	Agree	Disagree	Agree
% Agree + Strongly Agree		55	47	43	78
Modal response	**Low Income**	**Agree**	**Strongly Disagree**	Disagree	Agree
	High Income	**Agree** [a]	**Agree**	Strongly Agree	Agree
	Very High Income	**Strongly Agree**	**Strongly Agree**	n/a	n/a
% Agree + strongly agree	**Low Income**	**25**	**25**	18	91
	High Income	**60**	**60**	49	76
	Very High Income	**67**	**67**	n/a	n/a

a – Multiple modes exist. The smallest value is shown.

The data shows (via a Mann-Whitney U test) that those familiar and not familiar with ethanol do not have a significantly different opinion of the travelling to Lancha, although the modal responses are different. Households familiar with ethanol do not judge the disruption in supply to have affected their access to ethanol, and that supply is constant, although there is a significant difference (Kruskal-Wallis) in the distribution of responses across income-stratified samples. However, the distance to the MakoBu office is a barrier for the Low Income sample, whether they are familiar with ethanol stoves or not. High and Very High Income households familiar with ethanol do not judge this distance to be a barrier, and when High Income households not familiar with ethanol were asked the same question they also responded favourably. However, this is then contradicted by the final statement which asked these households about distance using a distance judged to be comparative with kerosene. Here, the vast majority of households in both income groups responded that they would only travel up to one kilometre, confirming that access is a barrier.

6.4.5. Cultural Barriers to Uptake

Based on observational data, Survey 2 posed a final set of statements regarding potential cultural barriers due to the reported importance of charcoal in the coffee ceremony, as discussed above. The statements were "I would happily use an ethanol stove to make coffee" and the reverse – "I would still use charcoal to make coffee". There was no significant difference reported by a Mann-Whitney U test for those familiar and not familiar with ethanol within each statements, as shown in Table 6.15. However, the majority of households answered in the same manner to both questions, an indication of acquiesce bias but also possibly due to the phrasing of the questions. Therefore, taking the results of the second statement to address whether this is a barrier to uptake, it does indicate that the cultural importance of charcoal within the coffee ceremony would reduce uptake of ethanol stoves for this task. However, those Low Income households not familiar with ethanol indicated that they would substitute charcoal for ethanol.

The coffee ceremony can be daily occurrence but is particularly traditional when visiting friends and family or during festivals (Pankhurst 1997).

Therefore, such a cultural barrier across all income groups (as shown by the usage of charcoal outlined above) may still result in significant particulate emissions and associated health issues, minimising the savings accompanying ethanol adoption.

Table 6.15. Perceptions related to using ethanol to make coffee. The data suggests that the majority of households would continue to use charcoal when making coffee, and therefore this is a cultural barrier to ethanol uptake (statistically significant differences between samples in bold, p=0.05 or less, Mann-Whitney U (familiar Vs not familiar) and Kruskal-Wallis (income-stratified samples)).

		I would happily use the ethanol stove to make coffee		I would still use charcoal to make coffee	
		Familiar (n=55)	Not Familiar (n=62)	Familiar (n=55)	Not Familiar (n=62)
Modal response		Agree	Agree	Agree	Agree
% Agree + Strongly Agree		78	55	65	50
Modal response	**Low Income**	**Agree**	Agree	Agree	Disagree
	High Income	**Agree**	Agree	Agree	Agree
	Very High Income	**Strongly Agree**	n/a	Agree [a]	n/a
% Agree + strongly agree	**Low Income**	**85**	55	80	36
	High Income	**68**	55	56	53
	Very High Income	**100**	n/a	50	n/a

a – Multiple modes exist. The smallest value is shown.

6.4.6. Differentiation of Barriers across the Stratified Samples

As discussed above there were significantly different results between income stratifications regarding acceptability of ethanol stoves and this reflects the specific barriers to uptake for different income groups – for example, potential to purchase if stoves cost 300 Birr, willingness to travel to the MakoBu office and fuel choice for coffee brewing. Table 6.16 displays a summary of the significant barriers to the relevant income groups.

It can be seen that the Low and High Income households have more barriers to uptake than the Very High Income households, mostly due to their financial limitations and the current price of the ethanol stove and fuel. The movement of the High Income sample up the energy ladder also creates an alternative barrier as electric stoves are cheaper and offer the same health and efficiency benefits.

Table 6.16. A summary of the relevant barriers to ethanol adoption per sample. There are more barriers for the Low and High Income samples (✓is a barrier, × is not a barrier).

Is the following a barrier for this sample?	Low Income	High Income	Very High Income
Cost of the ethanol stove	✓	✓	×
Cost of the ethanol fuel	✓	×	×
Electric stove adoption	×	✓	×
Ethanol access	✓	✓	×
Cultural importance of charcoal	✓	✓	✓

In summary, for those familiar with ethanol already, the main barriers arising and preventing adoption are:

- Ethanol stoves are too expensive.
    - 300 Birr is more reasonable to the High Income households but is still prohibitively expensive for some Low Income households.
- The usage cost of ethanol is judged to be higher than the equivalent use of electricity, but does compare favourably to kerosene and gas.
- Whilst High Income households would travel to the MakoBu office, Low Income households would not be willing. The lack of willing is attributed to fewer transport options for these households, their more remote locations (on the outskirts of the city, i.e. near the forests as the women surveyed were all previously fuelwood carriers), and their familiarity with the current delivery system. In comparison, ownership of cars is more common in the High and Very High Income households, who are also more centrally located.

For those households not familiar with ethanol, the main barriers arising included those outlined above, and in addition:

- The price of ethanol fuel – High Income households report the fuel is reasonably priced but the Low Income households did not.

- Households in the majority in all samples would only purchase ethanol if it was available within one kilometre of their housing unit.

6.4.7. Solutions to Barriers

By producing stoves domestically, MakoBu aimed to reduce the cost of an ethanol stove to 320 Birr (£17) for a single-burner and 530 Birr for a double burner, making the technology more comparable to market prices of kerosene stoves (100 Birr) (Kebede 2012; Debebe 2008a). However, a major barrier to production is a copyright issue with the burner within the canister. This particular piece of the stove is protected by copyright initiated by Dometic, the Swedish producer, who are willing to sell the burner for $5/piece (Kebede 2012). However, this pushes the price of the stove beyond the desired 300 Birr. MakoBu is negotiating with Dometic to allow free use of the copyright but negotiations are continuing with no successful resolve, hence the delay in domestic production.

The other main barrier at this time is the limited access to ethanol. By limiting purchase to the MakoBu office, the number of potential customers is minimised, as this is up to ten kilometres away from some of the condominiums where stoves have been advertised. The intended solution was to install tankers on-site at condominiums, but the demand does not currently justify their installation and any installation would require permission from the municipal government which is proving to be difficult to acquire (Kebede 2012). MakoBu is attempting to increase supply by offering a delivery service to the condominiums in 100 litre containers, with a small surcharge of 0.25 Birr per litre, but this requires neighbours to co-ordinate their ethanol orders and has not been commonly utilised yet (Kebede 2012).

MakoBu are initiating early conversations with oil companies to discuss the sale of ethanol via their petrol forecourts, as for kerosene, but the current demand is not sufficient (Kebede 2012). However, the oil companies did express some interest for in the future, perhaps to replace kerosene as national subsidies are in the process of being removed and so kerosene prices will increase rapidly, which they expect to decrease demand.

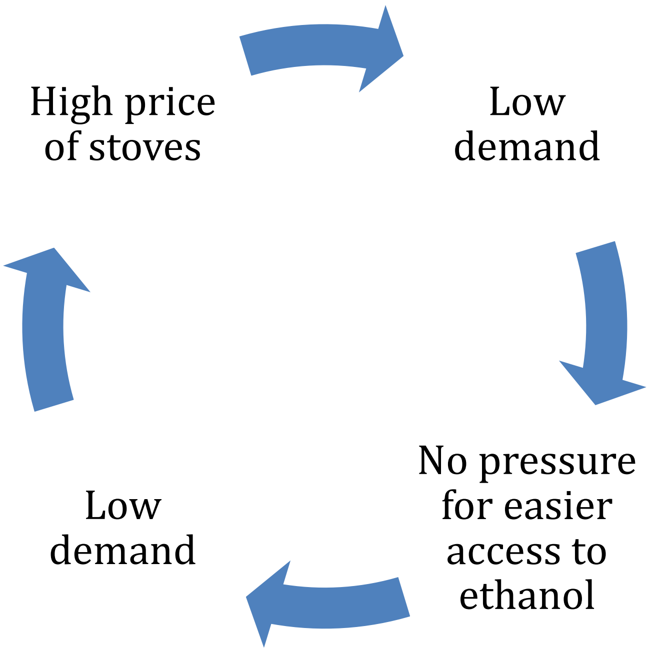
The cultural preference for charcoal is embedded in the Ethiopian culture and so it is expected that the competition with electric stoves is the most significant barrier for ethanol stoves. Electric stoves have the same benefits as ethanol stoves i.e. clean burning with no smoke emissions, reducing the frequency of respiratory disease; more efficient than traditional fuels with no fuel acquisition required, creating time savings; cheaper than alternative modern fuels, creating expenditure savings; and a safer technology, reducing burns and accidental fires. However, the hot plate stoves have a short lifetime (only 12% of electric stoves reported in Survey 2 were older than 4 years), and therefore the one benefit of ethanol stoves compared to electric stoves may be their longer lifetime and higher cost-efficiency over time.

There are also institutional barriers to ethanol adoption. The lack of ethanol during 2010-2012 was such an example of the irregular supply of ethanol since production began at Metehara Sugar Factory. Previously, the Gaia Association purchased ethanol from Finchaa Sugar Factory, the only producer prior to 2008. From May 2009, the Ethiopian Government directed all Finchaa's ethanol to the transport fuel blend in Addis Ababa, preventing purchase by any other actors, including the Gaia Association. The lack of available ethanol affected both the Gaia Association's commercialisation activities and activities in the refugee camps, where the distributed stoves were collected and put in storage (Tadele 2012). These barriers should be removed by the 2012/13 season as MSF begins producing at full capacity and other ethanol mills come online, as discussed further in Chapter 7.

The final opinions of MakoBu regarding the ethanol stoves are hopeful but that it is very early in the lifetime of a new technology – *"we started the project too early, there was not enough financial support"* (Kebede 2012). However, they believe that when the increase in national ethanol production is realised and the final kerosene subsidies are removed, the institutional barriers will be removed and ethanol will be much more competitive. They hypothesise that the increased supply will lead to decreased prices resulting in increased demand, which will allow for a greater variety in methods of access. A decrease in price is likely, as when all sugar estates expand fully the national ethanol market will be flooded. The mandated transport blend only requires current production levels whereas current expansion plans will mean this level will be exceeded by a factor of 38 (expanded further in Chapter 7). At this point, if ethanol stoves have reduced in price ethanol may become more competitive as the Government should start to encourage the domestic energy market to soak up the excess ethanol. However, it is also a possibility that the excess will be exported for profit and the domestic energy market will remain minimal.

The Gaia Association does not anticipate the demand for ethanol in the refugee camps decreasing in the future but is cautious in its projections for commercialisation due to the economic and political involvement of the national Government of Ethiopia. The Ministry of Trade is responsible for setting the ethanol price (13.5 Birr per litre in 2010/11 season) and the only information provided to the Gaia Association for future seasons was that "ethanol will be higher than kerosene". The price of kerosene in April 2012 was 15 Birr per litre, whilst the ex-factory price of ethanol was 6 Birr per litre (Ethiopian Petroleum Enterprise 2011b). Whilst transport adds an additional 0.7 Birr per litre, the national Government therefore makes 7.5 Birr profit via taxes on a litre of ethanol priced at 13.5 Birr per litre. The 100% mark-up reduces the confidence of such NGOs in the access to ethanol as their perception is that the Government views profit from ethanol as more important than the human security benefits provided. The Gaia Association have asked the Ministry of Trade to revise the price for ethanol as a household fuel and negotiations are ongoing (Tadele 2012). The current adaptive strategy of the Gaia Association is to maintain ethanol production for their own work via the construction of micro-distilleries, for which the procurement process is underway. Although there are a range of feedstocks such micro-distilleries could use, the Gaia Association is aiming to use molasses as in the sugar estate ethanol mills. However, access to molasses is difficult as there are rarely excess volumes available to purchase from the sugar factories. The main alternative is fruit waste, but this is seasonal and probably not sufficient for the production targets. Therefore, currently the system is in a vicious circle, as outlined in Figure 6.5.

Figure 6.5. The vicious circle of difficult access, expensive stoves and cheap alternatives, all of which are preventing the expansion of ethanol stoves.



Until the price of ethanol stoves reduces and demand increases, there will be no market pressure for increased access.

6.5.Potential for Uptake

For ethanol to be competitive it would have to have a similar usage cost to the most common fuels, if not lower. Competitiveness with kerosene and gas is crucial for ethanol to have a future in the domestic fuels market. However, as discussed above, the current price of the ethanol stoves (>1,000 Birr) makes competitiveness difficult. If production does start in Ethiopia and prices of the stoves reduces to 300 Birr, the potential for uptake will be much higher.

6.5.1. Usage Costs

By assigning a median value to the categorical data collected in Survey 2 regarding the age and cost of all utilised stoves within a household, an annual cost is calculated – i.e. the cost of the stove spread over its lifetime. Combining this with the annual specific expenditure on fuel (as also reported in Survey 2) produces an annual usage cost for each fuel type per household. For the electric stoves, a proportion of the total electricity expenditure was assigned to each stove, if used – one third for electric hot plates and one quarter for electric injera stoves. Poor reporting of stove costs minimises the number of households from whom mean usage costs could be calculated but the final usage cost data are displayed in Table 6.17, stratified by income.

Table 6.17. The usage costs of all utilised fuels shows for the Low and High Income samples, ethanol is the most expensive fuel, other than for gas (statistically significant differences between samples in bold, p=0.05 or less, Kruskal-Wallis).

Annual Usage Cost for stove and fuel (Birr)	Low Income			High Income			Very High Income		
	N	Mean	*St. Dev.*	*N*	Mean	*St. Dev.*	*N*	Mean	*St. Dev.*
Electric	*18*	748	*277*	*33*	865	*514*	*0*		
Electric Injera	***11***	**1894**	***1405***	***27***	**1169**	***798***	***1***	**820**	
Kerosene	*2*	2303	*2046*	*8*	1725	*1420*	*3*	758	*153*
Gas	*0*			*3*	4916	*3872*	*0*		
Ethanol	*7*	2907	*1937*	*22*	2325	*1889*	*2*	942	*102*
Charcoal	*10*	1955	*2088*	*37*	1089	*684*	*2*	1148	*605*
Fuelwood	*0*			*10*	225	*229*	*2*	1380	*1612*

For the Low Income sample ethanol has the highest usage cost, 26% more than kerosene. The High Income sample report a slightly lower ethanol usage cost but also a reduced kerosene usage cost. That the annual usage costs of electric hotplates are higher indicates substitution of kerosene for electric stoves and gas, which is reported for this sample only and has the highest usage cost across all fuels in all samples (4,916 Birr per year). The Very High Income sample report lower ethanol usage costs than the other two samples, presumed to be because of the high usage of electric and gas stoves but there is a lack of data to confirm this.

The above data supports the discussion of electricity use as a barrier to ethanol adoption in section 6.4.3, as Table 6.17 shows that electric hotplate usage costs are approximately a third of the ethanol usage costs. Therefore, for ethanol to be competitive, the mean usage cost (2,367 Birr) should match the average electric hotplate usage cost (824 Birr). The majority of the usage cost is a result of the ethanol fuel rather than the stove cost, as the majority of users received a stove free or at a subsidised price resulting in a mean annual cost of 204 Birr. Leaving the stove cost constant for now, i.e. presuming the stoves will drop to

300 Birr, to match the electric usage cost the ethanol fuel must reduce to 620 Birr per year, or a price of 3.6 Birr per litre. This price is slightly higher than the Gaia Association hypothesise the expected ethanol gate price (2.8 Birr per litre) and retail price (3.5 Birr per litre allowing for denaturing and distribution costs) to be, and therefore a valid possibility (Kebede 2012). However, it is lower than the current ex-factory price (6 Birr per litre) and substantially lower than the price MakoBu purchased ethanol from MSF for (13.50 Birr per litre) in the 2011/12 season, even when sold on at a subsidised price of 11.95 Birr per litre. Therefore, the price of ethanol – particularly dependent on the taxation applied to the ethanol by the Ethiopian Government – may prove to limit the potential for ethanol as a domestic fuel in comparison with electricity.

Currently the usage cost of ethanol is also more expensive than that of kerosene, which is 15 Birr per litre but with a lower stove cost (34 Birr per year) and lower usage (8 litres per month). As the price of kerosene increases with subsidy removal its competitiveness will increase. Therefore, the price of ethanol must reduce in a similar manner to be competitive – currently that would require a reduction in price per litre to 8.3 Birr, less than that required to be competitive with electricity.

The data in Table 6.17 does show that the usage cost of gas is substantially higher than that of ethanol, due to the combination of stoves that are more expensive and the higher price per unit. Whilst ethanol is 11 Birr per litre and the average household uses 14 litres per month, gas fuel costs, on average, 35 Birr per kilogram and the average household uses 16 kilograms per month. Therefore, there is an opportunity for ethanol to substitute gas consumption and create expenditure savings.

Although not examining ethanol specifically, Mekonnen et al. (2009) found that the use of multiple fuels in Ethiopia continued as income increased, so that income was not the only factor in determining adoption of fuel types. The use of multiple fuels at all income levels correlates with the data presented above and that other issues such as cultural preferences, availability and dependability have key roles in adoption. When examining willingness to pay for ethanol in Ethiopia specifically, Takama et al. (2011) found that low income households were more sensitive to the upfront stove cost, whilst middle-income households were more sensitive to the fuel cost, but that ethanol was the preferred option for cooking across all samples. The study proposes that for ethanol stoves to be adopted widely, financing mechanisms will be required for low income households and the price of ethanol should be lower than that of kerosene and charcoal (Takama et al. 2011). The proposal correlates with the findings in sections 6.4.1 that the price of the ethanol stove is a large barrier to uptake. However, the study is more optimistic than the findings of this section, which outline that whilst ethanol could compete with gas and potentially kerosene (if the ethanol price drops to 8.3 Birr per litre), ethanol is not likely to compete with biomass fuels or electricity.

6.6.Resilience Implications

This chapter frames ethanol substitution as a disturbance to the energy system at the household scale, and began with the hypothesis that the substitution of traditional household fuels for ethanol would enhance the resilience of a household due to the environmental, health, and time benefits of replacing such fuels. Alternatively, if the ethanol is priced too highly, substitution will erode the resilience of the household by increasing the proportion of disposable income spent on fuel.

The results presented within Chapter 6 shows that both these hypotheses are proved correct, but differentiated according to the income group of the adopter household. The reduction in smoke, and resulting decreases burden of respiratory disease, will increase the resilience of lower income households where stoves with high smoke emissions (biomass, charcoal) are the primary fuel source. Households collecting their own fuelwood also stand to increase in resilience, due to the time savings associated with substitution. However, whilst they stand to increase their resilience as substitution moves their household away from non-economic thresholds, their economic resilience stands to be decreased by cost of ethanol stoves, as substitution increases their expenditure on fuel. Spending a greater proportion of disposable income on fuel limits what can then be directed to other costs. For lower income households in Addis, even small changes to disposable income can affect important well-being variables, such as food, health and education of children. The higher income households commonly already use clean-burning fuels and spend little time collecting fuel, and therefore would not increase household resilience by substituting to ethanol. By substituting gas for ethanol, higher income households do stand to increase economic resilience by reducing fuel expenditure costs, but these households have a greater level of disposable income and these small changes are not likely to influence household resilience as they would for lower income households. Such resilience implications are addressed further in Chapter 7, which addresses ethanol substitution as a disturbance to the national biofuel system.

6.7.Conclusions

This chapter shows that the impacts of ethanol stove adoption are differentiated for households from different income stratifications. Whilst all households benefit from safer technology, only the Low and High Income households benefit from the cleaner burning fuel, as the Very High Income households already utilise fuels with this benefit. Conversely, only the Very High Income households benefit from fuel expenditure savings, upon substitution for gas, whereas ethanol increases household fuel expenditure in Low and High Income households, as shown in Table 6.18. However, it is shown that no households found time savings through the increased efficiency of the ethanol stoves or fuel acquisition, other than for those Low Income households collecting fuelwood themselves. It therefore appears as if Low Income households stand to benefit more from the adoption of ethanol stoves, but the chapter also shows that the delivery of these benefits is currently blocked by the high price of the ethanol stoves and fuel.

Table 6.18. A summary of the beneficial impacts resulting from ethanol adoption per sample. The benefits are different for different income groups (✓indicates this group stands to benefit from this impact, × that it does not).

Is this impact benefiting this sample?	Low Income	High Income	Very High Income
Health benefits	✓	✓	×
Time savings through efficiency	×	×	×
Time savings through fuel acquisition	✓	×	×
Fuel expenditure savings	×	×	✓
Safer technology	✓	✓	✓

Ethanol is more easily substituted for fossil fuels, kerosene and gas, as higher and increasing costs in the future will reduce the difference in their usage cost and that of ethanol. Section 6.5.1 shows that if the price of ethanol reduces to 8.3 Birr per litre as the price of kerosene increases, the majority of High Income households also stand to benefit financially, increasing the population who will benefit from the substitution to ethanol.

However, a main conclusion is that households in all income groups may already have skipped to the top of the energy ladder and utilise electric stoves as part of their energy mix. Households already using electric hot plates will gain the same benefits as ethanol stoves but at a lower cost (current prices). Electricity is widely available and subsidised by the Government, and therefore the findings of this chapter lead to a hypothesis that electricity usage will increase and diminish the demand for ethanol. Issues to do with the reliability of the electricity supply are reported in Survey 2 but the current expansion of hydro-electric power in Ethiopia should maintain the supply of low-cost electricity and increase its reliability.

Substitution away from biomass fuels entirely will be difficult due to the cultural importance of charcoal within the coffee ceremony, reducing the potential air emission benefits of ethanol adoption. In addition, the reported health benefits of substituting to ethanol may not be as large as hypothesised due to the low rates of fuelwood consumption. However, substitution would benefit the kerosene users, due to the reduction in incomplete combustion and resulting particulate matter emissions.

This chapter concludes that the only negative impact resulting from ethanol adoption is an increase in fuel expenditure for Low and High Income households. Secondly, there are significant perceived benefits to health and safety from adopting ethanol, and thirdly some of the hypothesised benefits are not realised – for example, time savings. The differentiation of these benefits across different income groups also limits the potential uptake of ethanol as a step up the energy ladder for the majority of households. Whilst prices remain as they are, ethanol may still have a role in higher income households –

particularly to substitute gas at the current price and kerosene at future prices (with the removal of subsidies). The chapter shows that a reduction in the price of ethanol stoves and fuel would cause this technology to be a more viable stove for lower income households, with greater well-being benefits related to the shift up the energy ladder. Currently however, ethanol stoves remain a niche technology that do not present enough benefits create a transformation within the consumption sub-system.

The differentiated impacts on actors within the consumption sub-system are synthesised with the results of the production sub-system in the next chapter, which assesses how the expansion of biofuels affects the resilience of the national social-ecological system in Ethiopia. Analysis at the national scale allows conclusions to be made in Chapter 7 about the future consumption of fossil fuels and ethanol within Ethiopia, and who stands to win or lose with the current and future levels of ethanol production.

7. The Impacts of Biofuel Expansion on the Social-Ecological Resilience of Ethiopia

This chapter synthesises the results presented in the food, energy and ecological sub-systems to examine the overall impacts on resilience of affected social-ecological systems (SES) when disturbed by the expansion of biofuels. As defined in Chapter 2, resilience is an emergent property of social-ecological systems that refers to the magnitude of change a system can experience before shifting into an alternative state, and can be observed through social and ecological states and relationships. This chapter examines the expansion of biofuels through a resilience framework to investigate the dynamics of the SES and to highlight the winners and losers, using the adaptive cycle. The adaptive cycle heuristic, as discussed in Chapter 2, suggests that SESs often follow a cyclical process, i.e. the slow accumulation of resources represented by an increase in potential and connectedness, followed by a rapid phase of release and reorganisation. This chapter tests whether the biofuels system in Ethiopia, at multiple scales, fits into such a cycle.

As discussed previously, the cultivation of sugarcane and the subsequent production of sugar and ethanol interacts with multiple variables of the social-ecological system at multiple scales, for example local and national food systems, local energy systems, the regional ecological system and international trade systems. There are various thresholds within each of these sub-systems and this chapter investigates whether the production of ethanol has led to any thresholds being exceeded, as this may lead to regime shifts and a change in the structure of the system. In addition, differentiating the impacts on all the actors within the system under study and examining power relations within each scale further highlights the complex nature of these systems, and demonstrates who are most vulnerable to potential regime shifts. Such an analysis goes beyond standard resilience studies, which focus on one scale of a system, underplaying the dynamic nature of interactions between actors and only highlighting the most desirable system for a particular stakeholder.

This chapter integrates the data analyses presented in Chapters 4, 5 and 6, based on multiple sources of primary data regarding food security, land use and production of ethanol in Metehara and Kesem Sugar Factories, coupled with consumption in Addis Ababa. The analysis examines the contemporary system while using the analysis of thresholds to deduce whether future planned expansion may bring about changes that are in effect shifts within adaptive cycles at multiple scales. The primary data were collected through household surveys and interviews in these multiple localities, and supplemented with documentary evidence and interviews with key stakeholders. The analysis in this chapter, particularly regarding cultural change and power relations, required higher levels of interpretation by the researcher than the quantitative analyses presented in Chapters 4, 5 and 6 due to the nature of qualitative data.

In summary, this multi-scalar analysis draws conclusions about the resilience of ethanol system in Ethiopia at the current level of production and the planned expanded level. The following sections analyse the disturbed scales, which vary over space and time, synthesising the results presented in the previous chapters and then applying the adaptive cycle to investigate system dynamics at the individual and coupled scales. The winners and losers at each scale are then highlighted, according to the different phases of the adaptive cycle.

The results shows that current levels of sugarcane and ethanol production have not surpassed many potential thresholds and therefore most of the sub-systems under study, and actors within them, are resilient to the disturbance of biofuel expansion performed to date. However, the planned expansion will have a much larger impact, replicating the regime shift already ongoing for pastoralist households across a much larger population. In addition, the larger scale of operation will more severely influence the ecological sub-system.

7.1. Household Scale – Pastoralist Social-Ecological System

Chapter 4 concludes that the majority of households in all samples analysed (Metehara Sugar Factory (MSF) employees, Metehara Residents, Pastoralists) did not report a change in access to entitlements or the initiation of coping strategies. Therefore, Chapter 4 concludes that the majority of households in the Metehara region have so far been resilient to the disturbances resulting from the expansion of biofuels at this scale, and have not reported a loss of food security. The only actors negatively affected by the expansion of the Kesem Sugar Factory are the pastoralist community of 600 households. Both the relocated group and those settlements still to be relocated lost access to arable land. Coupled with diminished access to grazing lands and water sources, households within both groups experienced a decrease in production entitlements - 42% of the Pastoralist sample reduced their livestock production and 85% their crop production. The loss of production entitlements was substituted for trade entitlements, maintaining the overall level of food access but coping strategies were initiated in 86% of households, indicating that maintaining this level of food security had pushed households closer to a threshold of insecurity.

The data therefore suggests that the pastoralist social-ecological system is in a release phase in the adaptive cycle – a rapid phase where potential decreases and connectivity increases, see Figure 7.1. In this phase, the reduced access to land and water resources, decrease in animal herd sizes, and decrease in income indicate the decrease in potential. Increased connectivity is due to the increased interaction with the sugar factory management and markets in Metehara. The adaptations made to entitlements and livelihoods by relocated pastoralists have maintained the release phase and have not yet led to a reorganisation phase, as the system structure retains the same characteristics as prior to relocation – i.e. overall levels of food security, livelihoods accessed, ecological resources used and governance frameworks within the community have remained the same. When relocation is imposed on all households within the Kesem Sugar Factory region, a reorganisation phase will occur and will result in a regime shift to a different form of resource dependence. Those responsible for the relocation of the Afar pastoralists anticipate a transition to a sedentary lifestyle, as demonstrated in the perceptions of the local Woreda Authority who highlight their concerns regarding diminished access to land:

"Grazing land will be prepared but is not extensive – people will need to change their behaviour from 100 to 10 cows – [we] need to change people to arable [farming] and more efficient animal farming. There will be one hectare per

household [of irrigated land]. If they grow sugarcane it can be sold to the project [KSF]. KSF also creates job opportunities as guards."
Awash Fentale Woreda Authority (2011)

Once all individual actors within the Afar communities are relocated in the new settlements the system is likely to move into an exploitation phase, where households adapt to the new livelihood and entitlement options available to them. This adaptive cycle is summarised below in Figure 7.1, with the phases determined by empirical findings in blue, and the phases outlining likely future developments (based on the evidence collected) in orange.

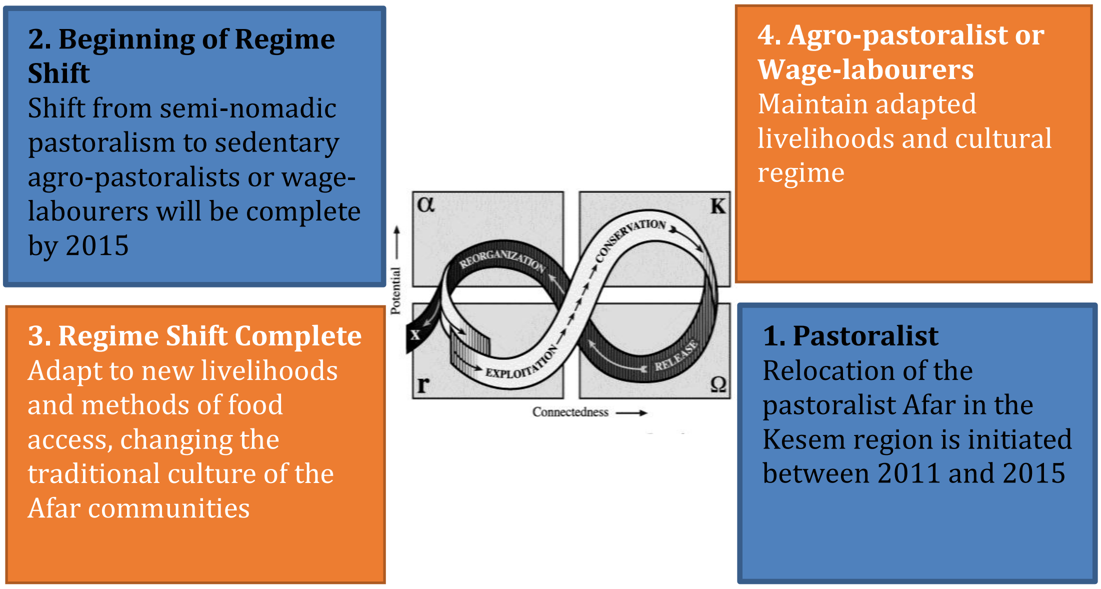


Figure 7.1. The adaptive cycle of the Afar pastoralist social-ecological system. The Afar are undergoing a regime shift from pastoralism to a more sedentary livelihood.

Chapter 4 concludes that the disturbances so far from the expansion of biofuels in Kesem have pushed pastoralist households much nearer to a threshold regarding food security and therefore human well-being, which when surpassed will leave households vulnerable to further disturbances i.e. increasing food prices or a decrease in food provided by the Productive Safety Nets Program (PSNP). Proximity to this threshold could lead to another reorganisation, with a different trajectory to that of the reorganisation due to relocation and described above in Figure 7.1, with more significant negative impacts on well-being for these households, requiring a further (but planned) transformation to an alternative lifestyle or change in location to restore well-being and food security.

Relocation will therefore lead to at least one regime shift, as the traditional livelihood of semi-nomadic pastoralism and the production entitlements associated with this are prevented by sedentarisation. Residing in settlements managed by the sugar factory and local Kebele authority will also replace the traditional governance mechanisms and common resource management practices. The change described above is referred to as a regime shift rather than a transformation due to the lack of intent by the pastoralists, although governance actors at the scales above (i.e. the Sugar Corporation and sugar estate managers) are aware of the implications for pastoralist communities.

There are, however, possible associated benefits of relocation, particularly access to services available in Metehara since the establishment of MSF – access to schools, health clinics and hospitals, electricity, piped water, along with job opportunities with fixed annual incomes. Therefore, as reflected on in Chapter 4, a key issue is that of the future potential negative impacts on the Afar, who are currently bearing the costs of the Kesem expansion. An analysis of the long-term effects of relocation with another pastoralist group, the Karayu, is shown below to present an answer to this issue.

7.1.1. Reorganisations of another Pastoralist Social-Ecological System

The conclusion that a reorganisation is imminent for the pastoralist communities is grounded in the analysis of previous relocations of pastoralist groups within the area, caused by the expansion of Metehara Sugar Factory in 1960-1980s. As discussed in Chapter 3, a Dutch company (HVA) established Metehara Sugar Factory in 1968 and cultivation has expanded during the past 45 years to the current operational level of 15,000 ha. Figure 7.2 shows that the total area of MSF steadily expands from 1970 to 1993. The area harvested indicates trends in expansion – this is a lower value than the area cultivated but proportional to the total area under control by the estate management (i.e.

including settlements). There are three main phases of expansion of harvested area within the 'Expansion' phase – from 1970-1975, 1977-1980, and 1982-86. The following phases are the 'Uncertain' phase, where domestic conflict within Ethiopia affected harvesting, and the 'Established' phase, where the total area remained relatively constant and the harvested area slowly increased. Increases in total and harvested area after 2008 reflect the inclusion of Kesem sugarcane in the MSF data.

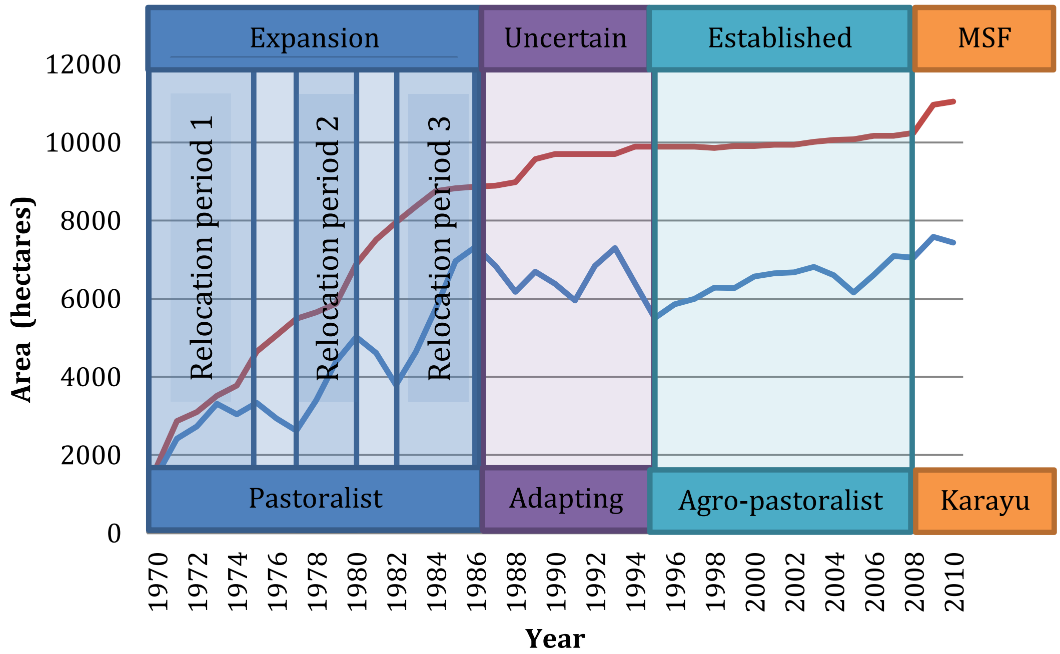


Figure 7.2. Expansion of Metehara Sugar Factory. The phases of expansion correlate with the reorganisations of the Karayu tribe and transformation from pastoralism. The red line represents the total area of MSF and the blue line the harvested area.

The three relocation periods contained within the 'Expansion' phase refer to the relocation of Karayu households who were residing in the area now occupied by MSF. The Karayu are a traditionally pastoralist tribe and were the only residents of the area until the sugar estate was established. The phases of MSF expansion correlate with the reorganisation of the Karayu from a pastoralist to agro-pastoralist social-ecological system. The impacts and changes within the Karayu system therefore provide a likely scenario for the trajectory of the regime shift the Afar pastoralists' social-ecological system will go through at Kesem Sugar Factory.

The Karayu are an Ethiopian tribe who reside almost exclusively within the Fentale Woreda, a district of approximately 134,000 hectares bordered by the Awash and Kesem rivers, with Mount Fentale in the centre and of which Metehara is the main urban settlement (see Chapters 3 and 5) (FEG Consulting 2006; Oromiyaa Region 2011). Although permanent settlements exist, traditionally the Karayu practiced transhumance and identified themselves as herders, although they were limited to a range of approximately 40 kilometres due to the regional boundaries with other tribal groups – specifically the Afar to the north and Amhara to the south (Beyene 2012). The Karayu identified dry and wet season grazing lands and access points on the Awash River for watering their herds and managed resources communally.

The Karayu were the dominant land users of the Metehara region until the establishment of MSF, the Awash National Park and other commercial agriculture estates in the area in the 1960s. The removal of access to grazing lands, and the forced relocation of some Karayu settlements led to decreased seasonal mobility of the Karayu over a twenty year period, who began enclosing land for private (rather than communal) use as a coping strategy after other users moved into the area (MSF and the Awash National Park) (Gebre 2009). The relocation package offered by MSF provided households directly relocated from the Gelcha, Abadir and Merti settlements to new ones on the edge, or even partly within, the sugar estate with access to irrigation channels - these households began to practice arable agriculture (MSF Management 2011). The relocation occurred in stages, as the estate expansion progressed, ending with the Abadir settlement, but by the 1980s the majority of Karayu in the Fentale Woreda had begun arable agriculture (Gebre 2009).

Applying the adaptive cycle to the Karayu social-ecological system, the livelihood shift indicates a reorganisation has occurred in the system compared to the regime in the 1950s, prior to the introduction of other users in the area. Pre-1960 the social-ecological system was in a conservation period, and exploitation had occurred approximately 200 years earlier when the Karayu first settled the area (Gebre 2009) and began to utilise the resources in the area such as vegetation for grazing, fuelwood and water. This reflects the pastoralist phase in Figure 7.2.

The SES settled into a conservation phase over time, until the changes enforced by the competition for resources with MSF led to a release phase between the 1960s and 1986, represented by the 'Adapting' phase in Figure 7.2 and resulting in a reorganisation and regime shift. The new regime was a more sedentary agro-pastoralist social-ecological system, reflected in a different pattern of resource use and governance due to the resulting livelihood diversification. There was also a transformation of the tenure system from the traditional communal land use to that of an individual tenure system, initiated in anticipation of competition for resources led to the enclosure of land and finalised by the relocation packages offered by MSF (Gebre, 2009).

Since 1986, the system has moved from an exploitation phase, with experimentation in livelihoods and resource management, to another conservation phase, where the majority of households identify as agro-pastoralists. In addition, the cultural traditions of the Karayu are being transitioned away from, as reduced land access makes it difficult to find appropriate sites for celebration of traditional rituals (Gebre 2009). Therefore, the Karayu and the ecosystem services they rely on have undergone a regime shift compared to pre-1960, as summarised in Figure 7.3. The regime shift to agro-pastoralism is predicted to be replicated for the Afar pastoralists relocated for the establishment of Kesem Sugar Factory.

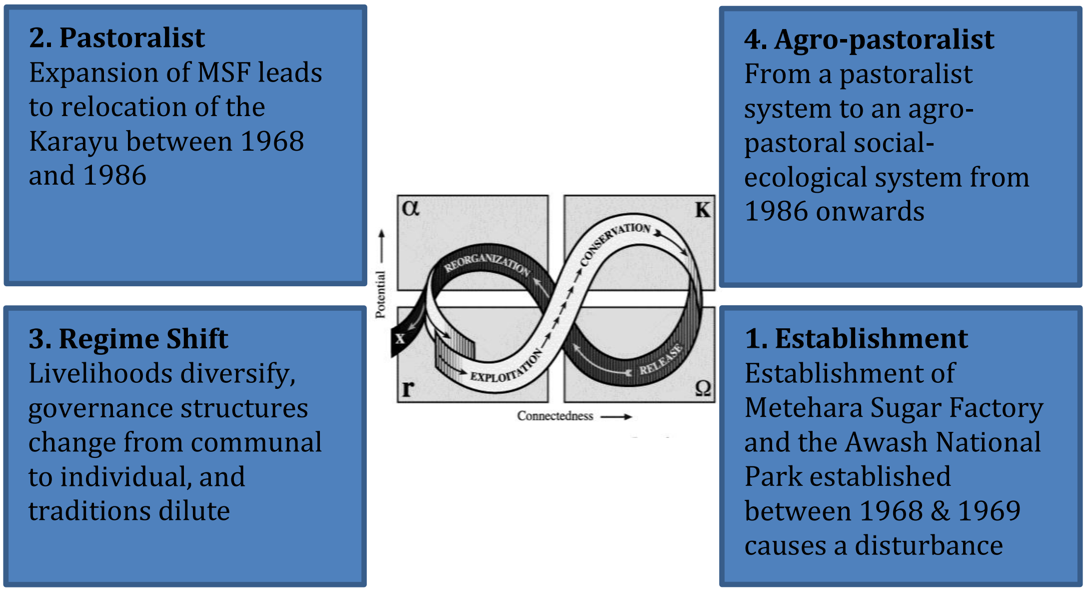


Figure 7.3. The adaptive cycle of the Karayu pastoralist social-ecological system. The Karayu have undergone a regime shift from pastoralism to agro-pastoralism.

Comparing Figure 7.1 and Figure 7.3, it can be seen that the two pastoralist systems progress through the same phases, from pastoralism, to a regime shift, to agro-pastoralism (although some of the Afar may become wage-labourers). Therefore, the experiences of the Karayu can be used as a likely scenario for the long-term effects of relocation on the Afar.

7.1.1.1. Future food security regimes for the relocated Afar

Section 7.1 concludes that there is the potential for reorganisation from pastoralism to benefit the relocated households in the long term. The entitlements survey reported on in Chapter 4 was also implemented in the Gola settlement, a Karayu agro-pastoralist community relocated in the 1980s and provided with access to irrigation channels. Although a small sample (n=27), the analysis below allows some inferences to be made about potential future impacts on food security for the Afar sample (n=91), to conclude whether the Afar will be winners or losers in the long-term.

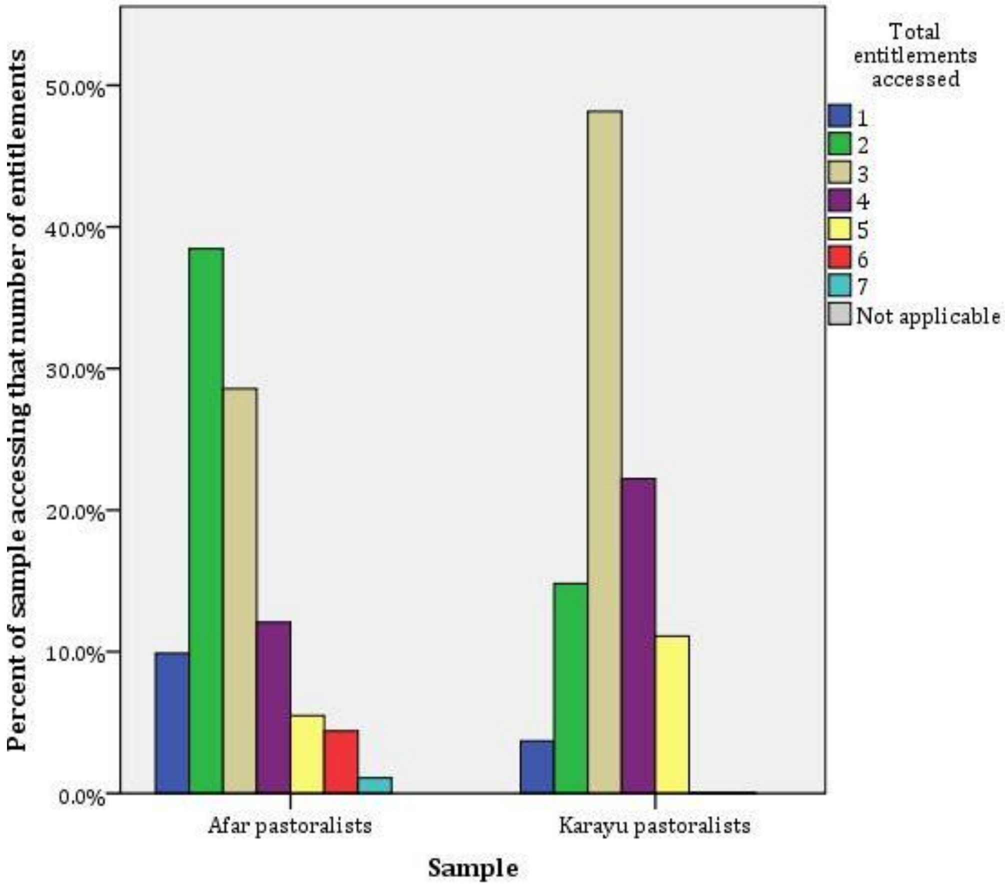


Figure 7.4. Total entitlements accessed by the pastoralist samples. Both samples reported a mean of three entitlement categories accessed but across different distributions.

The mean number of entitlements accessed is not significantly different, 2.8 (standard deviation of 1.3) for the Afar Pastoralists and 3.2 (standard deviation of 1.0) for the Karayu Agro-pastoralists. However, as Figure 7.4 shows, the distribution is significantly different between the two groups (Mann-Whitney U, $p = 0.030$) as results are skewed towards the lower values for the Afar sample which also reports a greater range of entitlements.

Furthermore, Table 7.1 presents the diversity of entitlements and shows that a Mann-Whitney U test found the levels of access for two entitlement categories to be significantly different – that of raising arable crops ($p = 0.00$) and trading goods for food ($p = 0.19$). That these are significantly different indicates that a regime shift regarding food security has occurred, as the majority of Karayu households now cultivate crops for their own consumption in addition to livestock rearing, and the trade of goods (a key livelihood strategy of pastoralism, trading animals or milk) has been removed for the Karayu, very few of whom trade. The prevalence of production of arable crops indicates that own-production supplemented by buying foodstuffs from markets is sufficient to keep the Karayu households fed. However, a reliance of more than a quarter of the sample on food-aid (from NGOs and Work For Food) is an indicator of low food security for these households.

Table 7.1. Entitlements accessed by the two pastoralist samples. The percentage of households raising livestock and trading goods were significantly different across the two samples (statistically significant differences between samples in bold, p=0.05 or less, Mann-Whitney U).

Entitlement Category	Entitlement Type	Afar Pastoralists (n=91)	Karayu Agro-Pastoralists (n=27)
Production	Livestock	75%	85%
	Crops	**3%**	**81%**
Trade	Buy	99%	100%
	Trade	**30%**	**7%**
Own Labour	Work for food	17%	7%
Transfer	Given by friends and family	20%	15%
	Given by NGOs	36%	26%
	Given by MSF	2%	0%
Other	Other	1%	0%

Whilst a similar percentage of households rely on livestock for production entitlements, Table 7.2 shows an independent t-test found the mean numbers of livestock kept is significantly different ($p < 0.007$) across the two samples.

Table 7.2. Average household livestock. The Karayu Agro-Pastoralists no longer rely on livestock for their livelihoods, but do for food (statistically significant differences between samples in bold, p=0.05 or less, independent t-test).

Livestock Type	Afar Pastoralists (n=91)	Karayu Agro-Pastoralists (n=27)
Chickens	2	1
Goats	**37**	**3**
Sheep	**19**	**3**
Cattle	**24**	**3**
Donkeys	**2**	**0**
Camels	**23**	**0**
Other	0	

The combination of small animal herd sizes yet 89% of the Karayu sample reporting crop or livestock production as a livelihood (as shown in Table 7.3) leads to the conclusion that such livelihoods are based on sales of crop not animal products. Therefore, animals are now a key food security entitlement but not a livelihood resource, corroborated by the lack of trade entitlement access in the Karayu sample and so it appears the Karayu raise animals for self-sufficiency rather than income, unlike the Afar. Their production entitlements are significantly different to the Afar pastoralists, who cannot cultivate crops and therefore the 90% relying on production livelihoods refer to livestock sales. Further data collected from the Karayu sample reflects some livelihood diversification but Table 7.3 shows the Afar Pastoralists already have a similar reliance on other livelihoods and therefore the transition from pastoral to arable production entitlements is the only significant difference with a regime shift.

Table 7.3. Livelihoods practiced by the two samples. Livelihood diversification in the pastoralist samples shows a reliance on farming but other livelihoods are already being carried out (statistically significant differences between samples in bold, p=0.05 or less, Mann-Whitney U).

Livelihoods	Afar Pastoralists (n=91)	Karayu Agro-pastoralists (n=27)
Salary	19%	4%
Small business (i.e. charcoal selling)	5%	4%
Non-agricultural wage labour (i.e. guard)	1%	4%
Agricultural wage labour (i.e. cane cutter)	3%	11%
Crop or livestock production	90%	89%
Government grants	0%	0%
Remittances from abroad	0%	0%
Other	0%	4%

A small proportion of the Karayu sample has also undergone a change in their access to entitlements over the past four years – 48% reported a decrease, mostly by one entitlement type. This decrease is far greater than in the Afar sample, where 17% reported an increase in entitlement categories accessed and 6% a decrease. The changes in the diversity of entitlements are outlined in Table 7.4.

Table 7.4. Change in entitlements from 2007 to 2011. For those reporting a change in entitlements, the change has been in opposite directions in the two samples.

	Afar Pastoralists (n= 24)		Karayu Agro-Pastoralists (n=13)	
	Now	4 years	Now	4 years
Animals	15%	18%	13%	0%
Crops	2%	11%	13%	0%
Buy	23%	4%	13%	0%
Trade	7%	4%	2%	3%
Work for food	6%	5%	0%	5%
Given FF	6%	1%	3%	0%
Given NGOs	7%	1%	5%	0%
Given MSF	0%	10%	0%	13%
Other	0%	22%	0%	11%

These changes were not attributed to any actions related to production at Metehara Sugar Factory, but instead were attributed to a shortage of irrigation access (25%), to prevent food shortages (42%) or to the action of the Government (33%). Chapter 4 shows that the Afar pastoralists have been relatively resilient to change so far, adapting to the loss of arable production entitlements by accessing trade entitlements and the PSNP to maintain food consumption although coping strategies were also required. In the Karayu, again, it is access to production entitlements that has been affected, but the households who reported change have begun to access both pastoral and arable production, as well as purchasing from markets, and have reduced their access of MSF aid and the PSNP project.

The Karayu and Afar are currently facing different disturbances, and have adapted in different ways. As Chapter 4 shows, in the face of disturbance, households adapt to maintain access and availability to food, and therefore a key indicator of food insecurity and the need to adapt is the level of coping strategies employed. The data presented in Table 4.8 shows that, as for the Afar, the majority of the Karayu sample is also employing coping strategies and an independent t-test (confirmed with a Mann-Whitney U test) reports there is no significant difference between the proportion of the samples employing coping strategies or mean coping strategy scores.

Table 7.5. Coping strategy scores. There was no significant difference between the two Pastoralist samples when reporting CSSs, and in both samples the majority of households are employing coping strategies (statistically significant differences between samples in bold, p=0.05 or less, independent t-test and confirmed with a Mann-Whitney U).

	Afar Pastoralists (n=91)	Karayu Agro-Pastoralists (n=27)
Mean Coping Strategy Score	5.6	6.2
Standard deviation	*6.0*	*8.6*
Minimum CSS	0	0
Maximum CSS	24	29
Percentage of households employing coping strategies	86%	85%
Percentage of households employing food related coping strategies	22%	15%
Percentage of households employing non-food related coping strategies	83%	81%
Mean Food CSS	3.0	3.6
Standard deviation	*6.1*	*8.9*
Mean Non-Food CSS	2.6	2.6
Standard deviation	*1.8*	*1.7*

The lack of difference indicates that the food security disturbances the Karayu Agro-Pastoralists are facing are requiring the same level of adaptation as the Afar Pastoralists.

Utilising the same measures of food security as in Chapter 4, the data presented here allows conclusions to be drawn regarding the impact of the regime shift from pastoralism to agro-pastoralism on food security. The regime shift of the Karayu Agro-Pastoralists has resulted in a different entitlements portfolio, with focus on arable production rather than pastoral production but an equal reliance on trade entitlements. The Karayu and Afar report the same median expenditure on food (100-199 Birr per week) and no significant difference in food expenditure as a ratio of total household income (0.59 for the Afar Pastoralists and 0.47 for the Karayu Agro-Pastoralists, p=0.09). A more diverse range of foodstuffs is produced by the average Karayu households, but the dietary diversity reported was not significantly different (p=0.22) although slightly higher in the Karayu sample, (454 (sd = 25.7) compared to 420 (sd= 13.1) in the Afar sample). However, a similar level of coping strategy employment indicates equal vulnerability of the Karayu households, although attributed to different disturbances. The ongoing regime shift of the Afar Pastoralists is therefore not likely to result in greater levels of food security.

However, food security is not the only area where benefits were hypothesised to be felt in the long-term by relocation. Table 7.6 presents data regarding the socio-economic status of the households in both samples. Key variables are combined to produce a wealth index score and displayed in Table 7.6, which shows that the regime shift of the Karayu has led to a significantly higher (independent t-test, p=0.000) mean wealth index when compared to the Afar Pastoralists.

Table 7.6. Wealth index score and factors. Afar Pastoralists have a lower overall wealth index score but a higher ownership of assets (statistically significant differences between samples in bold, p=0.05 or less, independent t-test and confirmed with a Mann-Whitney U).

	Afar Pastoralists (n=91)	Karayu Agro-Pastoralists (n=27)	*Significance*
Mean total household income	**1155**	**1783**	***0.013***
Standard deviation	*749*	*1903*	
Mean wealth index	**2.2**	**3.4**	***0.000***
Standard deviation	*0.9*	*1.1*	
Educated head of household	**9%**	**30%**	***0.005***
Children currently in education	**9%**	**30%**	***0.007***
Permanent housing unit	22%	11%	*0.156*
More than one room	**21%**	**41%**	***0.038***
Separate kitchen	**79%**	**59%**	***0.038***
Households with access to protected water	**68%**	**100%**	***0.001***
Non-biomass cooking	0%	0%	*n/a*
Non-biomass lighting	**5%**	**63%**	***0.000***
Households who have access to electricity	1%	0%	*0.588*
Households with a radio	**55%**	**30%**	***0.021***
Households with a telephone	48%	41%	*0.491*
Households with a television	0%	0%	*n/a*

The higher wealth index is a result of the better access to education, non-biomass lighting fuels and protected water for the Karayu. In addition, the household income of the Karayu exceeds that of the Afar Pastoralists, as well as the MSF Employees (1402, sd = 1014) and Metehara Residents (1603, sd=1241). However, the mean wealth index score is higher for both these samples than the Karayu or Afar – 6.7 (sd = 0.9) for the Employees and 8.0 (sd = 0.9) for the Residents, indicating that income is not the sole provider of these variables. There is also no significant difference (independent t-test and confirmed with a Mann-Whitney U test) between the Afar and Karayu regarding the ownerships of assets, and for some technologies the Afar Pastoralists have higher rates of ownership than the Karayu.

In conclusion, data on Karayu agro-pastoralist food systems does not indicate a significantly different level of food security than for Afar households. The lack of difference shows that the Karayu have adapted to their forced reorganisation into an agro-pastoralist culture, and maintained levels of food security, but are now vulnerable to new disturbances which have an equivalent effect on food security as relocation has for the Afar. Although the Karayu households reported a significantly higher mean income level and wealth index score then the Afar Pastoralists, their access to electricity and modern cooking fuels was non-existent. Therefore, although reorganisation into a sedentary regime does not appear to have reduced levels of well-being (compared against the current level of well-being for the Afar Pastoralists), it has also not reached the levels of the Metehara Residents or MSF Employees. The Karayu therefore have not become 'winners' in the long-term.

7.2. Regional Scale – Metehara Region Social-Ecological System

The results presented in Chapters 4 and 5 confirm that the current level of production at Metehara Sugar Factory has had limited negative effects on the social-ecological system bound by the limits of the MSF management. Expanding this regional boundary to the Woreda – hence including Metehara Town and the Awash National Park – opens the system up to other disturbances from biofuel production but again, these are limited and the system proves resilient to production of sugarcane and ethanol within it.

7.2.1. The Dynamics of the Metehara Region Social-Ecological System when Disturbed by Biofuels

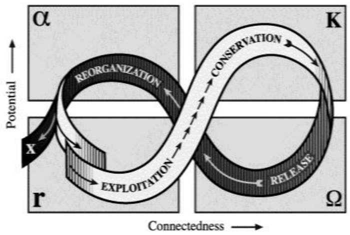
The original allocation of land in 1968 and the resulting change in governance of the resources in the area marked the re-organisation where this SES transformed from the prior state of an acacia shrubland ecosystem. As an initial state, this system provides ecosystem services that are desirable to the MSF managers – i.e. abundant land and water resources. However, the reorganisation is not desirable to the relocated Karayu Agro-Pastoralists, as described above, whose traditional livelihoods and culture relied on the previous regime. At this point, no other actors are involved in the SES. During the exploitation phase, the existing resources and ecosystem services are utilised to cultivate sugarcane in the area and support a growing population of employees. During the exploitation phase the sugarcane production and capital (financial and natural) accumulation increase, hence the potential (i.e. wealth) and connectedness of the system increase and continue to as the conservation phase progresses.

There have been two governance shifts at MSF based on changes at the national level. Firstly, there was a transition from the initial Dutch managers HVA to a nationalised organisation within the Sugar Corporation, following the collapse of socialism and establishment of the Mengistu Government in 1975. Secondly, the transition from the Mengistu Government to rule by the Ethiopian People's Revolutionary Democratic Front (EPRDF) caused the liquidation of the Sugar Corporation in 1992 and MSF became an autonomous public enterprise, although still responsible to the National Government through the Ethiopian Sugar Development Agency. Figure 7.2 and other secondary data from MSF shows that during both these transitions yield and area harvested were variable but maintained a relatively consistent level of production. The lack of change in output confirms that resilience is high in the foreloop phases (exploitation and conservation).

The foreloop phases can be prolonged for long periods of time and as of the time of data collection (2011), the system is still in the conservation phase. The transition from exploitation to conservation occurred when cultivation area stopped expanding, which, as discussed above and shown in Figure 7.2, occurred in 1993. Yields remain consistent during the conservation period, indicating potential remains high in the system. Figure 7.5 synthesises the dynamics of the adaptive cycle of the Metehara region, again using orange to differentiate likely future phases.

1. Regime Shift
The land is allocated to HVA who form Metehara Sugar Factory in 1968 causing a regime shift from acacia shrubland

2. Expansion
Between 1968 and 1993 the cultivation of sugarcane is implemented and expands to the current level of production



3. Established
Since 1993, cultivation and harvesting have continued and yields remain consistent

4. Future disturbances
Possible future releases may be due to reduced water availability, increased soil salinity or Lake Beseka expansion reducing yield

Figure 7.5. The adaptive cycle of the Metehara region social-ecological system. During the cycle the system changed from an acacia shrubland to a sugarcane monoculture.

The conservation phase indicates a release is approaching, primarily due to environmental degradation no longer supporting the current level of production. Although Chapter 5 shows the current level of production has not surpassed any thresholds affecting yield, it does highlight the potential thresholds (dependent on slow drivers) that the SES is approaching – namely those of water availability, salinity levels of soils and the encroachment of Lake Beseka. When the MSF management can no longer adapt to these drivers, the system will enter the backloop of the adaptive cycle and go through the release and reorganisation phases. The system could reorganise into an infinite number of regimes and hence it is not possible to predict the outcome. However, with the information known about the current regime it is possible to envisage a similar regime with smaller operations – limited due to the environmental degradation but desirable enough for the National Government to maintain their interests in due to the infrastructure and capital already invested in the system. Alternatively, a fast driver such as a crash in sugar prices or pest could cause a release and reorganisation into a system where operations cease.

7.2.2. Power Dynamics within the Metehara Social-Ecological System

To investigate the differentiation of costs and benefits on the actors within this system, primary data from interviews with representatives of key institutions in the region was synthesised with the quantitative data collected and presented in Chapters 4 and 5. All institutions reflected on the involvement of MSF in the local area, apart from Compassion International Ethiopia who limit their operations to urban families and did not report any influence by MSF in any way. The institutions reported a range of interactions MSF has with actors in the region in its current form, within the conservation phase of the adaptive cycle. The majority of institutions reported a lack of interaction between their institution and MSF, conceptualised as a lack of costs but also no specific benefits from its proximity.

The key message from the Awash River Basin Authority and Fentale Woreda is that the operation of MSF in the region does not create additional burdens on these institutions. Multiple interviews however reported MSF impairing certain groups of actors, resulting in negative impacts or displaced impacts on institutions, as shown in Table 7.7. Negative implications are most commonly reported for the relocated Karayu and previous employees who settle in the area and then require support from local institutions such as Child Fund and the Kebele authority. The production at MSF and new cultivation at KSF also perturbs the Awash National Park, as discussed in Chapter 5, where increasing usage of the Park by the pastoralists in the area leads to negative impacts. In contrast, MSF operations within the current conservation phase has led to positive impacts, but limited to those directly profiting from it – the employees and the National Government. The MOARD also reported benefits to the Karayu Agro-Pastoralists.

Table 7.7. Differentiation of impacts of MSF activities on different actors and institutions within the Metehara region.

Type of Impact	Reported impacts of expansion on institutions in the SES
Lack of impact	*"MSF is the biggest stakeholder and user [in the basin] but annual flow is enough for all users [as there is] no stress at the moment. The issues will be downstream."* Awash River Basin Authority
	"As a government institution, [MSF] works well, regarding many things. The Merti people [Employees] are not that much [of a] problem because [they earn] good salaries. In the town we distribute more food [aid] because of high prices." Fentale Woreda Authority
Negative impacts	*"MSF is bad for the Karayu, with the history of the establishment. They were displaced with guns because the land was very fertile and good for cattle. It affected people badly. Many families who work for MSF receive help – i.e. daily labourers from the Southern Nations [region in Ethiopia], they settle in the area and life is difficult, therefore they need help – especially in Addis Ketema."* Child Fund
	"Addis Ketema grew after MSF was installed, because many people live in Merti and moved to Addis Ketema when MSF expanded and took the land. The Kebele was established because of this new population in 1962. [Integration of the MSF worker populations is difficult] because there are excess people already in Metehara and Addis Ketema, even without Merti people – would be better if they had their own Kebele. The number of cases [of conflict] is high [in MSF] so [there are] emergency police in Merti but cases go to the judge here [in Addis Ketema]." Addis Ketema Kebele Authority
	"The sugarcane plantation is the most important economic activity in Ethiopia and is good for the country but bad for the ANP. Large carnivores migrating from the ANP to MSF make a temporary hiding place and are burnt which has an impact on the population. [The proximity of MSF] led to the paving of the Djibouti road, which leads to 24 hour traffic through the ANP, and the loss of two animals per day in traffic incidents. [The establishment of MSF] increased charcoal production [in the ANP] because the resources were taken for sugarcane and Karayu people began to take indigenous trees in the ANP. Now charcoal is made by other people – original labourers from MSF who settled and were trained by the Afar in how to make it." Awash National Park
Positive impacts	*"In some parts, MSF helps the communities. They took land from the pastoralists who used to migrate, and this is not accepted by the pastoralists. But MSF supports pastoralists [by providing] water by drainage canals and leftover cane tops. These are used mostly in droughts, when pastoralists migrate to MSF and are protected by MSF. Also, residents of 6-8 Kebeles work at MSF [and gain associated benefits]. There is some conflict between the employees and the pastoralists, usually if a drought goes on longer than two weeks."* Ministry of Agriculture and Rural Development

Therefore, the majority of local stakeholders are not affected positively or negatively by the presence of MSF, but certain actors feel strong negative implications. The distribution of the above actors is summarised in Table 7.8, which summarises the ‘winners and losers’ of the wider Metehara region social-ecological system for the different phases of the adaptive cycle, hypothesised for the future release and reorganisation phases.

Table 7.8. The actors within the Metehara region, distributed according to the effect of MSF, relative to the phases of the adaptive cycle.

Scale	Impact	Phase of adaptive cycle Exploitation	Conservation	*Release and reorganisation*
Metehara Region	***Winners***	National Government	National Government	*Awash National Park*
		MSF employees	MSF employees	*Relocated Karayu Agro-Pastoralists*
		HVA	Relocated Karayu Agro-Pastoralists	*Downstream Awash users*
	No effect		Metehara town residents	*Metehara town residents*
			Awash River Basin Authority	*Awash River Basin Authority*
			Woreda Authority	*Woreda Authority*
			MOARD	*MOARD*
	Losers	Relocated Karayu Agro-Pastoralists	Relocated Karayu Agro-Pastoralists	*MSF employees*
			Kebele authority	*National Government*
			Awash National Park	
			Downstream Awash users	

Within the exploitation phase, MSF was beneficial to the National Government – who received financial compensation for the land, HVA – who received the profits from sugar sales, and migrants into the area – who gained fixed or seasonal employment and the benefits associated with that. As discussed above, the Karayu Agro-Pastoralists were relocated and bore the costs of the regime shift. Once the system shifted into the conservation phase more actors became negatively affected by MSF, mostly other resource users in the region – i.e. the Awash National Park and downstream users of the Awash River, as MSF is the primary user and therefore controls to some extent the available flow downstream.

Within the Karayu communities there are mixed impacts of MSF, as highlighted above in Section 7.1.1 – some are given access to irrigation water whereas others were not, which has severe negative implications for those groups in terms of food security and requiring PSNP support. In addition, there is the provision of cane-tops (for grazing material and fuel) from within the MSF boundaries, for those who choose to access it. When considering the hypothetical distribution of impacts if the system was to release and reorganise into a different system, the above impacts would be reversed. The removal of MSF allows the ANP, Karayu and downstream users greater access to resources but removes the benefits employees and the National Government gain from MSF.

To summarise, there is a differentiation of impact within individual actor groups, as well as between actor groups, and the identification of this heterogeneity leads to a more nuanced understanding that there are unequal outcomes of such land-uses, resulting in different user groups having different visions of which regimes are desirable.

7.3. Regional scale – Kesem Region Social-Ecological System

This section presents an analysis of the adaptive cycle dynamics and resulting differentiation of impacts on actors resulting from the biofuel expansion in the Kesem region. The Kesem region includes the area under management of MSF for the Kesem site, i.e. the total area to be cultivated with sugarcane, the surrounding traditional Afar rangelands, and the Awash National Park. Including the ANP leads to an overlap of the system with the Metehara region SES but is necessary as the KSF leads to new impacts on the ANP. However, the KSF SES does not go further south than the border of the ANP, i.e. does not include Metehara Town or MSF, as this is in the Oromo region whereas KSF is in the Afar region and therefore under a different governance structure.

7.3.1. The Dynamics of the Kesem Region Social-Ecological System when Disturbed by Biofuels

The regime shift in the Kesem SES began very recently and is ongoing. Previously the region was an acacia shrubland ecosystem, occupied by Afar pastoralists and a small commercial fruit farm, with one settlement named Sabure – the administrative centre of the Kebele. The release phase began with the initial intention to begin cultivation at Kesem, which was decided in 2004 although not made public. Construction was immediately initiated on the Kesem dam that would provide the necessary irrigation water (Ministry of Water and Energy 2007). Reorganisation was not immediate, and began when cultivation and infrastructure construction started in March 2011. The delay was due to technical issues with the construction of the dam and difficulties in acquiring the necessary financial capital for the project. The benchmark schedule for KSF outlines completion of the expansion by 2015 (MSF Management 2011). Therefore, the establishment of the Kesem Sugar Factory is still in process and the system is in the exploitation phase of the adaptive cycle as the system is rapidly accumulating capital. When the area under cultivation reaches the planned level in 2015 and processing can be done on-site, the system is likely to reach the conservation phase, as shown in Figure 7.6.

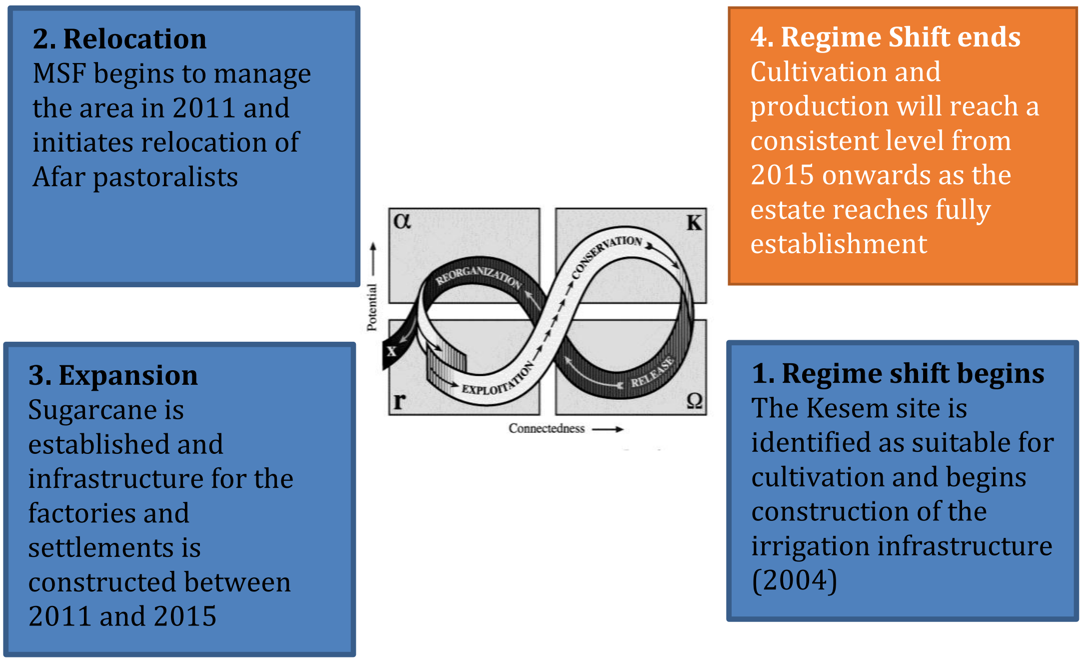


Figure 7.6. The adaptive cycle of the Kesem region social-ecological system. The cycle replicates the Metehara region dynamics.

7.3.2. Power Dynamics within the Kesem Social-Ecological System

There are fewer actors based within the Kesem system than the Metehara system, reflecting the lack of an urban population and associated actors, as in Metehara prior to the establishment of MSF. The reported impacts of expansion at Kesem Sugar Factory on the ANP and the Awash Fentale Woreda Authority are shown in Table 7.9.

Table 7.9. Differentiation of impacts of KSF activities on different actors and institutions within the Kesem region.

Type of Impact	Reported impacts of expansion on institutions in the SES
Negative impacts	*"In the northern area in Kesem expansion Afar people have lost grazing land and are 100% dependent on grazing in the ANP now, which is overloaded by cattle, goats and camels. Tourists come to see the natural habitat but the ANP is dominated by [domestic] animals.* *The encroachment of Kesem increases the effects of drought because of [Afar] settlements increasing. Traditionally these semi-arid areas were free from impact and rehabilitated very quickly [after rain] but this is decreased by 50% after grazing, where replacement is probably by an invasive species, which is carried by cattle onto the bare land. There are now six different types but prosopis is the main problem."* Awash National Park
Positive impacts	*"Change will not happen in 24 hours. It will be a gradual change as awareness increases of the impacts; we will have to work hard to show what else is in the world. People need money – there is an interest for that.* *KSF creates job opportunities as guards - 355 are proposed but this will be exceeded. Other options are masonry workers, carpentry, heavy truck driving – training for 100 people in technical schools [will be provided by the Government] and priority is given to pastoralists.* *[Relocation has two strands] – 1) to improve livelihoods and resettle, 2) to provide water, health, education and light [electricity]. Consider Metehara, people were taken by the sugar factory during the Derg regime but in this Government there are opportunities in the Oromia region – benefiting pastoralists who became farmers. Now in Metehara the government officials are coming from the native pastoralist [communities].* *The [Kesem] project is very useful for us – we are still not improved because of pastoralism and have no opportunities to develop, now we will have education, health [clean water supply], hospitals and other opportunities which lead to development. I need my child to compete with you [the interviewer] – we need new technology for the country to compete with the world and join globalisation."* Awash Fentale Woreda Authority

The release phase had few impacts on actors in the system as it only involved the National Government, who anticipated a massive increase in profits from sugar and ethanol, coupled with large job creation. However, no impacts were felt at this stage. The reorganisation phase initiated construction on-site and the associated job creation created benefits for those newly employed. However, the increased traffic directly through the Awash National Park was an immediate negative impact due to the associated road kill and disturbance of wildlife. The ANP also reported a lack of consultation or impact assessments during this phase – *"No impact assessment [was done] or [we're] not aware of one – it didn't work if there was one."* (Awash National Park 2011).

As discussed above, the first element of the relocation plan for the Afar Pastoralists was the removal of access to arable land and water for animals. The loss of access created large negative impacts on the Afar populations' traditional livelihoods and methods of accessing entitlements, as outlined in Chapter 4 and section 7.1. Changes in behaviour of the Afar population further negatively affected the Awash National Park.

The exploitation phase maintains this balance of impacts, and is producing a similar differentiation of impacts on actors as in the Metehara system – namely that pastoralists bear the costs of expansion via a loss of access to livelihoods and food security, and the National Government reaps the financial benefits alongside those who gain fixed employment. In contrast with the Metehara SES in the exploitation phase, there is already a settlement within the system – that of Sabure, the residents of whom are not reported to have received any benefits or costs at any stage of the adaptive cycle so far, as confirmed by the lack of impact on the Metehara town residents outlined in Chapter 4.

It is anticipated that the conservation phase will mirror the exploitation phase in the distribution of costs and benefits. However, the Awash Fentale Woreda Authority was particularly confident in the long-term benefits that KSF would bring to the relocated Afar, and that undergoing a regime shift into a sedentary culture would transition the Afar from losers to winners in this situation. Data presented in section 7.1.1.1. shows this may not be correct.

To summarise, there is again a differentiation of impacts between actors within the Kesem SES. There is also a differentiation within individual actor groups, specifically within the Afar Pastoralists where not all households reported reduced food security from relocation, and managers expect a differentiation of impacts for individual households over time – i.e. that the changing of livelihoods and provision of greater services will increase the wellbeing of the Afar households. However, as section 7.1.1 concludes, the transition from losers to winners has not been fully realised in the Karayu SES, and therefore is unlikely to occur here. The differentiated impacts are summarised in Table 7.10.

Table 7.10. The actors within the Kesem region distributed according to the impacts of the disturbance resulting from the establishment of KSF, relative to the phases of the adaptive cycle.

Scale	Impact	Phase of adaptive cycle			
		Release	Reorganisation	Exploitation	Conservation
Kesem Region	*Winners*		National Government	National Government	National Government
			KSF employees	KSF employees	KSF employees
				Awash Fentale Woreda	Awash Fentale Woreda
					Relocated Afar pastoralists
	No effect	National Government	Sabure residents	Sabure residents	Sabure residents
	Losers		Relocated Afar pastoralists	Relocated Afar pastoralists	Relocated Afar pastoralists
			Awash National Park	Awash National Park	Awash National Park

7.4. National Scale Social-Ecological System at Current Production Levels

The boundaries of this system refer to those of the Federal Democratic Republic of Ethiopia – i.e. the limits of governance of the Ethiopian National Government – and the impacts of biofuel expansion on this scale. Interview data with key actors at this scale provides primary data on which to analyse the impacts.

7.4.1. The Dynamics of the National Social-Ecological System when Disturbed by Biofuels

Within the national system, biofuel expansion has already gone through multiple iterations of the adaptive cycle. Prior to 2007, Finchaa Sugar Factory produced ethanol but there was no official government strategy on or publicly discussed interest in, biofuels. A backloop (release and reorganisation) began in 2007 when the Biofuels Strategy was published, outlining Ethiopia's plan for domestic biofuel production (discussed in Chapter 3). Additionally, to encourage international investors into Ethiopia, deals were created including low land rents, long rental agreement and minimal export taxes (Ethiopian Investment Agency 2011b). Such favourable conditions for investment initiated a large allocation of land between 2007-2010 for biofuel feedstock cultivation in Ethiopia, along with the planned production of ethanol at the other existing sugar factories in Ethiopia – Metehara and Wonji. By 2010, 1,113,000 hectares were allocated by the Ethiopian Investment Office across 46 privately run biofuel projects, 72% of which were run by foreign investors (Ethiopian Investment Agency 2011a). The majority of these investors planned to produce jatropha for biodiesel (Ethiopian Investment Agency 2011a). Land preparation and cultivation began on certain schemes in 2008, indicating the exploitation and conservations phases, but led to well-publicised conflicts (i.e. Babile Elephant Reserve (MELCA Mahiber 2008)) with prior users.

Poor initial yields coupled with an increasing focus on the negative impacts of biofuels in the global discourse led to many projects being abandoned by 2010, marking a release in the system. Indeed, of the 46 projects provided with licenses in the period 2007-2010, only 6 were operating in 2010 (Ethiopian Investment Agency 2011a). The system then reorganised with a focus on government-managed ethanol from sugarcane, initiated by the focus on sugarcane and ethanol within the 2010 Growth and Transformation Plan. The system is currently in an exploitation phase where sugarcane ethanol is seen as the most desirable regime and expansion is vast and rapid. It is expected that this phase will continue until 2015, when the planned expansion under the GTP is completed and cultivation and production reaches a constant level. The regime shift is outlined in Figure 7.7 below and the future scenarios for the system as a result of this reorganisation, based on point number 8 in orange, are discussed below in section 7.5.

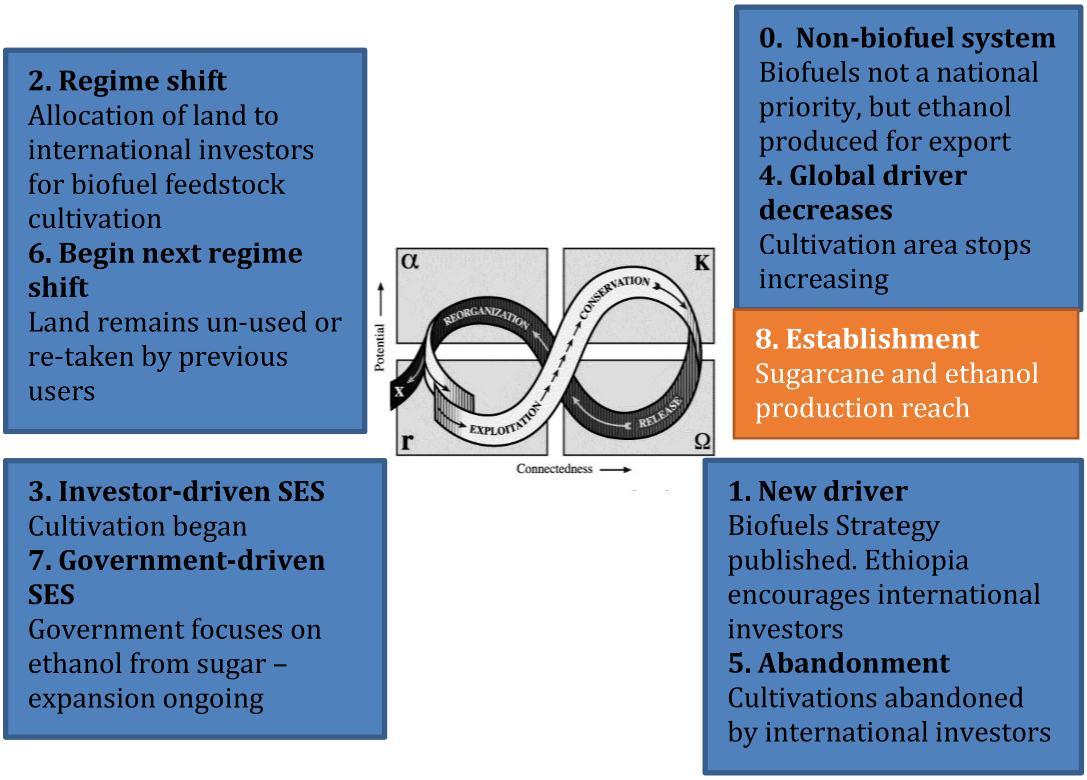


Figure 7.7. The adaptive cycle of the national social-ecological system. This system has been through multiple iterations of the adaptive cycle since 2007.

7.4.2. Power Dynamics within the National Social-Ecological System

Chapter 4 and the above analysis in sections 7.1 and 7.4.1 have concluded that the current level of biofuel production has not led to a regime shift for the majority of actors, but has begun the back-loop of the adaptive cycle for pastoralist households due to their relocation. The system dynamics have included two regime shifts at the national scale from no-biofuels, to investor-driven biofuels, to the current regime of government-driven ethanol from sugarcane. Discussing differentiation of impacts on actors at the national scale requires scaling up the relevant impacts from smaller scales discussed above, in addition to introducing new actors relevant at this scale.

The Ministry of Water and Energy is a newly created Government Ministry, merging roles within the previous Ministry of Mines and Energy and the Ministry of Water Resources. As well as managing the construction of new dams, for example the Kesem dam and the Gibe III dam, it also contains the Biofuels Development Coordination Directorate. However, its representative reported having little to do with bioethanol from sugarcane and mostly dealing with new projects growing biodiesel feedstocks (Biofuels Development Coordination Directorate 2011). Therefore, these institutions have not borne any costs or benefits due to the expansion of biofuels. However, the newly re-named Sugar Corporation (previously the Ethiopian Sugar Development Agency) has benefitted from the expansion of ethanol. Whereas the ESDA was located within the Ministry of Trade and Industry, the newly renamed Sugar Corporation was moved directly under the control of the office of the Prime Minister in 2011. It now receives large financial support from the national budget and foreign investment and representatives of other ministries and stakeholders reported in interviews that it has the most power regarding sugarcane and biofuel expansion.

In comparison, foreign investors bore the costs of reorganisation into the current regime and now have minimal involvement in biofuel production in Ethiopia – particularly with ethanol from sugarcane. Another actor group who lost out in the previous adaptive cycle and reorganisation phase of this adaptive cycle was highlighted by the NGOs interviewed – smallholders who began out-grower schemes with the foreign investors but did not receive fair payment when the schemes were operational, and then were left un-compensated when the projects were abandoned. Theses impacts are outlined in Table 7.11.

Table 7.11 also shows that the Ethiopian Wildlife Conservation Authority representative re-iterated the negative impacts biofuel expansion is having on the country's national parks and biodiversity, as discussed above regarding the Awash National Park and the lack of Environmental Impact Assessments was also raised by national NGOs.

Table 7.11. Differentiation of impacts of biofuel activities on different actors and institutions within the national system.

Type of Impact	Reported impacts of expansion on institutions in the SES
Negative impacts	*"Out-grower schemes have been seen in Ethiopia before – tea and coffee, initiated by government. Some were successful but for biofuels there was no community participation and … local livelihoods were impacted by out-grower schemes. Before farmers were getting double or triple the income. [The schemes were not] studied well and communities not informed well and so ended up losing their livelihoods… because farmers were replacing both food and cash crops because the initial promise is so huge. Communities should be consulted and involved in decision making, and caution is required. Compensation is required for local farmers, as are written agreement documents between the community and investors. There was no EIA and social impact assessment. Just jumped into the investment, which doesn't even benefit investors. But there's no implementation of the law because the, law's still in infant stages. We're struggling to make law-makers aware of this law – it's seen as anti-development by the Government."* MELCA
	"The social impacts have undoubtedly been huge. The communities trusted the investors to help them. The lack of success leads to longer term negative attitudes to government/private investors." Ethioscope
	"In general, [EWCA is] not against biofuels because they're environmentally friendly. Site selection matters though – [for example the] problem with Flora Eco Power and Babile Elephant Reserve: 4-5 years ago, FEP was given land that cut through BER – there was no EIA and the environmental impacts were never considered… [the biofuel projects] are associated with habitat fragmentation and decline." Ethiopian Wildlife Conservation Authority
	"Lack of EIA - internal/external pressure meant work started before strategy was formalised. [There were] big ambitions by the Government, like in other African countries. Some studies were incorrect – i.e. Land Use Assessment. There were problems implementing strategies because no supplementary materials [were available]. If the government is investing, it requires a third party with no links to the project to direct the study. NGOs have a role to play as watchdogs." Forum For Environment
Positive impacts	*"The future of biofuels within Ethiopia is promising – the Government gives attention to the department, which is emerging and picked out by Government. Ethanol is running in a good manner and blending facilities are increasing. The private investment for biodiesel is small but we will try to plant as out-growers within the Ministry of Agriculture, jatropha especially."* Biofuels Development Coordination Directorate

The differentiation of impacts outlined above echoes the findings of Chapter 5, where, although unquantified, Metehara Sugar Factory releases factory water and effluent into the Awash River unmonitored with negative implications for downstream users. Such an effect stands to be scaled up by increased production feeding into this river from Kesem and Tendaho Sugar Factories, whilst new pollution will be introduced to the Omo River. In addition, water availability will be a key issue for downstream users of rivers due to the large water footprints of the sugar factories. As Chapter 5 and section 7.2.2 both discuss, this will lead to negative impacts on downstream Awash River users relying on the river to maintain livelihoods – ranging from other large agriculture estates, smallholders and pastoralists.

Increasing ethanol production has led to a profit for the National Government, as after the investments in processing infrastructure there are minimal production costs due to the utilisation of a by-product and the resulting decrease in oil importation expenditure at the national level. So far, blending has been carried out by two companies – Nile Petroleum and Oil Libya (Ethiopian Petroleum Enterprise 2011a), at a E10 blend in Addis Ababa only. The ethanol blend also increases the resilience of petroleum users by decreasing variability in price and supply once ethanol blending commenced in the exploitation and conservation phases (2008 – E5, increased to E10 in Addis in March 2011).

Chapter 6 discusses the limited potential for ethanol stove adoption and specifically the differentiated benefits at the current level of production, concluding that the Low and High Income households benefit from the cleaner burning fuel, whereas Very High Income households have already adopted clean-burning fuels. Conversely, only the Very High Income households benefit from fuel expenditure savings, upon substitution for gas, whereas ethanol increases household fuel expenditure in Low and High Income households. Therefore, in the current phase of the adaptive cycle with the current price of ethanol stoves and access, only Very High Income households stand to benefit. Additionally, Chapter 6 also introduces the multiple benefits refugee households have gained due to using ethanol stoves. A summary of the differentiated impacts during the recent phases of the current adaptive cycle is shown in Table 7.12.

Table 7.12. Differentiated impacts on actors at the national scale for the current adaptive cycle.

Scale		Phase of adaptive cycle: Reorganisation	Phase of adaptive cycle: Exploitation
National	***Winners***	National Government	National Government
		Sugar Corporation	Sugar Corporation
			Petroleum users
		Refugee households	Refugee households
		Very High Income stove users	Very High Income stove users
	Losers	Foreign investors	Pastoralist households
		Low income ethanol stove users	Low income ethanol stove users
		High income ethanol stove users	High income ethanol stove users
		Out-growers	Downstream Awash users
			Awash National Parks

7.5. National scale social-ecological system at planned production levels

The above analysis highlights the main winners and losers at the current level of production, incorporating the ongoing expansion at Kesem Sugar Factory by another 20,000 hectares of sugarcane. However, as Chapter 3 outlines, the Growth and Transformation Plan (GTP) (2010 to 2015) outlines the expansion of sugarcane and ethanol production in line with the 'Green Development' Strategy and couples this with the expansion of medium and large scale irrigation from 2.5% of land coverage in 2010 to 15.6% in 2015 (Ministry of Finance and Economic Development 2010a). Such an increase translates to an additional 10 sugar estates in Ethiopia during the 2010 to 2015 period (W. Davidson 2011; Sugar Corporation 2013c). The total expanded production will create 2.3 million tonnes of sugar and 304 million litres of ethanol, for domestic consumption as a transport and household fuel (Ministry of Mines and Energy 2007; Ministry of Finance and Economic Development 2010a). This massive increase in scale – a 7-fold increase from the current level of sugar production – potentially produces a different balance of winners and losers due to the larger disturbances with the national social-ecological system, and these are outlined below, highlighting the key actors and potential thresholds.

7.5.1. Increased intake from the Kesem and Awash Rivers

As highlighted in section 7.2, downstream Awash users already bear the costs of ethanol production due to the large water consumption in the MSF. Upon completion of KSF, water removal from the Awash will have increased by 200%, as water taken from the Kesem will therefore not flow into the Awash. The decreased input into the Awash has not been highlighted by any studies or interviewees to have a negative impact on flow downstream, but as the river cannot currently provide full irrigation diversion during times of drought currently, this is only expected to worsen in the future with increasing numbers of users relying on the Awash (Tumebo 2008). New users include the Tendaho Sugar Factory in the Lower Awash (60,000 ha) and Fentale and Tibila Irrigation Based Integration Projects (30,000 ha) in Oromia (Alemehayu et al. 2011). A greater reliance on irrigated agriculture in the Awash Basin will require more stringent allocation of irrigation water, as MSF's location in the Upper Valley allows it to divert from the river what it requires, leaving downstream users particularly vulnerable in times of drought. Discussion of current water allocation highlights the lack of clarity regarding future allocations. Water allocation in Ethiopia is governed by the Ministry of Water Resources, on a basin scale. River Basin Integrated Development Master Plans form the basis of management of the basins, and in the Awash the Awash Basin Authority is responsible for the coordination, administration, allocation and regulation of surface water resources (Halcrow Group and GIRD Consultants 2009). However, there is currently a lack of clarity and accountability (highlighted by the lack of data and availability of policy documents) regarding allocation priorities for users in the basin, allowing government-run operations, such as the sugar factories, to take precedence.

Finally, climate change will have an effect on river flow in the future. Conway & Schipper (2011) highlight the variability in climate model projections for rainfall in Ethiopia, and conclude there is an overall tendency for slightly wetter conditions and higher rainfall variability. There are very few studies regarding the Awash, but Hailemariam (1999) projects a decrease in runoff between -10<-34% with a doubling of CO_2. Decreases in runoff will lead to future vulnerabilities to drought and the system moving to a nearer threshold regarding water availability.

7.5.2. Expansion in the Omo River Basin

Although some of this expansion will occur in the Awash River basin – including the analysed Kesem Sugar Factory and a new site further north in the Lower Awash area called Tendaho – the majority of expansion outlined in the GTP is occurring in the Omo River Basin, an overview of which is given below. Managed as the autonomous Omo Kuraz Sugar Factories Project, under the governance of the Sugar Corporation, this project will cultivate 175,000 hectares of sugarcane and supply 5 sugar factories, producing 1.9 million tonnes of sugar and 183 million litres of ethanol per year – 60% of the overall planned national output (Sugar Corporation 2013b). Such cultivation will require huge amounts of irrigation, presumably at a similar ratio to the calculated water footprint for MSF – 32 m^3 per litre of ethanol. The Gibe III dam has been constructed, partly to divert water for this use and partly to create hydro-electric power.

The Lower Omo, in the south west of Ethiopia, is one of the most culturally and biologically diverse regions in the world and as such was named a UNESCO World Heritage Site in 1980, in addition to containing the Omo and Mago National Parks. It is populated mainly by indigenous communities who are small in number and do not have regular contact with neighbouring groups or government officials (Human Rights Watch 2012b). Traditionally, certain groups were solely pastoral (raising goats, cattle and sheep) – for example the Daasanach, Bodi - but have begun to farm arable land due to reducing grazing areas in the past 50 years. Other groups are traditionally agro-pastoralist, practicing flood retreat cultivation on the floodplain of the Omo River, where staple crops such as sorghum and maize are cultivated (United States Agency for International Development 2005).

7.5.2.1. Pastoralists in the Lower Omo Valley

The GTP specifies that *"in areas convenient to irrigation development, resettlement of pastoralists on voluntary basis will be… undertaken"* (Ministry of

Finance and Economic Development, 2010:46). The expansion in the Omo valley is therefore supported by the GTP and justifies the relocation of pastoralists to the National Government. Therefore, the negative impacts on pastoral households discussed above in section 7.1 and the regime shift changing their cultural identity, livelihoods and food systems are likely to replicate across Ethiopia. Figure 7.8 (Survival International 2012) shows the planned expansion within the area for the Kuraz project – three blocks of approximately 80,000 hectares, each with a highlighted resettlement zone.

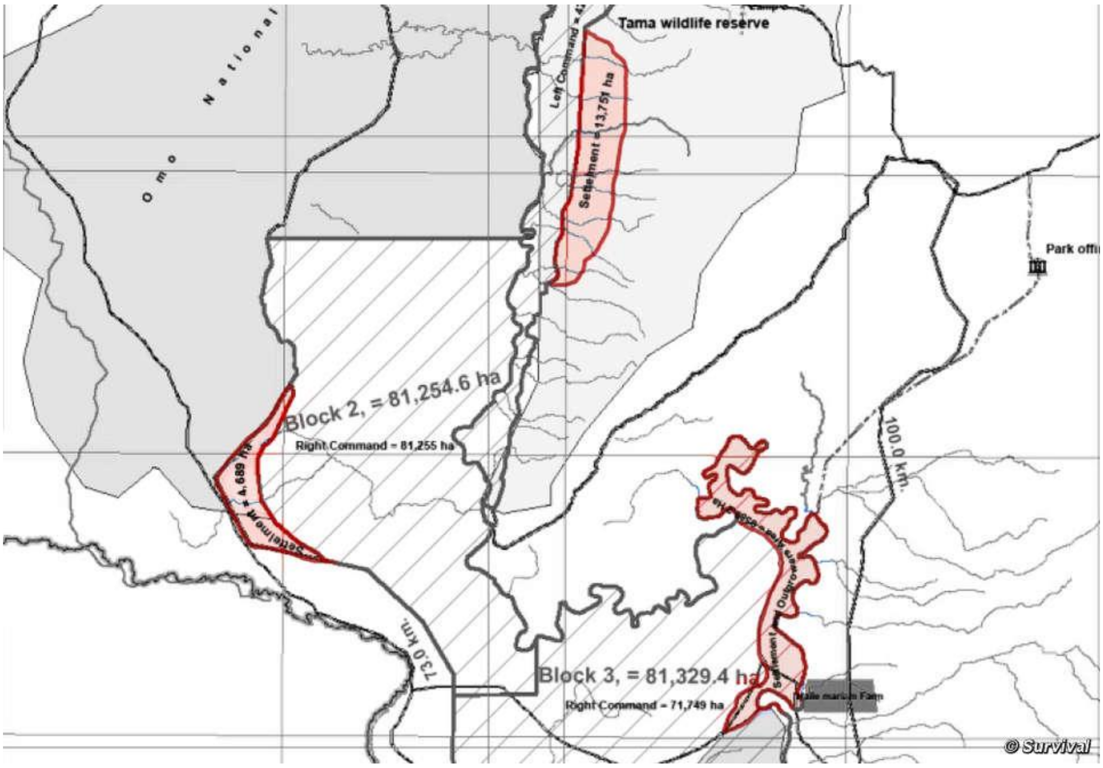


Figure 7.8. The planned expansion of sugarcane within the Omo Valley. Sugarcane estates will total 245,000 ha (Survival International 2012).

The area outlined for conversion is purported to support a population of 200,000 people from eight indigenous groups (Human Rights Watch 2012b). Table 7.13 lists the main groups who will be affected to give an indication of the populations affected and of the elements of the area's development which will affect the group (Federal Democratic Republic of Ethiopia 2008; University of Oxford 2012; Human Rights Watch 2012b). It shows that the population directly affected within the boundaries is approximately 166,000 people. Figure 7.9 shows the original distribution of settlements, arable land and grazing lands in the area to be cultivated with sugar for two groups – the Mursi and the Kwegu – but such data are not available for the other six groups in the region, who will be similarly be displaced.

Table 7.13. Further detail regarding the indigenous groups who will be affected by sugarcane cultivation in the Omo Valley.

Indigenous Group	Livelihood Classification	Total Population (2007)	Affected by:
Bodi	Agro-pastoralism	7,000	Sugarcane Block 1
Mursi	Agro-pastoralism	7,500	Sugarcane Block 1 & 2
Karo	Agro-pastoralism	1,500	Sugarcane Block 3
Nyangaton	Agro-pastoralism	25,300	Sugarcane Block 2 & 3
Daasanach	Agro-pastoralism	48,100	Private Investors
Suri	Agro-pastoralism	27,900	Sugarcane Block 2
Kwegu	Agro-pastoralism	1,970	Sugarcane Block 1
Hamer	Agro-pastoralism	46,500	Indirect impacts
Total		***166,000***	

Little official data are available about time-scales for the resettlement and the relocation packages offered to agro-pastoralist households, but development in the area began in May 2011 with road construction and factory development in the northern region of the basin (Oakland Institute 2011). Construction of the Gibe III dam began prior to this in 2006 and will be complete in 2013, although has already begun to fill and affect the local flood-regime (International Rivers 2011). Recent research has concluded that approximately 130 indigenous settlements already have reduced access to the banks of the Omo River, due to construction of irrigation canals (Human Rights Watch 2012a). In addition, in May 2012 a large flooding event (related to a newly constructed river barrier) inundated over 500 hectares of traditional agricultural lands (Human Rights Watch 2012a). Construction in the area has been accompanied with violence against the agro-pastoralists, as outlined by Human Rights Watch (2012a):

"During 2011 Human Rights Watch found that local government and security forces had carried out arbitrary arrests and detentions, used physical violence, and seized or destroyed the property of indigenous communities. Residents said military units regularly visited villages to intimidate residents and suppress dissent related to the sugar plantation development. According to local people anything less than fully expressed support for sugar development was met with beatings, harassment, or arrest."

Human Rights Watch (2012:2)

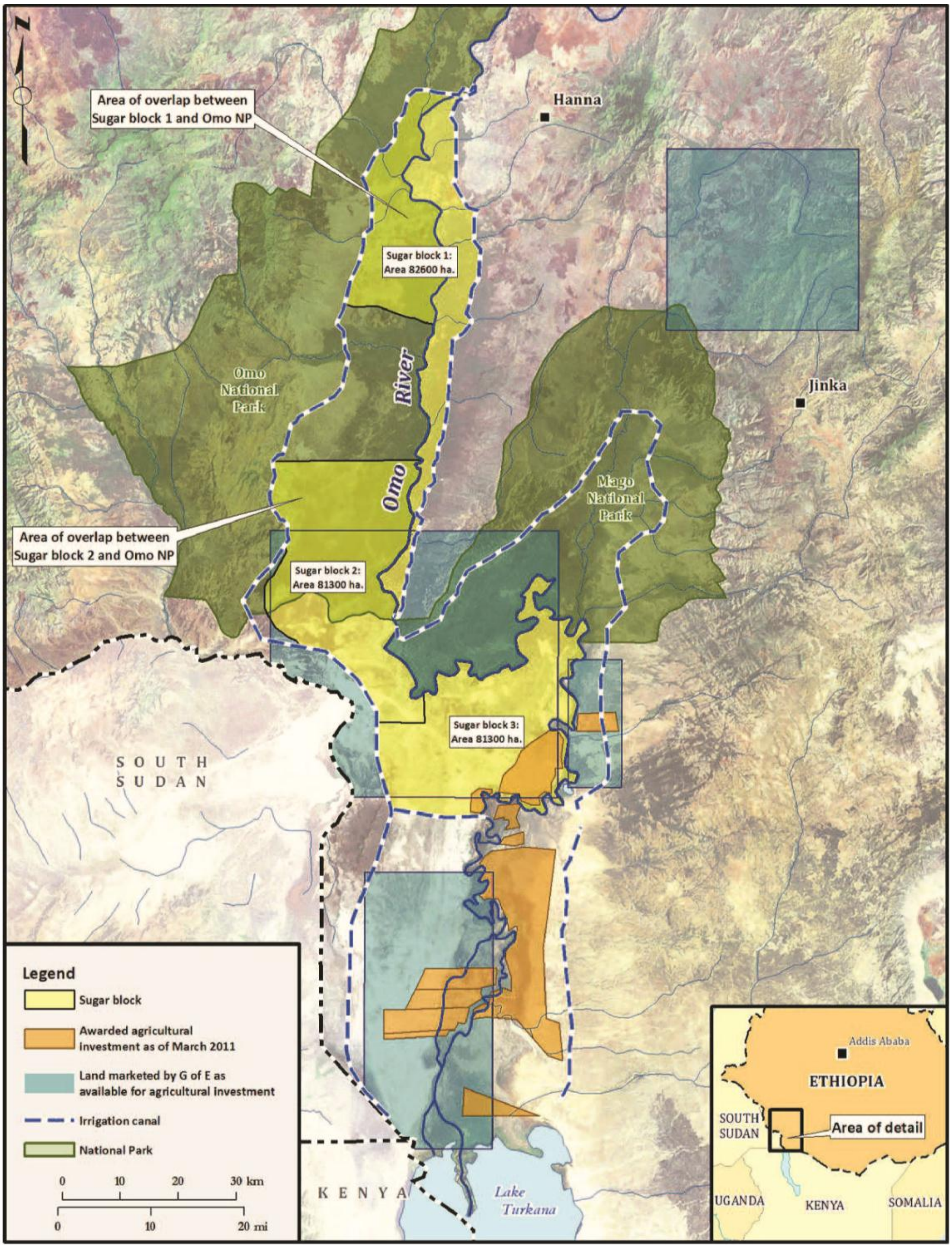


Figure 7.9. Areas where relocation will occur in the Omo. 58% of Mursi and Kwegu villages are planned to be displaced, along with 73% of cultivation sites, and a further 6 ethnic groups are affected (Human Rights Watch 2012b).

Chapter 4 shows a similar removal of access to traditional livelihoods, where the relocation of pastoralists has negative impacts on access to production entitlements and leads to the initiation of coping strategies as well as a larger reliance on the PSNP programme. The limited access to grazing lands and water sources affected herd size and therefore food access from the herd as well as economic livelihoods for the Afar pastoralist households in Kesem. However, Chapter 4 shows that the main issue affecting food security is the loss of land on which to grow tomatoes and onions, as a food source and a cash crop. The decreasing access to production entitlements is substituted by increasing trade entitlements – i.e. when households cannot produce their own food, they rely on markets from where they can purchase it. Therefore, decreased access to flood-plain agriculture and grazing lands in Omo will remove the traditional livelihoods of Omo agro-pastoralists and lead to similar decreases in productive entitlements resulting in a lock-in to trade entitlements, causing a regime shift for these households who will utilise their social-ecological system in different ways.

Whilst the scale of relocation is much smaller in Kesem, 600 households compared to approximately 40,000 in the Lower Omo, further findings from the Kesem SES can be inferred for the Omo SES and hence the national SES. In Kesem the system is still in the release phase of the adaptive cycle, but will lead to a regime shift for those pastoral households relocated. Currently, this is a conclusion dependent on scale – some relocated households have transitioned to a wage-agriculture lifestyle, with a reliance on trade-entitlements, but approximately a third of households have yet to be relocated and therefore can continue to graze animals. The Omo social-ecological system is in a similar phase. Reorganisation has not yet occurred as the majority of households still remain in isolated traditional settlements relying on traditional livelihoods of flood retreat cultivation and transhumance. It is envisaged once relocation is complete a reorganisation will occur, finalising the regime shift to a more sedentary culture with a greater integration into other (i.e. national) governance structures.

The imminent reorganisation of the pastoralist social-ecological system identifies these actors as one of the few groups to lose out with the expansion of biofuels in Ethiopia. However, as with the Kesem relocation, the question arises regarding the temporal element of transformation – if the level of well-being remains the same or improves in the future, will the relocated Omo agro-pastoralist transition into 'winners' rather than 'losers'? The analysis in 7.1.1.1 showed that a vast improvement in food-security and other measures of wealth well-being is not reported for the now sedentary Karayu households. Although their income exceeds that of the mean MSF Employee and Metehara Resident households, their level of food security is shown to be far lower, due to the high percentage of households employing coping strategies.

However, the presumed positives of sedentarisation also include greater access to education and health care, alongside greater job opportunities with fixed wages. In total 150,000 jobs are hypothesised to be provided in the Omo region. However, as shown with the Afar and Karayu Agro-Pastoralists in the Metehara region (Table 7.3) and by a researcher in the Omo region (Oakland Institute 2011) – a minority take work with the sugar estates, and the majority of jobs are filled by migrants to the area. The arrival of new populations in such areas can lead to increased rates of prostitution, sexually transmitted diseases, conflict, land degradation, and a loss of cultural identity.

In conclusion, a regime shift to sedentarisation does not seem to increase the level of wellbeing of agro-pastoralist households, confirming that those about to be relocated remain those bearing the costs of biofuel expansion with future planned expansions. It is therefore evident that sugarcane expansion in the Omo will lead to devastating impacts on the nation's indigenous culture, as changes to the land upon which those populations derive their livelihoods are potentially irreversible.

7.5.2.2. Ecological disturbances

Examining the environmental impacts at the national scale of the planned expansion, there are three main interactions creating losses:

1) The loss and fragmentation of the national parks in the Omo region
2) The negative impacts of large-scale hydropower due to the Gibe III dam
3) Altered water availability in the Omo River Basin for Lake Turkana in Kenya

In addition to the Omo and Mago National Parks, this region contains the Tama and Chelbi Wildlife Reserves, and Murule and Welishet Sala Controlled Hunting

Areas. All are to be affected directly by the Kuraz project – for example, the Tama wildlife reserve will lose its natural connection with the Omo River and some of the Omo National Park would be cultivated for sugar or used as land for construction of the sugar factories (Enawgaw et al. 2011). There was no consultation with EWCA regarding changes to national park boundaries and impacts on the areas under their management (demonstrated above in Figure 7.9). The main impacts highlighted by EWCA are the danger to animal movement with the planned open canals and the negative effects on numbers of large animals such as elephant, buffalo and game (Enawgaw et al. 2011).

The Gibe III dam is a huge investment in the electricity infrastructure of Ethiopia – it will produce 1800 MW of electricity, a proportion of which is envisaged to be exported, creating extra capital for the national budget, hypothesised by the National Government to increase national resilience. However, such a large-scale construction will dramatically affect the river regime and therefore all downstream users due to the effects on the ecological sub-system and resulting livelihoods. The river supports 500,000 people across a trans-boundary area (Ethiopia and Kenya), many of whom rely on the flood cycle of the river to fertilise riverside land for cultivation, or provide access to the water for herds, or for fishing (International Rivers 2011). Whilst the Ministry of Water and Energy propose an artificial flood to mimic the natural flood cycle, it would only last for 10 days whereas the natural flood builds over several months. Therefore, the flood would not reach all areas and will not support the current level of agricultural productivity.

As with the Metehara and Kesem regions – the availability of water within the Omo is of primary importance to allow consistent irrigation and output from the sugarcane estates. The availability of water is the main vulnerability for such estates, which have a large footprint (as calculated in Chapter 5) as water is required for cultivation and processing. Large water footprints create a further cost for downstream users to bear, both within Ethiopia and in Kenya, due to the transboundary nature of the Omo River, in addition to the Kuraz managers who potentially could be affected by drought. Estimations for the annual Omo River runoff required for irrigation range between 0.4<16%, but given current Government calculations of potential irrigation areas, even 16% may be an under-estimate (Avery 2010). Removal of Omo water for irrigation creates massive impacts on regime flow to Lake Turkana which receives 90% of its input from the Omo River – the Gibe III dam could lead to a drop in Lake Turkana's depth of 23 to 33 feet (7-10 meters) (International Rivers 2011). The resulting size decrease and increase in salinity would reduce the livelihoods the lake could support.

7.5.3. Productive Safety Nets Programme

Chapter 4 concludes that a greater proportion of pastoralist households rely on the Productive Safety Nets Program (PSNP) due to the current biofuel expansion. The PSNP participation has allowed their levels of food security to remain constant, indicating that these households are so far resilient to changes in entitlements. However, it pushes the households nearer to a threshold which when surpassed will leave the households vulnerable to further disturbances – i.e. increasing food prices or a decrease in food provided by the Productive Safety Nets Program (PSNP). Maintaining the current level of household food security by participating in the PSNP may also be reducing the level of resilience at the national scale. A price shock decreasing food access would shift a larger proportion of the population into the 'chronic food security' state required for registering for the PSNP, increasing the burden on the national budget and reducing the national resilience to shocks. Such a shock could result in the National Government bearing the costs of biofuel expansion in future backloop phases, whereas previously it has only benefited due to the increased income from ethanol sales.

7.5.4. Export markets

As seen in the foreloop phases of the most recent adaptive cycle, the expansion of biofuel blending in Ethiopia will result in a decreased budget expenditure on oil. The Biofuels Strategy for Ethiopia outlines the fact that seventy seven per cent of the export earnings are spent on oil products as a justification for the expansion in biofuels – therefore an increase in domestically produced ethanol will decrease reliance on oil imports for petroleum, by displacing some of the demand. By the same logic, the realisation of the potential for ethanol stoves will decrease demand for gas and kerosene. However, using the most recent data available from the World Factbook (Central Intelligence Agency 2013) and the Ethiopian Petroleum Enterprise (Ethiopian Petroleum Enterprise 2011b), whilst the import costs of oil products totalled nearly $1 billion in 2010/11, Table 7.14 shows that this was 29% of total export earnings, significantly less than the reported 77%.

Table 7.14. National level Ethiopian budgetary data shows that oil product imports accounts for 29% of export earnings.

	Total (US$, 2012 est.)	Proportion of total export earnings
Total budget (revenues) (CIA)	$6,080,000,000	
Total budget (expenditure) (CIA)	$7,220,000,000	
Total export earnings (CIA)	$3,160,000,000	
Total import expenditure (2012 est.) (CIA)	$10,600,000,000	
Total oil product import bill (2010/11) (EPE)	$930,000,000	29%

Furthermore, within the imported oil bill, only 9% was related to petroleum – 63% of the budget was spent on diesel imports, and 28% on kerosene and jet oil, as displayed in Table 7.15 (Ethiopian Petroleum Enterprise 2011b). Therefore, petroleum products only accounts for 2.7% of export earnings.

Table 7.15. Oil product imports within Ethiopia. Petroleum accounts for the smallest proportion of the Ethiopian oil imports bill.

Product	Pre-tax price ($/litre) (March 2011)	Total imports (2010/11) (MT)	Total imports (2010/11) (US$)	Proportion of national oil bill
Petroleum	1.14	149,000	$87,200,000	9%
Diesel	1.33	1,200,000	$583,000,000	63%
Jet oil + Kerosene	1.32	568,000	$259,000,000	28%

The small proportion of the Ethiopian budget spent on petroleum products conflicts with the focus on ethanol in the current national biofuels regime, as, financially, a focus on biodiesel would be far more profitable. Therefore, whilst there are savings to be made by substituting ethanol in the petroleum blend, the savings are minimal and will total less than one per cent of the import bill, as shown in Table 7.16. Enforcing a national E10 blend on the projected 2015 petroleum consumption and import bill (calculated using the average growth rates of petroleum consumption (12.7%, as indicated by import volume) and price (3.0% as indicated by $/MT)) would save $15 million in 2015. The demand for ethanol in blending may increase even further, as outlined by the Ethiopian Petroleum Enterprise:

"Two to three years ago ethanol stocks were very low therefore we could only do a 5% blend. Now, the new ethanol factories mean there is sufficient stock for E10. In the future we'll consider E25 – today Brazil is blending 24-25%. E85 is a possibility but requires different engines, although E10 is the maximum without modification to engines. Blending is a positive because it saves foreign exchange – in the future this could be 25%."
Ethiopian Petroleum Enterprise

However, the E25 ratio is not judged to be feasible in Ethiopia due to the lack of technological capacity in the Ethiopian car fleet. Therefore, the simplified economic analysis presented in Table 7.16 indicates that the Ethiopian Government has overstated the financial profitability of ethanol in reducing the expenditure on foreign oil products.

Table 7.16. Projected savings from the E10 blend. Savings will amount to less than 0.5% per year of the export earnings.

Year	Projected imports (MT)	Projected cost (US$ per MT)	Projected cost (US$)	E10 blend savings (US$)	Proportion of current import bill
2010/ 11	149,000	586	$87,200,000	$8,720,000	0.08%
2014/ 15	240,000	660	$159,000,000	$15,900,000	0.15%

The expansion of ethanol stove usage will further substitute oil products, but will also result in a minimal reduction in kerosene demand and resulting import expenditure. Project Gaia hypothesise that maximum stove usage would require 441,000 litres – 31 litres of ethanol required per year per stove in use, of which table shows the planned distribution (Stokes 2010). The demand for ethanol will therefore only displace $582,000 per year even at the maximum possible substitution of oil products, with a total substitution of kerosene for ethanol, where substitution is 1:1, kerosene to ethanol. Substitution therefore only accounts for 0.2% of the annual kerosene import total, as shown in Table 7.17.

Table 7.17. Ethanol demand within Ethiopia for stove fuel. The displacement of kerosene by ethanol due to stove substitution will only reduce national expenditure on kerosene imports by 0.2%.

	Commercialisation project	Refugee Camps	Other projects	Annual Total
Stoves	8,400	6,000	300	14,700
Ethanol demand (litres)	252,000	180,000	9,000	441,000
Value of kerosene displaced ($1.32/litre)	$333,000	$237,000	$11,900	$582,000
Proportion of kerosene import costs				0.2%

Therefore, after supplying ethanol to the petroleum blend and ethanol stove demand, at the predicted level of 2015 output there will still be over 273 million litres available for export, as shown in Table 7.18, potentially producing a huge amount of profit for the National Government. The EIA project the wholesale price of ethanol in 2015 will be $2.61 per litre (US Energy Information Administration 2013). Removing the $0.60 per litre ex-factory price, this creates $2.01 per litre profit for the Ethiopian Government, projected to total $549,000,000 in 2015 – increasing export earnings by 15%.

Table 7.18. Ethanol available for export. The majority of ethanol produced within Ethiopia upon the completion of the planned expansion will be available for export.

Year	E10 blend demand (litres)	Stove demand (litres)	Total ethanol output (litres)	Ethanol available for export (litres)
2015	30,400,000	441,000	304,000,000	273,000,000

Whilst this level of production will not put Ethiopia into the top ten ethanol producers worldwide (as of 2011 (F.O. Licht 2011)), the Ethiopian Government intend to achieve a 2.5% share in the global sugar market by 2017 (Ministry of Foreign Affairs 2013). The exportation of 55% of the planned production (2.25 million tonnes) would place Ethiopia in the top 10 sugar exporters, as shown Table 7.19. The Ethiopian Government predict that this level of exportation will raise a further $607 million of foreign currency per year (Ministry of Finance and Economic Development 2010b). Therefore, the combined effects of sugar and ethanol exports would raise the export earnings of the country by over $1 billion, or 27% (Ministry of Finance and Economic Development 2010b).

Table 7.19. The largest sugar-exporting countries. At the planned sugar exportation levels, Ethiopia will become the 8th largest exporter of sugar, pushing Cuba out of the top 10 (Ministry of Finance and Economic Development 2010b; Foreign Agricultural Service 2012).

Exporting Country	Rank	2012/13 (000 tons)
Brazil	1	25,000
Thailand	2	7,500
Australia	3	3,100
India	4	2,200
Guatemala	5	1,700
EU-27	6	1,500
Mexico	7	1,400
Ethiopia	**8**	**1,200**
Colombia	9	880
United Arab Emirates	10	750
Cuba	11	700

Therefore, it can be seen that the expansion of sugarcane and related production of ethanol will be huge creators of export earnings for the Ethiopian Government, although will not substantially decrease foreign expenditure on oil products. However, trading new commodities opens Ethiopia up to new vulnerabilities and disturbances in the global market.

7.5.5. Energy systems

Chapter 6 shows that the current level of production of ethanol limits the uptake of ethanol stoves and therefore the benefits, as shown in Table 7.12. However, at the end of the conservation phase, when ethanol is presumed to be more widely available and an increased access (i.e. via petrol forecourts, as kerosene is sold today) results in a greater market for ethanol stoves lowering their price, the Low and High income households also stand to benefit. However, this is still limited to urban households who already have access to non-biomass fuels. Additionally, the refugee households using ethanol stoves will continue benefiting from the use of ethanol as opposed to woodfuel.

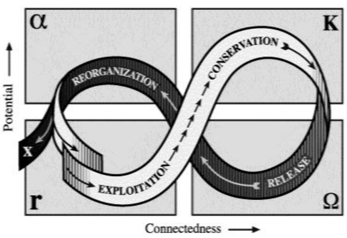
Even with the massive expansion of ethanol production and availability, unless the price of the ethanol stove is reduced it is unlikely to become a transitional technology within the urban populations, and reach the level of ethanol demand outlined above. It is therefore not likely to lead to a regime shift away from fuels in use today, particularly the biomass fuels that its proponents presume it will replace.

7.6. Overview of the Winners and Losers within the National SES

The above description of the dynamics of the national biofuels system in Ethiopia suggests that current production places it within the exploitation phase of the adaptive cycle. The data presented above regarding the differentiation of impacts on actors in the current exploitation phase (Table 7.12) is synthesised with the discussion in section 7.5 outlining differentiation of impacts on actors for the planned levels of expansion within the conservation phase and is shown in Figure 7.10.

Reorganisation Winners:
- National Government
- Sugar Corporation
- Refugee households
- Very High Income stoves users

Reorganisation Losers:
- Foreign investors
- Low income stove users
- High Income stove users
- Out-growers



Conservation Winners:
- National Government
- Sugar Corporation
- Petroleum users
- Refugee households
- Very High Income stoves users
- Low income stove users
- High Income stove users

Conservation Losers:
- Pastoralist households
- Downstream Awash users
- National Parks

Exploitation Winners:
- National Government
- Sugar Corporation
- Petroleum users
- Refugee households
- Very High Income stoves users

Exploitation Losers:
- Pastoralist households
- Low income stove users
- High Income stove users
- Downstream Awash users
- National Parks

Release Losers:
- National Government

Figure 7.10. Differentiated impacts on actors at the national scale in the current adaptive cycle.

Figure 7.10 demonstrates that the impacts are similar to those at the current level, but a significantly larger number of pastoralists stand to lose access to their livelihoods and undergo a regime shift, and more actors stand to gain from the adoption of ethanol stoves. It also shows that the National Government remains the main winner in the majority of phases, unsurprisingly as it is navigating the change. Such action by the National Government is not new in Ethiopia, just applied using a different mechanism in this example – sugarcane and ethanol. Such large-scale changes with other users bearing the costs have occurred before, as the Awash Master Plan sums up: *"It might be supposed a self-evident truth that alterations to the existing allocation of land and water resources by an external agency (whether government or a commercial company) would affect, for better or worse, the welfare of the population formerly using those resources. Nevertheless, until very recently, this simple cause-and-effect relationship appears not to have been tackled or resolved by those responsible for planning and implementing schemes in the (Awash) Valley, most of which were in any case designed to benefit the national economy rather than the local population."* (Halcrow, 1989:2). However, entering international trade markets for ethanol makes the national system vulnerable to new disturbances, which may cause a release into a new regime shift and result in the National Government losing the economic benefits it gained previously. Hence, it could potentially become the bearer of costs.

7.7. Overview of System Dynamics

In summary, the expansion of biofuels in Ethiopia has caused multiple disturbances over multiple temporal and spatial scales and the disturbances initiate the cyclical pattern outlined by the adaptive cycle. Figure 7.11 outlines the four key cross-scale interactions in the Ethiopian biofuels panarchy. The expansion of biofuels in Ethiopia results from the increasing global discourse on biofuels in the early 21st century, which acted as a driver and led to a national biofuels policy in Ethiopia in 2007 (1). The establishment of this national policy leads to multiple iterations of the adaptive cycle at the national scale, from a regime with no biofuels, to a regime characterised by foreign investor led jatropha establishment, to a regime characterised by sugarcane estates run by the National Government. Whilst all shifts have led to new disturbances, the transformation to a sugarcane ethanol system has resulted in large disturbances in the regional social-ecological system, via the establishment of new sugar estates (2). These disturbances will be increased as the planned expansion continues. Transformation at the regional scale has also created further transformation at the household scale (3) via the relocation of pastoralist households, which causes a regime shift from agro-pastoralists and pastoralists to sedentary livelihoods such as arable farmers and agricultural wage-labourers.

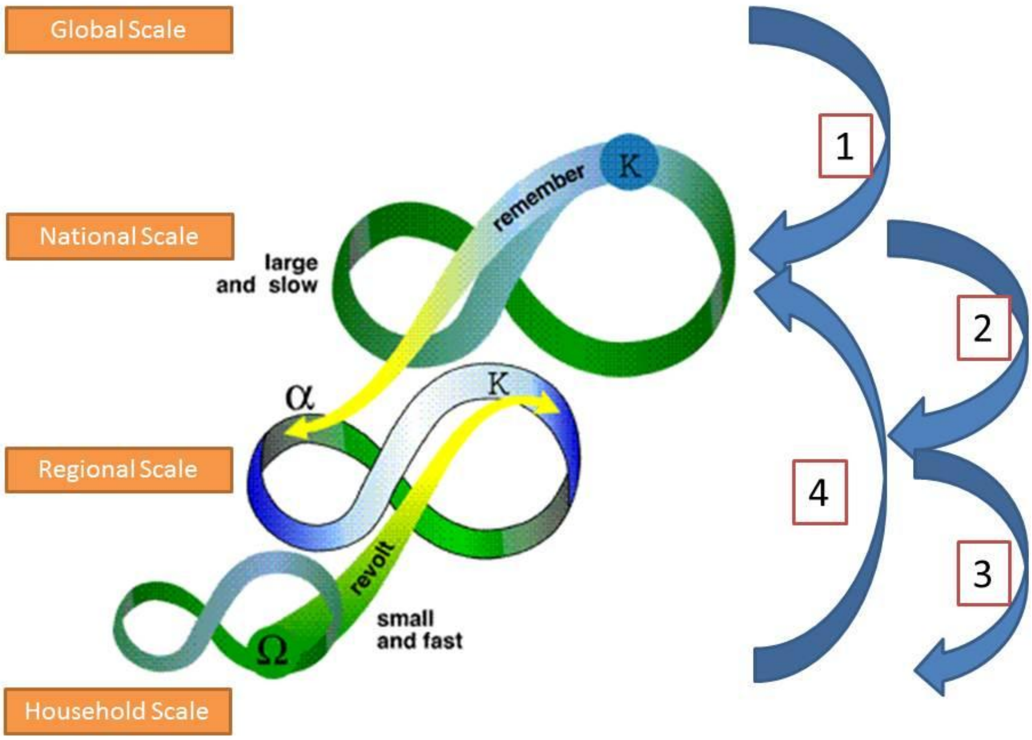


Figure 7.11. An overview of the cross-scale dynamics caused by ethanol expansion in Ethiopia.

Households have been resilient to this transformation (judged via maintaining food security) at the current level of production by adapting their methods of food access. However, this leads to a greater reliance on markets and the Productive Safety Nets Program, which in turn pushes households and food systems at the national scale closer to a threshold if there are disturbances in the future i.e. price shocks, droughts and reduces resilience at this scale (4).

The above analysis also allows the key variables with thresholds within the national biofuels system to be highlighted and these are shown in Figure 7.12, which outlines the endogenous (slow) variables within the national SES. Change in these variables drives further change within the system, and these relationships are shown via arrows, which represent possible cascading threshold effects. These variables are distributed between the three categories of social, economic and ecological. There are multiple exogenous (fast) variables within the system as well – these can influence the three sectors at all scales and can be envisaged as external to the boundary of the system presented in Figure 7.12. Exogenous variables include price shocks, changes in domestic demand, change in international markets and environmental shocks such as floods and drought..

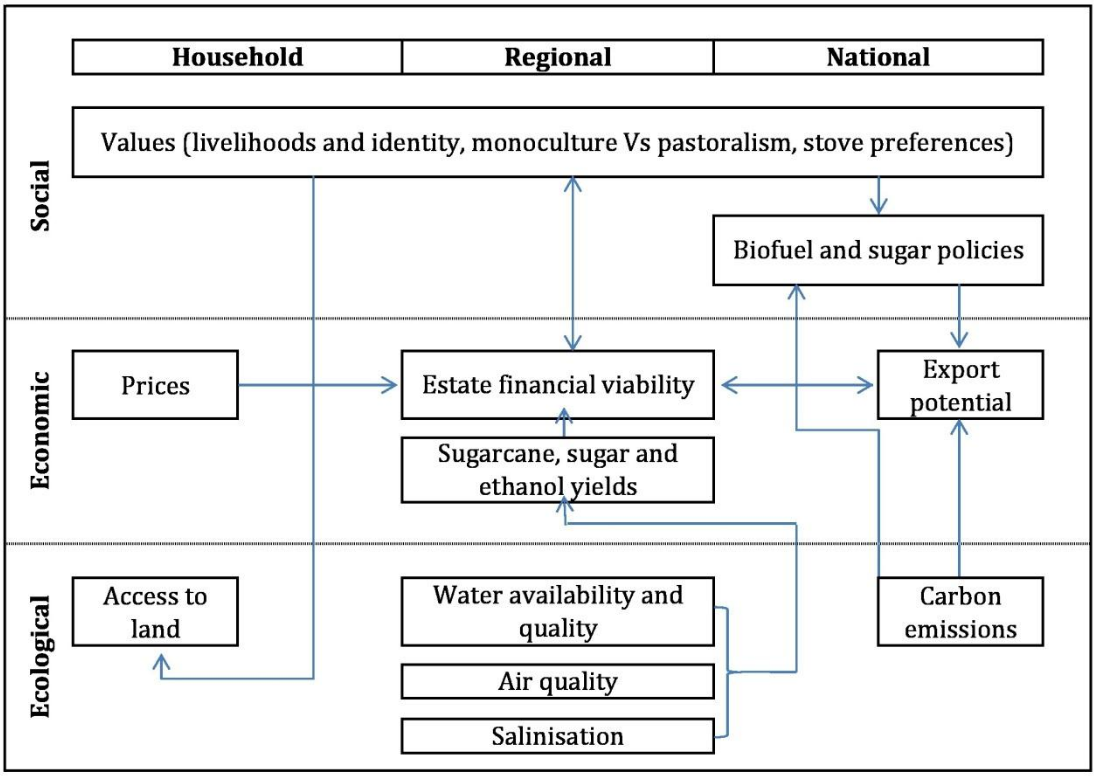


Figure 7.12. Slow variables in the SES that constitutes the national Ethiopian biofuels system. The arrows between boxes indicate possible cascading threshold effects.

Figure 7.12 shows that endogenous variables from all three categories – ecological drivers that influence yield, economic drivers that influence profit, and social drivers that influence policy supporting biofuel production –

influence the estate financial viability. As currently none of these drivers have led to thresholds being overcome, the sugarcane-sugar-ethanol system remains profitable and is therefore the most powerful driver on the national biofuels SES. Due to the two-way relationships between drivers such as values and export potential, the financial viability of the estate, including that of the new estates, will continue to influence other variables, such as livelihoods and transitions up the energy ladder.

7.8.Conclusions

Synthesising the data from Chapters 4, 5 and 6 within a resilience framework finds that the current levels of sugarcane and ethanol production have not surpassed many potential thresholds and therefore most of the sub-systems under study, and actors within them, are resilient to the disturbance of biofuel expansion performed to date. However, at each scale there have been winners and losers. The planned expansion will have a much larger impact, replicating the regime shift already ongoing for pastoralist households across a much larger population. In addition, the larger scale of operation will more severely influence the ecological sub-system, particularly by pushing the system closer to thresholds of water availability. The analysis of multiple nested scales using a resilience model demonstrates the need to examine all scales so to highlight the winners and losers, as only examining one scale underplays the dynamic nature of interactions between producers, consumers and those indirectly affected through biofuel expansion.

8. Conclusions

This thesis investigates the impacts on the resilience of social-ecological systems when disturbed by the expansion of biofuels. Examining the expansion of biofuels through a resilience framework illustrates the dynamics of the systems at multiple scales, using the adaptive cycle to identify potential thresholds and regime shifts – a novel contribution to the biofuels literature. In addition, highlighting the differentiated impacts for actors across multiple scales takes power relations into account, the lack of which is a common criticism of resilience studies.

The previous chapters have reported the impacts of the expansion of biofuels in one system, framed as a disturbance to multiple social-ecological systems at multiple temporal and spatial scales, within both the production and consumption sub-systems. This chapter presents the main conclusions from the evidence presented in this thesis, and then discusses the implications of this thesis for research and policy.

8.1. Summary of Results

Chapter 2 identified the need for empirical research to fill multiple research gaps. Firstly, the majority of biofuel analyses investigate the energy efficiency of large-scale first generation biofuels, and there is still little empirical data on other biofuel systems (Searchinger et al. 2008; Farrell et al. 2006; Fargione et al. 2008). Secondly, there are very few multi-scale, integrated assessments of biofuel expansion incorporating both production and consumption systems and their effects on both the social and ecological systems (Tilman et al. 2009; Hodbod & Tomei 2013). Thirdly, food systems have rarely been addressed through a resilience perspective (Ericksen 2008c; McMichael 2011; Fraser 2006; Ericksen 2008a), and finally – when applying a resilience framework, the majority of systems analysed examine the impacts of social change on ecological systems (Carpenter et al. 1999; Walker et al. 2009; Davis 1994; Walker et al. 1981). Empirical data of the impacts of human management on ecological systems and then resultantly on the social sub-system is particularly lacking. To address these research gaps, Chapter 2 suggested four key research questions, framed around the key impacts highlighted within the biofuels literature:

1. How does the expansion of biofuels affect the social-ecological resilience of household food systems?
2. How does the expansion of biofuels affect the resilience of the regional social-ecological system?
3. How does the use of ethanol as a household fuel affect the resilience of a household?
4. How does the expansion of biofuels affect the resilience of the national social-ecological system?

Chapters 4, 5, 6, and 7 respectively address these research questions, using evidence from the Ethiopian biofuels system. Within the Ethiopian system, the thesis presented data from production systems in the Metehara and Kesem regions, which contain an existing and an under-construction sugar estate respectively, as well as data from a consumption system in Addis Ababa. Chapter 3 acknowledged that the selection of this specific production system influenced the findings of the thesis, due to the proximity of other populations within the SES, who are lacking at other Ethiopian production sites. However, the chosen site is a useful case study as the future expansion of sugarcane-sugar-ethanol systems in Ethiopia will also affect pastoralist and urban populations. It is also acknowledged that the thesis could have been framed around sugar as the commodity driving change in the system, rather than ethanol production. However, the method of ethanol production as a by-product, creating a vast economic profit from minimal input costs (solely infrastructure construction) in addition to the global and Ethiopian discourse on biofuels at that point in time was judged to be a sufficient driver to justify the expansion of sugarcane and hence sugar production, and therefore the study is framed with biofuels as the main driver.

The results from the multiple scales within these sub-systems were then synthesised and complemented with interviews with key actors so to analyse the impacts on resilience at the national level for Ethiopia. The following sections outline the conclusions from each sub-system.

8.1.1. Food Sub-System

Chapter 4 presented an analysis measuring the change in the diversity of entitlements alongside other food security measures to draw inference concerning the resilience of the household scale social-ecological system for three populations with varying degrees of involvement in the biofuels system. The production and expansion of biofuels in the Metehara and Kesem regions has had a limited impact on both the proportion of the population directly engaged in production (Metehara Sugar Factory employees) and those not engaged at all (Metehara Town residents). Here, the potential benefits to actors involved in production do not appear to be realised, as their level of food security is comparable to that of those not involved in biofuels.

Pastoralist households, who are at varying stages of the relocation process, experience the only negative food system impacts from biofuel expansion, as relocation results in a loss of their production entitlements. Around one quarter of these households diversified their entitlements and employed coping strategies compared to four years ago, prior to the biofuel expansion. Whilst this diversification reflects their current resilience, diversifying may actually be pushing these households towards a threshold, as the prior proportion of food accessed from production entitlements acted as a buffer to changes in food prices. The removal of the buffer leaves pastoralists households locked-in to trade systems and closer to food security thresholds, where a small change could push them into a more severe state of hunger, due to the current utilisation of response diversity within the system and erosion of future coping strategies. In addition, relocation has caused these households to undergo a social-ecological regime shift, where food security may remain satisfactory but access is lost to traditional livelihoods, and their food system becomes more sedentary and market-based. Chapter 4 also concluded that cross-scale interactions are occurring, where change at a household scale may be eroding resilience at the national scale due to high levels of reliance on the national Productive Safety Nets Programme.

8.1.2. Ecological Sub-System

Chapter 5 concludes that the ethanol production system in the Metehara region does not appear to have breached any significant ecological thresholds for the set of quantifiable indicators analysed. A low level of chemical inputs, coupled with a reactive method of management and large work force, allows a rapid and specific response to disturbances such as pests and nutrient deficiencies, all of which allows Metehara Sugar Factory to maintain very high yields. However, the sugar estate does cause trade-offs within the regional ecological system. The lack of monitoring of environmental quality masks the impacts of production on water and air quality within the life-cycle analysis presented in Chapter 5, and will also have down-stream impacts on other users, which could be particularly detrimental regarding water quality.

Chapter 5 concludes that water availability is a key variable within the regional ecological system, with direct implications for the productivity of both sugar estates. However, increased abstraction for Kesem Sugar Factory pushes the system closer to this threshold. Both estates have large water requirements, which create a vulnerability to changes in water availability from the Awash River in the future. Kesem Sugar Factory is also responsible for indirect encroachment into Awash National Park, resulting in large negative impacts on biodiversity. Finally, the newly constructed Kesem Sugar Factory has a large associated carbon footprint driven by the significant land-use change and construction of a reservoir for irrigation.

8.1.3. Consumption Sub-System

This thesis presents a novel consumption sub-system within Ethiopia – that of ethanol as a household fuel. Chapter 6 demonstrated that the impacts of ethanol stove adoption are differentiated for households from different income stratifications. Whilst there are significant perceived benefits to health and safety from adopting ethanol, all households benefit from safer technology upon substitution, whereas the only the low and high income households benefit from the fuel being cleaner burning, as the highest income households already utilise fuels with this benefit. Conversely, these households experience the only negative impact resulting from ethanol adoption, as substitution requires an increase in fuel expenditure, whereas the highest income households benefit financially from substitution of high-cost gas. Some of the hypothesised benefits are not realised – for example, time savings, which were only reported for the lowest income households collecting fuelwood themselves.

This differentiation of impacts leads to no clear impact on resilience for any income group. Chapter 6 concluded that low-income households stand to benefit more from the adoption of ethanol stoves, but that the high price of the ethanol stoves and fuel delivery blocks such benefits and therefore limits the potential uptake of ethanol as a step up the energy ladder for these households. For these households, whilst decreasing smoke emissions in the home may increase household resilience by decreasing the burden of respiratory disease, it is coupled with a decrease in economic resilience, as ethanol requires a greater proportion of a low-income household's disposable income. Whilst ethanol stove and fuel prices remain as they are, ethanol may still have a role in higher income households – particularly to substitute gas at the current price and kerosene at future prices (with the removal of subsidies). Chapter 6 demonstrated that a reduction in the price of both ethanol stoves and fuel would cause this technology to be a more viable stove for lower income households, with greater well-being benefits related to the shift up the energy ladder. Currently however, ethanol stoves remain a niche technology that do not present enough benefits to create a transformation within the consumption sub-system.

8.1.4. National Social-Ecological System

Chapter 7 synthesises the results presented in the food, energy and ecological sub-systems to examine the overall dynamics within the multiple social-ecological systems (SES) disturbed by the expansion of biofuels, concluding with an analysis of dynamics at the national scale. This analysis shows that current levels of sugarcane and ethanol production have not surpassed many potential thresholds and therefore most of the sub-systems under study, and actors within them, are resilient to the disturbance of biofuel expansion performed to date. However, the planned expansion will have a much larger impact, replicating the regime shift already on going for pastoralist households across a much larger population. In addition, the larger scale of operation will more severely influence the ecological sub-system, particularly by pushing the system closer to thresholds of water availability.

Chapter 7 also analyses the key drivers and the differentiation of impacts on actors within the Ethiopian biofuels system. It highlights the Ethiopian Government as the main winner in both the current and planned levels of production. By navigating the transformation from a non-biofuels regime to a sugarcane-ethanol regime, the Ethiopian Government stands to make large profits from the exportation of ethanol, although the hypothesised substitutions of income expenditure on oil products are over-stated. As the most powerful actor, the Ethiopian Government also influences other variables within the national social-ecological system, be they ecological (water availability, biodiversity, carbon emissions), social (attitudes to relocation) or economic (energy prices, incentives for large-scale agriculture), but is dependent on the financial viability of the sugar estates. Whilst the sugarcane-sugar-ethanol system is so profitable, it is a powerful driver on the national SES and so will continue to influence other variables, such as livelihoods and transitions up the energy ladder, creating losers at smaller scales i.e. pastoralists, downstream water users, and the country's National Parks.

8.2. Policy Implications of these Findings

This thesis has demonstrated that the expansion of biofuels in Ethiopia has caused multiple disturbances over multiple temporal and spatial scales, some pushing the system towards or over thresholds, creating winners and losers. Empirical data of such disturbances and cross-scale interactions is key when considering the implementation of new biofuel schemes, still a key policy for both mitigation to climate change and/or economic development in many countries (REN21 2013). Such considerations are particularly apt in developing countries, where policies aimed at stimulating economic development based on natural resources can threaten the resilience of large proportions of their population who also rely on these natural resources for their livelihoods (Ewing & Msangi 2009; Bekunda et al. 2008).

8.2.1. Implications for Biofuel Policies in Ethiopia

The Growth and Transformation Plan in Ethiopia is one such policy, which in combination with the Biofuels Development and Utilisation Strategy supports the expansion of sugarcane and ethanol as one mechanism through which to deliver the targets of the GTP (Ministry of Finance and Economic Development 2010a). Chapter 7 has shown that rapidly increasing the national output of sugarcane, sugar and ethanol production will lead to economic gain at the national level via exportation but is associated with high costs for certain groups within the population – particularly pastoralists. Chapter 7 has demonstrated that their culture is not valued by the Ethiopian Government, who values more highly the economic efficiency of alternative land uses, particularly sugarcane farming.

Chapters 4 and 7 assess the detrimental regime shift pastoralist households are undergoing because of the forced relocation. The Government is transforming the regional social-ecological system to a sugarcane monoculture, and in the process is transforming the SES pastoralists were a part of. The transformation results in reduced access to the ecosystem service the pastoralists traditionally used and forces a shift from semi-nomadic pastoralism to a sedentary lifestyle and either small-scale arable livelihoods or wage-labour. Chapter 7 has also shown that this regime shift is intended by national level actors, who are aiming to transform Ethiopia into a middle-income country and do not feel that this is compatible with pastoralist cultures. However, there is no intention to transform at the household scale, and so for the pastoralists it is a regime shift rather than a transformation, as they have no role in the management of the system.

The lack of options the pastoralists have within this regime shift stems from the lack of property rights individual households possess, and hence the power of the Ethiopian Government in controlling such transformations. Chapter 4 outlines the relocation packages offered by the sugar estate to the pastoralist households, and demonstrates that the compensation package is another tool via which the Government can navigate the transformation, and its contents limit the alternative regimes the pastoralist households could transform into.

Therefore, there is a need for some pressure, whether domestic or international, to be directed towards the Ethiopian Government to highlight the value of the cultural diversity that is being eroded by the expansion of sugarcane, particularly in view of the expansion underway in the Omo Valley and outlined in Chapter 7. The provision of safeguards for property rights would protect such diversity, and hence the ability of such populations to maintain their traditional livelihoods and food systems.

However, what Chapter 5 has also demonstrated is that sugarcane-ethanol production for domestic consumption has had relatively benign ecological impacts up to a certain scale, and has not led to thresholds within the system being overcome, as seen in other biofuel systems – such as jatropha-biodiesel in Ethiopia or palm oil-biodiesel in Indonesia (Obidzinski et al. 2012; MELCA Mahiber 2008). Therefore, the results show that utilising a high-yielding crop as a second-generation biofuel and limiting the scale of such operations to satisfy domestic demand rather than export can be supported by the ecological sub-system. However, analysis of the Ethiopian system does show that the planned rapid and vast expansion pushes the system closer to thresholds in both the ecological and social systems, and will make systems at multiple scales more vulnerable to future disturbances. The limited flexibility and response diversity will make the system particularly vulnerable to climate change, due to its large water requirement – a factor not acknowledged by managers of the sugarcane-ethanol system. Entering new international markets also creates new vulnerabilities, and therefore disturbances such as price shocks could have huge implications for the Ethiopian Government, but also on the large proportions of the population who will be directly or indirectly involved in biofuels in Ethiopia.

8.2.2. Implications for Biofuel Policies at the Global Scale

The increased awareness of climate change by national governments led to the rapid introduction of biofuel policies in many developed countries as a method of reducing greenhouse gas emissions whilst decreasing dependence on fossil fuels and hence increasing their energy security. Chapter 2 highlighted that 2011 was the first year in the modern biofuels regime where global biofuel production did not increase – however, this still leaves 72 countries, provinces or states with biofuel policies and many more with production in preparation or underway (REN21 2012). The discussions of food versus fuel, economic returns and carbon debts have altered the global discourse by removing the idea of biofuels as a 'silver bullet' and the slowing rate of biofuel expansion can be attributed to this change in discourse (von Braun & Pachauri 2008; Searchinger et al. 2008; Pimentel et al. 2009). However, it is expected that there will be a lag period as biofuel expansion begins in developing countries who have only recently drafted biofuels legislation or begun processing. Therefore, biofuels are still a global driver on agricultural systems worldwide, and stand to have a hugely detrimental impact on the populations dependent on natural resources within such countries, as found within Ethiopia.

The biofuels debate stands to be particularly detrimental when located within the land grabs phenomenon, and the Ethiopian system analysed in this thesis adds to this debate as an example of a government-managed land grab, as opposed to foreign-investor led. As Chapter 2 outlined, such large-scale investments reduce access to resources for local communities reliant on the ecological sub-system for their livelihoods, whilst directing the agricultural outputs to export markets (De Schutter 2011). In addition, the rapidity of the introduction of land grab schemes may lack transparency or community dialogue whilst accelerating the market for land, and in countries where tenure rights are informal or lacking, there is little protection for the existing users against displacement (Wolford et al. 2013). Such loss of access invokes a loss of traditional livelihoods and can have major negative impacts on food security (Cotula et al. 2008; Anseeuw et al. 2012). The results within this thesis confirmed the hypothetical negative impacts associated with land grabs for actors reliant on the natural resources within a region.

These negative impacts are critical evidence within the land grabs debate, particularly as an example of the importance of land-rights in protecting detrimental regime shifts in culture. In turn, the land grabs phenomenon is of critical importance to the development field as it goes against the long-term strategy of promotion of land rights as a solution for lawlessness, political instability, environmental degradation, production inefficiencies and political corruption (Wolford et al. 2013; Morris et al. 2009). Whilst such titling allowed land grabs to occur, via the transfer of titles, social movement and civil society activists also argue that communities are being pushed aside precisely because they have customary or traditional forms of access that are not respected in the rush to parcel off areas (Cotula et al. 2009; Zoomers 2010; Borras et al. 2010). Therefore, such land transfers are occurring in states where the *"governance of the land sector and tenure security are weak"* (Arezki et al. 2011:3) and where national level governance is unable to provide tenure security, formal land markets or sufficient social safety-nets (Wolford et al. 2013). Within this context, Ethiopia is viewed as such a state due to its tenure system, which provides a weak level of tenure security for smallholders and pastoralists (Federal Democratic Republic of Ethiopia 1995; Ali et al. 2011; Gebre 2009). This reiterates the implication for such countries worldwide with poor tenure security, and the need for some form of pressure on Governments of these countries to highlight the need to protect such vulnerable households.

This thesis therefore demonstrates a cautionary tale for other developing countries implementing biofuels at such a vast and rapid rate. Whilst a relatively small scale of sugarcane-sugar-ethanol systems has been economically viable where there is a demand for both sugar and ethanol domestically, particularly where there is some potential for ethanol as a household fuel, it should be limited to reduce such negative impacts on other land-users and so not to introduce new vulnerabilities to the system. Although the economic gains are potentially large, the costs are passed down to actors at smaller scales, often the poorest households who are dependent on natural resources.

8.3. Implications for Research

This thesis has contributed to multiple research gaps, as highlighted in Chapter 2. This section discusses the research gaps filled, and contributions to the wider areas of literature, as well as highlighting future areas for research.

8.3.1. Implications for Research into the Impacts of Land Use Change

Biofuels are an example of human interventions driving environmental change and introducing new forms of variability, and hence disturbance, to social-ecological systems. Such interventions are commonly discussed within the literature and are thought to be *"generally harmful to social resilience and human welfare"* (Adger 2000:350). As stated above, a recent category of such interventions is the land grab phenomenon (De Schutter 2011; Friends of the Earth 2010; Robertson & Pinstrup-andersen 2010; Cotula et al. 2009). The literature has shown that biofuels are one of the drivers for land grabs (Zoomers 2010) and yet there still remains a lack of evidence on the impacts of such land-use transformations, particularly regarding the social impacts, as much of the biofuels literature is based on modelling studies or purely ecological studies (Searchinger et al. 2008; Farrell et al. 2006; Fargione et al. 2008; Tilman et al. 2009; Hodbod & Tomei 2013). The results of this thesis provide a multi-scale, integrated empirical evidence of the impacts of biofuel expansion on the ecological, social and economic systems, contributing critical evidence of such impacts to the biofuels literature. It also provides evidence of a relatively unusual land grab narrative.

The land grabs literature often summarises the land grabs phenomenon as the foreign influencing the domestic – the reality is obviously much more complex and this thesis presents another narrative, a country conducting its own land grab and via the state rather than private investors. Whilst the state is often invoked as a key player in land grabbing, other case studies present different narratives from this Ethiopian example – Mozambique, where there are still foreign investors but domestic institutions are key in shaping the land acquisition process (Fairbairn 2013); Colombia, where paramilitary groups are key actors in recent land transfers (Grajales 2013); Guatemala, where land grabbing has occurred by elites such as cattle ranchers, narcotics traffickers and plantation managers (Grandia 2013); and Madagascar, where state and local elites may seek to reassert their authority by imposing new constraints on foreign investors' access to land (Burnod et al. 2013). This reiterates the Ethiopian system as a relatively unusual narrative for land grabbing, particularly for biofuels, but one that results in the same detrimental impacts on those land-users reliant on resources.

The mixed impacts of biofuel expansion reported in this thesis confirm the proposals about the impacts of land grabs from a political economy framework, that the emergence of land transfers will intensify inequalities both between and within countries, particularly in the Global South (Cotula 2012; White et al. 2012; Margulis et al. 2013; Basu 2007). Evidence is emerging of such a differentiation of impacts specifically as a result of biofuel production (Borras Jr et al. 2011; Dauvergne & Neville 2010; Lima et al. 2011; Schoneveld et al. 2011; Skutsch et al. 2011; German et al. 2011; Achten & Verchot 2011; Obidzinski et al. 2012) but this thesis contributes evidence from a country and a feedstock where such a study has not been carried out before.

In a wider context, the land grabs debate, and biofuel expansion within it, feeds into the literature on resource scarcity, and particularly conflict regarding land-use change, for example, in comparison to the resistance to Reducing Emissions from Deforestation and Forest Degradation (REDD) projects, cattle grazing on forest frontiers, mining and oil exploration. Resistance to land-use change is not a new phenomenon, as land-use change will always produce winners and losers. Previous studies, for example of resistance to climate change adaptation interventions requiring land-use change, have confirmed that interventions and discourses produce additional stressors on vulnerable communities (Beymer-Farris & Bassett 2012; Lynch 2012; McDowell & Hess 2012; Marino & Ribot 2012). This thesis replicates the results of such studies examining other causes of land-use change and finds that, again, those reliant on natural resources stand to lose the most, whilst actors at a higher scale experience the benefits. This should therefore inform all the relevant literatures that land reform is an important area of research within which to examine how these impacts could be minimised, to distribute the benefits more evenly.

The biofuels literature also highlights the expectation from economic models that biofuel expansion will result in food price and therefore net-wealth changes, distributed unevenly, so that commodity producers in rural areas reap the benefits, whilst food consumers in urban areas experience the costs (Zilberman et al. 2013; Dewbre et al. 2008; von Braun et al. 2008; Ajanovic 2010; German & Schoneveld 2012; von Braun 2008b). The results within Chapter 7 demonstrate that the Ethiopian system reports the reverse of this – consumers in the nearby town are not affected negatively by biofuel production, and yet producers (although not of biofuel feedstocks) in the region lose due to the increased competition for land and their forced relocation. A key area of research is therefore that such differentiated impacts need to be better accounted for in standard economic models, to acknowledge other externalities in addition to changing prices.

In summary, the results of this thesis demonstrate that detailed empirical and context-specific research can add to the understanding of the impacts of biofuel expansion as a narrative of land-use change. As discussed above, biofuels are a relatively new global driver in both the agricultural and energy systems. This thesis contributes evidence on how national systems adapt to biofuels as a new driver, whilst highlighting the costs and benefits associated with their introduction. It also provides empirical data on a rarely studied biofuels regime – that of sugarcane-ethanol as a second-generation biofuel out of the Brazilian context. This is valuable as the literature highlights tropical sugar and cellulosic bioethanol as the most promising feedstocks, but the least analysed (von Blottnitz & Curran 2007).

8.3.2. Implications for the Resilience Literature

The concept of resilience provided a useful framework to examine such changes to a coupled human-natural systems (Nelson et al. 2007; Carpenter et al. 2001; Folke 2006). The analysis of multiple nested scales using a resilience model demonstrates the need to examine all scales so to highlight the system dynamics, including the resulting differentiation of impacts and associated winners and losers at all scales. Examining only one scale underplays the dynamic nature of interactions between actors and provides a partial picture of the system and its power dynamics.

Applying the adaptive cycle allows examples of regime shifts and transformation to be identified (Berkes et al. 2003; Holling 1986; Folke et al. 2010; Holling & Gunderson 2002). This thesis therefore contributes empirical evidence to the resilience literature, which still lacks evidence of such dynamics in social-ecological systems, particularly regarding power, social thresholds and regime shifts (Jerneck & Olsson 2008; Hornborg 2009; Davidson 2010; Cabell & Oelofse 2012). The thesis also demonstrates the strength of the adaptive cycle in analysing power dynamics associated with the different phases, building on the work of Beymer-Farris et al. (2012). Whilst the adaptive cycle is not a predictive tool and caution must be taken with applying the identified dynamics to future scenarios, the mechanisms identified regarding the formation or erosion of adaptive and transformative capacity are key in learning how to strengthen the resilience of similar systems in the face of such disturbances in the future. The findings of this thesis are context-specific but the process of identifying temporal and spatial dynamics of drivers and power are applicable in other systems facing disturbances regarding land-use change, such as biofuel expansion and land grabs, both now and in the future.

This thesis also corroborates some theoretical concepts within the resilience literature that are lacking evidence. Chapter 2 highlights the three key components of resilience, adaptability, and transformability, which interrelate across multiple scales – whilst adaptability allows adjustment within the current regime, transformability allows change into other regimes (Walker et al. 2004; Resilience Alliance 2011). The chapter then outlines the need for empirical evidence to support the argument that this transformational change at smaller scales will enable resilience at larger scales, as the crises leading to transformation are windows of opportunity for novelty and innovation (Folke et al. 2010). However, the evidence presented in this thesis shows that transformational change at smaller scales does not necessarily enable resilience at larger scales. For example, transformation at the regional scale due to the establishment of sugar estates has positive impacts on the resilience of the national scale, due to the economic benefits translated up the panarchy. However, this transformational change also erodes resilience at the household scale for certain actors, attributed to the lack of involvement of these actors in managing the social-ecological system they rely on for food and livelihoods.

The final contribution of this thesis to the resilience literature is associated with this cross-scale translation of resilience. This thesis supports the 'expanded-ecological' definition of resilience, that resilience is not a normative concept and therefore will not always be desirable (Brand & Jax 2007). For example, the majority of actors and systems within the present biofuels regime in Ethiopia have proven resilient to the expansion, judged by the maintenance of the system structures. Even the pastoralist households undergoing a regime shift have maintained their levels of food access, inferring system resilience throughout the transformation. However, the new regime is obviously not the desirable state for the pastoralists, whose culture revolves around production entitlements. Eroding adaptive capacity and response diversity could also push the system into a trap – a resilient state that is difficult to adapt or transform out of.

8.4. Concluding Remarks

The rapid introduction of biofuel policies has been coupled with a lack of empirical evidence of the differentiation of impacts on different scales and different actors. This thesis provides robust evidence for what has been speculated in conceptual studies in the literature – that biofuels cause differentiated impacts on social-ecological systems. The analysis of multiple nested scales using a resilience model has demonstrated the need to examine all scales so to highlight the system dynamics, so not to overlook negative impacts in scales other than the focal scale. As pressure for resources increases with issues such as population growth, development, and climate change, an understanding of the impacts biofuel policies and markets have on social-ecological systems is critical to help prevent the replication of such negative impacts in other systems.

The evidence presented in this thesis demonstrates that up to a certain scale, systems are resilient to the expansion of biofuels. Coupled with the power dynamics within this system, where those at larger scales are navigating the transformation and experiencing the benefits, whilst the costs are passed on to actors at smaller scales, the expansion of biofuels appears to be a long-term strategy for Ethiopia, and therefore could be a persistent policy choice worldwide. Such persistence in the face of the changing discourse around biofuels indicates they are not a short-term trend and are likely to be a part of the future energy regime. As the decarbonisation benefits of biofuels have been called into question, it is more likely that this will be for their economic benefits to developing countries rather than their decarbonisation benefits to developed countries. However, the literature shows that biofuels are not a silver bullet, particularly within developing countries – there is no 'free' land, and those with the least formal land rights are often the ones to lose out. Therefore, biofuels indicate a continuation of business as usual within the current system of resource allocation, where the differentiation of impacts further benefits the most powerful actors whilst negatively affecting the least powerful. Therefore, this thesis concludes that whilst biofuels have not had detrimental impacts on the majority of sub-systems influenced by their introduction, there are significant negative impacts on the most vulnerable groups of the population, and as such, biofuels are a part of the problem, not the solution to both economic development and decarbonisation.

Appendix 1

Energy Household Survey 1

Hello,

We are students from the University of East Anglia in England and Addis Ababa University, working with the Gaia Association (an NGO) and MakoBu Enterprises. We are studying the household energy use in Addis Ababa and would like to ask you some questions about your current household energy use. The survey will last 15-20 minutes.

Please note that all information we collect will be treated confidentially. All your answers will be added to those from other participants, and nothing you say will be quoted directly. Please feel free to say exactly what you want to say in response to the questions or to not answer questions you do not wish to. We will not share your personal information with any other person or institution.

Are you willing to spend some time with us to answer these questions?

Thank you, let's begin.

Questionnaire details	Date: Area:
Respondent's details	Name: Block & apartment number if in condominium:
Interviewer's details	Name:
Jenny present?	Yes [ ] No [ ] Partly [ ]

Office Use Only:

Questionnaire number	
Checked by:	
Date checked	
Complete?	Complete [ ] Incomplete [ ]
Coded by:	
Date coded	

Household Energy Baseline Survey

Time survey began………………….. Time survey ended………………………

Section A: Part 1: Area Identification

A1.1. Sub-City	A1.2. Kebele	A1.3. Condominium	**A1.4. Number**

A1.5. Observations about the construction materials used for the:

a. Exterior………………………………………………………………………
b. Roof…………………………………………………………………………
c. Floor…………………………………………………………………………

Section A: Part 2: Household Head Characteristics

A2.1. Is the head of household the respondent? (✓) Yes [ ] 1 No [ ] 0

A2.2. Name of head of household……………………………………………………....

A2.3. Sex (✓): Male [ ] 1 Female [ ] 2

A2.4. Educational level (✓):

Illiterate	[	] 1
Read and write	[	] 2
Primary Education	[	] 3
Secondary Education	[	] 4
University	[	] 5
Other (specify)	[	] 6…….

A2.5. Marital Status (✓):

Never married	[	] 1
Married	[	] 2
Divorced	[	] 3
Divorced and remarried	[	] 4
Widowed	[	] 5
Widowed and remarried	[	] 6

Section A: Part 3: Members of the Household

A3.1. What is the size of the household (number of people)…………………………

A3.2. What is the main religion of the household? (✓)

Ethiopian Orthodox	[	] 1
Islam	[	] 2
Catholic	[	] 3
Protestant	[	] 4
Traditional	[	] 5
Other	[	] 6………………………………

A3.3. What is the main language spoken within the household?

Amharic	[	] 1
Other	[	] 2

…………………………………………..

Section A: Part 3: Household Members Continued

	A3.4.	*A3.5.*	*A3.6.*	*A3.7.*	*A3.8.*	*A3.9.*
	Relation to HH	***Residence Status*** (✓)	***Sex*** (✓)	***Age***	***Educational Status*** (✓)	***Marital Status*** (✓)
	Extended family member means Aunt/Uncle/Cousin etc *If there is a servant/maid please note down in 'other' category*			*What is ___'s age in completed years?*	*If in school, write grade. If not, select box of completed stage.*	*Persons aged 15 and over.*
a	Is the HH [ ] 1	Resident [ ] Absent [ ] Visitor [ ]				
b	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..…………………….………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
c	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..…………………….………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
d	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..…………………….………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
e	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..…………………….………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
f	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..…………………….………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4

	A3.5.	A3.6.	A3.8.	A3.9.	A3.10.	A3.11.
	First Name of Household Member	***Residence Status*** (✓)	***Sex*** (✓)	***Age***	***Educational Status*** (✓)	***Marital Status*** (✓)
g	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..………………………..………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
h	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..………………………..………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
i	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..………………………..………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
j	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..………………………..………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
k	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..………………………..………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
l	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ……..………………………..………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1... Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried [ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4

A3.12. Which activities bring money into the household? (✓) *More than one can be selected*

None	Employment	Small business	Government grants	Remittances from abroad	Other
1	2	3	4	5	6

	Economic Status: for household members over 10 PLEASE SELECT : 7 Days / 30 Days (circle the time scale used)			
	A3.13.	A3.14.	A3.15	A3.16.
	How many days was the household member engaged in productive work? *Write the number of days worked, if no days write '0'*	Occupation (For those who have worked, are unemployed with previous experience or those who work but not during the last ___ days)	Estimated income from last ___ days in Birr	Reason for not working (i.e. no opportunity, ill-health etc)
a				
b				
c				
d				
e				
f				
g				
h				
i				
j				
k				
l				

Section A: Part 4: Housing Unit

A4.1. What is the type of housing unit? (✓) Condominium apartment [ ] 1
Detached permanent house [ ] 2
Detached improvised house[ ] 3
Attached permanent house[ ] 4
Attached improvised house[ ] 5
Other…………………………[ ] 6

A4.2. How many years have the household lived in the housing unit (✓)
Less than 3 [ ] 1
3 – 5 years [ ] 2
5 – 9 years [ ] 3
10 – 14 years [ ] 4
15 years or more [ ] 5

A4.3. What is the layout of the housing unit?
Studio [ ] 1
One bedroom [ ] 2
Two bedroom [ ] 3
Three bedroom [ ] 4
Other [ ] 5………………………………

A4.4. What is the type of tenure of the housing unit? (✓)
Owned and completely paid for [ ] 1
Owned with a mortgage [ ] 2
Rented from Kebele [ ] 3
Rented from Addis Ababa Housing Development Agency [ ]4
Rented from other organisation………………………………… [ ] 5
Rented from private household [ ] 6
Rent free [ ] 7
Other………………………………………………………………[ ] 8

A4.5. If rented, what is the monthly amount of rent in Birr?................................

A4.6. What type of kitchen does the housing unit have? (✓)
No kitchen [ ] 1
Modern kitchen, private [ ] 2
Modern kitchen, shared [ ] 3
Traditional kitchen, private [ ] 4
Traditional kitchen, shared [ ] 5

A4.7. Is there a radio in the housing unit? (✓) Yes [ ] 1
No [ ] 0

A4.8. Is there a telephone in the housing unit? (✓) Yes [ ] 1
(*Mobile or landline)* No [ ] 0

A4.9. Is there a television in the housing unit? (✓) Yes [ ] 1
No [ ] 0

A4.10. What is the main source of drinking water for members of the housing unit? (✓)

Tap inside the house	[ ] 1
Tap in compound, private	[ ] 2
Tap in compound, shared	[ ] 3
Tap outside compound, shared	[ ] 4
Protected well or spring	[ ] 5
Unprotected well or spring	[ ] 6
Other…………………………………………..	[ ] 7

A4.11. How does the household dispose of most of its garbage? (✓)

Public garbage service	[ ] 1
Private garbage service	[ ] 2
Thrown in vacant lots	[ ] 3
Thrown in river/stream	[ ] 4
Burnt	[ ] 5
Buried	[ ] 6
Other………………………………………	[ ] 7

Section A: Part 5: Household Expenditure

A5.1. What is a rough estimate for the household expenditure on food per 7 days? (✓)

0< 200 Birr	[ ] 1
201< 400 Birr	[ ] 2
401< 600 Birr	[ ] 3
601< 800 Birr	[ ] 4
801< 1000 Birr	[ ] 5
Over 1000 Birr	[ ] 6

A5.2. Excluding food and fuel, what are the other main expenditures of the household?

……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………
……………………………………………………………………………………………..

A5.3. Including food and fuel, can you rank the main household expenditures from highest to lowest?

1st	
2nd	
3rd	
4th	
5th	

Section B: Part 1: Energy apparatus in the household

Stove	*B1.1.* **Use**	*B1.2.* ***Material***	*B1.3.* ***Age***	*B1.4.* ***Cost***	*B1.5.* ***Location***	*B1.6.* ***Main***	*B1.7.****max***	*B1.8.* **Use per day**
Electric *a*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………….	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ….……….	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Kerosene *b*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………….	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ….……….	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Natural Gas *c*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………….	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ….……….	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Ethanol *d*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………….	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ….……….	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Improved stove for biomass *e*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………….	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ….……….	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Improved stove for charcoal *f*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………….	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ….……….	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4

Traditional biomass stove *g*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………..…	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 …..………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Traditional charcoal stove *h*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………..…	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 …..………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Open fire *i*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………..…	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 …..………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4
Other *j*	Cooking[ ] 1 Heating [ ] 2 Lighting [ ] 3	Mud [ ]1 Clay [ ]2 Metal [ ]3 Other [ ]4 …………….	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3	1-200 Birr [ ]1 201-400 Birr[ ]2 401-600 Birr[ ]3 Over 600Birr[ ]4 Incl. in rent [ ]5	Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ………………..…	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 …..………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5< [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4

B1.9. What type of lighting does the housing unit use and how many of each type?

Incandescent light bulbs [ ] 1………………… Fluorescent light bulbs [ ] 2……………………………
Candles [ ] 3………………... Kerosene lamp [ ] 4……………………………
Other………………………….. [ ] 5……………………………………………………………………………

Section B: Part 2: Fuel consumption in the household

		B2.1.	*B2.2.*	*B2.3.*	*B2.4.*	*B2.5.*	*B2.6.*	*B2.7.*	*B2.8.*	*B2.9.*
Item		**Cooking**	**Heating**	**Lighting**	**What is a typical unit of measure?**	**What is the weight or volume of a typical unit?**	**How many units were *used* in the past 7 days?**	**How many units were *purchased* in the past 7 days?**	**What is the average price per unit?**	**Rank the fuels in order of importance**
		✓ *if used*			*Unit*	*Kg or Litres*	*Number*	*Number*	*Birr*	*1=most important*
Uses no fuel	a									
Fuelwood *Go to B2.1.1.*	b									
Leaves, bark and twigs	c									
Charcoal, coal	d									
Dung, manure	e									
Crop residue	f									
Sawdust	g									
Kerosene	h									
Natural Gas	i									
Biogas	j									
Liquefied Petroleum Gas	k									
Candles	l									
Electricity	m				See question B2.2.1.					
Other (specify)	n									

For the fuels used, what are the key sources the household relies on?

		B2.10.	*B2.11.*
Fuel Type		**Source** *(I.e. person, company, location – please write down name)*	**What is the one way distance members of your household travel typically to purchase or collect … ?**
	a		_______________ km ______________hours
	b		_______________ km ______________hours
	c		_______________ km ______________hours
	d		_______________ km ______________hours
	e		_______________ km ______________hours

Section B: Part 2: Fuel wood and other biomass – if answered yes to fuelwood in B2.1.

B2.1.1. How did the household acquire fuel wood, leaves, twigs etc during the past 7 days?

Self-collected	[ ]	1	Go to B2.1.12.
Purchased	[ ]	2	Go to B2.1.9.
Combination of both	[ ]	3	

If self-collected…

B2.1.2. From where did you collect the fuel wood? (✓)

Own land	[ ]	1
Communal forest	[ ]	2
Natural forest	[ ]	3
Own farmland	[ ]	4
Other	[ ]	5…………………………………………

B2.1.3. How frequently did you collect fuel wood in the past 7 days?

……………………………………………………………………………………

B2.1.4. What is the average length of the trip (time) to collect fuel wood?

……………………………………………………………………………………

B2.1.5. What is the average one-way distance travelled?

……………………………………………………………………………………

B2.1.6. How were you collecting fuel wood? (✓)

On own back	[ ]	1
On donkey or mule	[ ]	2
Other	[ ]	3……………………………………………

B2.1.7. Who collects the fuel wood? (✓)

Female adults	[ ]	1
Female children	[ ]	2
Male adults	[ ]	3
Male children	[ ]	4

B2.1.8. Is the wood for any other purpose than fuel wood? (✓)

Yes	[ ]	1
No	[ ]	2

B2.1.9. For what other purposes (other than cooking, space heating, lighting, water heating)?

………………………………………………………………………………………

B2.1.10. What proportion of the wood bought or collected is used as fuel wood? (✓)

Most of the wood	[ ]	1
Half of the wood	[ ]	2
Very little of the wood	[ ]	3

Section B: Part 2: Electricity

		B2.2.1.	B2.2.2.	B2.2.3.	B2.2.4.
Sources of electricity		**Does your household have electricity from …?**	**How much electricity did the household consume during the last 30 days?**	**What is the basis for the electricity charges that you pay for?**	**How much did the house-hold pay for electric-ity in the last 30 days?**
		(✓)	*kWh*	(✓)	*Birr*
Electricity from a public company or government ………………… …………………	a	Yes [ ] 1 No [ ] 0		Utility meter [ ] 1 Pay neighbour [ ] 2 Included in rent [ ] 3 Don't pay [ ] 4 Other [ ] 5 ……………………..…...	
Electricity from a friend or neighbour	b	Yes [ ] 1 No [ ] 0		Utility meter [ ] 1 Pay neighbour [ ] 2 Included in rent [ ] 3 Don't pay [ ] 4 Other [ ] 5 ……………………..…...	
From source other than government ………………… ………………… ……………………	c	Yes [ ] 1 No [ ] 0		Utility meter [ ] 1 Pay neighbour [ ] 2 Included in rent [ ] 3 Don't pay [ ] 4 Other [ ] 5 ……………………..…...	

B2.2.5.	B2.2.6.
On average, how many hours a day is electricity available?	**How many times in the last 7 days did electricity fail for more than 15 minutes?**
Hours/Day	*Number*

		B2.2.7.	*B2.2.8.*	*B2.2.9.*	*B2.2.10.*
Energy in the community (✓)		**In your opinion, is ___ readily available in this kebele?**	**In your opinion, is ___ expensive in this kebele?**	**In your opinion, does ___ cause health problems?**	**In using ___ safe in this kebele?**
Fuel wood, leaves, bark, twigs	a	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Charcoal, coal	b	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Kerosene	c	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Natural Gas	d	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
LPG	e	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Ethanol	f	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Electricity	g	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Other………………… ……………..	h	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0

Section B: Part 3: Smoke in the home

A8.1. Does the stove produce smoke? (✓) Yes [ ] 1
No [ ] 0

A8.2. Is the area vented to remove smoke? I.e. is there a chimney? (✓) Yes[ ] 1
No [ ] 0

Of the members of your household… *(✓)*

	B3.3.	*B3.4.*
Member of Household	**Who does the cooking?**	**Who is present when cooking occurs?**
Female adults	[ ] 1	[ ] 1
Female children	[ ] 2	[ ] 2
Male adults	[ ] 3	[ ] 3
Male children	[ ] 4	[ ] 4

B3.5. Do the people who cook and who are present when cooking occurs seem to have more respiratory illnesses than the other members of your household? (✓)

Yes [ ] 1
No [ ] 0

B3.6. How often (on average) do those household members suffer from coughing, chest or nose congestion, and sore throat? (✓)

Very often (i.e. 3 or more times per year) 1	Often (i.e. twice a year) 2	Not a lot (i.e. once per year) 3	Hardly ever (i.e. can't remember the last time) 4

Section C: Part 1: Networks

For the following problems in your household, who would you contact for assistance?

		C1.1.	*C1.2.*
(✓)		Financial problem leading to a shortage of fuel or food	Unfortunate event that is not financial (i.e. a death in the family)
No One	a	[ ] 1	[ ] 1
Family in the Kebele	b	[ ] 2	[ ] 2
Family in Addis Ababa	c	[ ] 3	[ ] 3
Family out of Addis Ababa	d	[ ] 4	[ ] 4
Neighbours	e	[ ] 5	[ ] 5
Friends	f	[ ] 6	[ ] 6
Religious leader or group	g	[ ] 7	[ ] 7
Community leader	h	[ ] 8	[ ] 8
Patron/employer/ benefactor	i	[ ] 9	[ ] 9
Political leader	j	[ ] 10	[ ] 10
Mutual support group to which you belong	k	[ ] 11	[ ] 11
Assistance organisation to which you do not belong	l	[ ] 12	[ ] 12
Other………………………………………………	m	[ ] 13	[ ] 13

Are you or is someone in your household a member of any the following groups, organisations or associations?

		a	*b*
	Type of organisation or association	**Member?**	**Degree of participation**
C1.3.	Idir	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active[ ] 3 Not active [ ] 4
C1.4.	Religious	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active[ ] 3 Not active [ ] 4
C1.5.	Social	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active[ ] 3 Not active [ ] 4
C1.6.	Other (specify)……………………… ………………………………….. …………………………………	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active[ ] 3 Not active [ ] 4

C1.6. Can you rank the organisations in order of importance to your household?

1st	
2nd	
3rd	
4th	

C1.7. Overall, are the same people members of these different groups? (✓)

Little overlap [ ] 1
Some overlap [ ] 2
Much overlap [ ] 3

(✓)		**Idir**	**Religious**	**Social**	**Other**
		a	*b*	*c*	*d*
C1.8.	Are members mostly of the same extended family?	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.9.	Are members mostly of the same religion?	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.10	Are members mostly of the same gender?	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.11	Do members mostly have the same occupation?	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.12	Are members mostly of the same age group?	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.13	Do members mostly have the same level of education?	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.14	**Do you think that by belonging to this group you have acquired new skills or learned something valuable?**	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0

Appendix 2

Energy Household Survey 2

Hello,

We are students from the University of East Anglia in England and Addis Ababa University, working with the Gaia Association (an NGO) and MakoBu Enterprises. We are studying the potential for ethanol stoves and would like to ask you some questions about your current household energy use. The survey will last 15-20 minutes.

Please note that all information we collect will be treated confidentially. All your answers will be added to those from other participants, and nothing you say will be quoted directly. Please feel free to say exactly what you want to say in response to the questions or to not answer questions you do not wish to. We will not share your personal information with any other person or institution.

Are you willing to spend some time with us to answer these questions?

Thank you, let's begin.

Questionnaire details	Date: Area:
Respondent's details	Name: Block & apartment number if in condominium:
Interviewer's details	Name:
Jenny present?	Yes [ ] No [ ] Partly [ ]

Office Use Only:

Questionnaire number	
Checked by:	
Date checked	
Complete?	Complete [ ] Incomplete [ ]
Coded by:	
Date coded	

2012 Household Energy Survey

A0.1. Who is doing this survey? (✓)

Condominium follow up [ ] 1 Original survey number.........
Condominium stove demonstrator [ ] 2
Adopter [ ] 3
Non Adopter [ ] 4

Section A: Part 1: Area Identification

A1.1. Sub-City	A1.2. Kebele	A1.3. Condominium

Section A: Part 2: Household Head Characteristics

A2.6. Is the head of household the respondent? (✓) Yes [ ] 1 No [ ] 0

A2.7. Sex (✓): Male [ ] 1 Female [ ] 2

A2.8. Educational level (✓):
Illiterate [ ] 1
Read and write [ ] 2
Primary Education [ ] 3
Secondary Education [ ] 4
University [ ] 5
Other (specify) [ ] 6.........

A2.9. Marital Status (✓):
Never married [ ] 1
Married [ ] 2
Divorced [ ] 3
Divorced and remarried [ ] 4
Widowed [ ] 5
Widowed and remarried [ ] 6

Section A: Part 3: Members of the Household

A3.4. What is the main religion of the household? (✓)

Ethiopian Orthodox [ ] 1
Islam [ ] 2
Catholic [ ] 3
Protestant [ ] 4
Traditional [ ] 5
Other [ ] 6...................................

A3.5. What is the main language spoken within the household? (✓)
Amharic [ ] 1
Other [ ] 2 ....

A3.3. How many people live in this household? ....

A3.4. How many are adults and children?
Adults..................................Children...............................

A3.5. How many household members earn money? ....

A3.6. Which activities bring money into the household? (✓) *Select **ALL** that are relevant.*

None	Employment with regular salary	Small business	Government grants	Remittances from abroad	Other ....
0	1	2	3	4	5

A3.7. What is the monthly household income (from all members earning money)?

....

Section A: Part 4: Housing Unit

A4.12. What is the type of housing unit? (✓)
Condominium apartment [ ] 1
Detached permanent house[ ] 2
Detached improvised house[ ] 3
Attached permanent house[ ] 4
Attached improvised house[ ] 5
Other…………………………[ ] 6

A4.13. How many years have the household lived in the housing unit (✓)
Less than 3 [ ] 1
3 – 5 years [ ] 2
5 – 9 years [ ] 3
10 – 14 years [ ] 4
15 years or more [ ] 5

A4.14. What is the layout of the housing unit? (✓)
Studio [ ] 1
One bedroom [ ] 2
Two bedroom [ ] 3
Three bedroom [ ] 4
Other [ ] 5………………………………

A4.15. What is the type of tenure of the housing unit? (✓)
Owned and completely paid for [ ] 1
Owned with a mortgage [ ] 2
Rented from Kebele [ ] 3
Rented from Addis Ababa Housing Development Agency [ ]4
Rented from other organisation………………………. [ ] 5
Rented privately [ ] 6
Rent free [ ] 7
Other…………………………………………………. [ ] 8

A4.16. If rented or there is a mortgage, what is the monthly amount of rent in Birr?
....

A4.17. What type of kitchen does the housing unit have? (✓)

No kitchen	[ ] 1
Modern kitchen, private	[ ] 2
Modern kitchen, shared	[ ] 3
Traditional kitchen, private	[ ] 4
Traditional kitchen, shared	[ ] 5

A4.18. Is there a radio in the housing unit? (✓) Yes [ ] 1
No [ ] 0

A4.19. Is there a telephone in the housing unit? (✓) Yes [ ] 1
(Mobile or landline) No [ ] 0

A4.20. Is there a television in the housing unit? (✓) Yes [ ] 1
No [ ] 0

A4.21. What is the main source of drinking water for members of the housing unit? (✓)

Tap inside the house	[ ] 1
Tap in compound, private	[ ] 2
Tap in compound, shared	[ ] 3
Tap outside compound, shared	[ ] 4
Protected well or spring	[ ] 5
Unprotected well or spring	[ ] 6
Other……………………………………….	[ ] 7

A4.22. How does the household dispose of its garbage? (✓)

Public garbage service	[ ] 1
Private garbage service	[ ] 2
Thrown in vacant lots	[ ] 3
Thrown in river/stream	[ ] 4
Burnt	[ ] 5
Buried	[ ] 6
Other………………………………………	[ ] 7

Section A: Part 5: Household Expenditure

A5.4. What does your household spend, on average, on ***food per 7 days***? (✓)

0 – 99 Birr	[ ] 1	600 – 699 Birr	[ ] 7
100 – 199 Birr	[ ] 2	700 – 799 Birr	[ ] 8
200 – 299 Birr	[ ] 3	800 – 899 Birr	[ ] 9
300 – 399 Birr	[ ] 4	900 – 999 Birr	[ ] 10
400 – 499 Birr	[ ] 5	1000 – 1199 Birr	[ ] 11
500 – 599 Birr	[ ] 6	Over 1200 Birr	[ ] 12

A5.5. What does your household spend, on average, on ***fuel per 7 days***? (✓)

0 – 9 Birr	[ ] 1	60 – 69 Birr	[ ] 7
10 – 19 Birr	[ ] 2	70 – 79 Birr	[ ] 8
20 – 29 Birr	[ ] 3	80 – 89 Birr	[ ] 9
30 – 39 Birr	[ ] 4	90 – 99 Birr	[ ] 10
40 – 49 Birr	[ ] 5	100 – 199 Birr	[ ] 11
50 – 59 Birr	[ ] 6	Over 120 Birr	[ ] 12

A5.3. **As well as food and fuel**, what are the other main things the household spends money on? (✓)

School fees	[ ] 1	Health fees	[ ] 2
Transport	[ ] 3	Telephone	[ ] 4
Water	[ ] 5	Children costs	[ ] 6
Electricity	[ ] 7	Membership fees	[ ] 8
Other	[ ] 9...		

A5.4. **Including food and fuel**, can you rank the main household expenditures from highest to lowest (i.e. from most to least)?

1st	
2nd	
3rd	
4th	
5th	

A5.5. Considering your sources of income and expenditures, please select which statement best fits your situation. (✓)

We can regularly pay for these items without worrying too much about the costs	[ ] 1
We can't spend as much as we would like but food is always on the table	[ ] 2
We must sometimes borrow money to pay for schooling and food	[ ] 3
We often spend a few days without food and kids don't go to school	[ ] 4

Section A: Part 6: Electricity

A6.1. Do you have electricity? (✓)
Yes [ ] 1
No [ ] 0

A6.2. From where? (✓)
EEPCO [ ] 1
Generator [ ] 2
Other.. [ ] 3

A6.3. How do you pay for your electricity? (✓)
EEPCO meter on house [ ] 1
Local EEPCO office [ ] 2
Pay neighbour [ ] 3
Included in rent [ ] 4 *Go to A7*
Free [ ] 5 *Go to A7*
Other [ ] 6................. ....

A6.4. How much do you pay every 30 days?..

A6.5. What type of lighting does the housing unit use? (✓)

Incandescent light bulbs	[ ] 1	Fluorescent light bulbs	[ ] 2
Candles	[ ] 3	Kerosene lamp	[ ] 4
Other…………………………..	[ ] 5		

Section B: Part 1: Energy apparatus in the household - *Which stove types do you use for cooking in this household?*

	B1.1.	*B1.2.*	*B1.3.*	*B1.4.*	*B1.5.*	*B1.6.*	*B1.7.*
Type	**Age of stove**	**Cost of stove**	**Location**	**Main use**	**Maximum pots held**	**Period of time used per day**	**Rank importance** *(1=most)*
Electric Stove *A*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ……………………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ……………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	
Electric injera stove *B*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ……………………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ……………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	
Kerosene Stove *C*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ……………………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ……………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	
Gas Stove *D*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ……………………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ……………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	
Ethanol Stove *E*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ……………………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ……………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	
Charcoal stove *F*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 ……………………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 ……………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	

Biomass stove *G*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 …....……………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 …..………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	
Other *H*	Under 1 year [ ]1 1 – 4 years [ ]2 Over 4 years [ ]3		Kitchen [ ]1 Living room [ ]2 Outside [ ]3 Other [ ]4 …....……………	Baking[ ]1 Meals[ ] 2 Coffee[ ]3 Other [ ]4 …..………	1 [ ]1 2 [ ]2 3 [ ]3 4 [ ]4 5 < [ ]5	0-30 minutes [ ]1 31-60 minutes[ ]2 61-90 minutes[ ]3 Over 90 mins [ ]4	

How much of these **cooking** fuels do you use and how often?

Fuel	B1.8. **Amount used** *(Specify units- litres, sack, KG etc)*	B1.9. **Frequency of Purchase**	B1.10. **Total Cost**	B1.11. **Source** *(I.e. person, company, location – please write down name)*	B1.12. **What is the one way distance members of your household travel typically to purchase or collect … ?**
Natural Gas D					.... km ....hours
Kerosene C					.... km ....hours
Charcoal F					.... km ....hours
Ethanol E					.... km ....hours
Fuelwood or biomass G					.... km ....hours
Other H..............................					.... km ....hours

Section B: Part 3: Ethanol Stoves

B3.1. Are you familiar with ethanol stoves? (✓) Yes [ ] 1 No [ ] 0

If yes...

a. How did you hear about the ethanol stoves? (✓)

Saw advertising in condominiums	[ ] 1
Saw billboard	[ ] 2
Saw demonstration in the condominium	[ ] 3
Saw demonstration elsewhere	[ ] 4..........................
Friend/Family	[ ] 5
Colleague	[ ] 6
Given by Project Gaia	[ ] 7
Other	[ ] 8............................

i. If you were given a stove by Project Gaia/MakoBu Enterprises, do you use it?(✓) Yes [ ] 1 No [ ] 0

B3.2. Have you purchased an ethanol stove? (✓) Yes [ ] 1 No [ ] 0

B3.3. Why? (✓ *all that apply and * most important reason)*

No knowledge of stoves	[ ] 1	Ethanol fuel is cheap	[ ] 6
Ethanol fuel not available	[ ] 2	Ethanol stoves are safer	[ ] 7
Stoves too expensive	[ ] 3	Stoves are more efficient	[ ] 8
Fuel too expensive	[ ] 4	Less smoke	[ ] 9

Other [ ] 5 ....
....

If yes to any B3.2.a. or B3.3....

B3.4. What did your ethanol stove replace?

Charcoal stove	[ ] 1
Kerosene stove	[ ] 2
Gas stove	[ ] 3
Electric stove	[ ] 4
Other	[ ] 5..

B3.5. How much did you used to spend on fuel per month?.................................

B3.6. Is it a single or double burner? Single [ ] 1 Double [ ] 2

B3.7. How much did you pay for your ethanol stove?...................................

B3.8. Ignoring the initial cost of the stove, as your **total monthly** expenditure on fuel (✓):

Increased?	[ ] 1
Decreased?	[ ] 2
Stayed the same?	[ ] 3

For all those familiar with ethanol stoves: Do you agree or disagree with the following statements?

B3.9. The cost of the ethanol stove (1047 Birr single burner or 1760 Birr double burner) is reasonable

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.10. The stoves are too expensive

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.11. If the stove cost 300 Birr I would consider purchasing one

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.12. The cost of the ethanol fuel (13.5 Birr/litre) is reasonable?

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.13. The usage cost is cheaper than kerosene.

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.14. The usage cost is cheaper than charcoal.

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.15. The usage cost is cheaper than gas.

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.16. The usage cost is cheaper than electricity.

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.17. The availability of ethanol is constant and not a problem

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.18. I am happy to travel to MakoBu office (Lancha) to purchase ethanol

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.19. I would happily use the ethanol stove to cook meals

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.20. I would happily use the ethanol stove to make coffee

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.21. I would still use charcoal to make coffee
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.22. The ethanol stove seems safer than a kerosene stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.23. The ethanol stove seems safer than a charcoal stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.24. The ethanol stove seems safer than a gas stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.25. The ethanol stove seems safer than an electric stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.26. It is quicker to cook on an ethanol stove than on a kerosene stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.27. It is quicker to cook on an ethanol stove than on a charcoal stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.28. It is quicker to cook on an ethanol stove than on a gas stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.29. It is quicker to cook on an ethanol stove than on an electric stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.29. Do you have any other comments about ethanol stoves?
....
....
....

Do you know anyone else using an ethanol stove?

Name	***Address***	***Telephone Number***

For those not familiar with ethanol stoves...

B3.30. The cost of the ethanol stove (1047 Birr single burner or 1760 Birr double burner) is reasonable

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.31. The stoves are too expensive

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.32. If the stove cost 300 Birr I would consider purchasing one

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.33. The cost of the ethanol fuel (13.5 Birr/litre) is reasonable?

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.34. The usage cost would have to be less than kerosene for me to consider buying one

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.35. The usage cost would have to be less than gas for me to consider buying one

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.36. The usage cost would have to be less than electricity for me to consider buying one

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.37. I am happy to travel to MakoBu office (Lancha) to purchase ethanol

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.38. I would only purchase ethanol from within 1km of my house

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.39. The ethanol stove is not familiar, I wouldn't use it.

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.40. I would happily use the ethanol stove to make coffee

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B3.41. I would still use charcoal to make coffee

Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

Section B: Part 4: Environmental Health

A8.3. Do you think the air quality in this area is (✓): Good [ ] 1
Average [ ] 2
Poor [ ] 3

A8.4. How often (on average) do household members suffer from coughing, chest or nose congestion, and sore throat? (✓)

Very often (i.e. 3 or more times per year)	Often (i.e. twice a year)	Not a lot (i.e. once per year)	Hardly ever (i.e. can't remember the last time)
[ ] 1	[ ] 2	[ ] 3	[ ] 4

A8.5. Does your stove produce smoke? (✓) Yes [ ] 1
No [ ] 0

A8.6. Is the area vented to remove smoke? (✓) Yes [ ] 1
I.e. is there a chimney or is the stove outside? No [ ] 0

Of the members of your household… *(✓)*

	B4.5.	*B4.6.*
Member of Household	**Who does the cooking?**	**Who is present when cooking occurs?**
Female adults	[ ] 1	[ ] 1
Female children	[ ] 2	[ ] 2
Male adults	[ ] 3	[ ] 3
Male children	[ ] 4	[ ] 4

If the household purchased an ethanol stove...

B4.9. Have you noticed any change in the frequency of such respiratory illnesses since using the ethanol stove? (✓) Yes [ ] 1 No [ ] 0

If yes...

B4.9.a. Has the frequency (✓): Increased [ ] 1 Decreased[ ] 2

Do you agree or disagree with the following statements? (✓)

B4.10. There is less smoke than from a kerosene stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B4.11. There is less smoke than from a charcoal stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B4.12. There is less smoke than from a gas stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

B4.13. There is less smoke than from an electric stove
Strongly Agree [ ] 1 Agree [ ] 2 Don't agree or disagree [ ] 3
Disagree [ ] 4 Strongly Disagree [ ] 5 Don't know [ ] 6

NOT FOR CONDOMINIUM FOLLOW UPS:

Energy in the Community

		B5.1.	*B5.2.*	*B5.3.*	*B5.4.*
(✓)		**In your opinion, is ___ readily available in this kebele?**	**In your opinion, is ___ expensive in this kebele?**	**In your opinion, does ___ cause health problems?**	**In using ___ safe in this kebele?**
Fuel wood, leaves, bark, twigs	a	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Charcoal, coal	b	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Kerosene	c	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Natural Gas	d	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Ethanol	e	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Electricity	f	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
Other………………… ……………..	g	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0

Appendix 3

Entitlements Household Survey

Tyndall°Centre
for Climate Change Research

Jennifer Hodbod

Postgraduate Researcher

Hello,

We are students from the University of East Anglia in England and Addis Ababa University.

We are studying the Metehara sugar estate and its surroundings. We would like to ask you some questions about your household, especially about the members of this household, the fuel you use and the food you eat.

Please note that all information we collect will be treated confidentially. All your answers will be added to those from other participants, and nothing you say will be quoted directly. Please feel free to say exactly what you want to say in response to the questions I'm going to ask you or not answer questions you do not wish to. We will not share your personal information with any other person or institution.

Are you willing to spend some time with us to answer these questions?

Thank you, let's begin.

Questionnaire details	Date: Area:
Is the respondent willing to take part in a group interview in a few weeks? If yes...	Name: Phone: House number:
Interviewer's details	Name: Language spoken:
Jenny present?	Yes [ ] No [ ] Partly [ ]

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Code for visits- please ✓ accordingly

Respondent qualifies	
Questionnaire completed	
No one at home	
Does not qualify	
Vacant house	
Respondent cannot communicate with any form of assistance	
Refusal	
Contact person refused	
Interview refused by selected respondent	

Office Use Only:

Questionnaire number	
Checked by:	
Date checked	
Complete?	Complete [ ] Incomplete [ ]
Coded by:	
Date coded	
Data entered into spreadsheet by:	
Date entered into spreadsheet	

Entitlements Survey

Section A: Part 1: Area Identification

A1.1. Town/Village	A1.2. Kebele	A1.3. House Number (Or other identification)

A1.4. What materials is the house made out of?

a. Walls...……………………………………………………………………

b. Roof…..…………………………..……………………………………

c. Floor……………………………………………………………………

Section A: Part 2: Household Head Characteristics

A2.1. Is the head of household answering the questions? (✓) Yes [ ] 1 No [ ] 0

A2.2. Sex (✓): Male [ ] 1 Female [ ] 2

A2.3. Educational level (✓):

Illiterate	[	] 1
Read and write	[	] 2
Completed Primary School	[	] 3
Completed Secondary School	[	] 4
Completed University (Bachelors)	[	] 5
Other (specify).................................	[	] 6

A2.4. Marital Status (✓):

Never married	[	] 1
Married	[	] 2
Divorced	[	] 3
Divorced and remarried	[	] 4
Widowed	[	] 5
Widowed and remarried	[	] 6

Section A: Part 3: Members of the Household

A3.1. What is the main religion of the household? (✓)

Ethiopian Orthodox	[	] 1
Islam	[	] 2
Catholic	[	] 3
Protestant	[	] 4
Traditional	[	] 5
Other	[	] 6……………………......

A3.2. What is the main language spoken within the household? (✓)

Amharic	[	] 1
Other	[	] 2 ………………………

A3.3. What ethnicity does the household class themselves as? (✓)

Oromo	[	] 1
Amhara	[	] 2
Karayu	[	] 3
Afar	[	] 4
Other	[	] 5..

A3.4. Does this household live in the village permanently or seasonally? (✓)

Permanently [ ] 1
Seasonally [ ] 2

A3.5. How many years has the household lived in this region (even if seasonally)? (✓)

Less than 1 [ ] 1
1 to 5 years [ ] 2
5 to 10 years [ ] 3
Over 10 years [ ] 4
Always [ ] 5

A3.6. Does any member of this household work for the Metehara Sugar Factory? (✓)

Yes [ ] 1
Used to, now retired [ ] 2 Go to A4.1.
No [ ] 0 Go to A4.1.

A3.7. Is this member a seasonal or permanent employee of the Metehara Sugar Factory? (✓) Seasonal [ ] 1 Permanent [ ] 2

A3.8. What work does this household member do at Metehara Sugar Estate and Factory? (✓)

Piece rate field work [ ] 1
Cane cutter [ ] 2
Sugar Mill [ ] 3
Ethanol Mill [ ] 4
Office work [ ] 5
Management [ ] 6
Supervisor – field [ ] 7
Supervisor – mill [ ] 8
Contract [ ] 9
Service [ ] 10
Other [ ] 11....................................

Section A: Part 3: Household Members Continued

A3.9. How many people live in this household? …………………………………… Please give more details on each member:

	A3.10.	*A3.11.*	*A3.12.*	*A3.13.*	*A3.14.*	*A3.15.*
	Relation to HH (✓)	***Residence Status*** (✓)	***Sex*** (✓)	***Age***	***Educational Status*** (✓)	***Marital Status*** (✓)
	Extended family member means Aunt/Uncle/ Cousin etc. If there is a servant/maid please note down in 'other' category			*Age (completed years)*		
A	Is the HH [ ] 1	Resident [ ] 1 Absent [ ] 2 Visitor [ ] 3				
B	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………………………………………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
C	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………………………………………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
D	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………………………………………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
E	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………………………………………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
F	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………………………………………………	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4

	A3.10.	A3.11.	A3.12.	A3.13.	A3.14.	A3.15.
	Relation to HH (✓)	***Residence Status*** (✓)	***Sex*** (✓)	***Age***	***Educational Status*** (✓)	***Marital Status*** (✓)
G	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………...………………………..…………….	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
H	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………...………………………..…………….	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
I	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………...………………………..…………….	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
J	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………...………………………..…………….	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
K	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………...………………………..…………….	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4
L	Is the HH [ ] 1 Spouse [ ] 2 Child [ ]3 Sibling [ ]4 Parent [ ]5 Extended family member [ ] 6 Other [ ] 7 ………...………………………..…………….	Resident [ ]1 Absent [ ]2 Visitor [ ]3	Male [ ]1 Female[ ]2		In school [ ]1 Primary [ ]2 Secondary [ ]3 Higher [ ]4	Unmarried[ ]1 Married [ ]2 Divorced [ ]3 Widowed [ ]4

A3.16. Which activities bring money into the household? (✓) *Select **ALL** that are relevant.*

None	Regular Salary	Small business	Wage labour (non-agricultural)	Wage labour (agricultural)	Crop/Livestock Production	Government grants	Remittances from abroad	Other ……………………. …………………….
[ ] 0	[ ] 1	[ ] 2	[ ] 3	[ ] 4	[ ] 5	[ ] 6	[ ] 7	[ ] 8

<table>
<tr><td></td><td colspan="4">Economic Status: for ALL household members over 10
(Past 30 Days)</td></tr>
<tr><td></td><td>A3.17.</td><td>A3.18.</td><td>A3.19</td><td>A3.20.</td></tr>
<tr><td>Family Member</td><td>How many days was the household member engaged in work?

Write the number of days worked, if no days write '0'</td><td>Occupation

(For those who have worked, are unemployed with previous experience or those who work but not during the last 30 days)</td><td>Estimated income from last 30 days in Birr</td><td>Reason for not working (i.e. no opportunity, ill-health etc)</td></tr>
<tr><td>A</td><td></td><td></td><td></td><td></td></tr>
<tr><td>B</td><td></td><td></td><td></td><td></td></tr>
<tr><td>C</td><td></td><td></td><td></td><td></td></tr>
<tr><td>D</td><td></td><td></td><td></td><td></td></tr>
<tr><td>E</td><td></td><td></td><td></td><td></td></tr>
<tr><td>F</td><td></td><td></td><td></td><td></td></tr>
<tr><td>G</td><td></td><td></td><td></td><td></td></tr>
<tr><td>H</td><td></td><td></td><td></td><td></td></tr>
<tr><td>I</td><td></td><td></td><td></td><td></td></tr>
<tr><td>J</td><td></td><td></td><td></td><td></td></tr>
<tr><td>K</td><td></td><td></td><td></td><td></td></tr>
<tr><td>L</td><td></td><td></td><td></td><td></td></tr>
</table>

Section A: Part 4: Housing Unit

A4.1. What is the type of housing unit? (✓)

Condominium apartment	[	] 1
Detached permanent house	[	] 2
Detached improvised house	[	] 3
Attached permanent house	[	] 4
Attached improvised house	[	] 5
Other…………………………	[	] 6

A4.2. How many years have the household lived in the housing unit (✓)

Less than 1	[	] 1
1 – 2 years	[	] 2
3 – 4 years	[	] 3
5 – 9 years	[	] 4
10 – 14 years	[	] 5
15 years or more	[	] 6

A4.3. What is the layout of the housing unit?

1 room	[	] 1
2 rooms	[	] 2
3 rooms	[	] 3
4 rooms	[	] 4
Other	[	] 5…………….............………….

A4.4. What is the type of tenure of the housing unit? (✓)

Owned and completely paid for	[	] 1
Owned with a mortgage	[	] 2
Rented from Kebele	[	] 3
Rented from other organisation……………………….	[	] 4
Rented from an individual	[	] 5
Provided rent free by Metehara Sugar Factory	[	] 6
Other………………………………………………….	[	] 7

A4.5. **If** rented or there is a mortgage, what is the monthly amount of rent/mortgage in Birr?..

A4.6. What type of kitchen does the housing unit have? (✓)

No kitchen	[	] 1
Modern kitchen, private	[	] 2
Modern kitchen, shared	[	] 3
Traditional kitchen, private	[	] 4
Traditional kitchen, shared	[	] 5

A4.7. Is there a radio in the housing unit? (✓)

Yes	[	] 1
No	[	] 0

A4.8. Is there a telephone in the housing unit? (✓) Yes [ ] 1
(*Mobile or landline)* No [ ] 0

A4.9. Is there a television in the housing unit? (✓) Yes [ ] 1
No [ ] 0

A4.10. What is the main source of **drinking water** for members of the housing unit? (✓)

Tap inside the house [ ] 1
Tap in compound, private [ ] 2
Tap in compound, shared [ ] 3
Tap outside compound, shared [ ] 4
Protected well or spring [ ] 5
Unprotected well or spring [ ] 6
Other……………………………………… [ ] 7

A4.11. How does the household dispose of most of its **garbage**? (✓)

Public garbage service [ ] 1
Private garbage service [ ] 2
Garbage service organised by MSF [ ] 3
Thrown in vacant lots [ ] 3
Thrown in river/stream [ ] 4
Burnt [ ] 5
Buried [ ] 6
Other…………………………………… [ ] 7

Section A: Part 5: Household Fuel Use

What fuels does the household use and what for? (✓ multiple if required)
Rank the **cooking** fuels from most (1) to least important.

Fuel (✓)	**A5.1. Cooking**	**A5.2. Rank**	**A5.3. Lighting**
Charcoal	[ ] 1		[ ] 1
Fuelwood or biomass	[ ] 2		[ ] 2
Kerosene	[ ] 3		[ ] 3
Electricity	[ ] 4		[ ] 4
LPG	[ ] 5		[ ] 5
Other...	[ ] 6		[ ] 6

How much of these **cooking** fuels do you use and how often?

Fuel	A5.4. **Units Used** *(Litres, sack, KG etc)*	A5.5. **Total Cost**	A5.6. **Frequency of Purchase**
Charcoal			
Fuelwood or biomass *Also fill in A7.1.*			
Kerosene			
LPG			
Other....................................			

A5.7. What is a rough estimate for the **total** household expenditure on **fuel** per **7 days**? (✓)

0< 10 Birr	[ ]	1
20< 40 Birr	[ ]	2
40< 60 Birr	[ ]	3
60< 80 Birr	[ ]	4
80< 100 Birr	[ ]	5
Over 100 Birr	[ ]	6

A5.8. **Not including food and fuel**, what are the other main things the household spends money on? (✓)

School fees	[ ]	1	Health fees	[ ]	2
Transport	[ ]	3	Telephone	[ ]	4
Water	[ ]	5	Children costs	[ ]	6
Electricity	[ ]	7	Membership fees	[ ]	8
Other	[ ]	9...			
Other	[ ]	10..			

A5.9. **Including food and fuel**, can you rank the main household expenditures from highest to lowest (i.e. from most to least)?

1st	
2nd	
3rd	
4th	
5th	

A5.10. Considering your sources of income and expenditures, please select which statement best fits your situation. (✓)

We can regularly pay for these items without worrying too much about the costs	[ ] 1
We can't spend as much as we would like but food is always on the table	[ ] 2
We must sometimes borrow money to pay for schooling and food	[ ] 3
We often spend a few days without food and kids don't go to school	[ ] 4

Section A: Part 6: Electricity

A6.1. Do you have electricity? (✓) Yes [ ] 1
No [ ] 0

A6.2. From whom? (✓) Provided free by Metehara Sugar Factory[ ] 1
Contract with Government Electricity Company [ ] 2
Other.. [ ] 3

A6.3. How do you pay for your electricity? (✓) Meter on house [ ] 1
Local EEPCO office [ ] 2
Pay neighbour [ ] 3
Included in rent [ ] 4
Free [ ] 5 *Go to A7*
.... Other [ ] 6

A6.4. How much do you pay every 30 days?...

Section A: Part 7: Fuel wood and other biomass – if answered yes to fuelwood in A5.1.

A7.1. How did the hhold acquire fuel wood, cane stalks, biomass etc during the past 7 days?

(✓) Self-collected [ ] 1
Purchased [ ] 2 Go to A7.8.
Combination of both[ ] 3

If self-collected…

A7.2. From where did you collect the biomass? (✓)

Own land [ ] 1
Own farmland [ ] 2
Public woodland [ ] 3
Natural forest [ ] 4
Sugar fields [ ] 5
Other [ ] 6………..……………………….

A7.3. How often did you collect biomass in the past 7 days?

………………………………………………………………………………..

A7.4. How long (time) does a normal trip take?

……………………………………………………………………………………..

A7.5. What is the average distance travelled TO the place you collect biomass (miles)?

……………………………………………………………………………………

A7.6. How were you collecting biomass? (✓)

On own back [ ] 1
On donkey or mule [ ] 2
Other [ ] 3………………………………………

A7.7. Who collects the biomass? (✓)

Female adults [ ] 1
Female children [ ] 2
Male adults [ ] 3
Male children [ ] 4

A7.8. Is the wood for any other purpose than biomass? (✓)

Yes [ ] 1 *I.e. Animal feed*
No [ ] 0 *Go to A8.*

A7.9. For what other purposes (other than cooking, space heating, lighting, water heating)?

……………………………………………………………………………………………

A7.10. What proportion of the biomass bought or collected is used **as fuel**? (✓)

Most of the wood [ ] 1
Half of the wood [ ] 2
Very little of the wood [ ] 3

Section A: Part 8: Environmental Health in this Area

A8.1. Do you think the air quality in this area is (✓):

Good [ ] 1
Average [ ] 2
Poor [ ] 3

A8.2. Why?

....
....
....
....

A8.3. How often (on average) do household members suffer from coughing, chest or nose congestion, and sore throat? (✓)

Very often (i.e. 3 or more times per year)	Often (i.e. twice a year)	Not a lot (i.e. once per year)	Hardly ever (i.e. can't remember the last time)
[ ] 1	[ ] 2	[ ] 3	[ ] 4

A8.4. Does your stove produce smoke? (✓)

Yes [ ] 1
No [ ] 0

A8.5. Is the area vented to remove smoke? I.e. is there a chimney? (✓)

Yes [ ] No [ ] 0

Of the members of your household… *(✓)*

	A8.6.	*A8.7.*
Member of Household	**Who does the cooking?**	**Who is present when cooking occurs?**
Female adults	[ ] 1	[ ] 1
Female children	[ ] 2	[ ] 2
Male adults	[ ] 3	[ ] 3
Male children	[ ] 4	[ ] 4

A8.8. Do the people who cook and who are present when cooking occurs seem to have more respiratory illnesses than the other members of your household? (✓)

Yes [ ] 1
No [ ] 0

A8.9. How often (on average) do these household members suffer from coughing, chest or nose congestion, and sore throat? (✓)

Very often (i.e. 3 or more times per year)	Often (i.e. twice a year)	Not a lot (i.e. once per year)	Hardly ever (i.e. can't remember the last time)
[ ] 1	[ ] 2	[ ] 3	[ ] 4

A8.10. Do you think the water quality in this area is (✓):

Good [ ] 1
Average [ ] 2
Poor [ ] 3

A8.11. Why?

....
....
....
....

Section B: Part 1: Dietary Diversity

I would like to ask you about the different foods you have **eaten in the past 30 days.** Could you please tell me whether you ate the following foods:

Often	At least every other day	16-30 days	O
Sometimes	Once or twice a week	4-15 days	S
Rarely		1-3 days	R
Never		0 days	N

	Item	Frequency (✓)			
		O	S	R	N
	Cereals				
B1.1.	Injera				
B1.2.	Bread				
B1.3.	Wheat				
B1.4.	Maize				
B1.5.	Tef				
B1.6.	Rice				
B1.7.	Sorghum				
B1.8.	Pasta				
B1.9					
	Tubers				
B1.10.	Sweet Potato				
B1.11.	Irish Potato				
B1.12.	Cassava				
B1.13.					
	Vegetables				
B1.14.	Tomatoes				
B1.15.	Onions				
B1.16.	Beans				
B1.17.	Carrots				
B1.18.	Spinach (Gomen)				
B1.19.	Cabbage				
B1.20.					

	Item	Frequency (✓)			
		O	S	R	N
	Fruits				
B1.21.	Oranges				
B1.22.	Mangoes				
B1.23	Papaya				
B1.24.	Avocado				
B1.25.	Bananas				
B1.26.					
	Meat				
B1.27.	Beef				
B1.28.	Chicken				
B1.29.	Sheep				
B1.30.	Goat				
B1.31.	Fish				
B1.32.	Eggs				
B1.33.					
	Others				
B1.34.	Cow's milk				
B1.35.	Sugar				
B1.36.	Salt				
B1.37.	Coffee				
B1.38.	Tea				
B1.39.					
B1.40.					

Section B: Part 2: Food Availability

B2.1. Do you produce your own food? (✓) Yes [ ] 1
No [ ] 0

B2.2. Do you keep any animals (not including cats and dogs)? (✓)
Yes [ ] 1
No [ ] 0 *Go to B2.11.*

If yes, list the animals owned:

		B2.3.	B2.4.	B2.5.	B2.6.
Livestock Type		**Number** *(Now)*	**Number kept consistently for breeding**	**Number to be sold**	**Number for household food**
Chickens	A				
Goats	B				
Sheep	C				
Cattle	D				
Donkeys	E				
Camels	F				
Other	G				

B2.7. What is the contribution of your own livestock to household food consumption? (✓)

Never [ ] 0
Frequently [ ] 1
Sometimes [ ] 2
Only on holy days and ceremonies [ ] 3

B2.8. If frequently or sometimes, which produces are most important for your household? (✓)

Meat	a	1st [ ]1	2nd [ ]2	3rd [ ]3
Milk and milk products	b	1st [ ]1	2nd [ ]2	3rd [ ]3
Eggs	c	1st [ ]1	2nd [ ]2	3rd [ ]3

B2.9. Is your own production enough to feed your household throughout the year? (✓) Yes [ ] 1
No [ ] 0

B2.10. How has the number of livestock you own changed since four years ago? (✓)

Less [ ] 1
More [ ] 2
No change [ ] 3

B2.11. Do you grow any crops? Yes [ ] 1
No [ ] 0 *Go to B3.1.*

B2.12. How much land do you have on which to produce your own food? (✓)

Less than 1 ha [ ] 1
1-2 ha [ ] 2
More than 2 ha [ ] 3

Which plant crops have you grown **many times** in the last **4 years**?

		B2.13.	B2.14.	B2.15.	B2.16.
Crop Type		**Proportion of land under this crop**	**Yield**	**Is this enough to feed your household for the year?**	**Do you sell any of this crop?**
(Name)		*(i.e. ¼, ½, ¾)*	(KG or sacks)	(✓)	(✓)
	A			Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
	B			Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
	C			Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
	D			Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0
	E			Yes [ ] 1 No [ ] 0	Yes [ ] 1 No [ ] 0

B2.17. What are the 3 most important **food** crops for your household?

1st	
2nd	
3rd	

B2.18. What are the 3 most important **cash** crops for your household?

f1st	
2nd	
3rd	

Section B: Part 3: Food Access

B3.1. If not produced by yourself, where else do you get the food eaten in your household? *Select all that apply and rank.*

	(✓)	**Rank (1= most important)**
Buy at market/shops	[ ] 1	
Trade other goods for food	[ ] 2	
Work for food	[ ] 3	
Given by friends/family	[ ] 4	
Given by assistance organisations	[ ] 5	
Given by Metehara Sugar Factory	[ ] 6	
Other.......................................	[ ] 7	

B3.2. If bought, where do you purchase your essential food items most often?

Market/shops in MSF [ ]1
Market/shops in Metehara town [ ] 2
Market/shops further afield [ ] 3

B3.3. How much do you spend, on average, **per week (7 days)** on food? (✓)

0 – 99 Birr	[ ] 1	600 – 699 Birr	[ ] 7
100 – 199 Birr	[ ] 2	700 – 799 Birr	[ ] 8
200 – 299 Birr	[ ] 3	800 – 899 Birr	[ ] 9
300 – 399 Birr	[ ] 4	900 – 999 Birr	[ ]10
400 – 499 Birr	[ ] 5	1000 – 1199 Birr	[ ] 11
500 – 599 Birr	[ ] 6	Over 1200 Birr	[ ] 12

B3.4. Has the way you source food changed in the past **4** years? (✓)

Yes [ ] 1
No [ ] 0 Go to B4.1.

B3.5. If yes, **4 years ago**, how did you source the food your household consumed? (✓)

	(✓)	**Rank (1= most important)**
Produced plant crops on own land	[ ] 1	
Livestock farming	[ ] 2	
Buy at market/shops	[ ] 3	
Trade other goods for food	[ ] 4	
Work for food	[ ] 5	
Given by friends/family	[ ] 6	
Given by assistance organisations	[ ] 7	
Given by sugar estate	[ ] 8	
Other.......................................	[ ] 9	

B3.5. What **do you think** has been the reason for this change?
....
....
....
....

Section B: Part 4: Household Food Insecurity and Coping Strategies

In the past **30 days**...

B4.1. Did you worry that your household would not have enough food? (✓)

Never	[ ]	0
Rarely (once or twice)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.2. Did this translate into altering your eating habits? (✓)

Yes	[ ]	1	
No	[ ]	0	*Go to B4.12.*

B4.3. Did you or any household member have to eat a limited variety of foods due to a lack of resources? (✓)

Never	[ ]	0
Rarely (once)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.4. Has the quantity of food served to adults in the household been reduced? (✓)

Never	[ ]	0
Rarely (once)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.5. Has the quantity of food served to children in the household been reduced? (✓)

Never	[ ]	0
Rarely (once)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.6. Have you borrowed food or relied on help from friends/relatives? (✓)

Never	[ ]	0
Rarely (once)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.7. Have you had to consume stored seeds/grains at any point? (✓)

Never	[ ]	0
Rarely (once)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.8. Have household members skipped meals, because there wasn't enough food? (✓)

Never	[ ]	0
Rarely (once)	[ ]	1
Sometimes (3- 10 times)	[ ]	2
Often (More than 10 times)	[ ]	3

B4.9. Other than alter eating patterns, did your household do any of the following to address food shortages in the **past 30 days**? (✓)

Nothing	[	] 0
Selling labour power in exchange for food or money *(more so than normal)*	[	] 1
Short term migration for wage work to urban areas	[	] 2
Borrowing grain or cash from merchants	[	] 3
Food Aid	[	] 4
Selling livestock	[	] 5
Selling domestic assets (excluding land)	[	] 6
Pledging land	[	] 7
Selling land	[	] 8
Others..	[	] 9

B4.10. If there were difficulties in providing food for your household in the **past 30 days**, what do you think was the main cause? (✓)

Increased food prices	[	] 1
Decreased household income	[	] 2
Shortage of rain	[	] 3
Other agricultural issue	[	] 4...............................
Other	[	] 5..............................

B4.11. Has the food consumption of the **past 30 days** been **normal** for this time of year? (✓)

Yes [ ] 1 No [ ] 0

In the past **4 years...**

B4.12. Did you worry that your household would not have enough food? (✓)

Never	[	] 0 *Go to B4.18.*
Rarely (once or twice in 4 years)	[	] 1
Sometimes (at least one a year)	[	] 2
Often (More than 10 times in 4 years)	[	] 3

B4.13. Did this translate into altering your eating habits? (✓)

Yes	[	] 1
No	[	] 0

B4.14. Other than alter eating patterns, did your household do any of the following in times of food shortage in the past **4 years**? (✓)

Nothing [ ] 0
Selling labour power in exchange for food or money [ ] 1
(more so than normal)
Short term migration for wage work to urban areas [ ] 2
Borrowing grain or cash from merchants [ ] 3
Food Aid [ ] 4
Selling livestock [ ] 5
Selling domestic assets (excluding land) [ ] 6
Pledging land [ ] 7
Selling land [ ] 8
Others... [ ] 9

B4.15. Were these food shortages (✓):
Seasonal [ ] 1 Throughout the year [ ] 2

B4.16. If seasonal, can you indicate in which seasons food shortages occur in your household (✓): Belg [ ] 1
Meyer [ ] 2
Other [ ] 3..

B4.17. Can you speculate as to the cause of food shortages in these times? (✓)
Increased food prices [ ] 1
Decreased household income [ ] 2
Shortage of rain [ ] 3
Other agricultural issues [ ] 4...............................
Other [ ] 5...............................

B4.18. At any time in the past **4 years**, did a lack of food in your household affect the health or ability to work of household members? (✓)
Yes [ ] 1
No [ ] 0

Section C: Part 1: Networks

For the following situations in your household, who would you contact for assistance?

		C1.1.	*C1.2.*	*C1.3.*
(✓)		Advice i.e. on farming, children's future or health	Financial problem leading to a shortage of fuel or food	Unfortunate event that is not financial (i.e. a death in the family)
No One	a	[ ] 1	[ ] 1	[ ] 1
Family in the Kebele	b	[ ] 2	[ ] 2	[ ] 2
Family in the Woreda	c	[ ] 3	[ ] 3	[ ] 3
Family out of the Woreda	d	[ ] 4	[ ] 4	[ ] 4
Neighbours	e	[ ] 5	[ ] 5	[ ] 5
Friends	f	[ ] 6	[ ] 6	[ ] 6
Religious leader or group	g	[ ] 7	[ ] 7	[ ] 7
Community leader	h	[ ] 8	[ ] 8	[ ] 8
Patron/employer/ benefactor i.e. Sugar Factory	i	[ ] 9	[ ] 9	[ ] 9
Political leader	j	[ ] 10	[ ] 10	[ ] 10
Mutual support group to which you belong	k	[ ] 11	[ ] 11	[ ] 11
Assistance organisation to which you do not belong	l	[ ] 12	[ ] 12	[ ] 12
Other………………………… …………………….................. ...	m	[ ] 13	[ ] 13	[ ] 13

Are you or is someone in your household a member of any the following groups, organisations or associations?

		a	*B*
	Type of organisation or association	**Member?** (✓)	**Degree of participation** (✓)
C1.3.	Idir	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active [ ] 3 Not active [ ] 4
C1.4.	Religious	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active [ ] 3 Not active [ ] 4
C1.5.	Social	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active [ ] 3 Not active [ ] 4
C1.6.	Other (specify)……………………… ………………………………….. …………………………………	Yes [ ] 1 No [ ] 0	Representative [ ] 1 Very active [ ] 2 Somewhat active [ ] 3 Not active [ ] 4

C1.15. Can you rank the organisations in order of importance to your household?

1st	
2nd	
3rd	
4th	

C1.16. Overall, are the same people members of these different groups? (✓)

Little overlap [ ] 1
Some overlap [ ] 2
Much overlap [ ] 3

(✓)		**Idir**	**Religious**	**Social**	**Other**
		a	*b*	*c*	*d*
C1.17	Are members mostly of the same extended family?	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.18	Are members mostly of the same religion?	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.19	Are members mostly of the same gender?	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.20	Do members mostly have the same occupation?	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.21	Are members mostly of the same age group?	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.22	Do members mostly have the same level of education?	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0
C1.23	**Do you think that by belonging to this group you have acquired new skills or learned something valuable?**	Yes [ ]1 No [ ] 0	Yes [ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0	Yes[ ] 1 No [ ] 0

List of Acronyms

µS	Microsiemen
AAHDP	Addis Ababa Housing Development Project
ANP	Awash National Park
AR4	Fourth Assessment Report
ARI	Acute Respiratory Infection
BOD	Biological Oxygen Demand
CH_4	Methane
CO	Carbon Monoxide
COD	Chemical Oxygen Demand
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
E5	Ethanol Blend: 5% Ethanol, 95% Gasoline
E10	Ethanol Blend: 10% Ethanol, 90% Gasoline
E25	Ethanol Blend: 25% Ethanol, 75% Gasoline
EC	Electrical Conductivity
EEPCo	Ethiopian Electric Power Corporation
EF	Emission factor
EPRDF	Ethiopian People's Revolutionary Democratic Front
EREDPC	Ethiopian Rural Energy Development and Promotion Center
ESDA	Ethiopian Sugar Development Agency
EWCA	Ethiopian Wildlife Conservation Authority
FAO	Food and Agriculture Organisation of the United Nations
FAOSTAT	Food and Agriculture Organisation of the United Nations Online Database
FCS	Food Consumption Score
FFC	Former Fuelwood Carriers
FUW	Factory Used Water
GA	the Gaia Association

GHG	Greenhouse Gas
GHI	Global Hunger Index
GNI	Gross National Income
GSS	Good Shepherd Sisters
GTP	Growth and Transformation Plan
GWP	Global Warming Potential
ha	Hectare
HVA	Handels vereniging Amsterdam
IPCC	Intergovernmental Panel on Climate Change
kg	Kilograms
km	Kilometres
KSF	Kesem Sugar Factory
kWh	Kilowatt Hour
l/ha	Litres per hectare
LCA	Life Cycle Analysis
m	Metre
m^3	Cubic Metres
MSF	Metehara Sugar Factory
MT	Mega Tonne
MW	Mega Watt
N_2O	Nitrous Oxide
Na^+	Sodium ion
NGO	Non-Governmental Organisation
NMVOC	Non-Methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
NTU	Nephelometric Turbidity Units
PAH	Polycyclic Aromatic Hydrocarbons
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
PM	Particulate Matter

PSNP	Productive Safety Nets Programme
REDD	Reducing Emissions from Deforestation and Forest Degradation
SAR	Sodium Adsorption Ratio
SD	Standard Deviation
SES	Social-Ecological System
SPSS	Statistical Package for the Social Sciences
TPES	Total Primary Energy Supply
TSP	Total Suspended Particles
UNHCR	UN High Commissioner for Refugees, or UN Refugee Agency
WFP	World Food Programme

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