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Gender specific perspectives among smallholder farm households on water-energy-food security nexus issues in Ethiopia

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Abstract

The water-energy-food security nexus concept is a widely recognized analytical approach to consider and achieve sustainable development goals. However, the water-energy-food security nexus concept has mostly been analyzed at higher scales in a top-down manner, while examples of bottom-up and local scale applications remain limited. Breaching this gap, the research presented in this paper describes and assesses the water-energy-food nexus from a smallholder farm household perspective in the context of rural Ethiopia through a gender-specific lens. We adopted the “Actors, Resources, Dynamics and Interactions” participatory approach to co-develop a mental model of this nexus concept. Using this approach, we were able to examine the key elements and interlinkages among major nexus related resources that affect management according to gender. The results indicate that there are four aspects that differentiate between male and female farm household management with respect to the water-energy-food nexus. These differences include gender specific productive roles, perceptions of target resources, access to external actors, and decision making with respect to target resource management and utilization, which may affect the dynamics and governance of important components of the water-energy-food nexus.

Keywords: ARDI method, bottom-up approach, energy-food-land linkages, gender roles, intra-household heterogeneity, mental model

JEL codes: Q

1. Introduction

The water-energy-food (WEF) nexus concept has become central to sustainable development (Allouche et al. 2015) for technical assessments to improve resource management and system efficiency (Hoff 2011; Scott et al. 2015), identifying trade-offs and optimizing synergies across nexus sectors for the governance of natural resources (Bazilian et al. 2011; Howells et al. 2013) and the design of efforts to alleviate poverty and food insecurity (Guta et al. 2017; Hoff 2011; Ringler et al. 2013). Interactions among WEF nexus components play a vital role in the living standard outcomes of rural households, and can be captured and/or affected through changes in household behaviors or activities. For example, changes in residential energy use substantially influence household income and greenhouse gas emissions (Hiremath et al. 2010). Access to water for household use is vital for their health, agricultural production and thus for both food and energy security (Rasul 2014). Promoting WEF nexus based approaches for the sustainable management of these resources requires an understanding of the nature of the relationships among food, water and energy (in this case fuelwood) resources, and the potential consequences of changes resulting from possible interventions (Bizikova et al. 2013). It is also important to understand that different stakeholders might influence WEF nexus dynamics in distinct ways at the household level (Djanibekov and Gaur 2018). International private sector actors were among the active participants in the formulation of the WEF nexus concept, because it is perceived as both an opportunity (e.g., green economy) (Hoff 2011) and a constraint to business activities (e.g., resource scarcity).

The security of WEF resources remains the core element of the WEF nexus challenge (Bizikova et al. 2013; Hoff 2011). Nevertheless, the concept of security goes beyond access to related resources; it also includes the capacity to utilize these resources, as well as the social dynamics and power relationships that affect the use and management of these resources (Biggs et al. 2015). Previous studies have applied the WEF nexus for analyses in the context of social networks and institutional interactions (Stein et al. 2014); the related food-energy-environment nexus linked to national context issues in the Nile Basin (Karlberg et al. 2015); implications of decentralized energy solutions on nexus dynamics and the role of forestry (Guta et al. 2017); and trade-offs between energy use and agricultural production among rural household members (Djanibekov and Gaur 2018). To the best of our knowledge no study has yet examined gender dimensions of the WEF nexus concept and gender specific perspectives of WEF nexus implications for rural landscapes; including gender specific resources, drivers influencing nexus dynamics (e.g., access to [external] actors promoting bio-energy alternatives), and their interlinkages. Reflecting gender perspectives of the WEF nexus concept helps to identify specific local factors that may determine the degree of resource security and management sustainability. Hence, this paper explores the WEF nexus concept through a gender lens among smallholder farmers in rural Ethiopia by focusing on the different components (or elements) and associated actors.

1.1 Gender and gender-specific perception of the WEF nexus

Several depictions of nexus frameworks are offered in the literature. Wichelns (2017) reviewed these frameworks and concluded that each provides a unique perspective of the WEF nexus, including its drivers and impacts. However, one of the shortcomings raised in that review are the many missing components of WEF nexus dimensions (i.e., agricultural issues such as land, labor and livelihoods). Ringler et al. (2013) emphasized that WEF nexus outcomes should be evaluated for the poor because their well-being is highly interrelated with nexus dynamics, but often in conflict with the maintenance of environmental integrity. Unfortunately in developing countries, especially in Sub-Saharan Africa, resource access for the poor remains both a practical and policy challenge. Inequitable access to basic resources (e.g., water and land) is especially prevalent among women. Achieving gender equality and equity is one of the Sustainable Development Goals (i.e., Goal 5, <https://sustainabledevelopment.un.org>) and yet very few studies have considered the potential for differential effects of WEF nexus interventions with respect to gender (Djanibekov et al. 2016; Djanibekov and Gaur 2018), while almost no in-depth efforts are featured in global discussions about linkages between gender and WEF nexus policy approaches or interventions. Women in developing countries are often intensively involved in agriculture (FAO 2011). In many Sub-Saharan African countries women are responsible for providing food for their households in addition to procuring fuelwood for cooking and potable water (Arndt et al. 2011). If the target of a policy or intervention is at the local scale, the relevance of gender to WEF nexus dynamics should be considered, as gender relations often influence control over, access to, and the use of these resources (Quisumbing et al. 2008; 2015). This includes the question of whether the introduction of technology to improve energy efficiency or bioenergy will translate into improved quality of life for both women and men.

How an individual views or perceives the world, as well as their expectations and hopes for the future, are shaped by daily experiences, which are rooted in socio-economic or governance relations and variables affecting social locations (such as the intersection of race/ethnicity, class, culture, age and gender) (Amott and Matthaei 1996; Meares 1997; Villamor et al. 2015). In addition, differential gender response to renewable and other nontraditional energy sources (e.g., modern biomass and biofuels) (Mirzabaev et al. 2015; Ringler et al. 2013) has received little attention (Mekonnen et al. 2017; Villamor and van Noordwijk 2016). Therefore, examination of the extent to which daily experiences and routines of farm household members are influenced by gender may offer explanations for variability in perceptions of WEF nexus issues. In this study, we explore gender as one of many factors influencing WEF nexus concept perspectives at the local household level by developing mental model of nexus systems (Villamor 2014).

Mental models are internal representations of external reality that people use to interact with the world around them (Jones et al. 2011). Elucidating household level perspectives of the nexus concept helps to understand (and delineate) different conceptualization related dynamics (Jones et al. 2011; Lynam and Brown 2012). Through gender-specific mental models, men and women can simulate their interactions with these dynamics (according to their real life experiences, perceptions and understanding of local systems) (Jones et al. 2011). Mental models can provide a collective representation of reality-based systems to attempt to improve decision-making processes (Dray et al. 2006; Elsayah et al. 2015); to identify and inform strategies for overcoming stakeholder knowledge limitations and misconceptions associated with a given resource (Morgan 2002); and to facilitate the exploration of variability among different stakeholders' understanding of a particular issue in order to find ways to improve inter-stakeholder communication (Abel et al. 1998; Dah-gbeto and Villamor 2016). In this study, we adopted the Actor, Resources, Dynamics, and Interactions (ARDI) method developed by Etienne et al. (2011) as part of a companion modeling approach. This method focuses on encouraging stakeholders to describe, explain, and predict the purpose, form, function, and state of a given system so as to elicit causal knowledge. This approach has mainly been applied to natural resource management (Balbi et al. 2010) and socio-ecological systems (Lynam et al. 2012). We adopted the ARDI method to co-conceptualize WEF nexus systems according to gender through a series of focus group discussions and workshops, where male and female farmers (in this case the target participants) were aided by facilitators to collectively articulate a mental model of a WEF nexus system.

2. Methods

2.1 Study area

The study area included two major regions of Ethiopia, Amhara and Oromia regional states. These regions constitute the majority of the upper Nile Basin and are critical to the management of the water resources for the entire basin. Within these regions we selected three *kebeles* (the smallest administrative units in Ethiopia, equivalent to neighborhoods or wards), Gebezermariam and Bichena Debir in Amhara, and Sire Morose in Oromia. The study area selection was mainly based on security concerns of the researchers and facilitators during field data collection. The immediate landscape surrounding most of the *kebeles* in these regions include a mosaic of crops, pastures and small woodlots. The area available for crop cultivation is relatively limited because most land is not arable. Only one of the study site *kebeles* has river access, which is a local source of irrigation water (i.e., for modern irrigation systems). Other water needs are met by rainfall, springs, and pump or manually operated wells. The majority of the population engages in rain-fed agriculture, a minority has irrigated farmland. Springs used for irrigation only flow during the rainy season (November to February) and dry up between February and May. According to the respective Woreda (equivalent of a district, composed of multiple *kebeles*) Administrative Offices, the three *kebeles* host approximately 1,763 households, of which 20% (356) are female-headed households. Typical livestock includes cattle, horses, donkeys, sheep, goats, and poultry. Mining is an important economic activity in the study area, supporting approximately 235 people.

2.2 ARDI approach

The ARDI approach, which is the conceptual framework of this study, is described in detail by Etienne et al. (2011). This approach frames the elicitation of individual knowledge that then leads to the emergence of collective learning. Sharing of representations of each stage leads to progressive emergence of a collective mental model. There are four different stages to this approach, which are briefly described below.

- i. Identifying key actors (A): by listing stakeholders and their corresponding management entities and linkages between them. The participants (in this case male and female farmers) identify these stakeholders as either “direct” (whose practices have direct impacts on key resources) and “indirect” (whose actions can influence the direct stakeholders to change their practices).
- ii. Identifying key resources (R): by listing the relevant resources (exclusively to products) of the study area according to the key stakeholders previously identified. For this study WEF resources were targeted.

- iii. Identifying key dynamics (D): by listing the main processes that drive resource dynamics in the study area. The processes may deal with ecological (e.g., water flow), economic (e.g., changing agricultural input prices), or social dynamics (e.g., collectivism or cultural identity).
- iv. Eliciting interactions (I): by collectively constructing an interaction diagram describing linkages among the stakeholders and resources identified. The participants also suggest a verb that characterizes the type of action that generates each linkage.

2.3 Data collection and analysis

A teach study site we conducted a gender-segregated focus group discussion (FGD) based workshop and key stakeholder interviews. To select the participants for the FGD workshop, we first coordinated with the respective Woreda Administration Offices of the selected *kebeles*. The *woreda* representatives contacted local farmers to identify those willing to participate in the workshop activities. Initially, we conducted an exercise with a mixed-gender group; however, it became apparent that female participants would not speak openly in the company of men, so we decided to conduct gender segregated pretests before holding the FGD workshops. We conducted two pretests with male-only and female-only groups in the *kebele* Aleltu in Oromia to refine the central discussion questions for the FGD workshops. The pre-test participants included extension officers, *woreda* representatives, and local farmers identified by *woreda* representatives as experts. We then conducted six FGD workshops (one female-only group and one male-only group per study site). Each group was composed of seven to nine participants. Each FGD workshop lasted for approximately four hours.

There were two central discussion questions posed during the FGD-workshops were.

- (1) How do (male and female) farmers manage their land for food and energy (fuelwood) production, and to conserve water?
- (2) What are the (potential) drivers of changes in the targetfood and energy resources?

Within the discussion of each question, follow-up questions were asked according to the ARDI method, including:

- Who are the main stakeholders that interact with farmers regarding land management (actors)?
- What are the main resources of the managed landscape (resources)?
- What are the main processes that drive changes in resource production (dynamics)?
- How do farmers use the WEF nexus resources (interactions)?

The last question builds on the interactions between the users and resources, and is crucial for synthesizing the responses to the first three questions, which contribute to the mental

model of the local WEF system. We analyzed the results of the six FGD-workshops based on the integration of all actors, resources, dynamics and interactions organized into two graphical conceptual diagrams of the nexus system. Based on those diagrams, we differentiated elements by gender. The stakeholder interviews yielded us the verification of crop production and prices, relationship/interaction of external actors with male and female farmers, and farmers' daily activities as well as well their time used for farming activities.

After identifying the key elements of the local WEF nexus system from a gender perspective, we conducted two additional gender segregated workshops in July of 2017 in Aleltu to validate and verify the key results. In these final FGD workhops there were seven participants in the male-only group and nine participants in the female-only group. We further verified the general daily activities of both male and female farmers during the workshop.

The results of the qualitative data analyses were compared with the descriptive statistics from the Ethiopia Socio-economic Survey conducted by the World Bank for 2013–2014 (CSA-LSMS-WB 2015), which are derived from 3,744 households, as a basis for triangulation (**Table 1**). That survey was financed and conducted by the World Bank in order to examine linkages among agricultural development and household income activities in the country. We ran a regression analysis with this dataset to determine the factors affecting time allocated for fuel collection between male and female farmers using the statistical software STATA 15.0 ¹.

Table 1: Descriptive statistics of rural households in the study area in Ethiopia

Variable	HH ^a gender	<i>n</i>	Average	Std. dev.	Min	Max
Labor availability (# of persons > 16 yr)	Total	3,744	2.59	1.42	0	10
	Female	974	1.97	1.42	0	10
	Male	2,770	2.82	1.36	0	10
Number of females per hh (>16 yr)	Total	3,774	1.48	0.871	0	9
	Female	974	1.56	0.882	1	9
	Male	2,770	1.46	0.866	0	7
Number of males per hh (>16 yr)	Total	3,774	1.40	1.019	0	7
	Female	974	0.76	0.943	0	4
	Male	2,770	1.62	0.949	0	7
	Total	3,136	23.04	28.68	0	258

¹<https://www.stata.com/>

Variable	HH ^a gender	<i>n</i>	Average	Std. dev.	Min	Max
Time spent on agriculture/males (hours)	Female	367	17.74	24.79	0	154
	Male	2,769	23.75	29.08	0	253
Time spent on agriculture/females (hours)	Total	3,573	11.71	19.82	0	220
	Female	974	11.90	19.35	0	133
	Male	2,599	11.64	19.99	0	220
Time spent harvesting/household (hours)	Total	3,039	439.54	664.13	0	11,004
	Female	652	270.55	450.10	0	5,772
	Male	2,387	485.71	704.54	0	11,004
Time spent on fuel collection/males (hours/day)	Total	3,133	0.16	0.74	0	15.58
	Female	2,599	0.46	0.98	0	9.00
	Male	2,769	0.16	0.76	0	15.50
Time spent on fuel collection/females (hours/day)	Total	3,572	0.44	0.98	0	10.33
	Female	287	1.34	1.42	0.02	10.33
	Male	109	0.06	0.41	0	3.00
Time spent on water collection/females (hours/day)	Total	2,222	0.73	0.82	0.02	10.00
	Female	560	0.68	0.89	0.02	10.00
	Male	1,662	0.74	0.80	0.02	8.00
Time spent on water collection/males (hours/day)	Total	423	0.72	0.98	0.02	10.00
	Female	63	0.73	0.69	0.03	3.00
	Male	360	0.72	1.02	0.02	10.00
Asset value in previous year (USD)	Total	3,682	132.26	236.94	1	9,367.86
	Female	930	95.18	133.12	1	2,482.76
	Male	2,752	145.12	261.68	1	9,367.86
Total livestock (TLU)	Total	2,995	4.92	5.29	0	85.13
	Female	622	3.66	3.97	0	28.94
	Male	2,373	5.26	5.54	0	85.13
	Total	3,530	48.26	142.27	0	4000

Variable	HH ^a gender	<i>n</i>	Average	Std. dev.	Min	Max
Total chemical fertilizer purchased (kg)	Female	869	26.85	64.84	0	600
	Male	2,661	55.25	159.01	0	4000

Source: CSA-LSMS-WB (2015)

Note: [a] HH = household head; 1 USD = 27.5 Ethiopian Birr.

3. Results

3.1 Direct actors

Gender specific perspectives of the direct actors involved in access to and management of local WEF nexus resources among farmers are summarized in **Figure 1**. The female-only groups identified six direct actors, whereas the male-only groups identified seven direct actors, of which one was specific to the energy sector. Cooperatives are perceived as direct non-governmental actors that provide access to credit and resources such as seeds, fertilizers and solar panels. All of the identified sector actors are coordinated by the Administrative Office/Bureau (**Table 2**). This suggests that the Administrative Office/Bureau serves as a mediator between sectoral actors and farmers. From the farmers' perspective, all sector actors operate in collaboration except for the Mineral and Energy Bureau, which only coordinates with the Agriculture Bureau and Administrative Office. In terms of the resources used by farmers that are derived from these actors, male farmers exhibited greater specific knowledge regarding tangible and intangible resources offered by the actors. Female farmers were more likely than male farmers to identify the Health Bureau associated with the energy sector because it promotes improved cooking stoves that reduce negative health impacts relative to traditional stoves. In addition, there is typically a more direct connection between female household heads and the Health Bureau relative to male household heads (**Figure 1**).

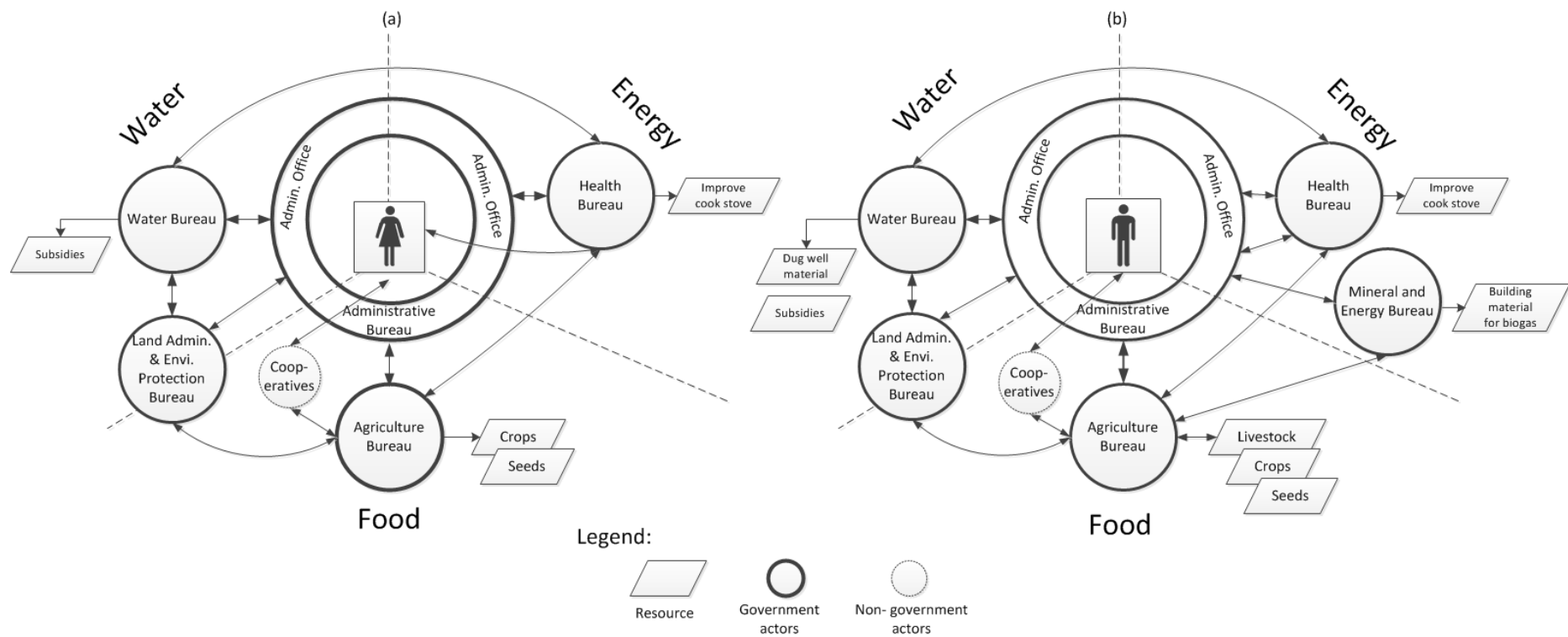


Figure 1: Graphical representation of direct actors identified by female-only (a) and male-only groups (b) in the study area

Table 2: Direct actors, resources and interactions identified by female-only and male-only groups in the study area

Key actor	Resources	Interactions	
		According to females	According to males
Agriculture Bureau	Training, improved seeds, technology, equipment, and improved poultry	Trains farmers in various agricultural practices, works with cooperatives and the Administration Office/Bureau, assesses the agricultural input needs of farmers, and submits requests to cooperatives	Trains farmers in various agricultural practices (land preparation, appropriate fertilizer application, and post-harvest management), works with cooperatives and the Administration Office/Bureau, and assesses the agricultural input needs of farmers
Land Administration and Environmental Protection Bureau	Land certification, conflict resolution, and communal land management (knowledge)	Issues land certificates; resolves conflicts; and collaborates with the Administration Office/Bureau, Water Bureau, and Agriculture Bureau	Issues land certificates, resolves conflicts, and collaborates with the Administration Office/Bureau and judiciary agencies
Administration Office/Bureau	Rules and regulations	Coordinates all activities in the kebele; collaborates with the Land Administration and Environmental Protection Bureau, Administration Office/Bureau, Agricultural Bureau, and Health Bureau	Coordinates all activities in the kebele and collaborates with/ controls all kebele actors
Water Bureau	Financial support, technical support, potable water development, and chemical water purification (chlorine)	Covers 80% of water system construction costs; provides water treatment and maintenance services; works in collaboration with Health Bureau, Administration Office/Bureau, and Land Administration and Environmental Protection Bureau	Covers 80% of water system construction costs; provides water treatment and maintenance services; supplies building materials for well construction; and works in collaboration with the Health Bureau and Administration Office/Bureau
Health Bureau	Information on sanitation, family planning (contraceptives), and improved cooking stoves	Creates awareness about family planning, sanitation and uses of improved cook stove; provides information on contraceptive methods; trains farmers in health (and livelihood) improvements; and collaborates with the Administration Office Bureau, Agriculture Bureau, and Water Bureau	Provides sanitation, hygiene and improved cooking stove training; and collaborates with the Administration Office/Bureau, Agriculture Bureau, and Water Bureau

Key actor	Resources	Interactions	
		According to females	According to males
Cooperatives	Improved seeds, fertilizer, consumer goods (i.e., edible oil and sugar)	Supplies agricultural inputs and consumer goods; and cooperates with the Agriculture Bureau, Administration Office/Bureau, and Amhara Credit and Savings Association	Supplies agricultural inputs (fertilizer, improved seeds, pesticides, herbicides); and cooperates with the Agriculture Bureau and Administration Office/Bureau
Mineral and Energy Bureau	Biogas establishment materials (cement, equipment, subsidies), and minerals	-	Maps kebele mineral resource sites; submits maps to Land Administration and Environmental Protection Bureau; and works with cooperatives, the Administration Office Bureau, and Agricultural Bureau

As perceived by the participants, there were additional actors that were indirectly influencing the direct actors (**Table 3**), however, according to household heads their role in WEF nexus decisionmaking are less important than the actors that coordinate via the Administrative Office/Bureau. These indirect actors include a government agency that coordinates with international organizations (e.g., World Vision) with respect to soil and water conservation issues, while churches and mosques serve as media for soil and water conservation awareness. Female participants expressed greater preference for traders and small- and medium-sized enterprises than their male counterparts.

Table 3: Indirect actors, resources and interactions identified by female-only and male-only groups in the study area

Actor	Resources	Interactions	
		According to females	According to males
JICA/IFAD/KFW (international organization projects)*	Electric grids, financial support, water pumps	Financed the establishment of pumps to access ground water and electric grids that provide kebele electricity, and collaborates with Administration Office/Bureau and Water Bureau	Raised awareness of natural resource management; electric grid connection for construction of kebele potable water system; and collaborates with Administration Office/Bureau

Actor	Resources	Interactions	
		According to females	According to males
Church and Mosque	Spiritual services, sacred forest	Raises awareness of soil and water conservation through information exchange (involving students)	Raises awareness of soil and water conservation through information exchange (involving students)
Traders	Pesticides, insecticides, improved vegetable seeds, livestock medicines	Sells agricultural inputs to farmers and purchases agricultural outputs	-
School	Motivation	-	Motivates farmers during soil and water conservation campaigns
Small and micro enterprises	Financial support, potato seeds, beehive (materials), training	Organizes unemployed people to engage in various income generating activities such as vegetable production, mining, bee keeping, and works with cooperatives, the Administration Office/Bureau and the Agricultural Bureau	Organizes unemployed people to engage in various income generating activities such as vegetable production, mining, bee keeping, and works with cooperatives, the Administration Office Bureau, Agricultural Bureau, and the Mining and Energy Bureau
World Vision (NGO)	Financial support, childhood food nutrition, poultry, improved cooking stoves, fruits, vegetables, and cattle	Provides direct financial support to disabled people, farm equipment, agricultural inputs, improved cooking stoves; and covers expenses of food and school, etc.,	Provides direct financial support to disabled people, farm equipment, agricultural inputs, improved cooking stoves; covers expenses of food and school, etc.,
Irrigation Bureau	Equipment for irrigation pond construction	-	Facilitates construction of small-scale irrigation systems and works with World Vision, the Agricultural Bureau, and the Administration Office/Bureau

* Projects had already been phased out.

3.2 WEF nexus resources

Energy use

Households primarily depend on bioenergy sources to meet their residential energy demand due to the lack of access to electricity from centralized grid. Fuelwood derived from eucalyptus (*Eucalyptus globulus*) trees is the major source of household domestic energy, followed by

dried cattle dung (hereafter 'dung cake') and crop residues (dried vegetative material from crops such as straw and stubble from cereals and legumes).

Fuelwood is collected on household farms or purchased from other farmers. On average, households spend around three months per year in the preparation and collection of fuelwood. This includes harvesting trees as well as splitting and stacking fuelwood to dry, which are responsibilities typically undertaken by adult male household members; whereas, women and children are responsible for transporting fresh cut fuelwood from harvest sites to households. Hired daily laborers, adult male relatives, or neighbors serve as substitutes if there are no adult male household members. Households can generate between 300 and 750 kg of fuelwood from a single eucalyptus tree. The entire process of converting a single (harvestable size) eucalyptus tree into fuelwood requires between nine and 27 hours. A daily laborer hired to perform these tasks is paid from 3 to 9 USD/day in 2017. Households are forbidden from collecting fuelwood in communal forests and subject to a fine for noncompliance with this prohibition.

Dung cake is the second most commonly used energy source for meeting domestic needs. It is commonly used during summer seasons and typically prepared during the winter between December and May. Women and children collect cattle dung from household farm fields and pastures. On average, household women and children spend half an hour each day or around nine hours per week (combined hours of labor for all household collectors) during those months for dung collection. A grown woman can prepare approximately 100 dung cakes within three hours. Dung cake is used for cooking *wot* (a traditional stew) and for baking *injera* (a dietary staple). In addition, dung is used by all farmers directly as an organic soil additive or else composted and used to improve soil fertility for household vegetable production. According to the workshop participants the use of dung reduces fertilizer costs by 28 USD/ha. Due to the scarcity of raw material (i.e., due to the limited number of cattle) the amount of dung used for soil fertility treatment per household is minimal; hence, it is only applied for household vegetable production. Even if sufficient raw material (cattle dung) were available, it is cumbersome to compost dung in large amounts because it requires substantial labor for preparation and transport from pasture areas. In addition, composting cattle dung requires approximately 50 liters of water during the decomposition process. During the winter some households may collect dung cake from communal grazing areas.

Crop residues (mainly from maize) are also used as fuel for domestic energy needs, especially for cooking, boiling water, and heating purposes during the winter months. Women and children are responsible for collecting and transporting crop residues from farm fields to households. Kerosene is the main energy source for household illumination needs (as lamp fuel) and estimated mean monthly household expenditures on kerosene are about 1 USD. Local farmers rarely use charcoal as a household energy source.

Renewable energy technologies such as solar and biogas were initially introduced to one of the *kebeles* (Sire Morose) by the *Woreda* Agricultural Office, but only eight of the households that participated in the FGD workshops had adopted these technologies. Based on information obtained from the study participants, biogas is primarily used for illumination purposes (as lamp fuel) and to a lesser degree for cooking. An initial cost of 61 USD is required to install a biogas digester and the remaining costs can be covered by a government subsidy (from the Mineral and Energy Bureau). Overall, renewable energy technologies are rarely used by households due to their high costs and are typically only used for household illumination purposes.

The majority of households used improved cooking stoves (energy-efficient stoves) made from concrete or local earthen materials. According to workshop participants, improved stoves made from concrete are more efficient and release heat more slowly (i.e., over a longer period) than stoves made of local materials, but they are more expensive. Regardless, the performance of improved stoves of both construction types was considered together in the analyses relative to traditional stoves. Improved stoves cost approximately 6 USD. Estimates of mean daily household energy consumption by stove technology are presented in **Table 4**. Overall, household fuelwood and dung cake consumption using improved stoves is roughly half that of traditional stove use. Household domestic energy consumption exhibits seasonal variability, with particularly greater consumption during winter months.

Table 4: Estimated daily household energy consumption by stove type

Energy source	Consumption traditional stove (kg/day)	Consumption improved stove (kg/day)	Price (USD/kg)*	Season
Fuelwood	15–30	7.5–15	0.06–0.12	All
Dung cake	10	5	0.26	summer (<i>Kiremt</i>)
Crop residues	44	22	Not estimated	winter (<i>Bega</i>)
Charcoal	0.6	0.6	0.06–0.21	All

Note: * At the time of writing.

Energy consumption estimates provided by men-only groups are far lower than estimates provided by their women counterparts. This difference is likely related to the fact that women are almost exclusively responsible for cooking activities, suggesting that women are much more likely to have accurate knowledge on relevant energy consumption than men.

Food security and income

The main sources of household income are the sale of crops and livestock such as oxen or sheep and their products. Females put relatively greater emphasis on crop production as a livelihood source than men. Other income sources include the sale of (*Eucalyptus*) trees and vegetables.

Workshop participants identified different local crops produced for both subsistence and income generation (**Table 5**). The most productive local crops are teff and maize, which are considered staple food items and important income sources. Currently people in the study area prefer to sell teff at local markets rather than consume it because it has the highest commercial value relative to other crops. Vegetables produced for both subsistence and commercial purposes include onion, cabbage, pepper, pea, potato and sugarcane.

Table 5: Characteristics of major crops identified by both men and women

Crop	Sowing period	Harvest period	Yield per hectare (quintal)*	Market price per quintal (USD)
Maize	Mar 28-May 18	Oct 24-Nov 24	8	22
Teff	Jul 22-Aug 13	Oct 28-Jan 8	13–17	56–76
Wheat	–	Jan 8-Feb 8	8	32
Barley	Jun 24- May 24	Sept 11-Oct 7	12	31
Bean	Jun 24-Jul 20	Nov 8-Dec 8	8	88
Pea	May 18-Jun 24	Sept 11-Oct 8	8	88
Lentil	Aug 30-Sept 25	Jan 8-Feb 8	7	110

Note: *1 quintal = 100kg

Dominant crops produced in the study sites include cereals (wheat, barley, teff, and maize), pulses (bean, pea, grass pea), and oil seeds. Male farmers identified maize as the most productive crop, followed by teff. Current mean market prices for teff range from 66 to 174 USD/quintal. Workshop participants reported that vegetable production had been increasing over the four previous years because of the expansion of irrigation and greater access to improved vegetable seeds.

Participants observed that farmers with access to irrigation for growing vegetables have greater income relative to residents in *kebeles* that rely on rain-fed agriculture. Households

generate additional income from artisanal non-farm activities such as pottery, textile weaving, metal work, and mining.

Although men reported a similar reliance on agriculture as a primary livelihood means as women, they specifically mentioned the importance of eucalyptus trees. Due to generally inadequate soil productivity for crop production, households often set aside farmland for commercial eucalyptus production. Income generated from the sale of trees is often used to cover costs of fertilizers, school expenses, renting cropland and other household expenses. Eucalyptus trees are typically harvested 3–5 years after planting. Participants indicated that eucalyptus production alleviates harvest pressure on native tree species. Eucalyptus is preferred for production purposes because the species cultivated locally is fast growing and serves multiple purposes such as providing home construction, fuelwood and fencing materials. However, participants also identified negative impacts of eucalyptus production on the local environment, particularly on soil and water resources, and thus trees are usually planted on marginal land like slopes and gullies. The land adjacent to eucalyptus groves is typically used for livestock grazing rather than crop cultivation.

Water resources

As noted earlier, a majority of farmers in the study area engage in rain-fed agriculture. Local water sources include the river, springs, pump operated wells, and manually operated wells. Small-scale irrigation systems are uncommon in the study area. Diesel generators are used to pump irrigation water. Irrigation systems are often used for subsistence fruit and vegetable production. Water was not perceived as a critical resource by study participants of either gender. Rather, the time spent for water collection (**Table 1** and **Figure 3**) was considered an important aspect affecting the collection of other nexus resources (e.g., energy resources) as presented in **Table 1**.

3.3 Drivers of the WEF nexus system

Social

Both male and female farmers are subject to similar social, ecological and economic processes that drive local WEF nexus system dynamics. According to all participants, rapid population growth is the most prevalent problem in Ethiopia because of increasing pressure on limited land and other natural resources. The resulting shortage of arable land contributes to emigration from rural areas, mostly by rural youth. The major migrant destinations are urban areas of Oromia (Dello-Bale and Wollega) and Amhara (Hawi and Armacho), as well as Addis Ababa and neighboring towns. Most migrants seek work opportunities as day laborers. Youth unemployment rates are high (Denu et al. 2005). Children are sometimes hired locally as labor for herding cattle. According to participants the average annual payment for a child working as a livestock herder is approximately 110 USD.

Ecological

Soil degradation and particularly soil productivity declines due to soil erosion and deforestation were identified as major ecological factors affecting WEF nexus system dynamics in the study sites. Participants reported that these processes have reduced the availability of biomass energy resources. Soil productivity is also decreasing due to overgrazing and increased use of cattle dung and crop residues for meeting domestic energy needs, reducing their availability for application as organic fertilizer. Furthermore, mean household livestock numbers have declined due to pasture and associated fodder shortages. Workshop participants also mentioned weather variability as a common problem, including temporal rainfall patterns and temperature (increases).

Economic

Farmers reported that both income and expenses have been increasing in recent years. Overall, they identified a decline in poverty over the last 10 years. Participants observed that more farmers have access to improved agricultural technologies such as improved seeds, fertilizers, appropriate agronomic practices, and pesticides. According to the farmers mean household income has increased in recent years due to improved farm productivity, income diversification via increasing common sources such as small-scale irrigation systems, greater tree production, increased livestock finishing prior to slaughter, and reduced social expenses such as spending on wedding ceremonies and cultural festivals.

Workshop participants reported that the prevalence of share-cropping and land rental arrangements are increasing in the *kebeles*. Local municipalities pay limited compensation to farmers evicted from land that is leased to commercial interests. Current lease rates for commercial operations are approximately 35 USD/m².

Technical support from extension agents and different actors has helped farmers increase productivity on smaller areas of land. Farmers reported that expenditures on fertilizers, improved seeds, pesticides, school expenses, and purchased food items (e.g., cooking oil, sugar, etc.) have exhibited a steadily increasing trend.

3.4 Interactions

Gender based perceptions of the resources, dynamics, and interactions are presented in **Figure 2**. The interactions represent actions undertaken by key farmers to utilize the target resources. Synthesizing the key elements identified by participating farmers resulted in the conceptual model of the local WEF system according to gender. Although the mental models of both male and female farmers identified very similar resources and drivers of change, there is some differentiation in terms of actions performed with target resources and their uses.

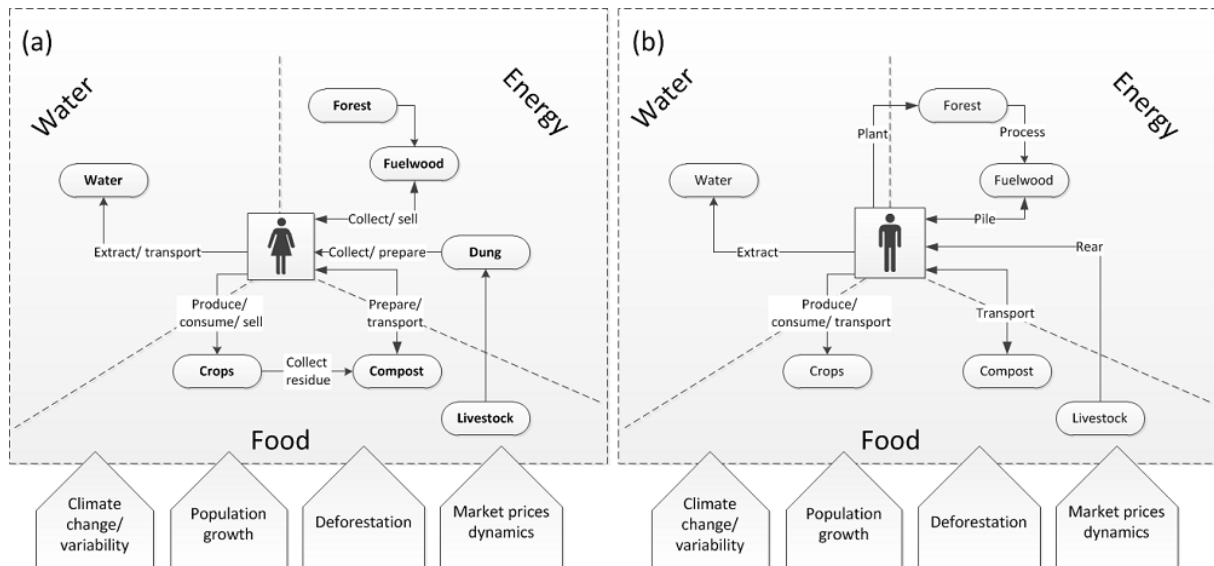


Figure 2: Conceptual frameworks of the local WEF nexus system according to gender

Some actions reported by workshop participants have temporal characteristics. Gender-specific tasks are particularly apparent on a daily basis. Daily activities in relation to the access to and management of WEF nexus resources by gender are presented in **Figure 3**. Both males and females share several productive roles, such as chores related to feeding and caring for cattle. Several gender-specific productive roles mentioned earlier were confirmed by workshop participants, such as the differentiation of tasks related to fuelwood procurement mentioned (**Figure 3**) and primarily female and/or children responsibilities related to water (for cooking and drinking) and dung cake collection and preparation. Activities such as raising cattle, transporting fuelwood and collecting crop residues and cattle dung are often shared with household children during holidays and on Sundays. Based on daily activity cycles, the specific roles of females in crop production are not obvious, but may be flexible relative to other domestic roles. Because females are responsible for domestic roles such as meal preparation and energy resource collection, it might be difficult to isolate specific productive roles (i.e., sowing and harvesting crops) from other domestic roles. In contrast, male-specific productive responsibilities are more clearly distinguishable.

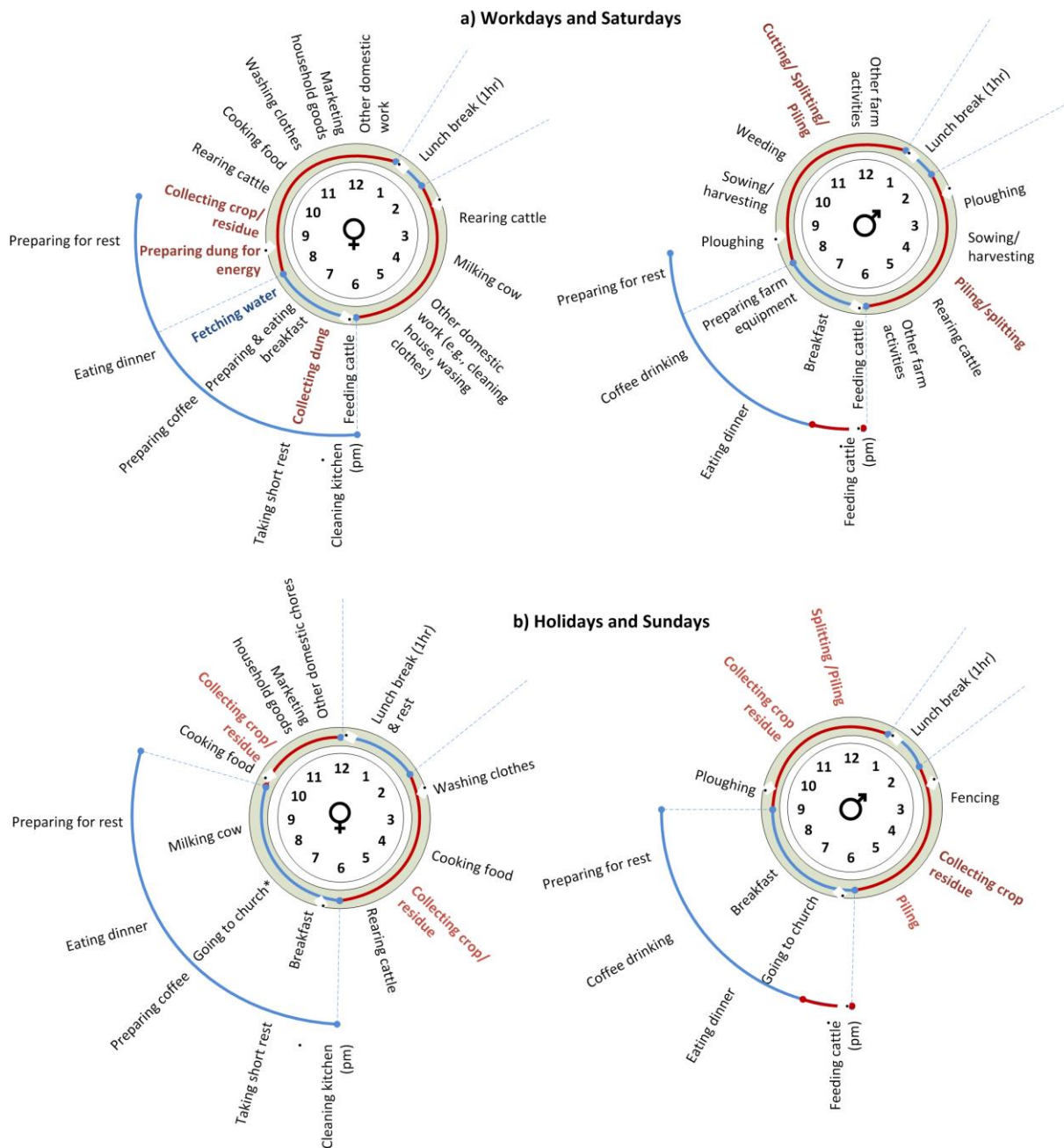


Figure 3: Daily activity cycles of male and female farmers in the study area

Using the World Bank dataset (CSA-LSMS-WB 2015; **Table 1**), **Figure 4** presents the factors associated with the amount of time spent on domestic energy collection (i.e., firewood and dung cakes). For female-headed households, five variables were significantly associated with the amount of time spent on domestic energy collection. Among the variables identified (**Figure 4a**) the time spent on water collection and agriculture by females and yields from teff had the highest impact (measured as the coefficient of standardized variables). Five variables were also significantly associated with the amount of time spent for domestic energy collection for male-headed households (**Figure 4b**). Among these variables, sorghum yields, time spent on water collection by males, and total household farm areas had the greatest

impact. Both gender types are influenced by their time spent on water collection. Nevertheless, the female-headed households reduced their time spent on energy collection when their main energy source for cooking is either firewood or charcoal. In male-headed households the amount of time spent on energy collection increased significantly as the time spent by female household members on domestic energy collection increased (**Figure 4b**).

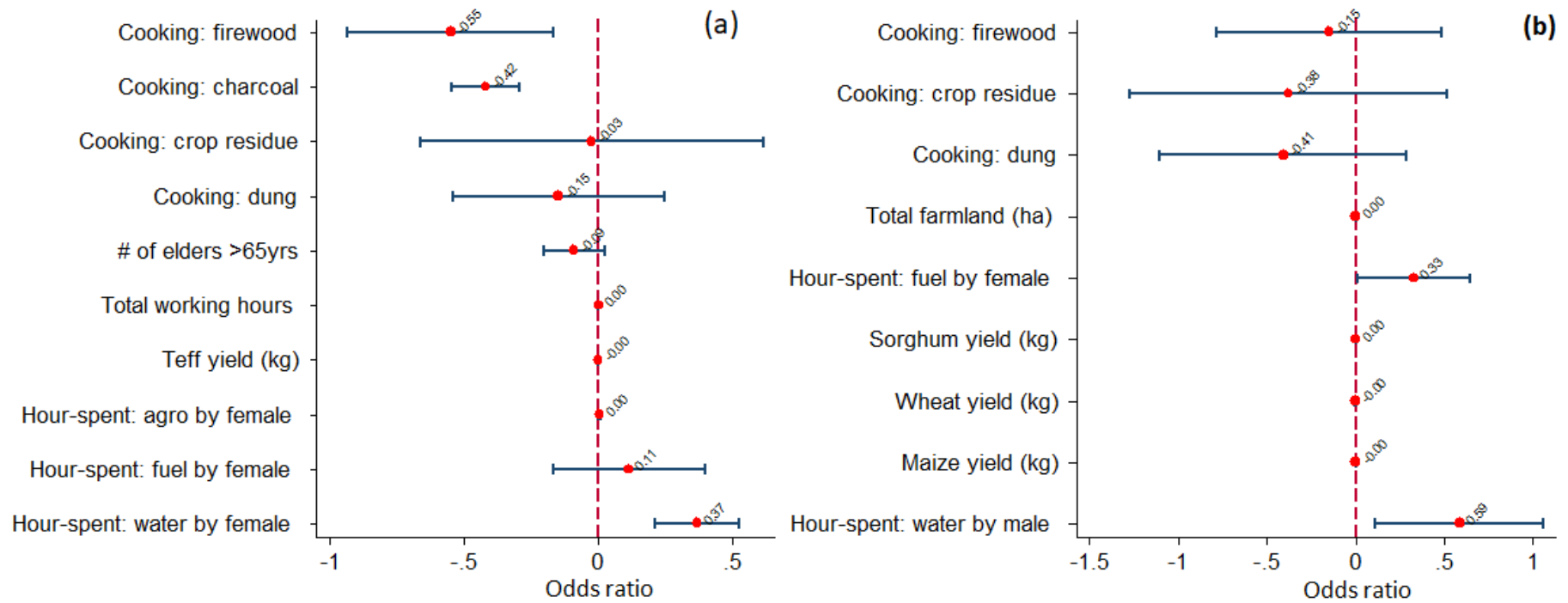


Figure 4: Determinants of the amount of time spent on energy resource collection by female-headed (a) and male-headed households (b)

4. Discussion

4.1 Gender-specific differences

Understanding WEF nexus issues at the local level has its own complexities, which can be described as follows:

- i. *Access to key actors that shape WEF nexus dynamics*—Our findings show that male and female farmers had differential access to key actors with broad scales of influence. For example, males reported access to a broader spectrum of actors involved in elements of the WEF nexus than females, particularly with respect to energy, minerals, and irrigation. This was reflected by relatively greater awareness of energy alternatives (i.e., biogas, grid electricity) among male-only groups. On the other hand, females were more likely to interact with merchant and health actors. Due to increased demand and prices for teff, farmers are more likely to sell teff normally produced for household subsistence purposes. As mentioned earlier, female participants also exhibited greater knowledge of the use of improved cooking stoves and related energy consumption. Both male- and female-only groups underscored the role of government actors in affecting WEF dynamics. According to Hoff (2011) the WEF nexus concept is concerned with addressing externalities across multiple sectors, with a focus on system efficiency rather than the productivity of isolated sectors. Our results confirm the state-driven and centralized governance structure in Ethiopia that extends to the *kebele* level. Since local administration offices coordinate with actors in other sectors, this governance structure may promote resource efficiency technologies at the local level. However, as observed during the interviews, administration offices direct natural resource management outreach to male farmers (as household heads). According to one female workshop participant, *“my husband is the one talking to the administration representative and frequently with extension agents; anyway, it is his job because he is the head of the household, and that’s what the head of the household should do.”* Gender oriented outreach may present a significant challenge when the head of the household is female.
- ii. *Perception of resources*—The results indicated gender-specific perceptions of relevant resources. Men explicitly regard livestock as a resource (for livelihood and recognition) because men use livestock (e.g., oxen) for farming activities (e.g., ploughing). Whereas females were more likely to identify products derived from livestock such as cattle dung and milk as (energy and food) resources; they use livestock products and undertake activities such as preparing/collecting and selling of cattle dung and milk (**Figure 2**). These perceptions are associated with gender-specific tasks and/or the degree of direct benefit from resources.

- iii. *Gender-specific roles*—Productive roles are activities that generate income and have either an actual or potential value. Reproductive roles are activities related to biological reproduction and the maintenance of home and family members. Community management labor are activities at the community level that ensure the allocation, provision and management of items consumed collectively such as water, health care and education (Moser 1993). Time allocation to daily tasks among women appears to be more flexible, in that they participate in all three spheres (**Figure 3**). The role of females is dominant in the reproductive sphere, while time and effort are largely concentrated in the productive sphere among men. However, in spite of the relatively blurred representation of women’s daily tasks, they are mainly responsible for energy resource collection. Scheurlen (2015)² noted that women in Ethiopia spend more time on fuelwood collection than men. A similar finding is shown in **Table 1** and **Figure 4**.
- iv. *Decision to utilize resources*—Although it is commonly understood that in a patriarchal social system like that found in Ethiopia, males are considered the household decision makers; however, decisions of whether or not to use cattle dung for domestic energy, a soil treatment, or for compost are commonly made by household females. Contrarily, decisions regarding livestock and eucalyptus production are mainly made by household males. Other factors may affect decision making, for example whether or not to sell teff harvests may be highly dependent on market value. Studies of factors that influence decision making regarding (biomass) energy use have identified some of these alternative influences. For example, household consumption of biomass energy sources may change due to ownership of an improved stove (Mekonnen et al. 2015), which is also reflected by reductions in energy resource consumption among households in our study area. Other influences include the distance to biomass energy resource collection areas, livestock (particularly oxen) ownership, certain demographic characteristics, (Mekonnen et al. 2015), and off-farm wages (Djanibekov et al. 2016; Djanibekov and Gaur 2018).

These may be important factors that influence how household decisions are made (especially if interventions are introduced), how such decisions may affect a household biophysical environments, feedback effects on future decisions (Elsawah et al. 2015; Villamor et al. 2014), and the sustainability of WEF nexus resources.

4.2 Insights into the WEF nexus

The WEF nexus approach is an expression of trade-offs (Kurian 2017). Often times trade-offs relate to stakeholder perspectives (and response to a given situation) along with the concept

² Using the 2005 IFPRI-CIMMYT household dataset

of resource efficiencies (Villamor et al. 2017). In this case trade-offs may emanate from these gender-specific differences. For example, males may tend to reduce WEF nexus trade-offs at the *kebele* level because they have access to a broader spectrum of actors involved in WEF resources relative to females. This might also suggest that males have more opportunities to access higher level and more influential WEF actors. On the other hand, because of gender-specific roles and decisions, male and female farmers may focus their attention on only one or two nexus resources. For instance, females may focus more on dung cake as an energy source, whereas males may focus more on fuelwood. On the other hand, a male farmer may use a majority of his time on raising livestock, while a female farmer may use more of her time on crop and dung cake production. Areas where there appear to be tradeoffs between allocation of time spend for WEF nexus resources are presented in **Figure 4**. Time spent on firewood collection by female-headed households is negatively associated with teff yields; whereas male-headed household time spent on domestic energy collection and preparation is negatively associated with wheat yields. Thus, working together collaboratively with all household members to define the role and activity of household members can reduce trade-offs and foster synergies on WEF nexus resources at both the household and *kebele* levels (Djanibekov et al. 2015).

One very important question is if the introduction of technology to improve energy efficiency or bioenergy use will translate into greater leisure time (or greater availability for off-farm activities) for women or men. This is a key question for addressing gender inequality and enhancing quality of life (e.g., self-development) in rural areas. According to Meares (1997), time for self-development is not something most women consider an important facet of quality of life in rural areas. If productive activities of men change, it can affect the labor activities of female household members. For example, if household men find off-farm work or emigrate in search of paid labor, they relinquish responsibilities for farm management tasks such as raising cattle or poultry and cultivating vegetables and other crops. In fact, no family member is exempt from contributing labor in the productive sphere. Self-development may be facilitated, however, if radical changes are implemented to female responsibilities in the reproductive sphere (Meares 1997). Nevertheless, the labor transition within households (from primary to secondary sectors) is one of the critical WEF nexus system dimensions identified by Smajgl et al. (2016). Accordingly, the more household members who engage in secondary and tertiary sectors, the more likely that energy (i.e., electricity) demand will grow. Whether this critical system dimension applies or not in the context of Ethiopia remains unanswered and requires further analysis (considering that migration is one of the socio-economic dynamics raised by the respondents).

Despite the Ethiopian national government's efforts, such as the Growth and Transformation Plan in 2010 and the Climate-Resilient Green Economy (CRGE) strategy in 2012 (which established a national pathway for agricultural and rural development), heavy reliance on fuelwood, dung cake, and crop residues is prevalent in rural areas. There is also a tendency

for farmers to intensify crop production (e.g., teff) in response to high market value; however, since fuelwood and dung cake remain the preferred domestic energy sources for many households, time spent on domestic energy collection by female-headed households may be negatively affected (**Figure 4a**). Indeed, WEF nexus framework and interventions discussed at the global scale may not apply to local contexts. Thus, attention should be given to the political economy of the WEF nexus (Stein et al. 2014), especially in rural contexts, as well as consideration of gender-specific perceptions of WEF nexus components. Ringler et al. (2013) suggested that the development and dissemination of technologies for improving resource-use efficiency (e.g., integrated soil fertility management) should be targeted with consideration of policies and gender-based perceptions of WEF nexus (Bryan et al. 2013). The gender-based decision making can also be influenced by market, agricultural production, climate and other changes, in which case the response of decision makers might change, e.g., men might be more involved in selling eucalyptus trees if its price increases. Hence, in future research it is important to consider the change in gender roles when the changes in external settings occur.

5. Conclusions

Male and female farmers in the study area of rural Ethiopia shared similar understanding and perceptions of the local WEF nexus system. They exhibited particularly developed perceptions of energy-food-land resource linkages because they continue to rely heavily on fuelwood and agricultural by-products for their domestic energy needs. On the other hand, conceptualizing perceptions according to external actors, access to WEF nexus resources, nexus dynamics and processes involved, and their interactions, revealed dissimilarities between males and females that are likely to influence interactions with, and the dynamics of, the WEF nexus. These include gender-specific productive roles, access to external actors, perception of resources, and decision making regarding resource utilization. These differences should be considered for the promotion of energy supply innovations, particularly for replacing traditional biomass use at the local level. Our results provide insight into how linkages between men and women farmers and the relevant WEF nexus actors that they identified may be relevant for the management of WEF nexus resources.

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