Alien Plant Species: Environmental Risks in Agricultural and Agro-Forest Landscapes Under Climate Change

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Abstract Alien plant species have been essential for farming and agro-forestry systems and for their supply of food, fiber, tannins, resins or wood from antiquity to the present. They also contributed to supporting functions and regulating services (water, soil, biodiversity) and to the design of landscapes with high cultural and scenic value. Some of those species were intentionally introduced, others arrived accidentally, and a small proportion escaped, naturalized and became invasive in natural ecosystems—these are known as invasive alien species (IAS). Here, invasive means that these species have some significant negative impact, either by spreading from human-controlled environments (e.g. fields, gardens) to natural ecosystems, where they can cause problems to native species, or to other production systems or urban areas, impacting on agricultural, forestry activities or human

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health. Socio-environmental impacts associated with plant invasions have been increasingly recognized worldwide and are expected to increase considerably under changing climate or land use. Early detection tools are key to anticipate IAS and to prevent and control their impacts. In this chapter, we focus on crop and non-crop alien plant species for which there is evidence or prediction of invasive behaviour and impacts. We provide insights on their history, patterns, risks, early detection, forecasting and management under climate change. Specifically, we start by providing a general overview on the history of alien plant species in agricultural and agroforestry systems worldwide (Sect. 1). Then, we assess patterns, risks and impacts resulting from alien plants originally cultivated and that became invasive outside cultivation areas (Sect. 2). Afterwards, we provide several considerations for managing the spread of invasive plant species in the landscape (Sect. 3). Finally, we discuss challenges of alien plant invasions for agricultural and agroforest systems, in the light of climate change (Sect. 4).

Keywords Ecosystem service · Impact assessment · Introduction history
Plant invasions · Predictive modelling · Remote sensing

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1 Introduction

For millennia the introduction of alien species has been part of human culture and subsistence. The intentional cultivation of alien plant species has enhanced the local production of food, fiber and fuel throughout the history of agriculture and agro-forestry. Over time, this practice has inevitably lead to the selection of crop and tree cultivars that could adapt to and thrive in new areas with compatible environmental conditions, even if these were often distinct from those observed in the native range (Davis and Landis 2011). Some currently traded crops were once widespread weeds in disturbed ecosystems, characterised by particular features that make them well-adapted and fast-growing plants outside their native range (Doebley 2006). Similarly, a broad range of tree species that currently form the basis of many forestry enterprises have been planted for centuries to obtain timber and other products and services (e.g. erosion prevention; (Richardson 2011).

These long-term processes of human introductions and alien species adaptations to novel environments have thus shaped many contemporary agricultural and agroforest landscapes. However, current fluctuations in market demands have been pushing the trade of alien crops beyond the limits of local-scale economies (Davis and Landis 2011). Also, the increasing market competition for faster and higher production of commercial wood products led to large scale afforestation with alien tree species (Brundu and Richardson 2016). As a result, modern agriculture and agroforestry are grounded on the regional maintenance and international trade of many alien crops and trees (Davis and Landis 2011; Richardson 2011).

Depending on several ecological, economic, social and political factors, modern agriculture, agroforestry and the related trade can promote plant invasions, i.e. the spread of alien crops and trees outside their cultivation areas, leading to major impacts on the environment and society (Richardson and Rejmánek 2011). Besides threatening native biodiversity and ecosystems (Pysek et al. 2008; Simberloff et al. 2013), these plant invasions have been associated to drastic changes in the state of ecosystems and of their associated social systems, with various consequences for human culture, health and economy (Pejchar and Mooney 2009; Vaz et al. 2017).

Since invasive plants are particularly relevant in agroforestry, many cultivated trees rank among the most problematic invasive species world-wide (Richardson and Rejmánek 2011), leading to decreases in the production of forest resources and respective revenues (Garcia et al. 2010; Garcia-Llorente et al. 2011). There is also an increasing attention devoted to problematic trends of plant invasions in agricultural systems (Chytrý et al. 2009). Alien agricultural crops are introduced more frequently and at a higher abundance to new ranges, leading to higher propagule pressure, which increases invasion risk in land surrounding agricultural landscapes. Associated with these introductions there is also an increased unintentional transfer of pathogens, weeds and insect pests (Davis and Landis 2011; Garcia et al. 2010).

Although many currently traded crops and trees do not show an invasion potential or risk, some of these species may change their behaviour under climate change, for instance through adaptive physiological responses (Davis and Landis

2011; Krumm and Vítková 2016). Other species will profit from new climates, resulting in new invasions (Hannah et al. 2002) with consequences to human societies, economies and the environment. How problematic those new invasions driven by climate change will be depends on the characteristics of the species and on the effectiveness of invasive plant management in agricultural and agroforestry systems and in the surrounding landscapes. It is now widely recognised that the most time- and cost-efficient management option for potentially invasive species is to prevent the introduction and spread of those species as early as possible (Vicente et al. 2016; Hulme 2006; Davies and Sheley 2007).

Therefore, predicting and identifying future potentially invasive species, and anticipating where new invasions will most likely occur (Theoharides and Dukes 2007) under scenarios of climate and landscape change, is a major challenge in invasion science. Novel and more robust modelling tools (e.g., by means of species distribution models; (Kolar and Lodge 2001; Shmueli 2010) are being developed in the context of invasion risk assessment. These tools open promising avenues to minimize undesirable consequences of potential future invasions, thereby supporting efficient management that secures native biodiversity and promotes ecosystem functioning and the resulting services (MA 2005) Theoharides and Dukes 2007).

This chapter is organised as follows: it starts by providing a general overview on the history of alien plant species in agricultural and agroforestry systems worldwide (Sect. 1). Then, it focuses on the patterns, risks and impacts derived from alien plants that were originally cultivated but became invasive outside cultivation areas (Sect. 2). Subsequently, the chapter provides considerations for managing the spread of invasive plant species in the broader landscape (Sect. 3). Finally, this chapter discusses current and future challenges of alien plant invasions for agricultural and agroforest systems, in the light of climate change (Sect. 4), encouraging the wide application of predictive models from which management strategies can be designed to restore ecosystems structure, functions and services.

2 A Brief Historical Perspective on the Introduction of Alien Plant Species

Agriculture arose approximately 10,000 years ago. From the main centers of origin of Neolithic Agriculture practices, it has spread to most other regions of the world, transporting plants with edible seeds, fruits, leaves, stems and roots to new ranges (Mazoyer and Roudart 2006). In these new areas, introduced species together with domesticated local species and varieties ensured the survival of settlers. Agroforestry, i.e., the practice of cultivating tree species and agricultural crops in intimate combination, was an integrated land use that showed several advantages with the ultimate objective of food production in several territories since ancient times (Smith 2010). People cultivated food crops and created pastures on the cleared areas inside woodlands, where the soils were deep and rich in humus. Native and alien trees and shrubs (e.g. brooms, reeds, Indian-figs and Iron trees) were also used as fences to protect crops and cattle from strong winds and sunstrokes.

Until Modern times, agriculture or agroforestry diversification developed slowly but steadily. In the 18th and mainly in the 19th century, cumulative factors contributed to the globalization of these activities. Portugal, Spain, France, Netherlands and the United Kingdom were then European empires and developed colonial science and agriculture transferring live beings to and from their colonies in the four other continents and islands (Crosby 2004; Grove 1995; Murphy 2007; Rotherham 2011). The emergence of the concept of acclimatization led to "an intended and 'scientific' mediated transplantation of organisms" (Osborne 2000). Acclimatization societies, frequently supported by the states, promoted the exchange of plants for horticulture, satisfying aesthetical pleasing through collecting and gardening, and adapting new species to create more diverse, resilient and productive farming systems. Increasing transportation of people and livelihoods, and the booming transatlantic trade, also facilitated intentional and accidental introductions. Additionally, "philosophical travels" were made by naturalists in charge of finding, collecting and transporting species that could provide cultural and economic benefits in the arrival areas. Living plants and seeds were then cultivated in botanical gardens and later, if successful, distributed by farmers.

Towards the end of the 19th century, while agronomy became a science, and scarcity and hunger were a reality, farmlands and cultivated forests expanded with a whole new species composition (field crops and trees). Among intentionally introduced alien species, and others that arrived in association with them, a few escaped from gardens, fields and greenhouses and became invasive.

3 Invasive Plant Species Originally Cultivated in Production Systems and Their Impacts Outside Crop Areas

3.1 The Most Wide-Spread Plant Invasions

Biological invasions by weeds are intimately related with human history, as humans have not only enabled transportation of organisms from one site to another, they have also imprinted changes in the landscape that have facilitated the establishment of those organisms. When human settlements began to thrive, there was a huge increase of area occupied by crops and pastures at the expense of the natural forests, which originated the landscapes that we know today (Meeus et al. 1990). Weeds were the first plants introduced outside their native area, a process that started in ancient historical periods, making it difficult to determine the origin of some of those species. The first flow of weeds presumably occurred between Asia and

Europe, although there are indications of plant movements in the American Continent because of the intense agricultural activity practiced by the pre-Columbian cultures (Elton 2000). At the end of the 15th century, the exploration and colonization of distant areas of the globe began to substantially increase the number of naturalized species able to colonize areas outside their native range (Cousens and Mortimer 1995).

Some plant species that colonize agricultural fields are among the most common invasive species worldwide. Weed species from tropical areas such as C4 grasses are successful in many agricultural areas around the globe because of their drought tolerance and efficient photosynthetic pathway (Maillet and Lopez-Garcia, 2000). Some of these weed species with shorter lifespans have evolved to support environments other than their native areas, such as some C4 grasses (e.g. *Echinochloa crus-galli*) that are colonizing areas further north, as a result of the increased catalytic efficiency of some enzymes (Lee 2002).

Other species introduced by their interest for humans are nowadays a nuisance for agriculture and silviculture. Among those are the species of genus *Opuntia*, from America, and of genus *Acacia*, from Australia (Thuiller et al. 2006). In the majority of areas of the world, most weeds in a region are not native but were introduced by humans, often deliberately (Mack and Lonsdale 2001). And although there are common invasive weeds across the globe (e.g. *Acacia mearnsii*, *Arundo donax*, *Eichornia crassipes*, *Opuntia stricta*), others are only considered a problem in certain parts of the world (e.g. *Ulex europaeus*, *Euphorbia esula*), highlighting human facilitation as a major driver (Lowe et al. 2000).

3.2 Impacts on Ecosystem Services

Ecosystem services (ES) are the material and non-material contributions that ecosystems bring to human development and wellbeing (MA 2005). There are different frameworks to categorise ES, such as the *Millennium Ecosystem Assessment* (MA 2005), *The Economics of Ecosystems and Biodiversity* (TEEB 2010) and the *Common International Classification of Ecosystem Services* (Haines-Young and Potschin 2013).

These frameworks usually recognise three ES categories—provisioning, regulating and maintenance, and cultural services (MA 2005; TEEB 2010). Provisioning services include material and energy outputs from ecosystems (e.g., timber, food, water for consumption), whereas regulating and maintenance services comprise the benefits that derive from regulatory ecosystem processes (e.g., soil stabilization, climate regulation, pollination). Cultural services comprise the intangible benefits from ecosystems such as spiritual and cognitive enrichment, aesthetics, and recreation (Haines-Young and Potschin 2013; MA 2005).

In agricultural and agroforestry systems worldwide, the intentional cultivation of alien plant species has for long been a practice to obtain specific provisioning services, e.g. timber, pulp, forage or tannins (Davis and Landis 2011). Other alien plant species have further been cultivated to maximize regulating services (e.g. soil nitrogen fixation, land stabilisation, erosion protection) besides provisioning services (Richardson 2011). At a minor scale, in particular when planted in agroforestry systems, alien plant species can further contribute to cultural services, supporting landscape amenity and recreation (Foxcroft et al. 2008; Vaz et al. 2018).

However, some cultivated alien plant species can establish and spread beyond cultivation sites, i.e. they become invasive (Brundu and Richardson 2016). These invasive alien plant species (IAS) can alter ecosystem processes, in particular by reducing native biodiversity and competing with service-providing species (Levine et al. 2003; Simberloff et al. 2013; Vilà and Hulme 2017). For instance, IAS can indirectly affect provisioning services, by minimising the availability or reducing the quality of resources that humans use outside cultivation areas. Notable examples include the depletion of water for human consumption through several *Prosopis* and *Acacia* species, or livestock poisoning by *Prosopis juglans* and *Sorghum halapense* (Carruthers et al. 2011; Davis and Landis 2011; Richardson 2011). IAS can also change regulating services, by altering and disrupting ecosystem functions and processes outside production sites. Examples include the amplification of fire regimes by *Pinus radiata*, the reduction of stream flow by *Prosopis juliflora and Arundo donax*, and altered nutrient cycles by *Sorghum halepense* (Davis and Landis 2011; Dickie et al. 2014; Richardson et al. 2014).

Although IAS can have straightforward effects on provisioning and regulating services, IAS effects on cultural services may be perceived differently by different stakeholders (Vaz et al. 2018). For example, *Acacia dealbata* and a few *Pinus* species are by some people recognised for their ornamental (e.g. due to attractive blooms) and recreation (e.g. because of shade provision) values, respectively (Dickie et al. 2014; Vaz et al. 2017). At the same time, several *Eucalyptus* and *Acacia* species are perceived by other people as undesirable for aesthetic (e.g. invaded landscapes considered as monotonous) or spiritual (invaded areas associated to the lack of a wilderness character) values, respectively (Carruthers et al. 2011; Kueffer and Kull 2017; Vaz et al. 2018).

4 Managing the Spread of Invasive Plant Species in the Broader Landscape

4.1 Strategies to Tackle Invasive Plant Species

Given the economic, ecological and social impacts of widely dispersed invasive alien plant species (IAS), it is crucial to focus the existing (often limited) resources in management strategies that allow tackling them more successfully. In this context, it is vital to prioritize the prevention of new (potentially) IAS and the early-detection of new outbreaks in order to promote effective and timely management that limits new invasions.

Preventing the introduction of IAS into new areas is surely one of the most cost-effective management strategies (Pysek and Richardson 2010). In the context of this chapter, this may include preventing the spread of alien species grown in agricultural and agro-forest landscapes into surrounding areas; these invasion events may increase in the future as some species are expected to change their behaviour under climate change (Hellmann et al. 2008). Different actions can be considered, such as the implementation of crop monitoring protocols to detect alien plants starting to establish and escape, surveillance of dispersal routes and vectors to intercept new spreading events, raising awareness of different stakeholders and communities, etc.

Early Detection and Rapid Response (EDRR) are also crucial to minimize the impacts of IAS, being highly cost-effective when compared to management costs in later phases, and thus justifying a strong investment to improve protocols and techniques available. These include space- and air-borne remote sensing platforms for species monitoring and surveillance, species distribution modelling to map areas with higher potential for invasion, and the development of species identification tools and protocols. Although the extension of surveillance areas and the large diversity of potentially IAS make EDRR difficult (Pysek and Richardson 2010), in the context of cultivated areas, potential IAS are frequently identified and easier to target, and the surrounding area may be more restricted, turning early detection more feasible. Early detection may prioritize species or areas (e.g., habitats with higher conservation value surrounding crops, areas prone to invasion, species with higher invasive risk) in order to increase its effectiveness. Rapid response should include a rapid and detailed inventory of the populations occurring in all the surrounding area in a way to prevent small scattered foci from passing unnoticed, thus precluding eradication. Citizens or specific stakeholders previously trained can also be important allies in EDRR and associated surveillance and monitoring schemes (Holcombe and Stohlgren 2009).

IAS initially used as crops, but that nowadays promote negative impacts demanding their control, can be tackled through eradication, containment, control or mitigation, depending on the invaded extension and availability of resources. Associated with any of these options, it is essential to consider the monitoring of results (to learn from experience and adapt follow-up interventions), the persistence of management interventions, and eventually actions to actively restore the invaded areas. Although all these strategies are frequently very costly, complex and time-consuming, well-planned interventions based on strong technical and scientific knowledge, planned for medium-long term and involving the different stakeholders and their interests, allow reaching good levels of success. Nevertheless, when resources are insufficient, managers should pragmatically analyse if control is cost-efficient or if inaction may be preferable.

4.2 *Modelling and Detection Tools to Support Management*

4.2.1 Remote Sensing Based on Airborne Sensors

In recent years, the development of unmanned aerial vehicles (UAVs) has been an important contribution to the study of the ecological dynamics of invasive species. These airborne systems have become more reliable and functional, being able to operate with low planning needs and in increasingly demanding meteorological and terrain conditions. Although they do not have the capacity to cover large areas, as satellite systems or classical aerial photography, their implementation is inexpensive and, with the right combination of aircraft and sensors, the final results can be very useful.

UAVs have all the advantages of an aerial point of view to the landscape, and since they fly significantly lower than conventional flight systems, they can be used to obtain aerial photography with a very high resolution (Gonçalves and Henriques 2015). Typically, a small fixed wing or multicopter UAV system can cover areas between 80 and 200 ha with a single battery and with about 3–6 cm/pixel of ground sampling distance (Colomina and Molina 2014). The airborne sensors have also evolved. Nowadays it is possible to use several small RGB, multispectral and hyperspectral cameras available on the market, allowing the use of aerial imagery obtained with these systems with any remote sensing computational tool for vegetation study purposes (Ahmed et al. 2017).

A major advantage of these systems is that the collection of aerial imaging can be done simultaneously with georeferenced ground fieldwork for species identification. This ensures that the remote detection final results are more robustly validated. Besides the high spatial resolution, these systems also ensure a high temporal resolution of the monitored area, by repeating flights with the same flight plan. Accurate multispectral orthophotos and three-dimensional digital surface models are usually the most common products that are obtained with these systems. These products can be processed by the most common remote sensing software.

4.2.2 Habitat Distribution Models

Habitat suitability models (HSM; Guisan et al., in press) represent important tools for anticipating plant invasions and spread (Gallien et al. 2012; Peterson 2003), and thus for the management of invasive alien plants (Guisan et al. 2013; Meier et al. 2014; Richter et al. 2013; Venette et al. 2010), especially if based on ensemble modelling (Bellard et al. 2013; Stohlgren et al. 2010). In particular, HSMs could be embedded in adaptive management frameworks connected to national and international biodiversity databases (e.g. GBIF), to direct field monitoring and eradication efforts (Honrado et al. 2016; Venette et al. 2010). Their data results could in turn update the models in an iterative and adaptive way, as already proposed for the management of rare species (Guisan et al. 2006).

Early efforts applying HSMs to anticipate invasions proposed to fit models in the native range and project them into the invaded range (Peterson 2003), but issues were raised later about the possibility that species' ecological niches, on which these models are based, may change for some species after invasion, hampering the proper application of these models (Early and Sax 2014; Guisan et al. 2014) and references therein). This supports the use of data from both the native and invaded (exotic) range for building HSMs, which can then be applied more accurately in both ranges (Beaumont et al. 2009; Broennimann and Guisan 2008). Another important argument in favor of such combined ranges approach is that it makes more likely that the full ecological niche is captured in the HSM, whereas using local data (e.g., only in the invaded range) bears the risk of fitting truncated response curves and making wrong predictions (Petitpierre et al. 2016; Thuiller et al. 2004).

In general, the study of biological invasions will require hierarchical modelling approaches combining multiple scales (Pysek and Hulme 2005). Future modelling directions include (i) adding more dynamic components, such as dispersal and population dynamics, in HSMs though the further development of hybrid models (Ferrari et al. 2014; Gallien et al. 2010; Pysek and Hulme 2005); (ii) better understanding the dynamics of niche filling and expansion during invasions (Broennimann et al. 2014); (iii) improving the environmental predictors used in HSMs, such as new remotely sensed images (Andrew and Ustin 2009; Bradley 2014), as these are also typically used in more general monitoring programs (e.g. GEOBON); and (iv) fitting invasive species models in a hierarchical manner, combining the strength of local data at fine resolution with global data (e.g., to fit the whole species climatic niche) (Petitpierre et al. 2016).

4.2.3 Dynamic Ecological Models

Dynamic models are focused on ecological processes, which differ from static models by explicitly incorporating time-dependent changes in the state of a system (Jørgensen 2008). These models include, among others, biogeochemical dynamics (e.g. Soetaert et al. 2000), population dynamics (e.g. Kriticos et al. 2009), individual-based models (e.g. Nehrbass and Winkler 2007), and cellular automata systems (e.g., Crespo-Pérez et al. 2011).

The ability to anticipate invasive plant species trends and distribution patterns as ecological indicators under different socio-ecological scenarios depends on the accuracy to predict their invasiveness and the invasibility of threatened habitats (Peterson 2003). Therefore, biological invasion studies have been improved by creating dynamic models that simultaneously attempt to capture the structure and functioning of vulnerable systems, in which the potential invasive trajectory can be predicted a priori (Santos et al. 2011).

Although static Habitat Distribution Models have been widely applied in predicting invasive plant species distributions under global change scenarios (e.g., Vicente et al. 2016), their deterministic assumptions and the lack of integration with dynamic and/or stochastic processes limit their accuracy in capturing ecological responses to more local changes (Kandziora et al. 2013). In contrast, dynamic modelling can be adjusted to the local management requirements (objectives and parameters) and capable of responding with flexibility to specific contexts, guiding current decision-making (Cuddington et al. 2013). Therefore, dynamic models can complement static models to design and test specific cost-effective local conservation measures in the scope of invasive plant species broader management (Bastos et al. 2012). In fact, the combination of empiric, mechanistic and correlative modelling approaches is a promising research field, known as hybrid multi-modelling (Box 1), that enables to improve the understanding of the main drivers implicated on the spatial-dynamic patterns of invasive plant species (Buchadas et al. 2017).

Box 1—Dynamic models for supporting invasion management: a review

Dynamic models are preferential tools to guide management decisions (Cuddington et al. 2013). Based on a literature review, in which keywords related with "Invasion", "Management" and "Dynainic Modelling" were searched using ISI WOK (http://webofknowledge.com) (Buchadas et al. 2017), 59 publications on plant invasions in agricultural and agro-forest landscapes were considered. To investigate the extent and how dynamic modelling has been applied on management, we reviewed each one of the 59 publications to identify their modelling approach (i.e., purely dynamic vs. hybrid models; Fig. 1), management type (i.e., active management targeting later stages of the invasion process, vs. passive management targeting early invasion stages), and if climate change was considered.

Dynamic models were more often applied in active management actions, such as invasion control. Contrastingly, hybrid models were more often applied in passive management, e.g. prevention and early-detection. Only 5% of publications considered climate change, which applied hybrid approaches

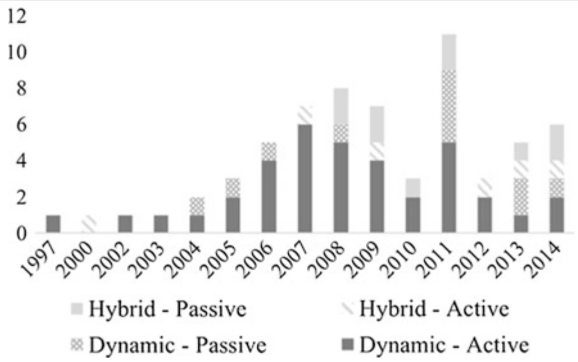

Fig. 1 Temporal evolution of the application of dynamic modelling approaches, dynamic or hybrid (static-dynamic) to support active or passive management actions on plant invasions in agricultural and agro-forest landscapes

for passive management. The ability of dynamic models to mimic demographic processes, such as dispersal and growth, is of key importance for active management measures. Still, the more recently applied, hybrid models have the capacity to deliver spatial outputs which are effective to support management at early invasion stages (from prevention to early detection), and to improve the monitoring and impact assessment of invasion processes. Furthermore, hybrid models may be relevant when considering the role of climate change, due to their capacity to effectively extrapolate invasion process beyond uncertain environmental conditions. Therefore, further use of hybrid approaches to study invasions management while considering climate change may constitute a research pathway to support invasion management in agricultural and agroforestry systems.

5 Challenges of Alien Plant Invasions in the Light of Climate Change

5.1 Forecasting

Because biological invasions are ongoing processes, anticipating their spread requires advanced predictive tools embedded in adaptive and iterative modelling frameworks (Baxter and Possingham 2011; Uden et al. 2015). These typically combine data from the native and invaded ranges (Broennimann and Guisan 2008; Beaumont et al., 2009) to limit effects of niche changes between ranges (Guisan et al. 2014). It is however not enough to anticipate spread under current climate, as predictions may differ in future climates (Bellard et al. 2013), as shown for various mountains (Petitpierre et al. 2016), for North America (Bradley et al. 2010) or for South-Africa (Parker-Allie et al. 2009). Additionally, changes in other factors, such as land use (Vicente et al. 2011) or global trade (Seebens et al. 2015), may also influence predictions. Models that incorporate climate or land use changes scenarios may also anticipate how invasions will threaten protected areas (Kleinbauer et al. 2010) or rare and endangered species (Vicente et al. 2011).

Perhaps the greatest challenge for forecasting invasions in future conditions is when novel situations—new climate or new land uses, for instance—will characterize some areas in future times (van Klinken et al. 2009; Vicente et al. 2011; Webber et al. 2011), as projections there will be entailed with greatest uncertainty. Another important challenge for future projections is to find robust ways to build hierarchical models, based on hierarchical studies of biological invasions (Pysek and Hulme 2005), that combine models of entire species' climatic niches at the global scale with local models incorporating the species requirements in the area of interest (Petitpierre et al. 2016).

5.2 Predicting Impacts on Ecosystem Services

Detailed knowledge of how climate change will mediate IAS escaped from agriculture and agroforestry systems, and how these species will affect ecosystem services, is lacking. Still, there is a clear recognition that climate change can alter habitat conditions that facilitate or hinder IAS performance, and thereby the effects of IAS on ecosystem services (Brundu and Richardson 2016; Krumm and Vítková 2016; Nie et al. 2017).

It has been shown that agricultural and agroforestry IAS, such as *Acacia dealbata*, *Robinia pseudoacacia*, *Salix alaxensis* and some *Lupinus* species, will potentially spread into areas that are currently unsuitable, due to more favourable future climate conditions (Gassó et al. 2012; Kleinbauer et al. 2010; Pickart et al. 1998; Vicente et al. 2013; Wasowicz et al. 2013). Accordingly, the impacts that these IAS currently have on ecosystem services (e.g. increased fire regimes, water depletion) will likely be altered (Hellmann et al. 2008; Nie et al. 2017).

Future research should prioritise studies on the interactions between IAS, ecosystem services, and management practices in agriculture and agroforestry systems under different climate change scenarios (Richardson et al. 2010). Such interactions should be investigated considering the complex and context-specific interlinks between ecological impacts, social valuations and perceptions, and management decisions (Dickie et al. 2014; Vaz et al. 2017).

5.3 Adaptive Management

With changing climate and with the foreseeable introduction of new alien species, the occurrence of new IAS with novel traits that behave differently under new environmental conditions (including e.g., new interactions pests and diseases; (Pauchard et al. 2016) will likely increase. Thus, management will have to be adaptive to successfully tackle species for which reliable observational data from the past do not exist (ghost of invasion past problem, (Kueffer et al. 2013). Dealing with this challenging situation will only be possible through a flexible approach that allows management priorities and strategies to be continuously adapted, considering the response of ecosystems to management actions. Adaptation needs to be based not only on new research, but also on the ways ecosystem services are perceived and valued by local stakeholders, considering the social, technological, economic, environmental and political contexts (Foxcroft and McGeoch 2011). To foster such an approach, continuous knowledge exchange between practitioners, scientists and other stakeholders is needed, data flows supported by adaptive monitoring must be enabled (Honrado et al. 2016), and legal and institutional frameworks must be adapted so that they become more flexible and focused on anticipation and early response. There is also a need to develop a more balanced approach towards evaluating invasive species and their effects on ecosystems based not only on their negative impacts but also on their positive roles in socio-ecological systems (Vaz et al. 2017).

Box 2—Alien tree species in coffee agroforestry systems—implications for ecosystem functions anil services

Coffee (*Coffea canephora* and *C. arabica*) production depends on shading. Traditionally coffee is produced under a native multispecies tree canopy, however, increasingly monospecific shade tree layers composed of ail alien species (e.g. *Grevillea robusta*) are used. Ecosystem functioning and services differ substantially between native multispecics and alien monospecific agroforestry systems, as has for instance been shown in a long-term study in Kodagu (Western Ghats, India) (Garcia et al. 2010, Krishnan et al. 2011; Boreux et al. 2013, Nesper et al. 2017). The presence of insect pollinators and their visitation rates of coffee are affected by canopy composition. While habitat quality, tor instance tor bees such as *Apis dorsata*, is improved in a diverse agroforest (Krishnan et al. 2011), pollination can sometimes be reduced under a multispecies shade cover; possibly due to floral competition with coffee plants (Boreux et al. 2013). Lower predator abundance and/or diversity might be the cause for increased in testation by the coffee pest *Hypothenemus hampei* under an alien *G. robusta* canopy (Nesper et al. 2017). Further, there is a tendency towards reduced nutrient availabilities under *G. robusta* due to the low litter quality of this alien tree (Nesper et al. in review). There are also indications that microclimate and leaf phenology peaks become more extreme under an alien canopy (Nesper et al. in review), which might have important implications for resilience against climate change in a seasonal dry climate. Effects on ecosystem services can result in reduced coffee production and quality under alien shade trees (Nesper et al. 2017). These effects are partly due to the presence of a particular alien tree species, but result partly also from the replacement of old-grown multispecies canopies.

6 Conclusions

This chapter provided a general overview on the history, patterns, risks and impacts of alien plant species in agricultural and agroforestry systems. The major highlights are that, since pre-Columbus times, plant species have been moved across the world. Still, the increasing transportation of people and livelihoods, and the booming transatlantic trade during the 18th and 19th centuries facilitated intentional and accidental introductions of alien plant species. A proportion of these species has become invasive, namely *Acacia mearnsii, Arundo donax, Eichornia crassipes*, and

Opuntia stricta, that were able to expand beyond cultivation sites. These alien invasive species have many documented impacts in biodiversity and on provisioning, regulating and cultural ecosystem services. Management strategies, such as early detection and/or rapid response actions, are thus relevant for preventing undesirable impacts from these species. Modelling and detection tools are being increasingly applied to support effective management. These tools comprise, for example, the remote sensing information captured by airborne systems, the habitat distribution models, and the dynamic models. These approaches are even more relevant in the context of climate change. Specifically, they can be implemented to forecast and anticipate invasion processes, as well as to predict and prevent impacts on ecosystem services. These emergent are thus key tools for achieving adaptive management, allowing institutional frameworks to become well-adapted, -flexible and -focused on the anticipation and early response to invasions, their costs and benefits in socio-ecological systems.

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1 Introduction

Sudan, the third largest country in Africa, covers an area of about 1.86 million km^2, much of which is comprised of desert and arid lands. It lies within the tropical zone between 10° and 23° N and 21° 45″ and 38° 30″ E and bordering seven countries and shares surface and ground water with 12 countries. Its topography can be broadly characterized as vast plains interspersed by widely separated ranges of hills and mountains. The country is 29% desert, 19% semi-desert, 27% low rainfall savanna, 14% high rainfall savanna, 10% flood regions (swamps and areas affected by floods) and less than 1% mountain vegetation. The country's population is 40 million people and is divided administratively into 16 States. The economy has long depended on agricultural and livestock exports but in recent years gold and oil have been exploited.

An examination of Sudan's ecological zones indicates that the majority of its land is highly vulnerable to changes in temperature and precipitation. The mean annual temperature lies between 26° and 32° but in some areas it reaches 47 °C causing a lot of stresses and heat related diseases. The country's inherent vulnerability can be explained by the fact that food security is dependent on rainfall, particularly in the rural areas where about two thirds (65%) of the population lives. Rainfall is erratic and varies significantly from the North to the South. The unreliable nature of rainfall together with its concentration during the short growing season increases the vulnerability to failure of the rain-fed agricultural crops. A trend of decreasing annual rainfall in the last 60 years (0.5%) and increased rainfall variability is contributing to drought conditions in many parts of the country. This pattern has led to serious and prolonged drought episodes. For example, Sudan experienced a succession of dry years e.g. 1974, 1984 and 1991, which have resulted in severe social and economic impacts including many human and livestock fatalities, migration and displacement of several million people. Drought problems such as these will increase if trends continue (Fadl El Moula and Elgizouli 2008). Sudan experienced some severe floods of two specific types during the past several decades. The first type occurs during heavy rain when high levels of water overflow the River Nile and its tributaries, usually due to above normal rainy seasons in the Ethiopian Plateau. Severe floods were reported in 1946, 1988, 1994, 1998 and 2001. The other type of flood occurs as a result of heavy localized rainfall reported in 1952, 1962, 1965, 1978–1979, 1988 and 1997 (HCENR 2005). In addition to drought and floods there are other climate extreme events such as dust storms, thunder storms and heat waves.

In the arid lands of Sudan, soil erosion is also one of the major problems that have occurred as part of geological processes and climate change. Erosion is becoming more severe and it is accelerated by adverse human activities.

Wind erosion is an important land surface process which has received attention in many countries. The transport of the finest and most valuable soil particles by wind and water has led to degradation processes affecting the agriculturally used areas and pollutes the atmosphere (Roger and Michel 2013). Scientists have long been interested in the direct and indirect effects of wind erosion The earliest publication relating to aeolian processes was written by astronomer Godefroy Wendelin in 1646 (Stout et al. 2009). Wind erosion is a soil degrading process that affects more than 500 million hectares of land worldwide and creates between 500 and 5000 kg of fugitive dust annually (Grini et al. 2003).

The climate change and the associated effects on human society in general and agriculture in particular have set the problem of wind erosion in a broader perspective (Funk and Reuter 2006). Wind erosion has received more attention as a process responsible for decrease in soil fertility and as source of atmospheric pollution (Oldemann et al. 1990; Gobin et al. 2003; Warren and Bärring 2003). The removed soil particles may be deposited downwind to become part of the new landscape or may be transported to oceans where the rich nutrient dust enhances aquatic life (Morales 1977). The average annual soil loss resulting from raindrop splash and runoff from field slopes, is still most frequently used at large spatial scales (Renschler and Harbor 2002 and Panagos et al. 2014). In addition to soil fertility degradation, there is a disproportionate loss of soil organic carbon (Van Pelt et al. 2007) and soil fines may affect soil water infiltration and holding capacity, further affecting soil productivity in semiarid regions. However, estimating soil erosion rates and amounts began in the USA since the 1920s and rapidly advanced in the 1930s following the devastating impact of the "Dust Bowl" on the American Great Plains (Römkens 2010).

For effective biological control against wind erosion, some literature suggests that shelterbelts should be designed to contain 10 or more rows of trees and shrubs to provide maximum benefit to wildlife and land/home owners (IOWA 2010). Biological control through field investigations indicated the effectiveness of trees and shrubs to suppress moving sand compared to other mechanical measures (Al-Amin et al. 2006; Al-Amin et al. 2010; Shulin et al. 2008; Mohammed et al. 1999). However, in Sudan the main degraded zones are the arid and semi—arid zones where 76% of the human population lives (Ayoub 1998). Dregne et al. (1991) estimated that nearly 70 million hectares of Sudan land are very severely degraded. In North Kordofan, sand movement is a serious problem facing the land and people of Namla village. To alleviate this problem, wind breaks and shelterbelt are expected to reduce the severity of wind erosion. In this respect, experience derived from various international and national projects has demonstrated that people can devise their own alternative actions to deal with local problems. Therefore, community participation is a proven approach to addressing a number of agricultural and environmental problems. Hence, a number of experiments were conducted in Northern Sudan, White Nile and North Kordofan States so as to measure soil erosion and sand accumulation, to investigate the limitations for natural regeneration of vegetation, and to seek effective methods for controlling wind erosion with the involvement of local communities.

2 Materials and Methods

2.1 Mechanical and Biological Methods for Controlling Wind Erosion at Um Jawaseer Area in the Northern Sudan

This study was carried out at Um Jawaseer village in Merawe locality in the Northern State. Um Jawaseer area is located within the arid zone of Sudan. It lies between latitudes 16° 53′ and 16° 56′ N; and longitudes 31° 36′ and 31° 40′ E. The rainfall is generally low and erratic. The mean annual rainfall is 40 mm that falls between July and September. Average evaporation is 16.4 mm which is high enough to reduce effectiveness of precipitation. The relative humidity is 30.2%. Extreme high temperature characterizes the area during summer months reaching an average maximum of 39 °C and a minimum of 23 °C. The main wind direction constitutes the northeast strong dry winds blowing from October to June with sand storms resulting from the seasonal movement of the Inter Tropical Convergence Zone. However, during July to September the dominant wind direction is the southern wind but the direction is sometimes interchanged between west and east. Wind speed is 12.5 (km/h). The soil is sandy with low nitrogen and organic matter contents, low available P, very low CEC that can be considered as infertile but non-saline, non-sodic, with somewhat high bulk density, medium porosity and hydraulic conductivity and low available water capacity (AWC). Some patches of compacted soil and salinity are generally found in this area.

2.2 Effect of Mechanical Protection of Wind Erosion on Growth and Survival of Different Tree Species

A 3-factor randomized complete block experiment with three replications was conducted to study the effect of mechanical methods of protection against wind erosion as reflected on growth and survival of four indigenous tree species under rain fed conditions. The first factor comprised three methods of mechanical protection namely checkerboard, surface lying and a flat area with no mechanical protection as control. Checkerboards were made by tying palm leaves together to make a one meter high barrier which is constructed around the planted area for protection from wind. Surface lying was made by collecting dry bushes tied as a bundle so that the trees can be grown between two bundles. The control consisted of planting the trees without protection. The second factor comprised four tree species, namely *Salvadora persica*, *Moringa pregrenia*, *Acacia tortilis* and *Ziziphus spina christi*. The third factor consisted of the method of establishment by direct seeding or seedlings planting. Each treatment combination was represented by 4 trees making 96 trees per replication and a total of 288 trees. Survival and growth of the tree species were measured after one and two years from planting. Analysis of variance and Duncan's Multiple Rage Test at 0.05 probability level was used according to MSTAT-C software package.

2.3 Assessment of Soil Erodibility

Estimation of soil erodibility of individual grains is dependent upon their diameter, density and shape. Soil erodibility index was estimated using the procedure described by Chepil (1945). Soil erodibility is best estimated by carrying out direct measurements on field plots (Kinnell 2010). Panagos et al. (2012a) estimated soil erodibility based on soil texture and organic carbon data obtained from the Land Use/Cover Area Frame Survey (Toth et al. 2013).

To determine erodibility, a spade was pushed under the surface soil layer to a depth of 3 cm. five soil samples 0.5 kg each were taken and air-dried. The percentages of soil aggregates greater than 0.84 mm in diameter were determined using a sieve of the same size. Soil erodibility was determined using indices developed by Woodruff and Siddways (1965); and Skidmore and Siddways (1978). Erodibility is calculated by the following equation:

$$\mathrm{I}\ (\text{erodibility}) = \frac{\text{weight of grains} > 0.84\ \text{mm} \times 100}{\text{Total weight of sample}}$$

2.4 Assessment of Wind Erosion Using Sand Traps

Vertical sand traps were fixed in the north and south directions of the physical barriers (checkerboard and surface lying) for measuring wind erosion and sand movement. The vertical trap is a metal pipe with three levels 15, 30 and 45 cm from the surface of the ground. It has two windows in opposite directions. Each window is 1 × 1 cm and one of the windows is open and the other is covered with mesh to control the sand grains entering though the open one. The traps were discharged every three months and wind erosion (ton ha^{-1} day^{-1}) was calculated using the following equation:

$$\text{Wind erosion} = \frac{\text{weight of soil sample (g)} \times 100}{\text{number of days} \times \text{area of trap}}$$

However, in the newly established young tree belt, plastic cans (21 × 21 × 40 cm dimensions) were erected as horizontal traps in the windward and leeward directions of the shelterbelt. Four traps were constructed per each replication in each side of the young trees' belt. These traps were discharged every three months and the wind erosion (ton ha^{-1} day^{-1}) is calculated using the above equation.

2.5 *Effect of Shelterbelts on Sand Accumulation and Seedlings Establishment of Indigenous Tree Species*

This experiment was conducted in the leeward side of Um Jawaseer shelterbelt which is composed of six rows of six-years-old tree species namely; *Eucalyptus microtheca*, *Prosopis chilenses, Ziziphus spina-christi*, *Azadirachta indica, Conocarpus lancifolius* and *Acacia amplicips*. A two-factor randomized complete block design experiment with three replications was used. Four tree species namely *Acacia tortilis, Acacia oerfota*, *Leptadenia pyrotechnica* and *Zizipus spina christi* as factor one, were planted using 2 × 2 m between trees and 3 × 3 m between rows. Two methods of sowing viz. direct seeding and seedlings planting constituted the second factor. Each treatment combination was represented by ten trees making a total of 240 trees. Tree height, diameter, survival rate and number of branches were measured every 3 months. Soil erodibility was determined using Woodruff and Siddways (1965); Skidmore and Siddways (1978) indices.

2.6 *Degradation of Vegetation at Elgetaina Area in the White Nile State*

This study was carried out in central Sudan, east of Elgetaina town in the White Nile State (32° 15′ North and 14° 45′ East) during 2004–2006.The climate is atypical tropical continental, characterized by warm dry winter and hot rainy summer. The mean temperatures are 37 and 21 °C for summer and winter, respectively. Relative humidity is lowest in April (10%) and highest in August (67%). The mean daily evaporation is highest in April (20 mm) and lowest in August (10.8 mm). The wind blows in the dry season from the south-east direction at about 4.5 m/s. Dust storms (Haboobs) are common during the summer season. The soils of study area are classified as White Nile clays (Brawn et al.1991) with 60–70% clay content and are rather uniform in texture and profile features.

2.7 *Sampling*

Four sample plots of 500 × 500 m each were selected randomly in the study area and composition of the vegetation cover was assessed. A total of 40 soil samples were taken from two depths (0–30 cm)-(30–60 cm) during April 2004. Soil analysis was carried out at the Land and Water Research Centre of The Agricultural Research Corporation (ARC) Sudan.

2.8 Measuring Wind Erosion and Sand Accumulation at Namla in Western Sudan

This study was carried out at Namla village in North Kordofan State which lies in the Northern part of western Sudan at 71 km North East of Elobeid town. About 50% of the agricultural land (approximately 3000 ha) were covered by sand dunes. The annual rainfall is about 318 mm. The vegetation cover is composed of *Acacia senegal*, *Balanites aegyptiaca*, *Acacia tortilis*, *Ziziphus spina christi*, and *Leptadenia pyrotechnica*. But in the study area the soil is devoid of vegetation because of tree cutting, over grazing, and agricultural expansion. However, the understory vegetation is compound of *Cenchrus ciliaris*. *Cenchrus biflorus* and *Cassia tora*. The total population is 1645 mainly from Gawamaa tribe. The agricultural system is traditional, where sesame, sorghum and gum arabic constitute the main food and cash crops.

The Agricultural Research Corporation and the Forests National Corporation organized extension work and training for the local communities in order to control desertification thought the stabilizing of moving sands using seeds and seedlings grown in home nurseries.

2.9 Assessment of Wind Erosion Using Sand Traps

Vertical and horizontal sand traps were established for measuring wind erosion and sand movement in the study area. The horizontal traps were namely plastic cans with 21 × 21 cm dimension erected in the windward and leeward directions of the shelterbelt and arranged in three replicates used in the northern and southern wind directions. The traps were discharged every month and the wind erosion (ton ha^{-1} day^{-1}) was calculated using the previous equation. Vertical traps were erected in the northern and southern wind directions. The vertical trap is a metal pipe with three levels: 15, 30 and 45 cm from the surface of ground. It has two windows in opposite directions. Each window is 1 × 1 cm and one of the windows is open and the other is covered with a piece of mesh to control the sand grains entering though the open one. These traps were discharged every month and wind erosion (ton ha^{-1} day^{-1}) was calculated using previous equation. These vertical traps were constructed in front of and behind the shelterbelt in the northern and southern directions.

2.10 Assessment of Soil Erodibility

Estimation of soil erodibility of individual grains is dependent upon their diameter, density and shape. Soil erodibility index was estimated using the procedure described by Chepil (1945). Erodibility of soils with different percentages of non-erodible fractions was determined by standard dry sieving for a fully crusted soil surface regardless of soil texture. However, good soil structure and high aggregate stability are important parameters for improving soil fertility, enhancing porosity and decreasing erodibility (Bronick and Lal 2005). In practice, erodibility represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrological processes (Bonilla and Johnson 2012).

In measuring erodibility, a spade was pushed under the surface soil layer to a depth of 3 cm. Five soil samples 0.5 kg each were taken and air-dried. The percentages of soil aggregates greater than 0.84 mm in diameter were determined using a sieve of the same size. The soil erodibility index was estimated for each field sample using previous erodibility indices.

2.11 Effect of Shelterbelt on Sand Accumulation and Seedling Establishment

This experiment was conducted in the leeward side of Namla village. The tree species which were selected to control sand movement were *Leptadeniapyrotechnica, Acacia tortilis, Acacia senegal, Balanitesaegyptiaca, Faidherbiaalbida,* and *Panicumturgidum*in the under story. Two methods of sowing viz. direct seeding and seedlings planting were used. Tree height, diameter, survival rate and number of branches were measured every three months. Soil erodibility was determined using Woodruff and Siddways (1965); Skidmore and Siddways (1978) indices.

2.12 Home Nurseries (Individuals)

The Agricultural Research Corporation and the Forests National Corporation organized an extension work for the local community by training them on controlling desertification and sand dune stabilization using seedlings and seeds in home nurseries. The main species produced by the local people in home nurseries were *Acacia senegal*, *Acacia mellifera, Grewiatenex*, *Azdirachtaindica*, *Balanitesaegyptiaca* and *Ziziphus spina christi*.

3 Results and Discussion

3.1 Mechanical Control of Wind Erosion

The average erodibility of the soil at Um Jawaseer in the Northern Stateof Sudan was 16.8 (Table 1). Erodibility was calculated on the basis of indices developed by Woodruff and Siddways (1965) or 37.2 according to Skidmore and Siddway (1978). The former erodibility values falls within the values given in Skidmore and Siddoways (1978) table of erodibility. This result evidenced moderate wind erosion in the study area, where some materials of the soil were removed and some deposited. Breshears et al. (2008) measured sediment transport rates ranging from 0.17 to 27.4 g m^{-2} d^{-1}, respectively.

Table 2 shows soil accumulation (ton ha^{-1} day^{-1}) according to trap height, the highest (76.8 ton ha^{-1} day^{-1}) sand accumulation was obtained at the 15 cm height of trap followed by the 30 cm and the 45 cm heights, respectively. This result proved that sand movement in this area is in the form of surface creep. Seedlings planting under the three methods of mechanical protection showed that checkerboards has the highest survival (61.4%), followed by surface lying (57.8%) and the control (52.1%) as shown in Table 3. In this respect, studies conducted by Chepil (1945), Chepil and Woodruff (1963), Woodruff and Siddways (1965); and Skidmore and Siddoways (1978) showed that the quantities of various crop residues needed to protect soils from wind erosion have been determined and compared to an equivalent amount of flat small grain. The relationship between physical properties of the residues and erosion was modeled by Lyles and Allison (1976, 1980, 1981). Where the sand is fixed, soil formation can begin; fine particles are accumulated and a hard soil crust is formed on the dune surface improving both the micro-environment and the stability of the dune surface. The straw checkerboard can significantly increase the content of organic matter of the surface soil. The technique has several advantages such as: remarkable effect on dune fixation, ease of construction, rapid results, and no pollution of the environment. However, its labor cost is high and the replacement of the straw after 3–5 years can be a problem. The straw checkerboard decreases wind velocity near the ground surface and can prevent wind erosion of the soil. After establishment, the straw gradually rots and

Table 1 Estimation of soil erodibility at Um Jawaseer in the Northern State, Sudan

Sample	Aggregates greater than 0.84 mm	Erodibility (Woodruf and Siddways)	Erodibility (Skidmore and Siddways)
1	65	16.5	37
2	60	21.0	47
3	61	20.0	45
4	66	15.6	35
5	71	11.0	22
Average	64.6	16.8	37.2

Table 2 Sand accumulation (ton ha^{-1} day^{-1}) according to trap height at Um Jawaseer in the Northern State, Sudan

Trap height (cm)	Soil accumulation (ton ha^{-1} day^{-1})
15	76.79 a
30	56.69 b
45	15.96 c
P	P = 0.0001
SE±	3.1782

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

Table 3 Effects of establishment and protection methods on tree survival (%) at Um Jawaseer in the Northern State, Sudan

Method of protection	Method of establishment	
	Seeds	Seedlings
Checkerboard	46.9 d	61.4 b
Surface lying	44.3 e	57.8 b
Control	43.3 e	52.1 c
P	0.0001	
SE±	0.690	

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

converted to organic matter. Checkerboards are widely used for dune fixation in arid and semi-arid regions of China (Maki 1999). Research has shown that the straw checkerboard significantly increases the roughness length and decreases the sand content in the sand flux by as much as 99.5% (SDRS 1986; Liu 1987; Liling 1991; Wang 1991; Xu et al. 1998). The extent of dune fixation depends on the dimensions of the checkerboard. In this respect, a size of 1 × 1 m, as in the present study has remarkable wind break and dune fixation effects (SDRS 1986; Wang 1991).

There was also a highly significant interaction of species and method of protection ($P \leq 0.01$) on height growth (cm). *Ziziphus spina Christi se*edlings have the highest growth (>23.0 cm) in height under surface lying and control and also under checkerboard method.

The lowest growth in height for all the selected species was in the control compared with the other methods of protection. *Moringapregrina and Acacia tortilis*have reached about the same height using surface lying. Similarly *Ziziphus spina christi and Salvadorapersica* has the same height using checkerboard method. On the other hand, *Moringapregrina and Acacia tortilis* gave the lowest height growth (17.0 cm) using checkerboard method. *Salvadorapersica*has the lowest height growth (17.9 cm) as control. Surface lying gave the highest height growth in all the selected species followed by checkerboard and control (Table 4).

Table 4 Effect of species and method of protection on height growth (cm) at Um Jawaseer in the Northern State, Sudan

Species	Methods of protection		
	Checkerboard	Surface lying	Control
Salvadora persica	19.68 bc	19.11 bcd	17.93 cd
Moringa pregrina	16.96 d	19.88 bc	18.95 bcd
Acacia tortilis	17.90 cd	20.96 b	19.93 bc
Ziziphus spina christi	19.76 bc	23.65 a	23.21 a
P	0.01		
SE±	0.6803		

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

3.2 Biological Control of Wind Erosion Using Trees

The combined analysis of two-years on the effect of biological protection against wind erosion using the four species revealed highly significant ($P<0.01$) effect of the interaction of species and years on height growth (cm). *Acacia oerfota* has the highest growth (65.7 and 108.7 cm) compared with the other species in both years, respectively. *Ziziphus spina christi*has the lowest growth of 27.1 and 46.0 cm in both years, respectively. *Lyptadenia pyrotechnica* and *Acacia tortilis* showed no significant difference in their height growth in the first year and also in the second year of establishment (Table 5). The effect of species on diameter growth (mm) was found to be significant ($P<0.05$). The four species, i.e. *Ziziphus spina christi*, *Acacia oerfota*, *Leptadenia pyrotechnica and Acacia tortilis* have similar diameter growth in the first year of establishment with no significant difference among them. In the second year of establishment, *Acacia oerfota* has the highest growth (2.6 mm) in diameter which was significantly different from *Ziziphus spina Christi* but similar to the other three species (Table 6). Field investigations indicated the effectiveness of trees and shrubs to suppress moving sand compared to other mechanical measures (Al-Amin et al. 2006; Al-Amin et al. 2010; Shulin et al. 2008; Mohammed et al. 1999). However, the effectiveness of a barrier depends on its porosity. On the other hand, low porosity creates turbulence on the leeward side of the belt (Ki-Pyo and Young-Moon 2009). According to Kaul (1969) a windbreak strip is to be established on sand to prevent them from being blown away by winds for better established of field crops. Above authors suggested a five row shelterbelt in a pyramidal shape in a similar work to this study in dry areas. However, some literature suggests 10 or more rows of trees and shrubs to provide maximum benefit to wildlife and human dwellings (IOWA 2010). In this respect, shelterbelts in Sudan were established to stop drifting sand damage in Gezira scheme (Stigter et al. 1989).

Table 5 Effect of species and year on height growth (cm) of young trees at Um Jawaseer in the Northern State, Sudan

Species	2008	2009
Ziziphus spina christi	27.1 e	46.0 d
Acacia oerfota	65.7 c	108.7 a
Leptadenia pyrotechnica	42.7 d	67.9 c
Acacia tortilis	46.9 d	76.2 b
P	0.002	
SE±	2.372	
CV%	6.8	

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

Table 6 Effect of species and year on diameter growth (mm) of young trees at Um Jawaseer in the Northern State, Sudan

Species	2008	2009
Ziziphus spina christi	1.2 c	2.1 b
Acacia oerfota	1.3 c	2.6 a
Leptadenia pyrotechnica	1.1 c	2.3 ab
Acacia tortilis	1.2 c	2.3 ab
P	0.05	
SE±	0.036	
CV%	10.8	

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

3.3 Sand Accumulation

The 15 cm trap height accumulated significantly ($P<0.05$) the highest (73.25 ton ha^{-1} day^{-1}) amount of sand compared with traps of heights above the surface creep level (Table 7). Accumulation of sand in the horizontal traps during the two years using tree belts showed that autumn has significantly ($P<0.05$) the highest accumulation of sand compared with accumulation in the summer or winter season (Table 8). In addition, the high accumulation of soil in the horizontal traps supported the previous findings that most of the erosion in northern Sudan is by surface creep. Farah (2003) in his study of wind erosion in Khartoum State, found increased erosion from winter to summer and that Khartoum state is suffering from wind erosion in its four directions. He also found that the intensity of wind erosion in the soil surface decreased with the height of trap, which means that the major wind erosion is surface creep. Similarly, in this study, the trap height of 15 cm also gave significantly ($P<0.05$) the highest accumulation of sand in vertical traps. In the present study the mean daily wind load or accumulation was estimated at 73.25 ton ha^{-1} day^{-1} as compared with 76.79 ton ha^{-1} day^{-1} in the mechanical control method, indicating better wind erosion protection resulting from tree belts as compared to mechanical methods.

Table 7 Accumulation of sand (ton ha^{-1} day^{-1}) in vertical traps at Um Jawaseer in the Northern State, Sudan

Trap height (cm)	Sand accumulation (ton ha^{-1} day$^{-1)}$
15	73.25 a
30	48.64 b
45	41.84 b
P	0.0001
SE±	3.1038

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

Table 8 Effect of season and direction of sand traps on accumulation of sand in horizontal traps at Um Jawaseer in the Northern State, Sudan

Seasons	Accumulation (mean)	Direction	Accumulation (mean)
Summer	335.3 b	North	405.2
Autumn	524.7 a	South	430.2
Winter	393.1 b		
P	0.0002		0.559
SE±	28.8		29.9

Means with the same letters are not significantly different according to DMRT at $P \leq 0.05$

3.4 Degradation of Vegetation in the White Nile

The study area has a low woody vegetation cover. Only 10 trees in the whole study area were found and these are 5 shrubs of *Capparis decidua,* 3 trees of *Acacia tortilis* and 2 shrubs of *Acacia nubica* (Table 9). Most parts of the study area are bare land especially in plot 3. Vegetation consisted of the following species *Cassia senna* and *Panicum turgidum*. This is in addition to some sparse vegetation of *Chrozophora oblongifolia,* which is highly desired by camels. The ground vegetation was estimated at 20% in the study area. There were no viable seeds in the whole study area because there were no trees in this area and it contains some dead grass seeds.

Generally the soil at the study site is low in N and Organic carbon (Table 10). Cl content is high especially in the third sample. In all four samples we noticed that $CaCO_3$ was very high in all samples. Electric conductivity (EC) and exchangeable sodium percentage (ESP) increase with depth. The soil of sample 3 and 4 is saline and sodic (EC>4ds/m and ESP>15). In these two samples there were no trees but some grasses and bushes e.g. *Panicum turgidum* are present.

The high sodicity decreases the infiltration rate and inhibits the emergence of seeds. The high PH inhibits P availability. These soils need to be reclaimed by leaching the soluble salts by good quality water and addition of farm yard manure and gypsum to reduce the sodicity level and to improve the physical properties of the soil.

Table 9 Vegetation cover in sample plots at Elgetaina area in the White Nile, Sudan

Sample no.	Location	Trees	Shrubs	Species
1	14º 49′ 20 N 32º 26′ 35 E	2	3	*Trees: Acacia oerfota and, Acacia tortilis subsp. Radiana; Shrubs: Capparis decidua*
2	14º 49′ 17 N 32º 26′ 37 E	1	3	*Trees: Acacia oerfota and, Acacia tortilis subsp. Radiana; Shrubs: Capparis decidua*
3	14º 49′ 00.3 N 32º 26′ 54E	0	0	–
4	14º 48′ 43 N 32º 27′ 13E	0	1	*Only Capparis decidua* shrub.

Table 10 Soil chemical properties in 4 sample plots at Elgetaina area in the White Nile, Sudan

Sample	Depth (cm)	Exchangeable bases (Coml.+/kg)					Soluble cations and anions (meq/L)				
		Ca Co3	Na	O.C %	N %	PH paste	E.C (ds/m)	ESP %	Na	CL	HCO_3
1	0–30	1.28	1.93	0.06	0.02	7.76	1.40	6.6	8.55	5.7	2.25
	31–60	1.64	2.99	0.07	0.03	7.94	3.26	12.8	24.7	22.0	2.30
2	0–30	1.84	2.33	0.06	0.02	8.16	1.9	8.8	13.9	7.05	1.0
	31–60	1.52	2.24	0.07	0.02	8.28	1.55	8.6	11.4	2.3	1.15
3	0–30	5.08	12.06	0.10	0.04	8.36	8.45	38.4	74.5	61.0	4.2
	31–60	4.84	11.44	0.15	0.02	8.32	9.29	38.6	80.0	71.7	4.9
4	0–30	3.32	3.49	0.09	0.02	8.52	1.99	14.6	15.9	13.9	3.3
	31–60	3.36	7.08	0.05	0.02	8.56	4.41	24.8	38.4	35.0	3.2

The analysis indicates that the inherent fertility status of this soil is very low. It also has low water holding capacity and is susceptible to wind erosion. Due to the current droughts and misuse, the vegetation cover in this area is very low resulting in low carrying capacity of livestock. Hence, this study recommended reseeding of the area with drought and salt resistant trees for stabilizing the highly mobile sand dunes.

Table 11 Estimation of soil erodibility at Namla village in North Korrdofan State in western Sudan

Sample No.	Erodibility (Woodruf and Siddway)	Erodibility (Skidmore and Siddway)
1	80.1	179
2	83.2	187
3	90.1	206
4	75.6	172
5	80.6	182
6	77.5	175
7	75.3	169
8	79.5	178
9	86.3	193
10	92.8	208
Average	82.1	184.9

3.5 Estimation of Soil Erodibility in Western Sudan

Based on Skidmore and Siddway (1978) and Woodruf and Siddways (1965) the soil erodibility at Namla village was 82.1 and 184.9, respectively. The results showed that there is high erodibility in the study area (Table 11). However, the highest soil accumulation (106.1 ton ha^{-1} day^{-1}) was obtained at the 15 cm trap height. Accumulation by the 30 cm and the 45 cm height traps was also high reaching >30 ton ha^{-1} day^{-1}. This result proved that the wind in this area is blowing at different levels carrying sand accumulation at varying heights

Table 12 Accumulation of sand (ton ha^{-1} day^{-1}) in vertical traps at Namla village in North Kordofan State in western Sudan

Trap height (cm)	Soil accumulation (ton ha^{-1} day^{-1}) North of belt	Soil accumulation (ton ha^{-1} day^{-1}) South of belt	Reduction %
15	106.11	88.37	17.0
30	93.32	50.71	45.7
45	68.54	35.2	48.7

Table 13 Soil accumulation (ton ha^{-1} day^{-1}) in horizontal traps at Namla village in North Kordofan State in western Sudan

Trap distance from belt (m)	Soil Accumulation (ton ha^{-1} day^{-1}) North of belt	Soil accumulation (ton ha^{-1} day^{-1}) South of belt	Reduction %
01	536.6	339.33	36.8
10	254.42	156.62	38.4
20	159.63	109.73	31.3

Table 14 Threats faced by the community at Namla village in western Sudan before establishment of shelterbelts

Threats to environment	Respondents' views (%)
Desertification	86.1
Wind erosion	72.3
Overcutting	76.6
Environmental pollution	97.9
Land degradation	100

(Table 12). However, the soil accumulation is decreasing in the southern direction of the belt by more than >30%. Accumulation of sand is decreasing according to the distance from the belt (Table 13). However, Rubio and Recatalá (2006) proposed stoniness to be included in the soil erodibility index qualitative estimation. Erodibility is best obtained from direct measurements on natural plots (Kinnell 2010). Measured erodibility values have also been related to soil properties.

3.6 *Environmental and Socioeconomic Impact of Shelterbelts at Namla Village*

According to the respondent's views, land degradation, environmental pollution and desertification are the main environmental hazards faced by the community before establishment of the shelterbelts. However, wind erosion and overcutting of trees for fuel, are also negatively affecting the area and will also increase land degradation (Table 14). All respondents believe that land degradation is the major threat to agriculture and livestock production.

However, after the establishment of the shelterbelts, the respondent's views depicted high to moderate reductions in the previous hazards. Sand movement and wind erosion were reduced by more than 40%. The community mentioned that negative effects of drought and desertification were reduced by more than 60%. Over seventy percent of the respondents believed that the shelterbelts offered protection to their farms from sand blasts. In addition, the shelterbelts provided high protection or shelter to their animals and birds (Table 15). Therefore, as a result of above environmental enhancement, the shelterbelts are considered the main recreational site within the village.

Table 15 Effects of shelterbelts on the farms at Namla village in western Sudan

Benefits to environment	%
Decrease in sand movement	44.4
Decrease of wind erosion	48.9
Decrease of drought and desertification	62.2
Decrease of environmental degradation	66.7
Protection of the village and farms	73.3
Protection of animals and birds	97.6

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Using of Optimization Strategy for Reducing Water Scarcity in the Face of Climate Change

Mohammad Javad Zareian and Saeid Eslamian

Abstract Climate change is one of the most important factors that affect the availability of water resources in recent years. Many areas of the world are involved with droughts and water shortages due to climate change. Iran is one of the most notable areas in this field. The Zayandeh-Rud River Basin is of one of the most strategic areas in the central part of Iran in terms of water resources and consumption. In this study, the outputs of 15 GCMs related to the fourth assessment report of IPCC (AR4) are used for the analyzing the effects of climate change. A combination of the various GCM models is used through a weighting approach to generate the different climate change patterns including the ideal, medium and critical patterns. Then, the IHACRES model as a simple model designed to describe the dynamic response characteristics of catchments, was used to predict the natural inflow to the Zayandeh-Rud dam. Also, the Agro-Ecological Zones (AEZ) method that has been developed by the Food and Agriculture Organization (FAO) and International Institute for Applied Systems Analysis (IIASA), was used to determination of the effects of climate change on agricultural water demand. Based on the changes in the water resources and consumptions in the region, a non-linear optimization model was proposed to allocate the water between the different demands. The objective function was defined based on the minimizing of the water shortage during the next 30 years (2015–2044). The General Algebraic Modeling System (GAMS) software was used to solve this function. The results indicated that the annual water deficit of 610–1031 MCM will be occurred in different climate change patterns.

Keywords Zayandeh-Rud River · Climate change · IHACRES
GAMS · Water scarcity

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1 Introduction

Since 1950, the number of heat cycles has increased and it has increased the warm nights. In addition, areas affected by drought have also risen since rainfall has declined, but evaporation has increased due to warming areas. In general, the number of days with heavy rainfall that leads to an explosion has increased. The frequency of storms and tidal gaps varies greatly from year to year, but evidence suggests that their intensity and duration have increased since the 1970s.

While there are numerous evidence of drought in recent years, in many studies, the combination of total rainfall and average temperature are used to calculate drought indices. These indices have been calculated from the mid-twentieth century, showing widespread dryland trends in many parts of the northern hemisphere since the 1950s, as well as widespread drylands in many parts of southern Eurasia, South Africa, Canada and Alaska. The number of 4th and 5th storm categories has risen to 75% since 1970. The highest increase was observed in the Pacific North, India and the Southwest Pacific (Gellens and Roulin 1998).

Other parts of human life are also affected by climate change. Studies have shown that climate change reduces the yield of agricultural products and increases water consumption in this sector (Osborne et al. 2013; Roudier et al. 2011; White et al. 2011; You et al. 2009). Increasing the concentration of carbon dioxide in the atmosphere leads to a change in agricultural potential and water utilization efficiency of various products, as well as the expansion of agricultural-ecological potential towards poles and geographic latitudes. These positive results can be reduced with changes in temperature, quantities and distribution of rainfall, evapotranspiration pattern, radiation regime and indirect effects on land production capacity, such as increased pests, diseases and weeds, resulting in negative results. Therefore, in the long run, changes in climate patterns and agricultural potential, land potential and the ability of future generations to provide food and agricultural products significantly change (Fischer and Van Velthuizen 1996; Fischer et al. 2001; Sembroek and Antonie 1994). Other effects of climate change on agriculture include changes in the flow and storage of materials, the ecology of pests and diseases, the dynamics of rainfall regimes, plant response to temperature, CO_2 accumulation and plant tolerance to salinity.

In 2002, heat and drought severely reduced agricultural production in the world. As a result, agricultural production in the world was 90 million tones or 5% less. In 2003, the intense heat of Europe led to a decline in grain yield and 90 million tones more grain yield than its consumption. In 2004, rainfall improved, but in 2005 the United States drought reduced the world's grain harvest by 34 million tons.

The occurrence of extreme and rare floods is another part of the effects of climate change that causes a lot of damage (Arnell and Lloyd-Hughes 2014; Arnell and Gosling 2014). Melting the ice is another side effect of the heat of the planet. As the melting of the ice, more water enters the ocean. So the volume of water will increase and the evaporation rate will also increase. The water that rises with evaporation should land somewhere. So the number of storms and their severity will increase. Due to the heat of the atmosphere, rain is more likely to occur in the form of rain and the amount of precipitation is reduced to snow. As a result, mountain glaciers, the world's main reservoirs of water, are getting weaker, and storms and floods will become more severe.

Thus, the effects of climate change on the Earth's dynamism status are very broad and extend to socioeconomic segments (Stern 2006). These influences are to a degree that prompts politicians to provide incentive policies to prevent greenhouse gas emissions (Brunner et al. 2012; Jeffrey et al. 2001).

Climate change is a process that, in the long run, affects the Earth's climate processes based on changes in human greenhouse gas emissions. As previously mentioned, the greatest effects of climate change on the temperature and precipitation of the planet. The most important environmental processes affecting the future of mankind are due to the phenomenon of climate change. These processes include a wide range of atmospheric and hydrologic interactions, including floods, droughts, storms, and so on (IPCC 2007). So, among researchers, there is the conclusion that water resource management, not taking into account the effects of climate change, would not be very useful (World Water Assessment Program 2009). An important part of the effects of climate change on the hydrological cycle of water occurs on Earth. In other words, a large part of the hydrological properties in different parts of the world, the northern runoff, the surface water and underground water reserves, as well as the degree of flow (floods and droughts), undergo a change in climate. Under the conditions of climate change, many parts of the water consumer sector, including agriculture, urban, industrial and environmental, will have to respond to this situation. This answer will in many cases lead to conflicts over water demand. This is due to the increase in the human population, and many parts of the world will suffer from a shortage of supply and an increase in demand for water. Therefore, regardless of the comprehensive management of water resources in the absence of adequate water supplies, one cannot expect sustained supply and demand in the field of water resources. Such management should, by examining different aspects of water allocation between different uses, determine the priorities of each of the consumer sectors and, on the other hand, with regard to the availability of available water resources and the ability to store and release these resources, provide management scenarios Sustain in the region. Without such management, water resources, both surface and underground, will be seriously damaged in the long run (Smit et al. 2000).

Preparing different parts of water resources and resources to face the hydrological, social and economic impacts of climate change should be taken into account with regard to the adaptive capacities of the set in terms of pessimistic and optimistic forecasts. In such a situation, it is very important to pay attention to the hydrological parameters due to climate change. Under such a situation, the response of different consumers and their vulnerability to water scarcity. Therefore, the assessment of the effects of climate change on different water use sectors should be made according to appropriate responses to these conditions (Hutchinson et al. 2010).

Adapting a water resource system to climate change is based on understanding the talents and capabilities of that system to change the components of water resource allocation. To do this, the presentation of different approaches in the event of the occurrence of extreme values of hydrological parameters is inevitable. In such a situation, the consumption system will be able to respond to climate change in terms of minimum damage and sustainable development (Cohen et al. 1998; Srinivasan and Philipose 1996; Stakhiv 1994). The collection of relevant social, economic, and environmental information in each water supply system will help to define the limits and take appropriate management measures (Rayner and Malone 1998).

The degree of consistency of a water resource management system relative to climate change is not explicitly explored. The reason for this is the creation of many changes that are forced into the system and may lead to different and heterogeneous responses from consumers. Therefore, first and foremost, the components of compatibility with water scarcity conditions should be classified based on the desired responses (Krankina et al. 1997). This classification is subject to multiple time and space priorities. It can be assumed initially that no special management is performed in dehydration conditions, and thus ensure the maximum response of the system to the existing situation. Subsequently, based on the observed responses, it is possible to define different management scenarios for adapting the system to the provided responses (Bryant et al. 2000). In other words, some compatibility methods are presented after understanding the maximum responses. These methods can be defined according to different scheduling (Stakhiv 1994).

Another aspect of climate change-compatible measures can be found in the type of use. Part of the water consumption is dependent on the natural conditions in each region. Environmental expenditures cover a large part of this area, which in the long run adapts to underwater conditions. But we should not expect that the natural adaptation of the system would be low in accordance with the wishes of relevant managers in the water resources sector. Another part of these expenditures is done by human societies, which should be adapted to climate change and dehydration based on managerial vision. Different urban, industrial, and socioeconomic sectors need to define suitable water patterns, which should be defined primarily by water resource planners (Krankina et al. 1997). Planning to adapt water consuming sectors is mainly done by government agencies. These plans are designed to increase consumer awareness in order to reduce losses and increase water use efficiency (Bryant et al. 2000). The researchers refer to such plans as independent adjustments and against the natural adaptations of water users (Smit et al. 2000). The prediction and estimation of probable future adaptations are essential components of impact assessment studies and vulnerability of climate change. The likelihood of future climate change in a system depends to a large extent on the compatibility efficiency. In studies where no system compatibility is considered, the net or residual effects are too realistic estimates, resulting in greater systemic vulnerability, while in studies that have an effective adaptation to the system there is an estimated amount of vulnerability and the remaining effects less than their actual value. Therefore, having a proper understanding of the adaptation process and obtaining more information about the expected situations in which types of adaptation occurs is essential. It is important to have information on how, why, and when to make consistency in order to make informed judgment about the vulnerability of sectors, geographic regions and various communities (Kane et al. 1992; Tol et al. 1998).

The study of the effects of climate change on the Fraser River basin in Canada by Morrison et al. (2002) showed that during the period 2099–2099, the average flow of the river would increase by 5% and the maximum average flow would decrease by 18% (Morrison et al. 2002).

Hughes (2003) explores the climate change of the last century, illustrating future climate change and its ecological effects in Australia. The study of climate variables in the last century has shown that the average continental temperature in Australia has increased to 0.8 °C since 1910. Rainfall also showed a slight increase in the last century that it was more than summer in summer. In the case of rainfall, this trend is increasing on a regional and seasonal scale with a wider, broader continental scale. Also, a significant decrease in the average coverage was estimated during this period. The results showed that by 2030, the average annual temperature in most parts of Australia would be an increase of 0.6–2 °C. These changes are expected to be around 1–6 °C in 2070. Models also showed that the increase in maximum and minimum annual temperatures in the future would be similar to the variations in average temperature. While in past observation periods, the temperature rise was at most and at least more than the average temperature (Hughes 2003).

The results of the Kamga study on the upstream of the Benno River in Cameroon showed that by 2100 this region could see a decrease in rainfall of 4–13%, an increase in temperature of 1–3 °C, and a moderate decrease of the river flow by 3–18% (Kamga 2001).

Bekele and Knapp (2010) used three climate change scenarios (A1B, B1 and A2) and the SWAT model to assess the potential impacts of climate change on water supply in the Canadian Fox River Basin. Using climatic models, they produced climate scenarios for the study area and, using the Clear Delta switch, prepared these data for entering the hydrologic model. The produced climate scenarios showed an increase in temperature range from 0 to 3.3 °C and an annual rainfall change of −127 to 127+. The analysis of the results showed that rainfall changes cause significant fluctuations in the flow in the late summer and autumn, while the temperature increase strongly affects winter currents due to snow melt (Bekele and Knapp 2010).

Maurer (2009), using 16 models of GCM and A2 and B1 emission scenarios, investigated the hydrological effects of climate change in the Rio Lempa basin in Central America. To evaluate the effects of climate change, the VIC model was used as a distributed physical base model. The average temperature variation in the study area was estimated to be between 1.9 and 3.4 °C by 2099. 11 of the 16 models used predict the amount of rainfall in the future less than the present, so that the average rainfall under the A2 and B1 emission scenarios was reduced by 10.4 and 5%, respectively. Also, the amount of inflow into the dams in the area decreased by 13–24%, which was reported by the A2 scenario to be higher than the scenario B1 (Maurer 2009).

Minville et al. (2008) examined the uncertainty of the effects of climate change on the hydrology of one of the Scandinavian watersheds. In this study, five general circulation models and two climate scenarios together with the HSAMI integrated concept model were used as a rainfall/runoff model. The results of climate change in the future indicate a rise in temperature for all models and scenarios. In the case of rainfall, the results for diffusion models and scenarios were different. Considering all sources of uncertainty in this research, the most effective factor on the final results was the choice of the GCM model (Minville et al. 2008).

Gosain et al. (2006) examined the hydrological effects of climate change in Indian watersheds. Using SWOT distributed hydrologic model, they investigated the potential impacts of climate change in 12 river catchment areas. The results showed that the severity of droughts and floods in different parts may be more severe in the future. Also, the reduction of runoff was confirmed under greenhouse gas emission scenarios (Gosain et al. 2006).

The impact of climate change on the flow of Tamsi River flow in England was studied by Wilby and Harris (2006). In this research, uncertainty sources related to GCM models, microscopic methods, greenhouse gas emission scenarios, different models of rainfall-runoff simulation and their uncertainty related to their parameters, taking into account different weights and the Monte Carlo method Simulated. The results showed that the uncertainty associated with GCM models has the highest contribution and climate scenarios have the lowest contribution in estimating the runoff probability function. However, the main weakness of this research is the lack of weighting the uncertainty associated with GCM models that have the greatest impact on the outcomes of the system (Wilby and Harris 2006).

1.1 Case Study

The Zayandeh-Rud River Basin is located at 26,917 km^2 in the longitude 50° 24′–53° 24′ and latitude 31° 11′–33° 42′. The lowest and highest point in the basin is 1450 and 4300 m above sea level, respectively (Strauss et al. 2013). The region, located in the central and semi-arid region of Iran, is one of the strategic and complex regions of Iran in terms of the status of resources and water resources (Eslamian et al. 2012; Madani and Marino 2009; Zareian et al. 2014, 2017; Zareian and Eslamian 2016). The rainfall in this basin varies from 1500 mm in the west of the basin to 50 mm in the eastern regions of the basin (Moghaddasi et al. 2013). In general, a large part of the basin has a rainfall of less than 150 mm throughout the year. The average annual rainy days in this area are 70 days (Salemi and Murray-Rust 2004). Figure 1 shows the overall position of the Zayandeh-Rud River Basin in the central part of Iran.

Zayandeh Rud River is the most abundant river in the semi-arid region of Iran, which supplies most of the water needed in Zayandeh-Rud River Basin.

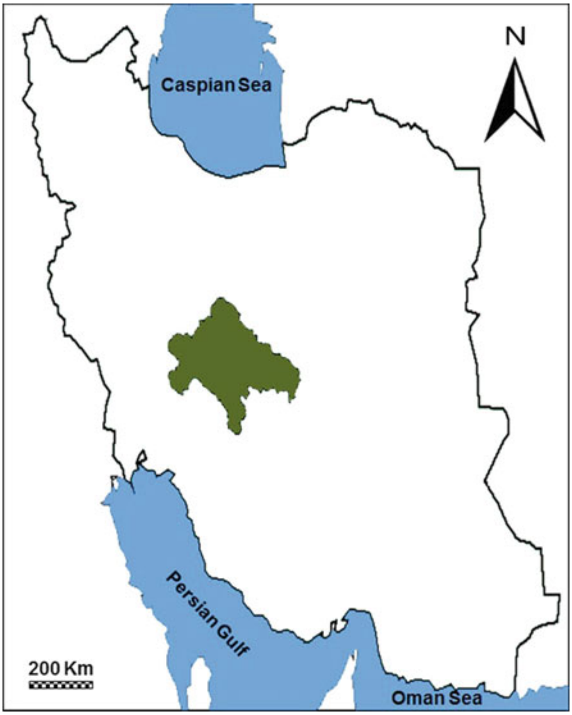

Fig. 1 The overall position of the Zayandeh Rud basin in the central part of Iran

The existence of this river in this basin is one of the main foundations of the formation of the ancient civilization of this region. Different sectors of water consumption in the Zayandeh-Rud River Basin, which include agricultural, urban and industrial areas, are highly dependent on the flow of water in the Zayandeh Rud River River. The expansion of urban areas, agricultural lands and industrial settlements along the river is quite clear.

The attraction that has been caused by the increasing development of this basin in various dimensions has encouraged the people of neighboring areas to migrate to this region, and along with that, the population of the basin has increased dramatically and created numerous industries and factories within the basin (Hashmi et al. 2011).

The synchronization of the conditions mentioned with the occurrence of climate change has made the situation more difficult for the catchment area. The increase in temperature and future rainfall in the Zayandeh-Rud River Basin has been reported by researchers (Fischer et al. 2001). As a result of future climate change, quantity and quality of water will also be affected, and the need for newer water resources will be felt (Zayandab Consulting Engineering Co. 2008; Zareian et al. 2014a, b, 2017; Zareian and Eslamian 2016).

1.2 Climate Change Modelling

According to the IPCC's fourth report, the base period of 1971–2000 has been set as the last base course for analyzing the output of GCM models (IPCC 2007). Therefore, the predicted values of temperature and precipitation were extracted by each of the 15 GCM models for the base period. This process was repeated individually for each meteorological station used. In order to calculate the difference between the values of observational data as well as the output data of GCM models from 1971 to 2000, Eqs. (1) and (2) were used (Zareian et al. 2014):

$$\mathrm{TE}_m^{G_i} = \left|\left(\bar{T}_m^B\right)_{G_i} - \left(\bar{T}_m^B\right)_O\right| \tag{1}$$

$$\mathrm{PE}_m^{G_i} = \left|\left(\bar{P}_m^B\right)_{G_i} - \left(\bar{P}_m^B\right)_O\right| \tag{2}$$

In the above equations, $\mathrm{TE}_m^{G_i}$ and $\mathrm{PE}_m^{G_i}$ are the absolute error values of each of the GCM models in estimating the values of temperature and rainfall. G represents the GCM models and their counters. $\bar{T}$ and $\bar{P}$ are average values of 30 years of temperature and rainfall. Indicator B represents the base year 1971–2000 and the index m represents the target month. Also represents the actual data observed at each station in 1971–2000. Simply put, Formulas (1) and (2) show how much difference between the output of GCM models and the actual values of data observed at each station and in each particular month of the year.

The period that was selected to predict the effects of climate change on the Zayandeh Rud River basin was the 30-year period from 2015 to 2044. Due to the use of two A2 and B1 emission scenarios, two general combinations for extracting temperature and rainfall parameters were defined using GCM models. The temperature and rainfall changes of each station are defined using relationships 3–6:

$$\Delta T_m = \sum_{G=1}^{15}\left\{\mathrm{WT}_m^{G_i} \times TCF_{Gi}\right\} \tag{3}$$

$$TCF_{Gi} = \left(\left(\bar{T}_m^F\right)_{G_i} - \left(\bar{T}_m^B\right)_O\right) \tag{4}$$

$$\Delta P_m = \sum_{G=1}^{15}\left\{\mathrm{WP}_m^{G_i} \times PCF_{Gi}\right\} \tag{5}$$

$$PCF_{Gi} = \left(\frac{\left(\bar{P}_m^F\right)_{G_i}}{\left(\bar{P}_m^B\right)_O}\right) \tag{6}$$

where ΔT_m is the difference between the temperature between the next period and the base period (°C), ΔP_m, the amount of precipitation difference between the next period and the base period (%) and $\left(\bar{T}_m^F\right)_{G_i}$ and $\left(\bar{P}_m^F\right)_{G_i}$ are the average 30 years of temperature and precipitation in the upcoming period, respectively (Zareian et al. 2014b, 2017).

In order to use the output of GCM models in meteorological studies and water resource issues, they should be converted to quantitative or monthly data values at any point by means of downscaling methods. This is done by weather generators (Hashmi et al. 2011). The LARS-WG model is one of the most well-known random weather generators capable of producing a daily weather data series.

1.3 Water Allocation Modelling

In order to allocate water in the future, at the downstream of the Zayandeh Rud dam, first all future imaginable water resources for this area were investigated. These resources include the surface water of the Zayandeh Rud dam, the transfer of water from other basins, and the underground water source.

The main source of surface water in the area was Zayandeh Rud Dam, fed by Zayandeh Rud River. The dam, which started its operation in 1970, is used as a means of adjusting the flow in cold and dry seasons.

This dam is located in the upper reaches of the selected land area, and its water, in addition to consumption in irrigation and drainage networks, also consumes industry and drink.

For the purpose of determining the lateral water consumption behind the Zayandeh Rud Dam, the average bill of 10 years of the dam (from 2004 to 2014) was considered average.

Therefore, other than usual uses in the fields of agriculture, drinking and industry, the share of evaporation from the Zayandeh Rud River Dam and unauthorized impressions should also be taken into account on the basis of the amounts obtained. Also, the volume as the base volume in the reservoir of the dam should be avoided in order to prevent the full drainage of the dam. This amount is between 150 and 200 million cubic meters, which is estimated at 200 million cubic meters. In other words, the total amount of water entering the dam can not be allocated to costs and the unwanted upstream costs (evaporation, remaining water volume in the tank and unauthorized harvest) should be deducted from it.

The main objective of optimization in this research is to reduce the difference between supply and demand of water based on a quadratic function. The objective function is intended to minimize water scarcity in the studied area as follows:

$$\min Z = \sum_{j=1}^{30}\sum_{i=1}^{12}(Supply - Demand)^2 = \sum_{j=1}^{30}\sum_{i=1}^{12}\left(Sh_{ij}\right)^2 \tag{7}$$

In this equation, Z is the objective function of minimizing the water deficit and Supply and Demand, respectively, the amount of water allocated to each of the expenditures. j represents the target year for optimization that varies from 2015 to 2044 for this research, or in other words, varies from 1 to 30. i represents each of the months of the year, which varies from 1 to 12.

1.4 Results

Figures 2 and 3 show respectively the annual water allocation for the baseline scenario in A2 and B1 scenarios. Table 1 also shows the summary of the annual water allocation values for both of the published scenarios. The results of the A2 emission scenario indicate that the average annual water requirement of different sectors in the ideal, moderate and critical climate change patterns will be 3505, 3572, and 3641 MCM, respectively. Of these, an average of 3051, 2939 and 2837 million cubic meters will be allocated. For the B1 emission scenario, the average annual total water demand in the three climate change models was calculated to be 3386, 3450, and 3498 million cubic meters, and the allocation would be equal to 3039, 2852 and 2746 million cubic meters. Therefore, on average, there will be an annual water shortage for climate change patterns in the A2 emission scenario of 454, 633, and 803 million cubic meters, respectively. These values in the B1 emission scenario will be 347, 576, and 752 MCM.

The annual amounts reported for allocations and water scarcity are based on a 30-year average over the period 2015–2044. In some years the amount of deficiency will be higher and in some years will be less than the average. For the A2 emission scenario, the highest amount of water requirement in all climate change patterns will occur in 2042, the smallest in 2029. The maximum water requirement for an ideal, moderate, and critical climate change pattern in the A2 emission scenario will be 4191, 4251 and 4333 MCM, respectively, which will account for 733, 852 and 1031 MCM of water deficit, respectively.

The highest amount of water requirement in the region is observed in the B1 emission scenario in 2041 and the lowest in 2017. The greatest deficit in the three climate change patterns will be 3876, 3450, and 3498 MCM respectively, with the lowest of 2924, 2980 and 3025 MCM, respectively. Therefore, the largest water shortage of the region will be 610, 802, and 906 MCM, respectively.

In Figs. 2 and 3, in addition to determining the total water consumption during the period from 2015 to 2044, the total amount of water allocation from the Zayandeh Rud Dam, groundwater resources, as well as the deficiency occurred on the basis of the baseline water allocation scenario. Climate change will affect all of the above mentioned parameters.

The results show that different patterns of climate change in two states will affect water scarcity. On the one hand, with increasing water requirements in the agricultural sector, they increase the total water requirement of the entire area and, on the other hand, by reducing the flow of the dam, reduces the possibility of the

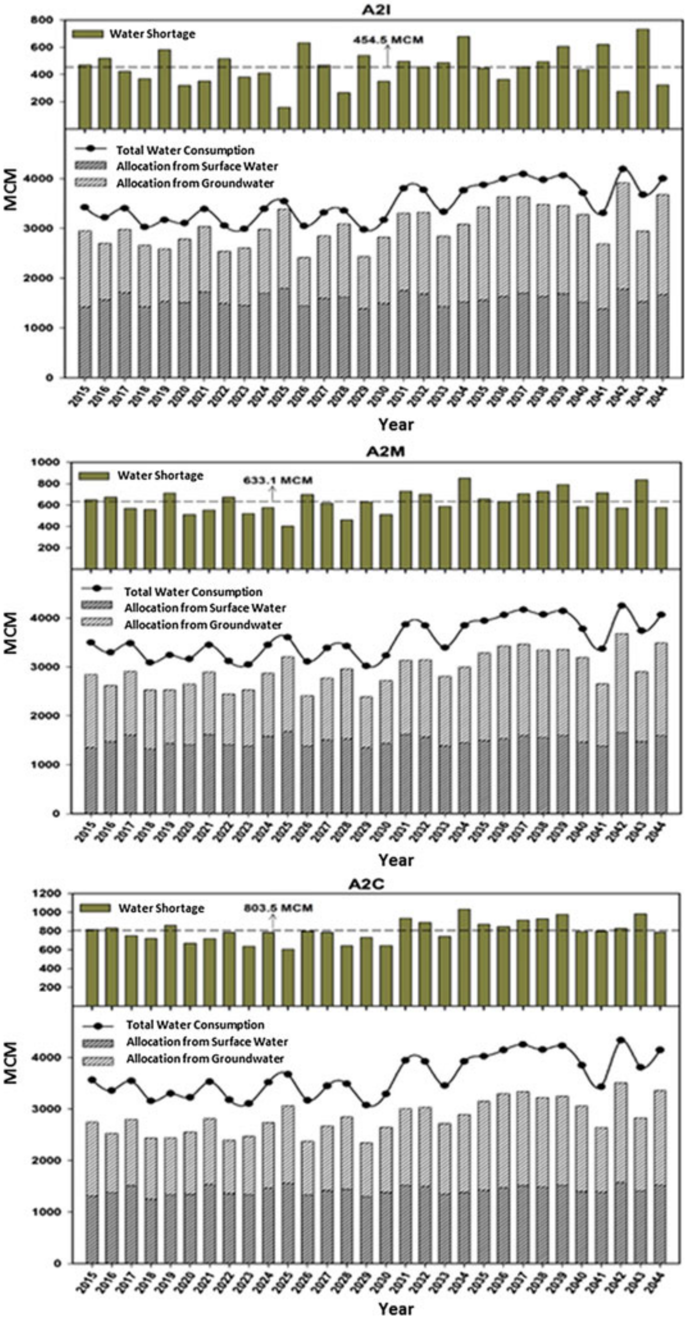

Fig. 2 Annual water allocation scheme in the basic management scenario under different patterns of climate change in the A2 scenario

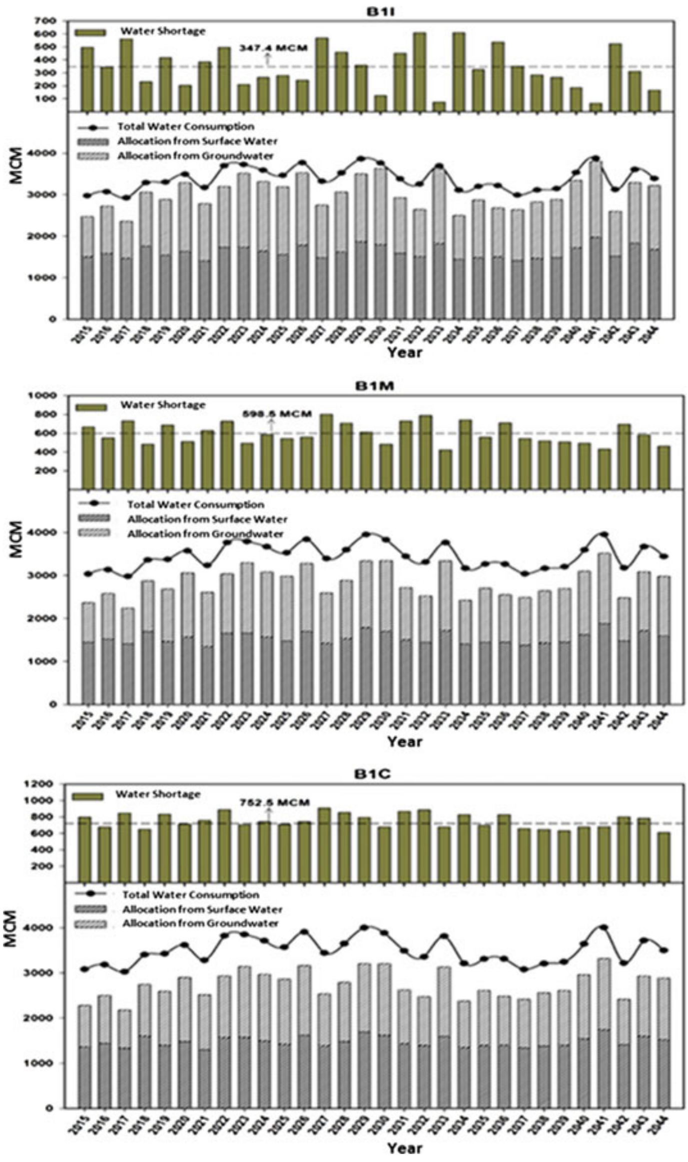

Fig. 3 Annual water allocation scheme in the basic management scenario under different patterns of climate change in the B1 scenario

allocation of surface water. In addition, the reduction of water consumption in the basin and the release of surface water will affect the return of water from different uses to groundwater resources. For example, in the case of moderate climate change, the amount of water allocation from the dam and underground water would be 1494 and 1445 MCM, respectively, in the A2 emission scenario and 1549 and 1303 MCM respectively in the B1 emission scenario. Because the amount of abandoned surface water in the B1 climate change pattern is more than A2, the amount of groundwater extraction in the B1 emission scenario can be reduced to a lesser extent than the A2 emission scenario.

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Climate Change Impact on Agriculture and Irrigation Network

Zohreh Dehghan, Farshad Fathian and Saeid Eslamian

Abstract In the last century, impacts of climate change phenomenon and its consequences such as changes in temperature, precipitation, evapotranspiration, and amount of available water have been observed in various aspects of human life, especially in agricultural sector. In the agricultural sector, performance of irrigation networks is known as one of the important and effective factors on crop yield and development of sustainable agriculture. These networks can be affected by climate change because the irrigation networks are designed based on the climatic variables and crop pattern of considered region. In this chapter, sprinkler irrigation network of Bilesavar, located in the north of Iran, is considered as study area in order to investigate the effects of climate change on climatic variables. Moreover, according to existing agro-industry in the study area, the impacts of climate change are investigated on available crop pattern in order to specify conditions in the region in terms of maintaining sustainable agriculture. Since the most irrigation systems are designed based on the water requirement of crop pattern and water delivery based on farmer demand in the required pressure and discharge, the performance of irrigation network are evaluated in terms of equity and adequacy indices. Eventually, the adaptation strategies to climate change will be discussed for maintaining performance, stability of pressurized irrigation system, productivity improvement, and an increase in efficiency.

Keywords Agriculture · Climate change · Irrigation network · Performance evaluation · Iran

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1 Introduction

According to the fifth IPCC report, increasing concentrations of CO_2 and other greenhouse gases have led to fundamental changes due to anthropogenic activities in the global climate over the course of the last century. The future global climate will be characterized by uncertainty and change, and this will affect water resources and agricultural activities (IPCC 2013; Adamowski et al. 2010). In the agricultural sector, there are multiple variables which will be affected due to the impacts of climate change; so that, in the longer term, the potential significant effect of climate change is nowadays recognized worldwide. Furthermore, the impact of climate change will depend on hydrometeorological and environmental conditions as well as the capacity to adapt to change. For instance, evapotranspiration is controlled by climatic variables (such as temperature, precipitation, net radiation, wind and relative humidity), and changes in climatic regimes can affect hydrological processes, yield production, and the development of agricultural activities (Allen et al. 1991; Yang et al. 2007; Perez Urrestarazu et al. 2010). Given the importance of agriculture, there is a significant need to understand the implications of climate change on agriculture, and to explore different adaptation options (Gohari et al. 2013).

Performance and vulnerability assessments of irrigation networks are an increasingly significant area of research with respect to impacts and adaptation to climate change (Fathian et al. 2016). From the viewpoint of agricultural water management, the phenomenon of climate change will have unfavorable effects on evapotranspiration and crop water requirements (CWRs), and there will be impacts on the performance of irrigation networks (Perez Urrestarazu et al. 2010). Irrigation networks will have to be designed for longer and higher peaks in irrigation water demand, which may cause problems in some of the present networks (Rodríguez Díaz et al. 2007). These changes will influence the planning and operational management, flow regime, and performance of irrigation networks. As such, the analysis of climate change impacts and adaptation strategies to maintain the performance and stability of irrigation systems, as well as improve their efficiency, are necessary (Calejo et al. 2008; Huang et al. 2011).

To date, many studies have been completed on the topic of climate change impacts on agriculture (e.g., Rosenzweig et al. 1995; Thomson et al. 2006; Brunsell et al. 2010; Vaze et al. 2011). Some of these studies are related to climate change impacts on agricultural products (e.g., Tatsumi et al. 2011; Dalezios et al. 2017); while others are related to modeling of climate change impacts on crop water requirements, irrigation systems and ect (e.g., De Silva et al. 2007; Fischer et al. 2007; Rodríguez Díaz et al. 2007). Since most studies have evaluated the performance of surface and pressurized irrigation networks in the current climate status. In recent years, the performance of irrigation networks, especially under climate change scenarios, has become a growing concern of the researchers, irrigation policy makers and donor agencies. For this purpose, a few studies evaluated the effects of future changes in the climate on irrigation networks. Perez Urrestarazu et al. (2010) used climate data in three periods (2050, 2079 and a base period), and evaluated an irrigation network using vulnerability indices such as equity and adequacy. The results of their study showed that climate change would have a major impact on network performance with existing cropping patterns, but that changes in cropping patterns could reduce this impact. Daccache et al. (2010) considered the impacts of climate change and the performance of pressurized irrigation water distribution networks under Mediterranean conditions. The results showed that under the current design, the irrigation system can tolerate a peak demand discharge, which is below the 2050s average. Accordingly, the performance of the system will fall significantly as the number of unreliable hydrants will increase so that, assuming the same cropping pattern, the threshold discharge will fail during peak demand periods. In another study, Karamouz et al. (2010) evaluated the improvement of urban drainage networks in Iran under climate change. However, to date, the effect of climate change on irrigation distribution networks has not been explored in Iran. On the other hand, introducing of water resources supply scenarios, as another contribution, has not been tackled yet in any study. Therefore, the main objective of this study was to explore and evaluate the performance of irrigation networks in terms of the vulnerability of systems under climate change and water supply scenarios. To accomplish this, a methodology is proposed in this study to assess the possible effects of future changes on irrigation networks, and it was applied in the Bilesavar irrigation network district in Northern Iran.

2 Materials and Methods

2.1 Study Area, Cropping Patterns and Data

The Bilesavar irrigation network is located in the Moghan plain in Ardebil province in Northern Iran (48° 15′ to 48° 20′ East longitude and 39° 21′ to 39° 28′ North latitude). In this area, increases of around 5 and 13% in the CWRs are predicted by 2010–39 and 2050–79, respectively, due to climate change (Dehghan 2012). The Bilesavar irrigation district is 3200 ha, with 21 field units or sectors and cropping patterns that are devoted to a wide range of crops such as wheat (40%), barley (15%), alfalfa (20%), cotton (20%) and lentil (5%). The area is covered by a well maintained pressurized network, which is designed to provide irrigation on demand with an irrigation efficiency of 80%, and a distribution efficiency of 100%. Table 1 shows the planting calendar and crop coefficients of the cropping pattern for the estimation of crop evapotranspiration and water requirements in this district. It can be seen that alfalfa is cultivated all months of the year, while wheat, barley, lentil, and cotton are cultivated during 8, 8, 4, and 7 months of the year, respectively. Water is taken from the Aras river and pumped using a system of 55 pumps from 21 pumping stations. The configuration of the system is not a looped network, in other words; the 21 pumping stations supply the water demand for 21 field units in

Table 1 Planting calendar and crop coefficients

Crop	Jan.	Feb.	Mar.	Apr.	May	June	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Wheat	0.4	0.4	1.2	1.3	1	1.04					0.4	0.44
Barley	0.4	0.4	1.3	1.3	1	1.04					0.4	0.44
Alfalfa	1	1	1	1	1	1.1	1.1	1.1	1.06	1	1	1
Lentil				0.4	1.1	1.1	0.75					
Cotton					0.4	0.6	0.84	1.2	1.15	1.11	0.88	

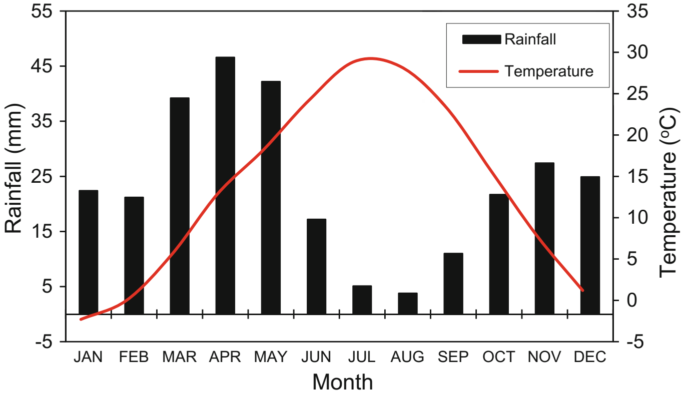

Fig. 1 Variations of monthly rainfall (mm) and temperature (°C) during the 1971–2000 period

independent networks. The main network is able to supply 3 L/s/ha on demand in each one of the 863 outlets, simultaneously. The irrigation period is 6 days and the irrigation time is 19 h. The assigned pressure in the outlet is 30 m. Data from the Pars Abad meteorological station, which was used as the data for the baseline period, was applied to predict climate variables as well. The record of the data is 30 years (1971–2000), and as shown in Fig. 1, the average, maximum, and minimum annual temperature and the average annual precipitation are 13.7, 30, and −2.3 °C, and 283 mm, respectively, in Pars Abad region (http://www.weather.ir/). The driest month is August, with less than 5 mm of rain. Most rainfall falls in April, with an average of 47 mm. July is the warmest month of the year. The temperature in July averages 28.9 °C. In January, the average temperature is −2.3 °C. It is the lowest average temperature of the whole year. There is a difference of 42.8 mm of precipitation between the driest and wettest months. The average temperatures vary during the year by 31.2 °C.

2.2 General Circulation and SDSM Downscaling Models

To estimate future climate change resulting from the continuous increase of greenhouse gas concentrations in the atmosphere, general circulation models (GCMs) are used. GCMs demonstrate significant skill at the continental and hemispherical scales, and incorporate a large proportion of the complexity of the global system, but are inherently unable to represent local subgrid scale features and dynamics (Wigley et al. 1990; Carter et al. 1994). The outputs of GCMs cannot be used directly for climate change studies, and they do not provide a direct estimation of the hydrological response to climate change (Dibike and Coulibaly 2005). This is due to the mismatch in the spatial resolution between the GCMs and hydrological models, and the large coarse resolution.

As a result, downscaling techniques are used to convert the coarse spatial resolution of the outputs of GCMs into finer resolutions, which may involve the generation of point/station data of a specific area using GCM climatic output variables (Dibike and Coulibaly 2005; Hashmi et al. 2009). Downscaling techniques can be classified into statistical and dynamical downscaling methods (Maraun et al. 2010). This study used a statistical downscaling method, SDSM, which has been widely applied to downscale GCMs, as can be seen by the over 170 publications that used this model (Wilby and Dawson 2012). In this study, the output from the Hadley GCM3 model (HadCM3) was utilized to downscale temperature and rainfall data for region study. The HadCM3 model is one of the major models used in the IPCC Third and Fourth Assessments, and it also contributed to the Fifth Assessment. It is widely considered to be quite useful, and as such was used in this study (Reichler and Kim 2008). Additional details regarding GCMs and downscaling models can be obtained in Hashmi et al. (2009), and Hassan and Harun (2012).

2.3 Climate Change and Water Supply Scenarios

The Intergovernmental Panel on Climate Change (IPCC) published a new set of scenarios in 2000 for use in the Third Assessment Report (Special Report on Emissions Scenarios—SRES). The SRES scenarios were constructed to explore future developments in the global environment with special reference to the production of greenhouse gases and aerosol precursor emissions. The SRES team defined four scenarios, labelled A1, A2, B1 and B2, which describe the way in which global population, economies, and non-climate policies may evolve over the coming decades. It has been useful to describe the scenarios with respect to two dimensions. The first dimension relates to a more economic (A scenarios) or a more environmental (B scenarios) orientation, while the second dimension relates to a more global (1) or a more regional (2) orientation. The scenarios are summarized as follows (Nakicenovic et al. 2000):

- A1: a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies;
- A2: a very heterogeneous world with a continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other storylines;
- B1: a convergent world with the same global population as in A1 but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies;
- B2: a world in which the emphasis is on local solutions to economic, social, and environmental sustainability, with continually increasing population (lower than A2) and intermediate economic development.

In this study, A2 and B2 scenarios related to the temperature and precipitation variables were applied in order to include the most salient scenario variables of demographic and economic development on the high and intermediate side (scenarios A2 and B2 respectively), and their results were subsequently compared (Hassan and Harun 2012). Furthermore, in this study, two water supply scenarios (as new contributions) were also considered and combined with A2 and B2 emission scenarios for adaption strategies in the future. In the first water supply scenario, it was assumed that there would be no limitation of water resources (NLWR) to supply increasing water demands of crops in the irrigation district. In the second water supply scenario, it was assumed that there would be limitations of water resources (LWR), and that the available water resources would not be able to supply increasing water demands. Therefore, in order to prevent of the yield of crops, reduce the damage to farmers, supply the crop water requirement and respond to the appropriate planting area in LWR condition, it is necessary to optimize the planting area.

In this study, the planting area was optimized using the LINGO model (Moghaddasi et al. 2010; Xie and Xue 2005). The LINGO software solve the objective function based on linear optimization model. In this study, the objective function was to maximum benefit which is equal to the product ($Max\,Benefit = F \times P \times A$) of the product yield ($F$: kg per hectare), the price of each product (P: \$/kg), and the optimized planting area for each crop (A: ha). The constraints introduced in LINGO in order to determine the optimized planting area for each crop are: (i) changes in A along with $\pm 20\%$ of current A (ii) maximum consumed water in the future should not be more than the current consumed water, (iii) all variables are greater than zero. These constraints was adopted from Moghaddasi et al. (2010) and Paimozd et al. (2010) according to the different adaptation strategies to climate change and the amount of irrigation water available to achieve maximum benefit. Finally, in order to assess the irrigation network under the previously mentioned scenarios, the climate change scenarios were coupled with water supply scenarios; these are given as A2 + NLWR, B2 + NLWR, A2 + LWR and B2 + LWR for the 2010–39 and 2050–79 periods.

2.4 Methodology

Figure 2 shows the methodology that was used in this study. As it can be seen, the SRES scenarios have been used in addition with the water supply scenarios. Therefore, rainfall, temperature, and other climatic data were obtained for the baseline, A2 2010–39, B2 2010–39, A2 2050–79 and B2 2050–79 for the case study irrigation district in northern Iran.

The CROPWAT model (Clarke et al. 1998) was used to estimate ET_o, CWRs, gross irrigation water requirements (GIWR), and the maximum flow required using the rainfall, temperature, other climatic data and the crop patterns (as input data into the model) for each scenario. The FAO Penman-Monteith equation was used in this model to calculate ET_o (Smith 2000). The irrigation network was modeled in WaterGems (Fig. 3), one of the most widely used hydraulic simulation models. The inputs were the hydraulic characteristics of the network. After running the simulations in all situations (baseline, A2 2010–39, B2 2010–39, A2 2050–79 and B2 2050–79), the key variables were obtained for calculating selected indicators (Calejo et al. 2008; Perez Urrestarazu et al. 2009, 2010) as described below.

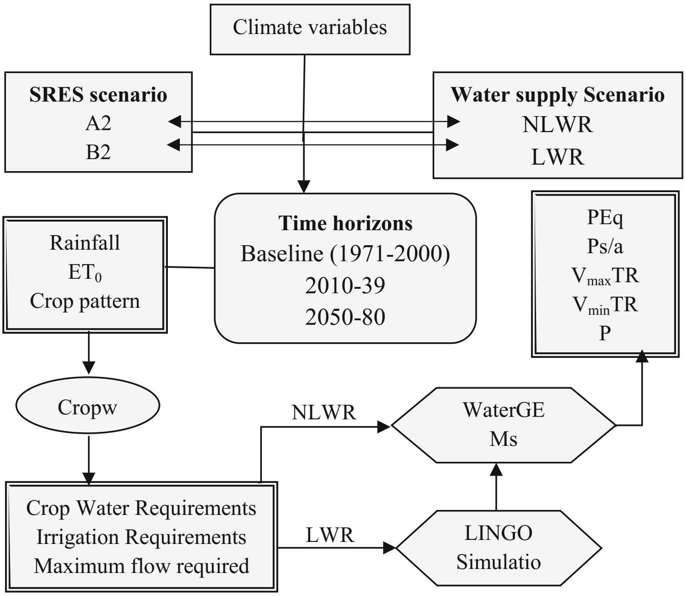

Fig. 2 Flow chart displaying methodology (*Note* PEq = Pressure Equity, Ps/a = Pressure ratio, $V_{max}TR$ = Maximum velocity ratio, $V_{min}TR$ = Minimum velocity ratio, P = Consumption energy of pumping)

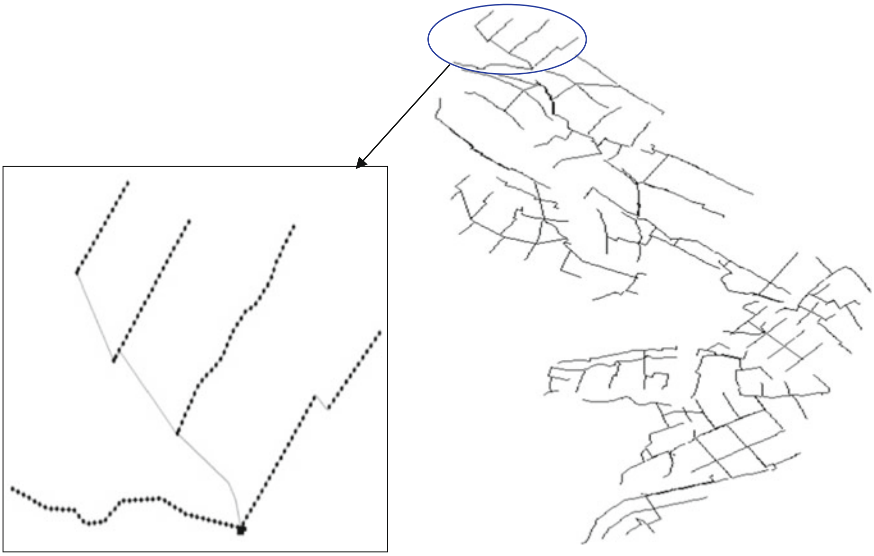

Fig. 3 Model of the network in WaterGems for the baseline

2.5 Network Performance

Climate change could affect the performance of the irrigation network due to increases in demand. The main constraint of an irrigation system is that the required flows should be supplied to water users with adequate pressure (Farmani et al. 2007). In this irrigation network the system is on-demand and the farmer has water available whenever he wants. It should be noted that the concept of the water available is based on the LWR and NLWR scenarios as explained in the previous section. Therefore, the limitations of irrigation systems depend on the given flow and pressure in the outlets, and if the system is overloaded, farmers may be obliged to cut off the supply and postpone irrigation (Rodríguez Díaz et al. 2007). Thereupon, these irrigation systems, in order to respond to the increasing demands, need to have a network with a higher distribution capacity, while it makes them much more expensive (Perez Urrestarazu et al. 2010). Hence, it is essential to have information on the future performance of the network. In this paper, in order to study the future behavior of the network, five performance indicators were used. Each indicator is expressed quantitatively, as an aspect of irrigation network performance standards, which helps to assess and monitor irrigation system (Perez Urrestarazu et al. 2010).

Pressure Equity (PEq)

This indicator expresses the uniform distribution of pressure between outlets in the network using the interquartile ratio:

$$PEq = \frac{\overline{P_{pq}}}{\overline{P_{bq}}} \tag{1}$$

where $\overline{P_{pq}}$ is the average pressure in the weakest quarter and $\overline{P_{bq}}$ is the average pressure in the best quarter, taking into account all the network's checkpoints. In this study, the pressure equity indicator refers to the pressure at the outlets which, for on-demand irrigation distribution systems, is not constant but depends on outlets simultaneously operating (Gorantiwar and Smout 2005; Perez Urrestarazu et al. 2010).

Simulated/Assigned Pressure Ratio ($P_{s/a}$)

This indicator represents the pressure obtained in the simulation with the one assigned in the outlets of the network:

$$\left(P_{s/a}\right)_i = \left(\frac{P_s}{P_a}\right)_i \tag{2}$$

where P_s is the simulation pressure in the checkpoint and P_a is the design (or actual) pressure in the i checkpoint. If $P_{s/a} < 1$, it means that this outlet will be working below the required pressure (Perez Urrestarazu et al. 2009).

Maximum Velocity Ratio ($V_{max}TR$)

This indicator represents the ratio of the measured to the permissible maximum velocity in the outlets. If the value of the index is greater than zero, the occurrence probability of water hammer in pipes increases and it causes an unsteady flow conditions into network:

$$V_{\max}TR = \frac{V_{\max}T}{V_{\max}TP} - 1 \tag{3}$$

where, $V_{\max}TR$ is the indicator of maximum velocity of water transmission, $V_{\max}T$ is the measured maximum velocity and $V_{\max}TP$ is the permissible maximum velocity of water transmission in the pipes (Mahdavi 2008).

Minimum Velocity Ratio ($V_{min}TR$)

This indicator determines the ratio of the measured to the permissible minimum velocity in the outlets. If the value of the index is lower than 1, the probability of sedimentation due to the low velocity of water in pipes increases:

$$V_{\min}TR = \frac{V_{\min}T}{V_{\min}TP} \tag{4}$$

where, $V_{\min}TR$ is the indicator of minimum velocity of water transmission, $V_{\min}T$ is the measured minimum velocity and $V_{\min}TP$ is the permissible minimum velocity of water transmission in the pipes (Mahdavi 2008).

Consumption Energy of Pumping (P)

This indicator represents the energy consumption of the pumping station:

$$P = \frac{V \times H}{0.102 \times E_a} \tag{5}$$

where P is the value of energy consumption (Kw), and V, H and E_a are the water volume, height and efficiency of pumping, respectively (Rodrıguez Dıaz et al. 2009).

3 Results and Discussion

3.1 *Comparison of Rainfall, Temperature and ET_o Values Among Scenarios*

Climate variables were calculated for the Bilesavar irrigation district to give an overview of the general differences between the two time periods on a monthly basis. Figure 4a–c shows the monthly average of temperature, rainfall, and ET_o values for the baseline (1971–2000), 2010–39, and 2050–79 periods, respectively. In general, scenario A2 results in more increases in temperature than B2 in each time period, and according to these scenarios, higher temperatures will be seen in 2050–79 compared to 2010–39 (Fig. 4a). According to scenarios A2 and B2, the months of June to September will experience higher temperature increases. Temperature may increase around 10 and 23% on average by 2010–39 and 2050–79 in comparison with baseline period, respectively.

In the case of rainfall, the results for each time period are different (Fig. 4b). For 2050–79, scenario B2 results in a higher increase in rainfall than A2 in each time period, while for 2010–39, an increase can be observed from November to February. Compared to the baseline, both A2 and B2 scenarios show a decrease from April to October for the two time horizons. Rainfall is seen to decrease by 4% on average by 2010–39, and by 7 and 1% for A2 and B2, respectively, by 2050–79. The outcomes of the climate change scenarios in case of the changes in the rainfall and temperature values in this section are in accordance with the study of Ashofteh and Massah (2009). They showed that the temperature increases and precipitation decreases in the Aidoghmoush area in Iran (an area near Ardebil province with a similar climate).

For ET_o, in comparison with the baseline, both A2 and B2 scenarios show an increase for each time period (2010–39 and 2050–79). Generally, scenario A2 results in a higher increase in ET_o compared to B2 in each time period for 2050–79,

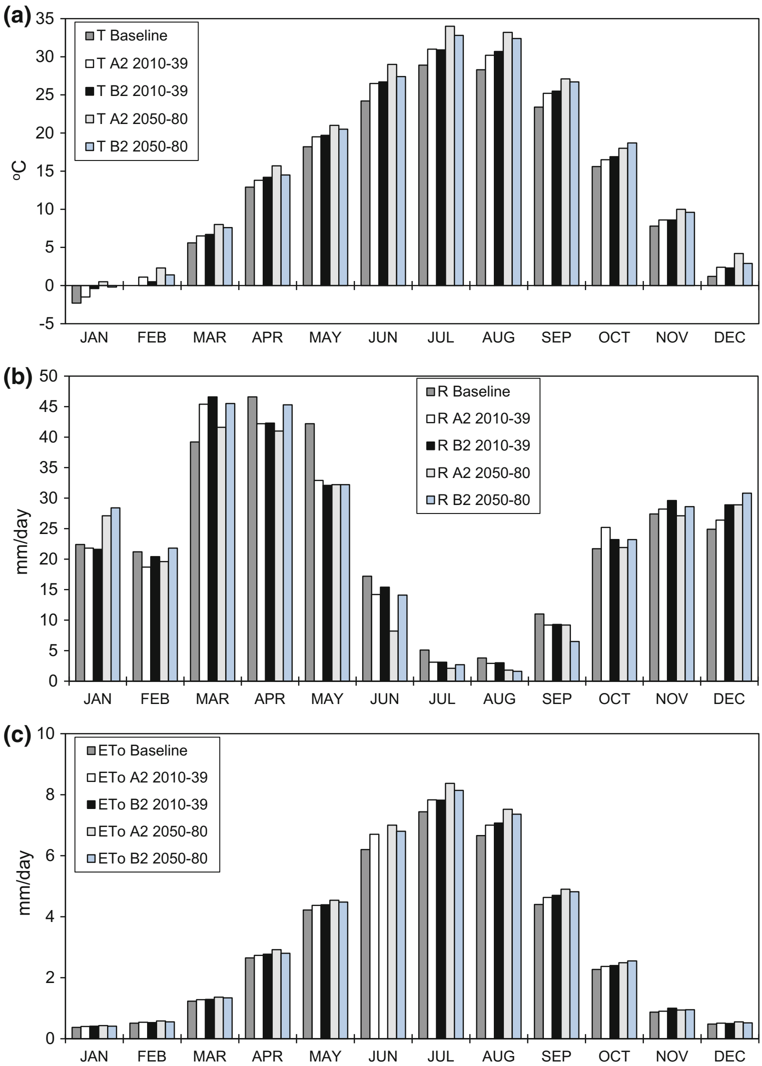

Fig. 4 Values of **a** temperature, **b** rainfall and **c** ET_o for all the scenarios

while for 2010–39, there is no difference between the values of ET_o in the A2 and B2 scenarios (Fig. 4c). ET_o is around 6% higher than the baseline for 2010–39 and 12% for 2050–79. Overall, the situation will be more unfavorable as in the months with peak demand, and the conditions will be more extreme (less rainfall, more temperature and ET_o).

3.2 Assessment of Cropwat Model Outputs Based on Climate Change

As mentioned in the previous section, because the value of ET_o in scenario A2 is higher than in B2 for both of future periods, the ET_o of scenario A2 was selected to estimate the GIWR, CWRs, and maximum flow of water supply (FWS) of the cropping patterns in the district. Figure 5a–c shows the annual values for GIWR, CWRs, and FWS for each crop in the baseline, 2010–39 and 2050–79 periods, respectively. GIWR is an effective factor in designing and managing irrigation networks, and is the quantity of water to be applied in reality, taking into account water losses. For 2010–39 (2050–79), GIWR may be 6 (13), 6 (13), 3 (12.3), 7.5 (10.7), and 5.8% (14.5%) higher than the baseline for wheat, barley, alfalfa, lentil and cotton, respectively (Fig. 5a). Consequently, the water volume of irrigation requirements increases due to the increase of GIWR. In light of this, the estimated water volume for the baseline, 2010–39 and 2050–79 periods are 16.5, 18 and 21 MCM, respectively. For 2010–39, CWR is higher than the baseline period for all crops, increasing around 5, 5, 2, 7, and 5% for wheat, barley, alfalfa, lentil and cotton by 2010–39. For 2050–79, CWR values are around 13, 13, 12, 12, and 12% higher than the baseline (Fig. 5b). In the case of FWS, there are more differences between scenarios which is the key factor affecting network performance (Fig. 5c). For 2010–39, FWS is 8, 8, 3, 10, and 6% higher than the baseline for all crops, respectively, while for 2050–79, the results show an increase of approximately 12% compare to the baseline for all crops.

The results of this study are in accordance with other studies. In an extensive study, Fischer et al. (2007) used climate change models and showed that irrigation water demand increased approximately 45% in the world during the 1990–2079. In another study, Knox et al. (2010) showed that irrigation water requirements increased between 20–22% for the A2 and B2 scenarios for the climatic period 2050 in the Mhlume region in Switzerland.

3.3 Evaluation of Network Performance Based on Climate Change and Water Supply Scenarios

Before interpreting the results of this section, it is important to briefly discuss the LWR scenario. The LWR scenario states that the network will not be able to supply water demands; therefore, there will be a water shortage because of the limitation of water resources supplies in the irrigation district (Banihabib et al. 2015). Assuming a constant volume of available water in all three time horizons, it will only be possible to supply 16.5 MCM of water. Given increasing water demand in the future periods, the outcomes of LINGO model showed that the optimum cultivated area is 159 and 155 ha (for the A2 and B2 scenarios, respectively) lower than the baseline in 2010–39 period, and 423 and 395 ha (for the A2 and B2 scenarios,

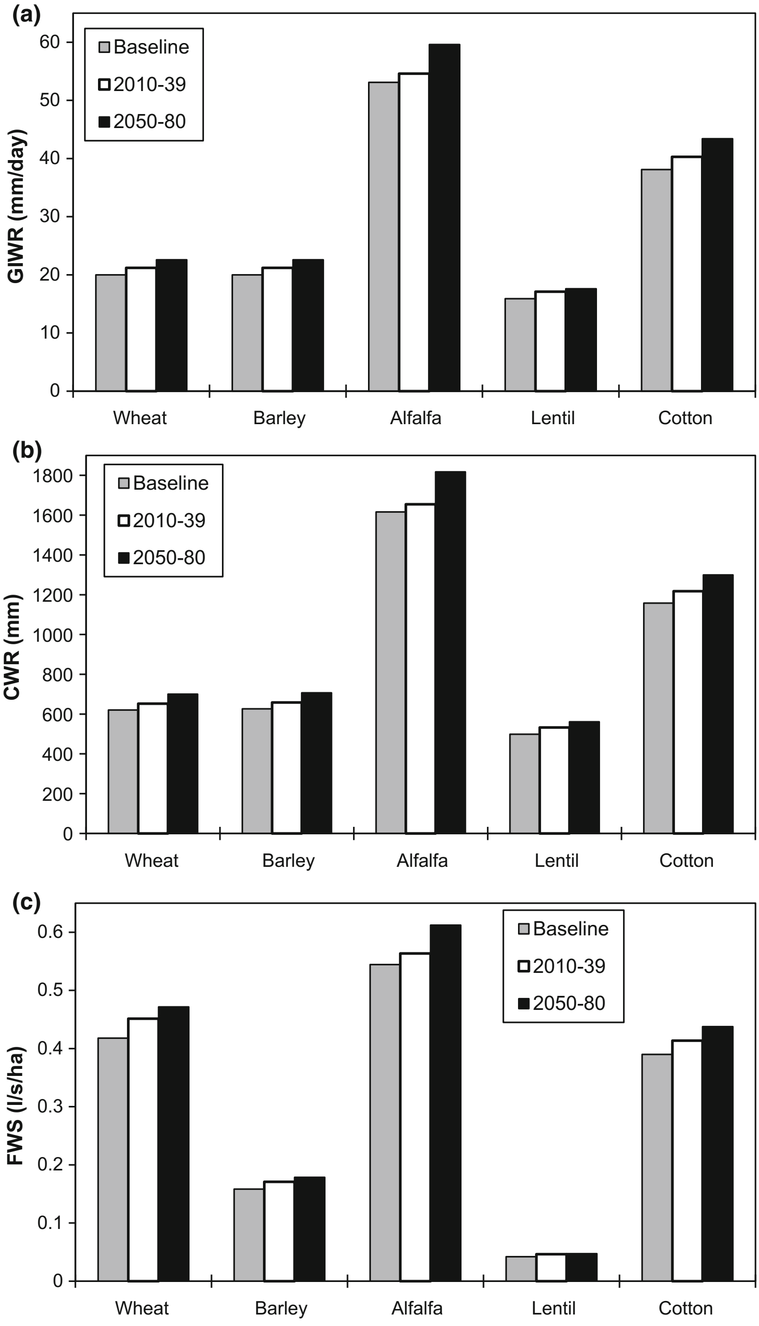

Fig. 5 Annual values of **a** GIWR, **b** CWR, and **c** FWS for all cultivated crops in district

respectively) in 2050–79 period. Furthermore, in order to calculate the performance indicators of the network, 9 different scenarios, as explained in Sect. 2.3, were used that were based on: 2 scenarios of water resources (LWR and NLWR), 2 scenarios of climate change (A2 and B2), and 2 time horizons (2010–39 and 2050–79) along with a baseline (note that the baseline is represented as no climate change and current water supply resources). The nine scenarios mentioned in this section were applied in the network simulation model created with WaterGems for a peak demand reference day using FWS and GWIR in the outlets. The results showed that the discharge of the network were 3.7, 4 and 4.3 cubic meters per second for baseline, 2010–39, and 2050–79 periods, respectively. In the case of the discharge of the outlets, the discharges were found to be 3.5, 3.7, and 4 L per second for these time horizons, respectively. When the necessary input data was introduced into the model, the results of the network pressure analysis showed that because of the increase in water demand, the pressures decreased in the network. It was found that for the baseline period, 61% of the outlets worked at a pressure between 40 and 50 m, but in future periods, more than of 55% of the outlets would work at a pressure between 30 and 40 m. This demonstrates the significant decrease of pressure in the network. Table 2 shows the average values of the indicators calculated for a peak demand reference day. Through the optimization of cultivated areas in conditions of water supply limitation, the water requirements of the cropping patterns was supplied and, indicators of network performance were evaluated (Table 2).

PEq are lower than the baseline in all scenarios, decreasing ~1.5% in B2 + NLWR to 22% in A2 + LWR for 2010–39, and ~2% in B2 + NLWR to 42% in A2 + LWR for 2050–79. On the other hand, PEq in LWR are ~20% (40%) lower than NLWR for 2010–39 (2050–79). The PEq values in LWR scenario shows that even by reducing the cultivated area in order to address the limitation of water supply, excess water demand still exists in the network. In case of the Ps/a indicator, compared to the baseline, both A2 + NLWR and B2 + NLWR scenarios show decreasing but minor differences (decreasing ~9%), while the other scenarios show major differences (decreasing ~17–47%). As a result, the number of outlets with Ps/a < 1 will increase ~63–146% (depending on the scenario type) in comparison with the baseline. Therefore, when the water demand increases in the network, the number of outlets with Ps/a < 1 in terms of pressure supply will increase. This means that, for example, in A2 + NLWR 2050–79, 450 more outlets will work under the assigned pressure. In addition, if LWR is taken into account, the number of outlets with Ps/a < 1 decreases ~6% and 7–13% in comparison with NLWR for 2010–39 and 2050–79, respectively. This is because in the LWR scenario, the cultivated area decreases in future periods, and part of the network is removed.

In the case of velocity indicators, results show that the $V_{min}TR$ and $V_{max}TR$ values compared to the baseline decrease (~7–25%, depending on the scenario type) and increase (~20–320%), respectively. In the Bilesavar district, by increasing the maximum velocity, changes in pressure between maximum and minimum discharge increases in the pipelines, and this may cause water hammer in

Table 2 Average values of the indicators calculated for a peak demand reference day

		Baseline	2010–39				2050–80			
			NLWR		LWR		NLWR		LWR	
			A2	B2	A2	B2	A2	B2	A2	B2
Pressure equity (PEq)		0.80	0.77	0.79	0.62	0.64	0.73	0.78	0.46	0.49
Simulated/assigned pressure ratio (Ps/a)	Max.	1.21	1.13	1.11	1.24	1.27	1.02	1.06	1.05	1.13
	Min.	0.83	0.73	0.72	0.34	0.35	0.60	0.62	0.23	0.25
	Av.	1.02	0.93	0.92	0.80	0.82	0.82	0.85	0.54	0.57
Outlets with Ps/a < 1		308	553	534	517	504	758	755	705	658
Velocity	Min.	0.27	0.22	0.24	0.22	0.25	0.20	0.20	0.23	0.23
	Min. TR	0.44	0.37	0.41	0.34	0.41	0.33	0.34	0.38	0.40
	Max.	2.24	2.79	2.81	2.95	2.98	3.01	3.05	3.50	3.74
	Max. TR	−0.10	0.12	0.13	0.18	0.21	0.20	0.22	0.40	0.42
Energy consumption (P)	Kw	1981.64	1990.01	1987.46	1890.51	1864.38	2272.83	2165.08	1963.71	1897.82

Table 3 Optimum temperature at planting date

Crop	Planting date	Optimum temperature (°C)	Germination (°C)
Wheat	Late Oct. –early Nov.	20–25	4
Barley	Late Oct. –early Nov.	20–25	4
Alfalfa	Apr. and early Sep.	25	1
Lentil	Late Mar.	18–30	15–25
Cotton	Early May.	34	15

the network. On the other hand, by decreasing the minimum velocity, the risk of deposits in pipes increases. With NLWR, energy consumption would be less than 0.5% higher than the baseline for 2010–39, but may increase $\sim$15% and 9% in A2 and B2 in 2050–79, respectively. With LWR, because some pumping stations have been removed in the network, energy consumption is lower than the baseline ($\sim$1–6%). In general, the results clearly show how climate change would have a significant impact on network performance with existing cropping patterns. The results of this research confirm the study of Perez Urrestarazu et al. (2010), who used a combination of emissions and European agricultural policy scenarios to evaluate the performance of the Fuente Palmera irrigation network in terms of the equity and adequacy of pressure at the outlets.

3.4 Discussion of Adaptation Strategies to Climate Change

– *Changing the date of planting*

Temperature is one of the environmental factors influencing different stages of plant growth. The reproductive stage in plants compared to the growth stages is very sensitive to high temperature and reproductive organs are very vulnerable to increasing temperature before or during flowering stages. Climate change in a region causes a limitation in the date of planting of a plant, therefore; change in the date of planting can be one of the adaption strategies as reported in other researches (Shahkarami 2009). The optimal temperature for planting each of plants and at least temperature for germination, according to the crop pattern of study area, is presented in Table 3. Moreover, Table 4 presents the optimum temperature at planting date for 2050–79 in study area.

As shown in Tables 4 and 5, the optimum temperature for growth of wheat and barley is between 20 and 25 °C; therefore, November will be an appropriate month

Table 4 Optimum temperature at planting date for 2050–79

Scenario	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
T-A2	0.5	2.3	8	15.7	21	29	34	33.2	27.1	18	10	4.2

Table 5 Gross irrigation water requirement (mm) by changing the planting date of wheat and barley in 2050–79

State	Crop	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Sum.
No adaption strategy	Wheat	0.1	0.2	1.2	4.6	5.5	9.9	–	–	–	–	0.2	0.1	21.8
	Barley	0.1	0.2	1.2	4.6	5.5	9.9	–	–	–	–	0.2	0.1	21.8
	Alfalfa	0.5	0.7	1.3	3.3	6	10.3	13.2	11.8	7.4	3.5	1	0.6	59.6
	Lentil	–	–	–	0.8	6.4	10.5	–	–	–	–	–	–	17.7
	Cotton	–	–	–	–	1.9	5.7	10	12.4	8.1	3.8	0.9	–	42.8
	Sum	0.7	1.1	3.7	13.3	25.3	46.3	23.2	24.2	15.5	7.3	2.4	0.8	163.7
Chang in the planting date of wheat and barely	Wheat	0.1	0.2	0.1	4.6	7.7	9.6	10	–	–	–	–	0.1	32.4
	Barley	0.1	0.2	0.1	4.6	7.7	9.6	10	–	–	–	–	0.1	32.4
	Alfalfa	0.5	0.7	1.3	3.3	6	10.3	13.2	11.8	7.4	3.5	1	0.6	59.5
	Lentil	–	–	–	0.8	6.4	10.5	–	–	–	–	–	–	17.7
	Cotton	–	–	–	–	1.9	5.7	10	12.4	8.1	3.8	0.9	–	42.8
	Sum	0.7	1.1	1.6	13.3	29.7	45.7	43.2	24.2	15.5	7.3	1.9	0.8	184.9

Table 6 Gross irrigation water requirement (mm) by changing the planting date of cotton in 2050–79

State	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Sum.
No adaption strategy	–	1.8	5.7	14.3	11.9	6.2	39.9
Changing the planting date of cotton	1	3.1	8	14.4	12.4	–	38.9

for germination and growth of those plants. Furthermore, as shown in Table 5, by moving the planting date from early October to early November in 2050–79 period, irrigation water requirement for wheat and barley increases. One of the reasons for this increase can be due to increase in the crop coefficient of those plants and locating in the growth and development stages with high temperature. In the case of cotton, it will be possible to shift the planting date from May to early April in 2050–79. As seen from Table 6, with this change, annual gross irrigation water requirement is only 1 mm less than before adaption strategy, which is not remarkable for adaption to climate change.

– *Changing the hours of irrigation*

One of the other adaption strategies to reduce the network's vulnerability is changing the hours of irrigation. The results show that in 2050–79, due to the increase in evapotranspiration, irrigation interval reduces from 7 days to 5 days. Moreover, in order to supply new water requirement in the irrigation network, the hours of irrigation should be increased from 19 to 27.6 and 29 h for 2010–39 and 2050–79 periods, respectively. Since the maximum irrigation hours per day, including 2 h of rest for pumping stations, are 22 h; therefore, the maximum of 22 h is considered for the network and its performance is evaluated with the evaluation indicators of interest.

– *Pressure equity indicator*

The values of this indicator (Table 7) show that the equity of pressure distribution is notably improved by increasing the hours of irrigation in the network. The reduction of water abstraction at the outlets and improvement of the irrigation network performance can be as one of the reasons for increasing the pressure distribution equity; so that, when the hours of irrigation increase, the plant's water requirement is supplied for a longer time without reduction in the performance of irrigation system.

Table 7 Pressure equity indicator by changing the hours of irrigation

Status	Period	Ppq	Pbq	Peq
No change in the hours of irrigation	2010–39	24.8	40.4	0.62
	2050–79	14.2	31	0.46
Changing the hours of irrigation	2010–39	35.7	49	0.73
	2050–79	24.6	40.8	0.6

Table 8 Pressure adequacy indicator by changing the hours of irrigation

Status	Period	Ps/a ave	Ps/a max.	Ps/a min.	Ps/a < 1
No change in the hours of irrigation	2010–39	0.80	1.24	0.34	517
	2050–79	0.54	1.05	0.23	705
Changing the hours of irrigation	2010–39	1.04	1.40	0.67	56
	2050–79	0.80	1.24	0.34	202

Table 9 Maximum and minimum velocity ratio indicator by changing the hours of irrigation

Status	Indicator	2010–39	2050–79
Changing the hours of irrigation	V_{max}	2.70	3.10
	$V_{max}TR$	0.08	0.24
	V_{min}	0.24	0.26
	$V_{min}TR$	0.40	0.44

– *Pressure adequacy indicator*

According to the Table 8, the values of pressure adequacy indicator presents that the status of pressure has been improved and the number of outlets, which will be working at a pressure less than the required pressure, has been decreased by increasing the hours of irrigation and subsequently, reducing the discharge at the outlets for 2010–39 and 2050–79 periods.

– *Maximum and minimum velocity ratio indicator in water transmission pipes*

The values of the maximum and minimum velocity ratio indicator under the status of changing the hours of irrigation are presented in Table 9. The results indicate the reduction of maximum velocity in pipes so that this reduction in 2010–39 is more considerable than 2050–79. The results also show that by increasing the hours of irrigation, minimum velocity ratio indicator increases and the sedimentation of particles due to the low velocity of water in the pipes decreases.

4 Conclusions

This study was an attempt to investigate the potential effects of climate change on the irrigation network of the Bilesavar district, in Iran in terms of evaluation indicators. In the case of climate change scenarios, the results showed that temperature may increase by 10 and 23% on average by 2010–39 and 2050–79, respectively. Rainfall may decrease by 4% on average by 2010–39, and by 7 and 1% for A2 and B2 by 2050–79, respectively. ET_o is expected to be around 6% higher than the baseline for 2010–39, and 12% for 2050–79.

Due to changes in the climatic conditions in the Bilesavar district, irrigation requirements may be higher in 2010–39 and 2050–79 by around 6 and 13% on average (depending on crop type) respectively, which could lead to an increase in the maximum flow requirements in the pumping stations and at the outlets. Furthermore, the results of the model outputs indicated an increase in discharge of the network that will lead to a rise in water demands for cropping patterns, and a drop in pressure at the outlets.

Due to predicted changes in the climate, the irrigation network will have problems in terms of pressure and discharge supply. The total discharge of the irrigation system in its current condition will increase from 3.7 to 4 and 4.3 cubic meters per second for the two future periods. It was observed that pressure equity and pressure adequacy (Ps/a) decreased for 2050–79; the pressure equity dropped on average from 81 to 46%, and the adequacy dropped on average from 1.03 to 0.54. In addition, the minimum and maximum velocity in the pipes showed major differences with the permissible velocity for 2050–79. At present, the system would still work properly in these conditions, but according to the results of this study, the network will face problems. The significant changes in CWR or IR will have a major effect on the network performance in terms of pressure.

In order to adapt to the demand with water supply restrictions in the Bilesavar district, the planting area has to be optimally reduced. The results indicated a reduction of around 5% and 13% of agricultural lands for the 2010–39 and 2050–79 periods, respectively. In addition, the results of the study specified that the optimal reduction of the planting area, in conditions where sufficient amounts of water cannot be supplied, is an appropriate strategy. In the case of other adaption strategies, changing the hours of irrigation and changing the date of planting can be effective strategies to adopt the irrigation system to climate change for the future periods. The methodology presented in this paper can be used in other studies to help identify the network area that could potentially have problems in the future, and to assess other irrigation districts with different characteristics.

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Implication of Climate Change and Food Security Status on Rural Farmers in Kura Kano State North–Western Nigeria

Salisu Lawal Halliru

Abstract This paper explores the food security context and the socio-economic consequences of climate change on rural farmers in Kura local government, Kano state, Nigeria. The purpose of the study was to ascertain the food security status of the rural farmers in the study area. Socio- economic consequences were ascertained. Agro forestry will serve as a win-win solution to the difficult decision between reforestation and agricultural land use; hence it increases the storage of carbon and may also increase agricultural productivity. Lottery sampling procedure was used in the selection of local government, communities and farmers for the research study. Structured questionnaire were used to obtain the data for the study. Food security index was used to ascertain the level food insecurity among the rural farmers in the communities. Descriptive statistics as a tool for analysis was used to analyze the data obtained. 98.5% of the respondent was married with dependants and low annual income of # 80,000 and below. Most farmers experienced loss of investment on farm lands, lives and income respectively. This study reveals that rural farmers suffered serious hardship they cannot produce what to feeds their families for at least six month in a year (food insecure). They also suffered ill health, such as malaria, water born diseases and skin infections among others. The study recommends that policy makers should encourage more recognition of food security in the state, support for adaptation activities in rural areas, enhance the role of civil societies and adaptation and mitigation.

Keywords Climate change · Food security · Rural · Nigeria · Farmers

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1 Introduction

Climate change has effects on agriculture because an agricultural activity depends on climate condition. That effect threatens our ability to advance global food security. Agroforestry, is the growing of trees in agricultural landscapes, has the potential to achieve sustainable agriculture in smallholder farming. Various Agroforestry practices are suitable for adaptation of agroecosystem to climate change. In view of t that Agro forestry will serve as a win-win solution to the difficult decision between reforestation and agricultural land use, hence it increases the storage of carbon and may also increase agricultural productivity. Agro forestry will serve as a potential mitigation strategy.

It is important to point out that the global climate or the climate of any part of the world has never been static. Climate fluctuations and climate change impinge on human affairs in diverse and many ways, climate determines the ability of man to feed him through its influence on agricultural production.

Agriculture is an important occupation and operation that provide income, employment and food to Nigeria thereby enhancing food security in the country, but in a situation of climate change, Agriculture in northern Nigeria as in other northern parts of west Africa, would evidently be impacted (IPCC 2007). This is applicable to Kano state where most rural communities engaged in farming and crop production for their livelihoods and attainment of food security.

There is a growing consensus in the scientific literature that in the coming decades the world will witness higher temperatures and changing precipitation levels. The effects of this will lead to low/poor agricultural products. Evidence has shown that climate change has already affecting crop yields in many countries (IPCC 2007; Deressa et al. 2008; BNRCC 2008).

Food security, livelihoods, and poverty in rural communities in northern Nigeria are determined by the agricultural production of the individuals and communities. Also rainfall and temperature rate dictate the amount of agricultural production, annually. Agriculture everywhere in the country, being dependent on rainfall, will be adversely impacted by increased variability in timing and amount of rainfall.

Production of grain crops like maize, guinea corn, millet and rice can be depressed. The openness of the region to high temperature also affects the level of soil fertility (Adogi 2008). The state of agriculture in Nigeria in recent times shows a continuous decline in exportation and increase in importation of agricultural products into the country. The share of Nigeria's agricultural products in total exports plummeted from over 70% in the 1960s to less than 2% in 2010 (Adogi 2008).

The major contribution to the decline has been liked with the negative effects of climate change on crop production in sub-Saharan Africa (Okunnola and Ikuomola 2010). It is predicted that the majority of Nigerian and African countries will have novel climates over at least half of their current crop year by 2050 (IPCC 2007).

2 Agriculture and Climate Change

Though the extent and nature of the effect of climate change on agriculture has not yet been accurately forecast; its impact so far on diverse farming regions of the world has been profound (McClean, et al. 2005; FOA 2007; Revkin 2008). Water sources have become unpredictable; with excess, little or no rainfall and flooding and inundation in coastal areas (Brown 2006; Dore 2005; Hopkin 2005).

3 Food Security and Climate Change

According to the FAO, food insecurity exist when people are not able to secure access to an adequate and safe diet which constrains them from leading an active and health life today. In addition, those who are currently food secure may become vulnerable to food security in the future. Potential impact of climate change on food security includes both direct nutritional effects (changes in consumption quantities and composition) and lively livelihood effects (change in employment opportunities and cost of acquiring adequate nutrition). Climate change can affect each of these dimensions FAO(2002).

4 Food Security in Changing Climate

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 need and food preference for an active and healthy life FAO(2002). Climate change has already caused and will continue to cause change in global temperature and precipitation pattern as well as changes in soil processes and properties (Meehl et al. 2007). This has lead to considerable concern that climate change could compromise food security, which would lead to an overall decline in human health.

5 Implication of Climate Change and Food Security in Nigeria

Countries in sub-saharan Africa, including Nigeria are likely to suffer the most because of their geographical location, low incomes, low institutional capacity as well as their greater reliance on climate—sensitive renewal natural resources sector like agriculture (Ebon 2009). Climate change is threatening agricultural sector because food production is affected when there is a change on the climate.

Once effects occur on agriculture it will equally has an effects on people who depend on agriculture as a means of livelihood. According to IPCC 2007, BNRCC 2008. Rough estimates is of the view that for the next 50 years or so, climate change may likely have serious threat to meeting global food needs than other constrains on agricultural system.

The number of people without food to eat on regular basis is increasing in a geometric progression. Over 60% of the world's undernourished people live in Asia and a quarter in Africa (FAO 2002). Climate change phenomenon affects agriculture in many ways, such as unreliability in the onset of the farming season, due to changes in rainfall characteristics; this can result to an unusual sequence of planting and replanting which may lead to food shortage due to harvest failure (Okoh et al. 2011).

6 Significant of the Study

Most climate change impacts research studies have been focusing on human perception on climate change while implication of climate change and food security status remains a poorly investigated area in research. At the same time cultivation of indigenous foods found growing in the forests that are important locally but have, to date, been under-researched by the scientific community. Climate change is recognized as one of the major worldwide challenges facing men and his environment and has become one of the areas of urgent concern and focus.

Agro forestry is one of the potential options which can be us or practice to mitigate the impacts of climate change and therefore there is need to conduct a research on the implication of climate change and food security status in our communities.

7 Aim and Objectives of the Study

The main aim of this research is to explore the food security context and socio-economic consequences of climate change on rural farmers in Kura local government area, Kano state from which the following specific objectives were derived:

(a) To determine the relationship between climate change and food security in the study area.
(b) To examine the food security status of rural farmers in Kura emanating from climate change using food security index.
(c) To examine the impacts of climate change event on food security of the farmers in the local government.

8 Method and Material

This study was carried out in Kura local government area Kano state, Nigeria. The area was selected because agriculture is the major economic activities in the area. The study area is located at the southern part of Kano state with a population of 144,601 million people (NPC 2006) with a land mass of 206 km^2, is located between 11° 46′ 12.84″N and longitude 8° 35′ 29.02″E it is about 900 km from the edge of the Sahara desert and 1140 km away from the Atlantic ocean approximately.

The study area shares boundary north and east with Kumbotso local government and west–south it boarders with Madobi and Garun Malan local government area respectively, extreme south–east it boarders with Bunkure local government area. (Fig. 1) The area has three marked temperature regimes; warm, hot and cold with mean annual temperature of 26 and 21 °C main monthly range of maximum temperature in December/January and over 35 °C which is hottest (April/May)wet season start in May and ends October. While November to February is dry cool season with hamattan haze. Vegetation is savanna (grassland) of Sahel Sudan guinea type.

Lottery sampling procedure was used for the selection of the communities and farmers for the research. Six communities were selected to represent the local government area. The measures for selecting the communities include the following:

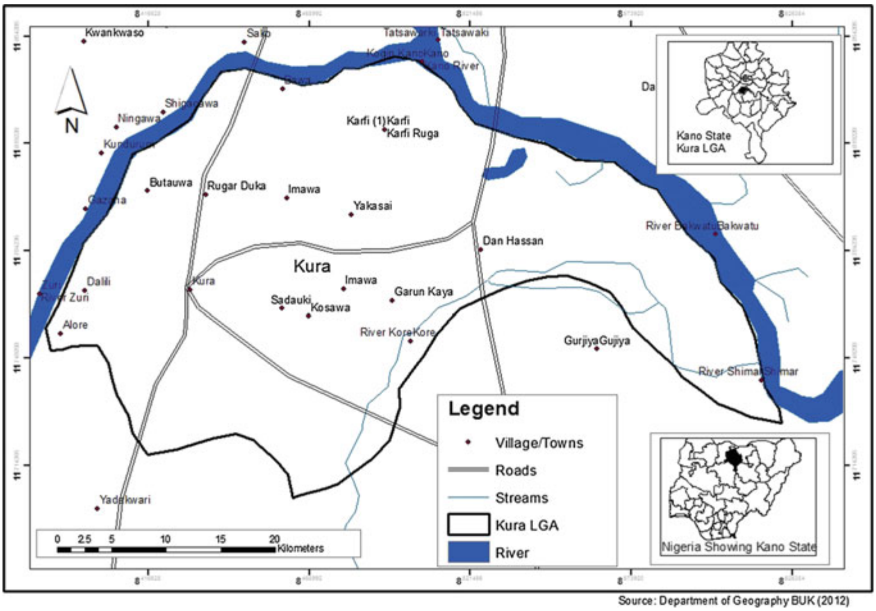

Fig. 1 Map of Kano state showing the study area *Source* Field study 2010

i. Community with a sizable number of farmers with at least ten (10) hectre of cultivable land.
ii. Community with all year round farmers i.e. engaged in farming activities during the dry and wet season.
iii. Agriculture- economy based community.

On view of the above, ***Imawa, Karfi, Gundutse, Bawa, Dukawa, Baure,*** were selected as the study location. A sample of 50 farmers were selected in each community based on snow ball method of one farmer directing the researcher to the next farmer this way a total of 300 sample were collected. The main source of data was through mean of annual temperature and rainfall from January 1991 to December 2013 were collected from Malan Aminu Kano International Airport Nigeria meteorological Agency (MAKIA-NIMET) for the study. The primary data were obtained through observation, discussion, interview and administration of structured questionnaire survey. Information sought was on personal information of respondents including their age, sex, marital status, educational level, additional information were sought based on their involvement in agricultural activities. Descriptive statistics were used to summarize the socio-economic characteristics and to determine the level of food insecurity as well as the food security status among the farmers. The researcher used period of six years in accessing farmers' agricultural activities in the study area from 2007–2012. The data gathered was analyzed using tables, percentages and other statistics techniques relevant for the data collected.

Food security index: food security index was used to determine the level of food in security among rural farmers that have been affected by drought, flood and other climate hazard over the past 40 years. Food security equation used by Felake et al. (2003) and ways of measuring farmers' food security status by Hoddinott (2001) in Emaziye et al. (2013) were adopted for this study. The equation is stated as:

$$C^x = Cj - Yi \tag{1}$$

C^x	food security index of rural farmers
Cj	quantity of food consumed (N = 1–5)
Yi	expected required food to be consumed (N = 5)
If $C^{x=}0$	rural farmer will be said to be a food secure.
If $C^x < 0$	then the rural farmer will be said to be a food insecure

Hoddinott (2001) in Emaziye et al. (2013) outline four ways of measuring household food security status; such as dietary diversity which involves determining the frequency and the number of different foods consumed by an individual over a period of time. Therefore food security index of rural farmers in these study was adopted from Emaziye et al. (2013), based on the total household daily consumption (carbohydrate, vitamins, water, proteins, minerals and fat/oil). A food secured rural farmer is expected to consume all the time categories.

Food insecure category was further categorized in mild food insecure, moderately food insecure and severe food in secure.
$(C^x = C^j - Y^j) = 4 - 5 = -1$ (Mild food insecure)
$(C^x = C^j - Y^j) = 3 - 5 = -2$ (Moderately food insecure)
$(C^x = C^j - Y^j) = 2 - 5 = -3$ (severe food insecure)

9 Correlation

Correlation was used to determine the relationship between calculated climate change variables coefficient of variation and food security of rural farmers in Kura local government.

$$F_s = A_{tcv}T_{cv} + A_{rcv}R_{cv} + A_{ycv}Y_{cv} + e$$

where,

F_s	food security
T_{cv}	temperature coefficient of variation (%)
R_{cv}	rainfall coefficient of variation (%)
Y_{cv}	food production (yield) coefficient of variation (%)
E	error term
A_{tcv}, A_{rcv}, A_{ycv}	Model parameter

Adopted from: Emaziye et al. (2013).

10 Result and Findings

The data on the personal variable of respondents shows 65% of them were within the age 43–53 the remaining were aged 54 above. On the marital status of respondents a total of 200 which represents 66.67% were married, 65% which is 21.6 were divorced, and 35 which represent 11.8% were single. On the educational level of respondents, 120 respondents which is 40% had Qur'anic education, 100 respondents which is 33.33% had primary education, and 80 respondents which is 26.6% had adult education. The respondents mean annual income is N 65,642 (Naira) about $378USD which is less than $1(one dollar) a day which shows a poverty situation of the rural farmers. This might probably due to climate change impact in the state.

In Table 1 above reveal that food security has a significant relationship with climate change variables using Pearson correlation, as temperature and rainfall contributed toward food security it is a well known fact that every crop has rainfall and temperature requirement for it survival as equally observed by the rural farmers in the study area these coincided with the findings of Emaziye et al. (2013).

Table 1 Relationship between climate change variables (temperature and rainfall) and food security in Kura local government

Correlation	Food security (Fs)	Temperature (T_{cv})	Rainfall (R_{cv})
F_s	1.000	–	–
Pearson T_{CV}	–	1.000	1.000
Correlation R_{cv}	–	−000	−000
F_s	–	–	–
Sig. T_{cv}	−000	–	–
(1-tailed) R_{cv}	−000	–	–
F_s	5	5	5
T_{cv}	5	5	5
N R_{cv}	5	5	5

Source field study 2013

Table 2 Respondents food security index

Food security index	Kura local government (n = 300)	Percentage (%)
Food secure	10	3
Mild food insecure	15	5
Moderately food insecure	125	42
Severe food insecure	**150**	**50**
Mean	Severe food insecure	

Source field study 2013

Table 2 above shows how food security index was used to ascertain the level of food security in the study area, and it is reveals that the area falls under severe food insecure with 50% due to shortage of rainfall and 42% moderately food insecure respectively. Based on these findings only 3% were food secured and 5% mild food secure. This was attributed to climate (drought) that resulted to crop failure and loss of investment on farmlands in the study area.

Table 3 above indicated that farmers in the study area experienced a severe impact of losses with 55% because the farmers in the study area depend mostly on climate-sensitive resources for livelihood. This is as a result of climate change event. These findings coincided with statement of Ebon (2009) where he stated that countries in sub Saharan Africa, including Nigeria are likely to suffer the most because of their geographical location.

Limitation and constraint of the paper

- Some of the respondents were illiterate which pose a problem of language barrier. Though the researcher spent time with the respondents trying to translate and interpret the questionnaire for them. However, the research assistants were familiar with local language mainly *Hausa* in order to reduce the limitation.

Table 3 Impact of climate change event on food security

Impact of loss	Kura local government(n = 300)	Percentage (%)
No effect	25	8.33
Low	16	5.33
Moderate	46	15.33
Severe	**165**	**55**
Very severe	48	16

Source field study 2013

- The scope of the study is only limited to Kura local area which is not enough to make generalization about the investigated issue.
- Inadequate finance to cover wider affected area in the region.

11 Conclusion and Recommendation

Climate change poses a serious threat in Nigeria Kura local government inclusive (study area) especially in the area of agriculture. As a result of reduction in precipitation and high temperatures and evatranspiration during droughts period has negatively impacted staple food production in the study area. Thus, a negative impact from climate change in Kura brings about increased poverty, water scarcity and food in security. First we learned that there is a significant relationship between climate change and food security in the study area as rainfall and temperature were contributors. Secondly food security index revealed severe food insecure situation. Thirdly the study revealed severe impact of losses of crops and investment. The study therefore recommends the following for future prospect;

Additional research is needed to further develop local farmers' ability to understand and address issues related to climate change, Agriculture and Agroforestry.
Campaigns' to raise awareness on the role on indigenous species in climate change adaptation.
There is need for development of appropriate policies and institutional infrastructure to catalyze adoption of Agroforestry.

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All errors and omissions, and all views expressed, remain solely my responsibility.

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Decentralised, Off-Grid Solar Pump Irrigation Systems in Developing Countries—Are They Pro-poor, Pro-environment and Pro-women?

Sam Wong

Abstract This systematic, evidence-based literature review examines the effectiveness of localised solar-powered small-scale irrigation systems (PVPs) in poverty reduction, environmental conservation and gender empowerment in developing countries. It suggests that PVPs are able to enhance farmers' adaptive capacity by raising agricultural productivity and their incomes. They also help mitigate climate change by reducing CO_2 emissions. The distribution of the benefits and costs, brought by PVPs, is, however, so uncertain that requires further scrutiny. PVPs are successful in rising energy-water efficiency, but the environmental trade-offs with the underground water depletion and e-wastes requires solutions. Using PVPs to achieve gender equalities may only be materialised if the structural discrimination against women in land ownership and access to resources is challenged, along with the interventions of PVPs in rural communities. This book chapter recommends more in-depth and longitudinal studies to explore the complex and long-term implications of PVPs. More evidence is also needed to assess the effectiveness of governance reforms in access of PVPs in poor communities.

1 Introduction

Climate change brings erratic weather patterns, which poses threat to rain-fed farming practice in developing countries (Alemaw and Simalenga 2015; Mendelsohn 2008). Irrigation proves effective in mitigating the impact of climate change by providing more predictable water supplies (GGGI 2017; IRENA 2016; FAO 2011). Yet, the heavy reliance on diesel in pumping the irrigation systems produces so much CO_2 that, in turn, speeds up climate change.

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The rising popularity of solar-powered irrigation systems (also known as photovoltaic water pumps—PVPs in short) to serve off-grid areas and to replace diesel-based irrigation systems seems to offer an answer to these questions. PVPs have been considered a 'game changer' in agricultural development in developing countries (Burney and Naylor 2012: 121). IRENA (2016) suggests that PVPs provide 'reliable, cost-effective and environmentally sustainable energy for decentralised irrigation services' (p. 50). Both the World Bank (2015a) and GGGI (2017) stress that PVPs, as a 'pro-poor' and 'pro-women' technology, deserve up-scaling.

This rosy picture is, however, not shared by all development scholars and agencies. EEW (2016), for instance, urges for caution. It argues that the one-size-fits-all intervention has yet seriously taken the contextual specificity of different developing countries into account. The barriers to the access to PVPs, such as affordability, are a few unresolved issues (Shinde and Wandre 2015).

Around the controversies of PVPs, this paper is intended to draw on evidence from existing literature to assess the actual impact of PVPs in developing countries in three aspects: poverty reduction, environmental conservation and women empowerment. Through a systematic, evidence-based literature review, it aims to differentiate claims from facts and to assess what PVPs have achieved and what have not. To achieve these goals, this paper focuses, not only on the irrigation technology, but also on the complex political and economic processes that shape human incentives in energy switch and influence the distribution of costs and benefits in PVP adoption.

This paper will first discuss the impact of irrigation around the 'water-energy-livelihood' nexus. After the theoretical and methodological section, it will evaluate the impact of PVPs in the 'pro-poor', 'pro-environmental' and 'pro-women' aspects with case studies, examples and evidence.

2 Evolution of Micro Irrigation Systems

Solar-powered irrigation systems are devices that use the 'solar cell from the sun's radiation to generate electricity for driving the pump' (Yu et al. 2011: 3176). They usually insist of an array of photovoltaic cells, a controller, a motor pump-set that pump water from a well or a reservoir for irrigation. PVPs are a generic term which touches on various solar-related interventions, such as drip, potted and sprinkler irrigation. Apart from irrigation, solar pumps are also used for providing drinking water for humans and livestock. There are diverse models in promoting PVPs in terms of ownership (individual vs collective/communal approach), payment (daily, weekly, monthly or annually) and organisation (individual vs. groups).

The current debate over the role of irrigation in social and agricultural development in developing countries has been around the 'energy-water-livelihood' nexus, amid issues, such as climate change, food security and renewable energy (Biggs et al. 2015). Agriculture absorbs most of the employment. For example, 45 and 50% of the workforces in Bangladesh and India are farmers respectively (World Bank 2015b). 40% of global population rely on farming for livelihoods

(IRENA 2016). 15% of total GDP in India comes from the farming sector. Apart from the economic importance, agriculture consumes 70% of global freshwater resources. Irrigation is particularly crucial to countries without sufficient surface water. For instance, Namibia relies on 50,000 boreholes for water supplies (SELF 2008).

While 20% of global cultivated land are under irrigation, only 5% is recorded in Sub-Saharan Africa (IRENA 2016). Most subsistence smallholders rely on rain-fed farming which leads to food insecurity and malnutrition. The promotion of electric- and diesel-based irrigation since the 1960s and 1970s has encountered numerous challenges. For instance, Bangladesh has installed 1.43 million diesel-based pumps and 320,557 electric-based pumps (Islam et al. 2017). However, electric-powered pumps are not always an option since many poor villages in developing countries are beyond the reach of national power grids. Only 5% of rural population in Kenya, for example, are connected to the electric grids.

In contrast, diesel-powered irrigation seems to offer a more realistic solution because the liquid-based innovation provides flexibility and convenience. According to the World Bank (2015b), diesel pumps consume 1 million tons of diesel globally, which is worth US$900 million. Diesel does not, however, come cheap. Bangladeshi government imported 2.9 million metric tons of diesel fuel in 2011–2012 and subsidised US$0.3 of each litre of diesel, which has exerted substantial fiscal pressure (Islam et al. 2017). Some farmers in India spend 40% of their annual revenues on diesel (IRENA 2016). They were also exploited by the middlemen who charged them higher diesel prices during peak irrigation and cropping seasons. Worse still, diesel pumps emit 6.73 million tons of CO_2 in Bangladesh alone, which has ameliorated the problems of climate change (Hossain et al. 2015).

In the light of these problems, the solar-powered irrigation technology has caught the attention over the past decade. The long-term costs of PVPs, in terms of the costs of fuel and maintenance, are claimed to be lower than that of their diesel-based counterparts. The use of solar energy, as a form of renewable energy, fits very well into the Clean Energy Mechanisms. As a result, the Moroccan government, for example, has promised to install 1 million sets of PVPs by 2022. The numbers of solar pumps in India are also expected to rise from 13,000 units in 2014 to 100,000 by 2020 (GGGI 2017).

3 Theoretical and Methodological Frameworks

How good are the PVPs? What impact have they made on the environment as well as on poor people's livelihoods? The mainstream approach in the literature tends to compare and contrast PVPs with electric- or diesel-powered irrigation systems over costs, performance and impact.

Development scholars and practitioners are keen to use the comparison to justify if, and how, the new technology is able to challenge the already operating conventional systems.

Yet, the comparative approach is not problem-free. Some researchers have been criticised for taking a binary thinking over ‘clean solar versus dirty diesel’ or ‘efficient solar versus inefficient diesel’ (Chandel et al. 2017). The explicit biases towards PVPs could sometimes affect the quality of the analyses. To address the limitations of the research design, there is a need to conduct a systematic literature review and use a set of objective indicators to measure the effectiveness of PVPs. This evidence-based work is particularly keen to examine scientific research and literature, based on three major criteria of comparison: (1) the short-term and long-term impact; (2) the quantitative and qualitative changes of people’s lives and the environment before and after the interventions; (3) the differences between the control and treatment groups.

To analyse the impact on poverty reduction, the following criteria will be taken into account:

– farmers’ incomes
– farmers’ adaptive capacity
– farmers’ social capital
– access and affordability
– opportunity of participation (in terms of decision-making power and ability to negotiate)
– access to resources, such as finance
– food security
– time-saving
– fuel-saving
– crop yields
– crop diversification
– cropping intensity
– impact on health
– government subsidies on fuel.

Over the environmental impact, the analytical criteria are:

– ground water level
– ‘water-energy’ efficiency
– carrying capacity of land
– noise and air pollution
– borehole contamination
– CO_2 emissions.

To evaluate the ‘pro-women’ claim, the following criteria will be adopted:

– women’s incomes
– women’s decision-making power
– access or control to resources
– capability of participation.

Theoretically, this paper pays attention, not simply to technological, but also to structural and political aspects around irrigation systems. The access and affordability issues reflect the decision-making and negotiation power of technology users. The inclusion and exclusion of certain technologies are related to the (un) even distribution of costs and benefits between groups.

In conducting the literature review, this paper has encountered several methodological challenges. As mentioned before, solar-powered irrigation systems are a generic term, which comprise different systems, such as drip and sprinkler irrigations. Their impact on farmers' livelihoods and the environment could be different. The diverse delivery models of PVPs have also made the comparison difficult. For example, the research by GGGI (2017) suggests that PVPs in East India tend to adopt the 'service-based delivery model with a capital subsidy scheme', whereas the 'grid-connected buy-back scheme and solar cooperative model' is more common in West India (p. 2). While the adoption of different management models is related to water availability of different regions, how each model is comparable with the diesel systems requires a more robust research design.

Another challenge is that the majority of comparative studies are conducted in a snapshot, rather than longitudinally. The longer-term impact is less well-documented. Additionally, a fair and scientific comparison between solar and liquid-based systems should be based on similar circumstances and contexts, such as crop types, planting size, environmental conditions and water quantity and quality (Maurya et al. 2015). Yet, this essential information is not often available in literature.

4 Pro-poor Analysis

The World Bank claims that PVPs are a 'lower-cost' option which enhances 'geographical equity in access to modern irrigation' (EEW 2016: 12). How true is this claim? This section will focus on four particular aspects: changes over productivity and incomes, the life-cycle cost analysis, farmers' adaptive capacity, and social capital building.

4.1 Changes Over Productivity and Incomes

The majority of the literature have suggested that farmers switching to PVPs have increased the crop production. Kishore et al. (2017), for example, stress that farmers in Bihar have witnessed a 9–10% increase in productivity after gaining access to irrigation from solar pumps. The rising yields, according to the literature, are the consequences of the expanding irrigated areas, multiple cropping and increasing cropping intensity. EEW (2016) finds out that PVPs have enabled farmers in India to increase the cropping intensity, from previously one cropping to three cropping a year.

The Ruti irrigation scheme in Gutu District, Zimbabwe, sponsored by Oxfam (2015), has replaced the old gravity-fed irrigation method with PVPs. The study suggests that, after the introduction of PVPs, 60 ha of land were irrigated and three harvests a year were materialised. The project has benefited 270 farmers and the production of maize has been improved to four to five tonnes per hectare. While the household incomes were all increased amongst the participant farmers, Oxfam has found out that the PVP project has benefitted the very poor group most by rising their household incomes by 286%, whereas the other two groups, the poor and the middle-income were recorded an increase by 173 and 47% respectively.

Research by Burney and Naylor (2012) also support the claim that PVPs help increase farmers' incomes. It found out that farmers in Northern Benin involved with PVPs earned US$0.69 more than their non-PVP counterparts on a daily basis. The rising productivity and higher incomes have significant implications for poverty alleviation. UNEP (2012) has suggested that a 10% increase in farm productivity would reduce poverty by 5 and 7% in Asia and Africa respectively.

An unintended, but positive, consequence of the adoption of PVPs is the rising crop diversity. Rather than focusing on staple food, solar-pumped irrigations have helped farmers increase both of the production and consumption of fruit and vegetables. Based on the solar market garden project in Northern Benin, Alaofe et al. (2016) find out that the PVP-involved households have increased their vegetable production. Similarly, Oxfam's Ruti irrigation scheme (2015) has recorded farmers' changing cultivation practices by making rotation between food crops and cash crops, such as potatoes, tomatoes and sugar beans, on the same fields. Growing and consuming more nutritious cash crops have significant gender and health implications since women play a key role in domestic food preparation. More fruit and vegetable intake would reduce the chance of micro-nutrient deficiency.

The sales of surplus vegetables and tomatoes to local markets, according to SELF (2008), have enabled poor families to buy staples and protein-rich food, especially in dry seasons. Burney and Naylor (2012) have made a similar conclusion on annual and seasonal food security. They have suggested that PVP-involved farmers, being able to purchase more food in dry seasons, have reduced the household food insecurity score by 17%.

Yet, not all research share the same conclusion about the links between the adoption of PVPs and the increase of crop diversification. Burney and Naylor (2012) has stressed that their research in Ghana and Zimbabwe could not find any evidence to support the claim that the introduction of PVPs automatically leads to more higher-value crop cultivation. They believe that changing cropping strategies and patterns are related to perceived risks amongst irrigation users.

The effectiveness of PVPs is affected by the seasonal change of radiation. In their research in Punjab, Pakistan, Naseem and Imran (2016) have found that the annual crop productivity was recorded a 5% increase when compared to the previous year after switching to PVPs. However, since the solar systems were less effective in winter, it caused dissatisfaction amongst some participants. This example has, therefore, shown that how to manage expectations and how well the participants are informed about the seasonal impact of PVPs are equally important.

Whether it is a good idea to increase crop intensity and farm productivity, induced by PVPs, also depends on local ecological contexts. Without paying sufficient attention to annual water recharge rates, groundwater levels and soil characteristics, Sarkar (2011) warns that short-term benefits could lead to long-term problems, such as waterlogging, salinization and land degradation. Citing a case study in China, EEW (2016) stresses that the long-term costs of land degradation and the depletion of water supplies are disproportionately borne by resource-poor farmers.

4.2 Cost Comparison

Another approach to the pro-poor analysis is to compare the costs and benefits of PVPs with their diesel- and electricity-based counterparts.[1] The majority of the literature seems to reach a consensus that PVPs are cheaper than the other irrigation systems in the long-run, and hence pro-poor in nature.

One of the most common comparative analyses is life-cycle cost analysis (LCC). LCC measures the net present values by comparing the total costs and total benefits, normally over a 20–25 years period (IRENA 2016). In terms of water pumping systems, the cost components include initial capital costs (such as costs of transport and installation costs), operational and recurring costs (such as fuel expenditure, operational costs, maintenance services and replacement costs and labour). The total benefit components include fuel savings and yield increases. The purposes of conducting the LCC analysis are to examine which system is the cheapest in the short- and long-term and to calculate the payback time of investment.

Our study has indicated that most of the literature have suggested that solar is the cheapest option when compared to other three types of fuels: diesel, electricity and gasoline. The LCC analysis by GGGI (2017) suggests that the total cost of PVPs is 64.2% of the 10-year life cycle cost of diesel water pumps. Similarly, Emcon (2006) finds that the LCC of PVPs are 20% lower than that of their diesel counterparts. The study by GIZ (2013), based in India, also indicates that the LCC of a 746 W diesel-based pumping system for a ten year period is nearly 36% higher than that of a PV-powered system of the same capacity. This means that the investment payment for PVPs is between 4 and 6 years (Chandel et al. 2015).

Based on the irrigation costs, in term of INR/m^3, through 5HP capacity pump over a 25-year period, EEW (2016) indicates that solar is much lower than diesel—0.18 and 0.32 respectively. Comparing solar and gasoline, a Guilan province-based study by Niajalili et al. (2017) shows that the LCC of gasoline-based pumping systems are 1.56 times of their PVP counterparts. In terms of the costs of solar and

[1]Some studies take a different perspective, comparing and contrasting the costs amongst solar-based irrigation systems. For example, Ali (2018) compares the initial cost and the levelised energy costs of PVPs, CDPs (concentrating disk pumps) and PTP (parabolic trough pumps) in Sudan and suggests that PVPs are the cheapest.

grid-based electricity, EEW (2016) show that solar is slightly cheaper than electricity in term of irrigation costs—0.18 and 0.19 INR/m^3 respectively.

All these studies agree that the up-front costs of PVPs are much higher than that of their diesel and electricity counterparts. Yet, the overall costs of solar panels have been decreasing. Solar does not require fuel, and the operational and maintenance costs of PVPs are neglectable. In contrast, EEW (2016) underlines three major problems of the diesel-based systems: volatile diesel prices, unreliable supply of diesel and complicated maintenance support, including replacement of parts and oil change and filter replacements (SELF 2008).

However, not all LCC studies support the superiority of PVPs. EEW (2016), for instance, shows that solar is actually less cost-effective than electricity-based pumps. Based on their LCC analysis in Namibia, SELF (2008) stresses that solar is cost-effective only in small- and medium-sized wells. The LCC of the big-sized wells is yet conclusive.

Another concern is about how LCC is actually conducted. To make reliable comparison, LCC researchers need to draw on similar criteria and conditions, such as system size and capacity, the depth of wells and the quantity of water being pumped up. However, Emcon (2006) highlights the methodological and practical challenges. For instance, he points out the significant performance differences between low and high quality diesel engines. The diesel maintenance costs between major and minor services also vary. Similarly, the efficiency of PVPs depends on how they are connected. Without batteries, PV modules power pumps directly, which save the maintenance costs of batteries. In calculating the actual and potential benefits, the PVP users may raise their revenues by increasing crop intensity and productivity, as indicated in the previous section. Yet, Hossain et al. (2015) caution that the benefits depend on the choice of crops and cultivation patterns. For example, in their case study of Bangladesh, PVPs are economically viable for growing tomatoes, brinjal and wheat crops, but not rice.

Scholars also question the rational choice assumptions underlying LCC—energy users will switch to cheaper technological options because of lower fuel costs and higher efficiency. Yet, costs is only one of many factors in energy and fuel switch. Social acceptance and cultural contexts, for example, play equally significant roles in shaping the transition.

Another criticism about the LCC analysis is about the confusion of cost and affordability. Many LCC scholars have suggested that PVPs are lower in LCC and they will bring long-term benefits to poor farmers. Yet, the initial costs of PVPs are much higher than that of their diesel counterparts. For example, the research by Niajalili et al. (2017) in Iran finds out that the up-front costs of PVPs are seven times of that of diesels. It will take nine years for both systems to be equal in total costs. The high initial costs deter poor farmers from using PVPs. Without addressing the access issues, poor farmers are not able to enjoy the long-term gains, suggested by the LCC analyses.

Heavy subsidies from governments on grid-connected electric and diesel-based pumps have been criticised for creating an unfair playing field to PVPs since the subsidies have distorted the actual costs of the technology. Yet, in many cases, PVPs also receive subsidies from the governments and development agencies, but the figures are not often clearly documented. Another challenge for LCC analysts is that the reduction of CO_2 emissions by switching diesel irrigation to PVPs would bring additional incomes to governments because of the carbon credit markets. However, this additional benefit is rarely mentioned in the LCC analysis.

4.3 Adaptive Capability and Social Capital Building

PVPs are often praised in the literature for enhancing poor farmers' adaptive capacity to tackle climate change and for making social capital to build trust and mutual support. Adaptive capacity is intended to improve farmers' resilience against erratic climatic patterns brought by climate change (Colback 2015). Social capital making fosters mutual learning of farmers based on social network building (Badenoch 2009). These two goals and impact are usually achieved through collective- or community-based solar pump irrigation models. In the case studies of Dhundi village in Gujarat, India, for example, the International Water Management Institute pulls six individual solar-pumped irrigators together and helps them form the Solar Pump Irrigators' Cooperative Enterprise (IWMI 2015). Through the mini-grid solar system and selling surplus power to the national grids, IWMI stresses that all participants are better off.

This rosy picture has, however, been challenged for who the actual participants are. Burney and Naylor (2012) suggest that successful PV adapters are usually not the poorest agricultural households. In their project in treadle pumps in Ghana, they compare and contrast 108 individual farmers (52 adopters vs. 56 non-adopters). Their study suggests that, although the adopters of the treadle pumps receive higher incomes that the non-adopter counterparts, they are more likely to have 'lower dependence ratios in their households' and have 'greater access to extension services' (p. 114). Similarly, asking who are more likely to adopt PVPs for irrigation, Ali (2018) find out that it is educated, young and wealthier Pakistan farmers in their case study who are more likely to embrace PVPs. Research by EEW (2016) and Kishore et al. in Rajasthan, India (2014) also reach similar conclusions about medium- to large-farm owners are more likely to install state-subsidised PVPs because of their knowledge and networks.

Regarding social capital building, Wong (2012) warns that switching to solar-based systems could, unwittingly, destroy poor people's social capital. Using rural villages in Bangladesh and India as examples, he suggests that solar home lighting systems could only benefit those who are in the same room. In contrast, diesel, kept in liquid, could be shared with more villagers who have plastic containers to keep diesel. Furthermore, how to keep the solar systems safe could easily become a security issue (Emcon 2006). Unlikely diesel pumps which can be kept indoors, solar panels are installed on roof. Apart from theft, physical damage by strong wind could bring additional stress to villagers.

The PVP literature has also mentioned the positive impact of PVPs on education and time saving. For example, Burney and Naylor (2012) examine the impact of PVPs in school attainment in their Ghanaian research and find out that villages having the PVP installation have recorded higher rates in school attainment. Yet, they have not provided explanations for the changes. Similarly, PVPs have also been acclaimed to free people from hand watering and walking long distance to fetch water. Yet, not many ethnographic studies have been conducted to examine the impact of the gain of time-saving on people's actual livelihoods.

In a nutshell, this section has demonstrated that the evidence to support the pro-poor claims, associated with PVPs, is mixed, and sometimes with contradictory results.

5 Pro-environmental Analysis

In this section, we will focus on four particular aspects: CO_2 emissions, groundwater extraction and depletion, soil conservation and land degradation, and e-waste. The general consensus in literature is that replacing diesel-based pumps by PVPs helps minimise CO_2 emissions. Yet, PVPs may not necessarily have lower environmental footprints than their diesel counterparts because of a lack of incentives in reducing groundwater over-extraction and the potential of e-waste.

5.1 CO_2 Emissions

The agricultural sector has been considered a big CO_2 emitter. 50 to 70% of total emissions are generated from energy activities in the agricultural sector (IRENA 2016). Numerous research, such as GGGI (2017) and Burney et al. (2010), has been conducted to compare and contrast the CO_2 emissions of different irrigation pumps. For example, an irrigation pump with 3.73 kW capacity, powered by solar, grid-electricity and diesel and run for 1250 h annually, the study by Jain et al. (2013) finds out that their annual CO_2 emissions are 0, 4 and 5.2 tonnes respectively. Based on this research, these authors estimate that reducing 50% of existing 10 million sets of diesel pumps in India would help cut 26 million tonnes of CO_2 emissions annually. Similarly, installing 50,000 PVPs in Bangladesh would help save 450 million litres of diesel.

5.2 Groundwater Depletion and Over-Extraction

Irrigation can affect groundwater cycle, especially the groundwater recharge. Research by Casey (2013) underlines the global retreat of water table by 0.3 metres annually. Improving water-energy efficiency, defined as ‘more crop per drop or per kilowatt-hour’ (IRENA 2016: 9), by better performed PVPs, could worsen the problems. As EEW (2016) explains, since the operational costs of PVPs are nearly zero, once installed, there is little incentive for farmers to conserve water. Without adequate groundwater recharge, it would lead to unsustainable water consumption, especially in arid and semi-arid regions.

The over-withdrawal problem could be worsened by the guaranteed buy-back schemes promoted by some NGOs. To conserve energy, surplus energy generated by PVPs is sold to national grid. One case study by GGGI (2017) illustrates that farmers in Gujarat, India, make US$900 profit for a farm as big as one hectare with a 7.5 kW solar pump. The fee-in tariff, according to the World Bank (2015a), turns PVP farmers to ‘micro-level independent power producers’ (p. 16). However, the short-term monetary gains become pervasive incentives for them to maximise water withdrawal, without paying sufficient attention to the long-term environmental sustainability. Worse still, the tariff schemes may only benefit rich farmers owning more PVPs with higher capacity. To address these problems, using remote surveillance technology to monitor farmers’ water usage and strengthening the power of groundwater regulators have both been proposed (El-kader and El-Basioni 2013).

Yet, the issues of over-extraction are context-specific. Comparing East and West India, GGGI (2017) discovers that a controlled underground water extraction could be beneficial, especially to East India. Being a flood-prone region, PVPs may help lower underground water table and produce porous alluvial aquifers. They both reduce surface water runoff and risk of flooding.

5.3 Land Degradation and Soil Conservation

Irrigation can reduce soil erosion and slow down land degradation by raising carrying capacity of grasslands. Xu et al. (2013), for example, have managed to use solar pump irrigation to cover a total area of 1.73 million hm^2 in Inner Mongolia. However, concerns have been expressed about the negative impact of the drop of groundwater level on the dynamic equilibrium of plateau permafrost. The thinning of permafrost in Qinghai could result in land subsidence (Yu et al. 2011).

5.4 E-waste Pollution

PVPs, unlike diesel pumps, minimise the danger of borehole contamination. However, an improper disposal of contaminating solar items, such as poly-silicon and cadmium telluride-based thin-film solar cells, could have significant negative impact on the environment. Dissimilar to developed countries, such as EU, which has got the Waste Electrical and Electronic Equipment Directive and the Restriction of Hazardous Substances Directive in place for PV recollection and decommissioning process, developing countries are weaker in regulation. How to enforce appropriate regulations of recycling in developing countries to avoid e-waste pollution is of some concern (Shamim et al. 2015).

6 Pro-women Analysis

Women play a significant role in agriculture in developing countries. The migration of men from rural to urban areas leaves women in charge of the farming operation. Yet, women-headed households are not only statistically poorer, but they are also often socially excluded from irrigation-related activities and community meetings because canal irrigation is considered a man's job (Nagrath et al. 2016). Additionally, women are crucial for domestic water supply, food preparation and family hygiene. Their decision-making power is, however, often constrained by rigid gendered division of labour and restrictive cultural norms.

In the light of all these cultural barriers, some development practitioners have been asking if the interventions of PVPs could offer an opportunity to challenge the gendered inequalities by reducing women's workload in water collection, and simultaneously, empowering women in participating in irrigation and other communal matters.

Literature provides strong evidence to support the claim that PVPs could substantially save women both time and energy in water collection for food production. For instance, the Oxfam-sponsored project in Zimbabwe suggests that, in order to irrigate their gardens, women walk 4 km on average on a daily basis to collect water from nearby dams. Research by SELF (2015) shows that the Solar Electric Fund helped 45 women form a co-operative in Benin in 2007. The installation of the PVPs have saved each women up to four hours per day.

In addressing women's poverty issues, quite a few PVP interventions target particularly women and set up women groups. As mentioned in the previous sections, the Solar Market Garden project in Northern Benin succeeds in raising the overall vegetable production amongst poor households. Evaluating the gendered impact of the project, Alaofe et al. (2016) discover that the project has made more positive impact on female participants. For instance, the women group increased their production of fruit and vegetable crops by 26%, whereas only 13.4% was achieved in non-women groups. Similarly, women involved with this project were three times more likely to increase their fruit and vegetable consumption when compared to non-women groups. The increased consumption of vegetables and fruit during the dry season amongst women participants is particularly crucial to the well-being of their families because the improved access to, and consumption of, nutrition-rich food help reduce under-nutrition of their children. IRENA (2016) therefore makes an optimistic remark, suggesting that: 'these experiences illustrate the disproportionately greater benefits of solar pumping solutions for women' (p. 15).

There is also evidence to show that the involvement of women in PVPs has not only raised women's incomes, but also increased their control of money. Drawing on the PVP project by the International Crops Research Institute for the Semi-Arid Tropics in Burkina Faso, which helped 20 poor pilot farmers, including five women, Belemvire (2007) found out that the women group earned US$1.16 per person on a daily basis, when compared to US$0.98 for the non-women groups. He explained the differences for the rise of vegetable production of the women group. The additional incomes have also helped women diversify their family diet by buying rice, sorghum and beans as well as slightly expensive food items, such as fish and cooking oil.

Being asked about the control of money, 52% of female participants in the Solar Market Garden project in Northern Benin, mentioned before, have reported that they had control over their garden incomes (Alaofe et al. 2016: 117). 57% of them have also suggested that they would spend more incomes on food, 54% on health care, 43% on gas, water and telephone, and 25% on education. The women in the project, who are poor and uneducated, have also expressed a sense of empowerment by being able to write something and make simple calculation after the engagement. Equally important, the project has also helped women secure civil documentation for their lands and gain access to numerous financial institutions.

Despite the positive impact, some academics are not certain whether the changes, brought by PVPs, really help challenge the unequal gendered structures. PVPs help reduce women's time and energy in water collection. However, there is a lack of in-depth research to examine whether it has liberated women from gender stereotypes, or simply shifted their workload to other domestic chores. While women's role in improving the well-being of their families is undeniable, there are concerns that PVPs could be used as an instrumental tool to reinforce, rather than challenge, women's gendered roles and positions. For instance, in their research in Sub-Saharan Africa, Burney and Naylor (2012) discovered that PVPs might have helped women increase their farming production, but the female members deliberately under-reported their actual production since they feared that the money they earned would be taken away or upset the family and communal harmony (p. 120).

The question about which groups of women actually benefit from PVPs is related to the distribution issues of benefits, costs and power. A study by Gugerty and Kremer (2008) in Kenya suggests that PVP-related projects tend to attract women who are younger, wealthier and better educated. Once the projects become well-established and financially sound, they warn that the older and less productive female members are likely to be expelled. The competition between different women groups has demonstrated that, without addressing the unequal social hierarchies and cultural practices, the interventions of PVPs might simply reinforce the subordinated positions of the weaker and less-educated women.

Similarly, increasing women participation in collective irrigation groups does not automatically increase their decision-making power. Using irrigation in rural India as an example, Girard (2014) suggests that institutionalising women in irrigation management could increase their visibility in formal meetings. Yet, without genuine empowerment, women are less likely to speak out in public arena because their involvement is simply considered ‘an extension of their domestic duties’ (p. 1).

7 Conclusions and Policy Implications

This paper has conducted a systematic and evidence-based literature review to examine if, and how, PVPs are effective in tackling three burning, and related, issues in developing countries, which are: poverty reduction, environmental conservation and gender empowerment. This review has shown a very mixed and complex picture. The PVP literature have reached two general consensus: PVPs help strengthen poor farmers’ adaptive capacities by raising their agricultural productivity, improving their household incomes and building social capital. They also help mitigate climate change by replacing diesel with solar energy to reduce CO_2 emissions. There is also some evidence to support the positive gendered impact of PVPs on raising women’s control of income and diversifying diets, and that improves the overall well-being of their families.

Some literature has, however, highlighted the problematic assumptions underlying the promotion of PVPs which focus on economic rationality and informed choice. Multiple and complex factors, affecting energy switch and the preferences for technology, have not been paid sufficient attention. The assumed even distribution of costs and benefits, particularly between men and women, has also been questioned.

The environmental debate around PVPs has been focused too much on CO_2 emissions. Yet, the rising energy-water efficiency, because of the technical improvement of PVPs, has resulted in undesirable environmental trade-offs, such as the depletion of underground water and e-wastes. From the gender perspective, the success in using PVPs to achieve gender empowerment hinges on how the structural power inequalities, between men and women, are understood and tackled. This literature review has demonstrated that many PVP projects may be successful in helping women groups raise their farming productivity and increase their. Nevertheless, some PVP interventions may, unwittingly, help reinforce gendered stereotypes. Women do not feel empowered in the process of participation in the PVP projects.

This book chapter suggests that more in-depth, longitudinal and mixed quantitative-qualitative research is needed in order to capture the long-term and complex impact of PVPs. More attention should be paid to the trade-offs between the impact on poverty reduction, environmental conservation and gender equality.

One of the major limitations of this book chapter is an inadequate analysis of the impact of governance in enabling, and constraining, PVP improvement. Governance is rules governing access to, and use of, water, energy and technology (Badenoch 2009). The World Bank (2016) has proposed several institutional changes to address the PVP-related issues, such as social acceptance, affordability and access. How effective the institutional strengthening is requires more robust research.

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Livestock Technologies and Grazing Land Management Options for Climate Change Adaption and Mitigation as a Contribution for Food Security in Ethiopia: A Brief Overview

Shigdaf Mekuriaw, Alemayehu Mengistu and Firew Tegegne

Abstract African countries, like Ethiopia, are particularly vulnerable to climate change because their economies largely depend on climate-sensitive agricultural production. Growth and Transformation Plan (GTP) of Ethiopia recognized climate change as a huge threat and focusing on mitigation issues. The GTP stipulates the country's ambition to build a climate resilient green economy by 2030. This paper looks at the potential of livestock technologies and grazing land management for mitigation and adaption to a changing climate. Research findings in Ethiopia showed that livestock technologies and management of grazing lands such as improving the quality of forage, feeding highly digestible forages, processing and preservation of feeds, use of controlled grazing instead of continuous grazing and inclusion of legumes in forage mixes, have a great response to climate change. The choices for application of the technologies and potential mitigation strategies primarily depend on the adoption and cost associated with it. Grazing land management not only mitigates climate change but also reduces soil erosion, increases carbon sequestration and contributes to the resilience of crop-livestock farming systems in Ethiopia. In conclusion, management of grazing lands and implementation of livestock technologies have good implications in mitigating climate change on top of income generation and thereby improving the livelihood of farmers in Ethiopia.

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1 Introduction

Climate change is widely considered to be one of the greatest challenges to modern human civilization that has profound socio-economic and environmental impacts (Ahmed et al. 2013; Khatri-Chhetria et al. 2017). Climate change is the common phenomenon worldwide. Ethiopia is among the most vulnerable countries in Africa as its economy heavily depends on subsistence rain-fed agriculture within a fragile highland ecosystem, which has been threatened by population pressure and land degradation (Somorin 2010). Historically it has been portrayed as a food deficit country with its people and animals suffering from recurrent droughts and floods. The famine that followed the 1984 droughts, which caused the death of up to a million persons and the 2006 catastrophic flood in Dire Dawa are crucial examples (Takele and Gebretsidik 2015). Climate change would affect particularly the economies of the rural areas where people are more dependent on livestock, fisheries and agriculture related activities for their livelihoods (Urquhart 2009).

Livestock in Ethiopia are extremely important as they serve a wide variety of functions in society from social to subsistence purposes (Kassahun et al. 2008). The economic importance of livestock provided more than 45% of agricultural Gross Domestic Product (GDP) in 2008–09 (Behnke 2010). With 60–70% of the population's livelihoods dependent on livestock in one way or another, livestock provide both food and income (Kimball 2011, unpublished). For many small-holder farmers livestock provide draught animal power, transportation and manure for fertilizing croplands. Livestock are also socially and culturally important in Africa for payment of dowry, celebrations and gifts to family members and also as a source of savings that is often safer, despite diseases and drought, than banking systems and easier to manage for farmers living in remote areas (Abela 2005). Throughout their long history, Ethiopians have constantly relied on livestock in order to survive. As the oldest form of assets in Ethiopia, cattle and other types of livestock have traditionally and still today serve as a significant indicator of wealth. Ethiopia is generally recognized to have the largest population of livestock of any other African nation (Halderman 2004). Ethiopia's dependency on livestock has in turn created a need to expand livestock production, to help feed and support the population that is growing at tremendous rate of 2.56% as of 2010 (CRGE 2011).

The livestock production system contributes to global climate change directly through the production of methane (CH_4) from enteric fermentation and both CH_4 and nitrous oxide from manure management (CRGE 2011). Among Ethiopian livestock species, the major contributors to Green House Gas (GHG) emission are cattle. Given the extensive livestock production practices, the cattle population is likely to increase from around 53 million (CSA 2013) to more than 90 million in

2030 (CRGE 2011), thereby almost reaching the cattle carrying capacity of the country and doubling emissions from the livestock sector.

Consequently, it is essential to develop a portfolio of strategies that includes adaptation, mitigation, technological development and research to combat climate change. It is imperative for countries to take a proactive role in planning national and regional programs on adaptation to climate variability (Ahmed et al. 2013). Therefore, this paper was initiated to identify the potential livestock technologies and grazing land management options for climate change mitigation and adaptation towards sustainable livestock agriculture.

2 Effects of Climate Change on Livestock Agriculture

It is predicted that climate change will double (by 25–50%) the frequency of droughts in the dry lands of Sub-Saharan Africa by the end of the century and drought periods are likely to last for longer (Umesh et al. 2015). Climate change is, therefore, a threat to the Ethiopian agrarian economy and livelihoods of millions of the poor. The key climate hazards are flooding, drought and rainfall variability (Nachmany et al. 2015). The effect of climate change hits the poorest people first as they are more dependent on climate-sensitive livelihoods such as livestock farming. Ethiopia is one of the first victims of climate change as evidenced by the catastrophic drought of 1984–1985 (Philander 2008). The occurrence of droughts and prolonged dry seasons are directly and indirectly affecting the livestock sector. Unplanned deforestation and drought bring unavailability of feeds and sustainable water resources for livestock use. If an animal experiences heat strain, it decreases feed intake and that causes the reduction of gross production (Rowlinson 2008). The present and future impacts of different climate events on livestock require the quick response during the flood and drought for the sustainable rehabilitation. Africa's livestock sector has been affected by climate changes through more frequent catastrophic events, reduced water availability, changes in the pattern and quantity of rainfall, an increase in temperature, changes in seasonality, a decrease in feed and fodder production, changing patterns and distribution of disease and altered markets and commodity prices (Tubiello 2012).

Various studies indicated that the trends in inter-annual and inter-seasonal rainfall variability like declining in amount, increasing in intensity, varying in the length of growing seasons with increasing temperature have negative implication on crop and livestock productivity (Kassie et al. 2013; Getachew 2015). It is obvious that the availability of pasture and water for livestock is determined by climate conditions and land use change. Increasing in temperature has a negative impact on livestock productivity as warming is expected to alter the feed intake, mortality, growth, reproduction, maintenance, and production of animals (Thornton et al. 2009). The direct effects include temperature and other climate factors such as shifts in rainfall amounts and patterns on animal growth, reproduction and milk production (Thornton and Herrero 2010). While the indirect effects of climate change include influence on availability of water, the quantity and quality of animal feed such as pasture, forage, crop yield and the severity and distribution of livestock diseases and parasites (Seré et al. 2008). In Ethiopia, the deterioration of rangelands and increases in woody browses can be expected to result in an increasing number of pastoralists maintaining mixed herds of browsing animals like camels and goats with smaller numbers of cattle and sheep (Kefyalew and Tegegne 2012).

It is expected that as temperature changes, optimal growth ranges for different forage species also change; species alter their competition dynamics, forage quality (like nutrient content) and quantity, and the species composition of mixed grasslands changes (Thornton et al. 2009). Hopkins and Del Prado (2007) noted that climate change can be expected to have several impacts on feed crops and grazing systems including changes in herbage growth brought about by changes in atmospheric CO_2 concentrations and temperatures; changes in the composition of pastures, such as changes in the ratio of grasses to legumes and changes in herbage quality. Under climate change (increase in temperature) the structural constituents of plant materials such as lignin, cellulose and hemicelluloses is reported to increase (Ford et al. 1979). Crop losses due to extremes in climate (temperature and rainfall) could result in less animal feed (crop residue) being available, especially in crop-livestock systems that predominates in the Ethiopian livestock production.

3 Climate Change Mitigation and Adaptation Strategies in Ethiopia

Ethiopia has identified different adaptation options in Climate Resilient Green Economy Strategy to reduce vulnerability of the people and economy to climate change impacts (EPA 2011). The strategy outlines four pillars focusing on Agriculture with emphasis on improving crop and livestock production practices for higher food security and farmer income while reducing emissions (ECRG 2011; Nachmany et al. 2015). The Government of Ethiopia also identified 37 potential adaptation options to address highly vulnerable sectors mainly agriculture, water and health (FDRE 2006). Mitigation potentials in Ethiopian pastoral systems using improved crop and grazing land management will increase soil carbon storage, and improved livestock management has great contribution to reduce methane emissions (Steinfeld and Gerber 2010; Abebe 2017). Moreover, improving the nutritive value of low-quality feeds in ruminant diets which are much available in Ethiopia, could increase animal and herd productivity, and consequently reduce methane emission (Hristov et al. 2013).

4 Livestock Technologies for Climate Change Adaption and Mitigation

The Government of Ethiopia, climate change national adaptation programme of action (NAPA 2007) report identified a range of adaption interventions that could potentially assist pastoralists to adapt to climate change. These include: additional care to avoid over-grazing and better manage stocking rates with pasture production; grazing with mixed herds of grazers and browsers; increased use of forage crops; water resource development; and the increased use of livestock feed supplementation. Khatri-Chhetria et al. (2017) also reported that technologies or interventions for reducing the emission of methane from grazing livestock include reducing livestock numbers by improving productivity, increasing the efficiency of animal production, genetic improvement, manipulation of the rumen microbial ecosystem, feed additives and improvement of farm management.

Livestock keepers have traditionally adapted to various environmental and climatic changes by building on their in-depth indigenous knowledge of the environment in which they live. However, the increasing human population, urbanization and land degradation have rendered some of those coping mechanisms ineffective (Sidahmed et al. 2008). Moreover, changes brought about by global warming are likely to happen at such a speed that they will exceed the capacity of spontaneous adaptation of both human communities and livestock species. These well-organized and knowledge-based national strategies are required to combat the effect of climate change on livestock production.

Several studies reported on how to adapt the livestock technologies to reduce the climate change impacts and action measures with the issue of sustainability of the developing countries (Demir and Bozukluhan 2012; Wang et al. 2012). Livestock keepers have traditionally been capable of adapting to threats to their livelihood. Indeed, one of the most widespread livestock systems in Ethiopia, pastoralism, has often been defined by its capacity to adapt to climatic uncertainty and other hazards. However, it is important to recognize that the outcomes of climate change are uncertain and that the way livestock keepers adapt will vary from location to location and household to household. The production and productivity among small holders is much lower than the potential that they can be increased through utilization of improved technology and practices such as; improved feeds and feeding, breed and breeding, health services, market efficiency.

4.1 *Feed Technologies*

Various feeding and grazing land management strategies such as rotational grazing, reseeding pasturelands, crop residues treatment with urea, forage development; efficient feed production techniques such as silage and urea molasses block preparation lead to a reduction of emissions for climate change adaptation (Bryan et al. 2011).

It can be seen that a significant factor affecting methane emissions is the animal's diet and this is subject to modification through feeding strategies particularly where the animal is fed a diet with a significant forage component (grazed or ensiled). Such approaches build on the considerable success that has been achieved in improving quality traits for animal production e.g. rye grasses with higher water soluble carbohydrate (WSC) content and increased digestibility (Abberton et al. 2007). Generally, diets of higher digestibility have these characteristics. Improving the nutritive value of the feed given to grazing animals by balancing the diet with concentrates, or by breeding improved pasture plants, should result in reduced methane emission (Ulyatt and Lassey 2005).

4.1.1 Improved Feed and Feeding Management

Literature results indicate that increasing feed utilization efficiency and improving the digestibility of feed are some of the options to reduce GHG emissions and maximize production and gross efficiency (Ominski et al. 2006). Enteric CH_4 emissions are highest when the animal is presented with poor-quality forage and has limited ability to select higher quality forage components as a result of reduced dry matter availability. On the contrary, methane production in ruminants tends to decrease with the quality of the forage fed. Boadi et al. (2004) demonstrated that forage quality has a significant impact on enteric methane emissions. Study conducted on steers indicated that CH_4 emissions of grazing steers that had access to high quality pastures declined by 50% compared to emissions from matured pastures (Oudshoorn 2009).

Feed resources in the mixed crop-livestock system in Ethiopia are mainly natural pasture grazing, crop residues and aftermath grazing, which all are characterized by poor quality (Tesfaye and Chairatanayuth 2007). So, improving the quality of these feeds is an important strategy to reduce methane emission from livestock. Changes in feeding system (e.g. roughage: concentrate ratio may reduce methane emission. Compared to forages, concentrates are usually lower in cell wall components, ferment faster than forage, giving rise to elevated levels of propionic acid. Sejian et al. (2015) suggested that CH_4 production can be lowered by almost 40% when a forage rich diet is replaced by a concentrate rich diet. Supplementation with concentrate feed especially for dairy cattle in potential dairy area is the best feeding strategy to reduce GHG emission from cattle (Bannink 2007). Feeding more concentrates to ruminants improves productivity and reduces enteric methane (even though volatile GHG in manure is increased) (Mekuriaw et al. 2014).

4.1.2 Ammonization of Roughage (Urea Treatment of Fibrous Feeds)

There is a huge amount of crop residue and native pasture with poor quality for animal feed in Ethiopia. Lack of degradable nitrogen in many fibrous residues can be corrected by supplementation with urea (ammonization). Straw ammonization technology reduces 25–75% of methane emissions per unit of animal produce-meat, milk and work; increases digestibility (by 8 to 12 points); increases nitrogen content (more than doubled); increases the intake (by 25–50%) and thus to the nutritive value (Klopfenstein et al. 1972; Pires et al. 2010; Liu et al. 2017). In addition, use of urea-molasses multi-nutrient block as supplement to fibrous feed enhance efficient rumen fermentation; improve the daily feed intake; improve body weight gain and body condition.

4.2 Genetic Improvement of Animals to Reduce Methane Emission

Ethiopia has the largest livestock population in Africa with different animal species (cattle, sheep, goat and camel). The cattle population in Ethiopia has historically grown in line with the expansion of the human population. The cattle population in mixed crop-livestock system is projected to double in 2030. Consequently, GHG emission from cattle is expected to increase. Production and productivity of Ethiopian livestock is poor compared to other countries. For example milk production potential of indigenous cattle breed is low (around 529–713 L per lactation) (EPCC 2015). However, a good first generation Holstein Friesian crossbred cow with moderate level of management can produce from 1726 to 2428 L of milk (EPCC 2015). This shows that if due emphasis is given to the effective functioning of key technological input and output markets, the cattle industry has huge potential to develop and contribute to mitigation of GHG emission. Artificial insemination (AI) and estrous synchronization are efficient technologies to deliver improved genotypes to a large number of dairy farmers in a short period of time. These techniques lead to replacing unproductive indigenous cow population with less number but more productive crossbred cows. This gives chance to farmers shifting to better management of fewer productive animals to mitigate climate change. Genetic improvement coupled with diet intensification could lead to substantial efficiency gains in livestock production and CH_4 output. This would result in fewer but more productive animals being kept, which could have positive consequences for CH_4 production.

In Ethiopian context, for methane emission mitigation option from cattle, 13% of indigenous cattle population in mixed crop livestock system will be replaced by crossbred dairy cattle which will also enhance milk yield production by 400%. This projection indicated that replacement of 13% of indigenous cattle population in dairy potential area by more productive cross-breeds will result in abatement potential equal to roughly 6 Mt CO_2e per year by 2030, assuming the indigenous and cross-breeds will emit around 1.08 and 1.5 tons CO_2e per year/head respectively. Increasing off-take rate is another strategy in decreasing GHG emission per animal; increasing socio-economic growth of the country in general and small holder farmers in particular.

4.3 *Diversification Towards Lower Emitting Animal Species*

Animal mix diversification has the potential to decrease the vulnerability of the herd to climate change, depending on the livestock species chosen. There are differences among livestock species in their ability to produce under given climate change. However, the economics of herd diversification, for example from cattle to small ruminant or poultry depends on the relative costs of different species and relative revenues, both under current and future climate condition. Beef is the primary meat consumed in Ethiopia, and the demand for beef is a major driver of the size of the cattle population in addition to the requirement for draught power. For this reason in Ethiopia, poultry specifically chicken meat offers a particularly attractive lower-carbon alternative to beef. Partial replacements of cattle with lower emitting species (poultry, sheep and goat, fish) would be an alternative option for mitigation of GHG emission from livestock. These low-emitting animals are high feed converters and low GHG emitters as compared to large ruminants such as cattle (Pachauri et al. 2014). Chickens are the most efficient in Ethiopia in terms of producing the most meat and protein per amount of GHG emitted (Lipson et al. 2011).

5 Sustainable Grazing Land Management Options and Carbon Sequestration

Sustainable grazing land management requires an understanding of how to use grazing to stimulate grasses to grow vigorously and develop healthy root systems, usage of the grazing process to feed livestock and soil biota, ideally maintaining 100% cover (plants and litter), and 100% of the time and provision of adequate rest from grazing without over resting areas of land. Improved grazing conditions will increase livestock productivity in rangelands, in turn increasing food security. Sustainable grazing management (often termed "holistic") is already being used in Namibia, South Africa, the Northern Rangelands of Kenya and Ethiopia (Reed et al. 2015).

5.1 *Proper Grazing Pasture Management*

Proper pasture management through rotational grazing would be the most cost-effective way to mitigate GHG emissions from feed crop production. Grazing management techniques intended to increase forage production through increased perennial species have the potential to increase above and below ground soil carbon stocks, and to restore degraded dry lands (IPCC 2007). The recommended management measures and strategies for free grazing are changing grazing intensity (number of cattle per area) and grazing period (starting time and length) depending on seasonal climatic conditions. Managing grazing intensity (stocking rate, rotations and their timing), including deep-rooted fodder species and legumes in fodder crops and pastures reduce synthetic nitrogen fertilizer, optimizing nutrient allocation in spatial herd management and grazing patterns. Further improvements of the grazing pasture are possible with the introduction of indigenous and exotic grasses, legumes, and drought resistant trees that can increase the supply of forage material available to livestock. It will also become increasingly important to conserve hay and promote improved management that can enable livestock to be moved between pastures to avoid over-grazing.

5.2 *Forage and Grassland Carbon Sequestration Technology*

Carbon sequestration in rangelands may provide an option to capitalize on the existing environmental management practices of livestock keepers and capture additional incentives for more effective management. Carbon stocks have been found to reduce when dry lands are converted from pasture to either plantation or arable land, whilst in some cases increases in carbon stocks are seen when native forests or croplands are converted to pasture. Carbon capture is increased with improved grazing management of rangelands and that also contribute significantly to improving the local and household economy. Batjes (2004) estimated that improved management of 10% of the African grazing lands could increase soil carbon stocks by 13–28 Mt-C year^{-1}. The primary reason given for increased carbon emissions and loss of soil carbon sequestered on degraded rangelands is overgrazing and so eliminating or moderating grazing intensities is proposed to increase carbon sequestered on these rangelands (Conant and Paustian 2002). Improved grazing management (management that increases production), leads to an increase of soil carbon stocks by an average of 0.35 t C ha-1 year^{-1} (Conant et al. 2015). In addition, introducing grass species and legumes into grazing lands can enhance carbon storage in soils (Calvosa et al. 2009).

6 The Way Forward for Policy Makers

As a country in the developing world with a substantial population growth rate, Ethiopia is struggling to feed itself. Understandably, agricultural expansion in Ethiopia is the government's top priority, according to the Federal Policy and Investment Framework from 2010–2020 documents. Paramount to Ethiopia's agricultural expansion is the livestock sector, which is estimated to account for 45% of agricultural GDP or more. Agriculture in Ethiopia is extremely vulnerable to climate change. A range of climate change scenarios and models suggest that many parts of Ethiopia are likely to experience such climate variability in the future. The farmers and local communities are the direct beneficiaries, and ultimately the enforcers, of the environmental policies seeking to mitigate the environmental impacts of livestock management in Ethiopia. Options and strategies that are cost effective and have no/minimum negative effects on livestock production hold a greater promise. This requires the government and policy makers direct manifestation and course of action. Consequently, community-based adaptation of livestock and participatory approach can be the greatest options for the policymakers to save the livestock sector. Moreover, carbon sequestration efforts help to reduce the impact of greenhouse gas emissions generated from livestock production. In order to effectively enact and monitor any potential livestock policy, there must be a prerequisite of full participation of relevant stakeholders to promote sustainable grazing land and livestock management practices. Successful livestock policy will require that all be involved with the policy making process and support the proposed measures to improve livestock productivity in order to reduce the negative externalities associated with livestock production suited for environment. Ethiopia will also need to develop a climate mitigation and verification capacity in order to benefit from the potential of livestock production for food security.

7 Conclusion and Recommendation

In terms of their contribution to GDP and household assets, livestock are crucial in Ethiopia's economy and social well-being. The damage of climate change is supposed to be more sever in the future. There are no alternatives except accessing high technology and advance knowledge for the sustainable development of the livestock sector. Climate smart grassland management systems sustainably increase productivity and resilience (adaptation), reduce greenhouse gas emissions (mitigation), and enhance food security. Reducing productivity gaps and increasing livestock production efficiency would contribute to mitigate climate change. Many different management practices can improve livestock production efficiency and reduce greenhouse gas emissions. Some of the most effective technologies include: improving grazing land management, supplementing cattle diets with needed nutrients, developing a preventive herd health program and improving genetics and reproductive efficiency. Moreover there are techniques that improve intake and digestibility of low quality feed resources which include urea treatment (ammonization), supplementing with urea-molasses-mineral blocks, and supplementing with high quality legume fodder or concentrate rations. Changes in livestock production practices such as intensification and/or integration of pasture management, introducing mixed livestock farming systems like feedlot fattening, and improved pasture grazing are some of production adjustment strategies recommended for climate change adaptation in mixed crop-livestock system. There are also technologies that have proven contributions in terms of both economic development and GHG reduction as learned from experiences of several developing countries. These technologies are compatible with the existing national development policies and strategies of Ethiopia. Therefore, the academia and policy makers need to understand applicable options as a measure for sustainable livestock management against climate change. Moreover, integration of mitigation and adaptation frameworks into sustainable free grazing management and development planning are an urgent need, especially in the developing countries like Ethiopia.

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Impacts of Climate Change on Food Security in Ethiopia: Adaptation and Mitigation Options: A Review

Tadesse Alemu and Alemayehu Mengistu

Abstract Climate change is happening and already affecting food security in Africa. Ethiopia is vulnerable to climate change because our economies largely depend on climate-sensitive agricultural production. Environmental changes, such as changes in rainfall variability, drought, warmer or cooler temperature (lead to change in growing seasons) and land cover change have increased concerns about achieving food security. Growth and Transformation Plan (GTP) recognized Climate change as a threat and opportunity for Ethiopia. Both climate change adaptation and mitigation issues considered; GTP stipulates the country's ambition to build a climate resilient green economy by 2030. Climate change impacts on agriculture and livestock is depending on changes in temperature, precipitation and climate variability (such as erratic rainfall, floods and droughts). The complex interaction of these variables makes it difficult to predict how climate change will impact at the regional level. Despite the relatively high knowledge of the subject among policy-makers and the prominent role being played by Ethiopia in International Climate Change Negotiations many factors, such as El Nlno, are contributing to the deterioration of the local climate and making the population ever more vulnerable to global and regional climate change. The Policies and implementation Strategies should emphasized on an integrated, evidence-based and climate smart approach to addressing food security at all levels, from the National to local levels, from research to policies and investments, and across private, public and civil society sectors to achieve the scale and rate of change required.

Keywords Adaptation · Coping strategies · Climate change · Environmental challenges · Climate smart agriculture

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1 Introduction

Growing consensus in the scientific community indicates that higher temperature and changing precipitation levels resulting from climate change will reduce crop yields in developing countries. Evidence from the Intergovernmental Panel on Climate Change (IPCC 2007) is now overwhelmingly convincing that Green House Gases (GHGs) induced climate change is a real and that the poorest and most vulnerable people will be the worst affected. IPCC (2014a) also predicts that by 2100 the increase in global average surface temperature may be between 1.8 and 4.0 °C. With increases of 1.5–2.5 °C, approximately 20–30% of plant and animal species are expected to be at risk of extinction (FAO 2007; IPCC 2014a, b) with severe consequences for food security in developing countries (IPCC 2007; Mekuriaw et al. 2014).

The links between climate change and food security have, to date, largely been explored in relation to impacts on crop productivity and hence, food production. For instance, Gregory et al. (2002) summarized experimental findings on wheat and rice that indicated decreased crop duration (and hence yield) of wheat as a consequence of warming and reductions in yields of rice of about 5% per °C rise above 32 °C (Gregory et al. 2008). Cline (2007) also estimates that global agricultural productivity will be reduced by 15.9% and developing country experiencing a disproportionally larger decline of 19.7%. Similarly, simulation of maize production in Africa and Latin America for 2055 predicted an overall reduction of 10% (Jones and Thornton 2003).

Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (IPCC 2007). The average temperature rose by about 0.3 °C during the first half of the 20th century, and by another 0.5 °C in the second half up to the beginning of the 21st century (IPCC 2007) very likely due to the observed increase in anthropogenic GHG concentrations. According to IPCC (2014a) report, there has been an increase in seasonal mean temperature in many areas of Ethiopia. The average annual temperature in Ethiopia increased by 1.1–3.1 °C by 2006, with an increase in the average number of 'hot' days and 'hot' nights per year (McSweeney et al. 2010). This has a severe impact on food production and animal health.

Climate change will act as a multiplier of existing threats to food security; it will make natural disasters more frequent and intense, land and water more scarce and difficult to access, and increases in productivity even harder to achieve. The implications for people who are poor and already food insecure and malnourished are immense (Gregory et al. 2008; UNFCCC 2009). Despite the uncertainty of climate impacts, it is clear that the magnitude and rate of projected changes will require adaptation. Actions towards adaptation fall into two broad overlapping areas: (1) better management of agricultural risk associated with increasing climate variability and extreme events, for example using climate smart agriculture, improve climate information services and safety nets, and (2) accelerated adaptation to progressive climate change over decadal time scales, for example integrated packages of technology, agronomy and policy options for smallholder farmer and food systems (Leslie et al. 2015). Maximization of agriculture's mitigation potential will require, among others, investments in technological innovation and agricultural intensification linked to increased efficiency of inputs, and creation of incentives and monitoring systems that are inclusive of smallholder farmers. More than 45 published articles, policy documents and international climate change reports were used and analyzed systematically. Therefore the objective of this paper was to assess the impacts of Climate change on food security and adaptation and mitigation options in Ethiopia.

2 Impacts of Climate Change in East Africa

The mean global combined land and ocean surface temperature appears to have risen 0.65 to 1.06 °C over the period of 1880–2014 (IPCC 2014a). As a result snow cover in the northern hemisphere decreases and the sea level rises. Africa is the continent that will be hited hardest by climate change. Unpredictable rains and floods, prolonged droughts, subsequent crop failures and rapid desertification, among other signs of global warming, have in fact already begun to change the face of Africa (Gregory et al. 2008; Thornton et al. 2008). Many climate scientists agree that climate change is very real, it is happening and it is happening now. We can no longer consider it a threat that is yet to hit us (Amsalu and Gebremichael 2009).

The impacts of climate change across Africa will vary: At mid- to high latitudes, crop productivity may increase slightly for local mean temperature increases of up to 1 to 3 °C, while at lower latitudes crop productivity is projected to decrease for even relatively small local temperature increases (1–2 °C) (IPCC 2007). In the tropics and subtropics in general, crop yields may fall by 10–20% by 2050 because of warming and drying, but there are places where yield losses may be much more severe (Thornton et al. 2008). The predictions showed that temperatures are expected to increase across the continent (IPCC 2014a). Seasonal average temperatures have risen in many part of eastern Africa, which will lead to increased plant stress and increased risks of drought.

In East Africa large water bodies and varied topography gives rise to a range of climatic conditions, from humid tropical climate along the coastal areas to arid low-laying inland elevated plateau regions across Ethiopia, Kenya, Somalia and Tanzania. The presence of Indian Ocean to the east, Regional lakes as well as high mountains induce localized climatic pattern in this region. In most of these countries, there are places where rainfall means are likely to decrease in the coming decades (Mario et al. 2010). Therefore rainfall in east Africa is very variable in time and space. Several physical processes, including El Niño Southern Oscillation, affect rainfall (IPCC 2014b). According to IPCC (2014b) warming of Indian Ocean is the cause of less rainfall and/or drought over eastern Africa in the last 30 years.

Nearly two thirds of Sub-Saharan Africans depend on livestock for some part of their livelihood. Climate change will affect the productivity of agricultural products as a result, major changes can be anticipated in livestock systems, related to livestock species mixes, crops grown, feed resources and feeding strategies (Anderson et al. 2010). The challenges for development are already considerable for Africans, and climate change will multiply the stresses. There are 300 million poor people in sub-Saharan Africa. Projections indicate an increase of arid and semiarid lands, and, in some countries, yield reductions in rain-fed agriculture of up to 50% by 2020 (Anderson et al. 2010). Therefore failure to manage agricultural climate change adaptation will cause a sharp decline in food production, famine and unprecedented setbacks in the fight against poverty in East Africa. Adapting agriculture to climate change is the key to food security in the 21st century in Africa (Anderson et al. 2010).

3 Climate Change in the Context of Ethiopia

Ethiopia is highly affected by climate change due to three main reasons; (i) about 80% of the population is largely depend on rain fed agriculture (ii) low income country (iii) varied geographical locations with different magnitude of climate impacts. Climate change induced El-Nino increase the average temperature and affect rainfall pattern in time and space leading to a recurrent drought which results in food insecurity particularly in dry and semi dry areas of the country. The country has experienced 16 major national droughts since the 1980s, along with dozens of local droughts. Recently in 2015/15 10 million peoples, in 2017 5 million peoples are food insecure, as a result of drought caused by climate change induced EL Nino.

In Ethiopia climate change is already taking place now, thus past and present changes helps to indicate possible future changes. Over the last decades, the temperature in Ethiopia increased at about 0.2–0.37 °C per decade (Kassahun 2008). The increase in minimum temperatures is more pronounced with roughly 0.4 °C per decade (Mengistu 2008; Kassahun 2008). The temperature will very likely continue to increase for the next few decades with the rate of change as observed (Kassahun 2008; Mengistu 2008; Mengistu and Mekuriaw 2014; IPCC 2014a).

The average annual volume of rainfall over the past 50 years (from 1951–2000) remained more or less constant for the whole country (NMSA 2001). Many authors agreed that mean annual rainfall showed a slight decreasing trend and higher year to year variation was observed in 1950–2010. However, rainfall distribution across the country shows a marked difference. There is a tendency for less rain to fall in the northern part of the country where there is already massive environmental degradation. The same trend can be observed in the south east and north east of the country which is both often affected by drought. However, in central Ethiopia where most of the population and the country's livestock are located, and where the soil is severely depleted and degraded, more rain is falling. The western and north-west parts of the country have also received more rain (Mengistu 2008;

McSweeney et al. 2010). Farmers and pastoralists are experiencing that the rain is becoming more unpredictable or is failing to appear at all. In some places the rain falls more heavily and the degraded soil is unable to absorb this ran which falls over a shorter period. According to Kassahun (2008), the farmers in the central part of the country have lost up to 150 tons of soil per hectare.

The rise in temperature and fluctuations in rainfall crate many problems for the pastoralists who live in the already drought stricken areas which are receiving less and less rain. They have already switched from cattle to goats and camels, as they are more able to endure the long periods of drought. In the central part of the country more rain will mean further erosion of the soil and lower crop yields for small holder farmers and lead to flooding in the more low lying areas. Climate change is affecting how long the farmers have to grow their crops. In addition, warmer weather provides better growing conditions for pests and other diseases that attack crops and destroy the farmers' harvests (Mengistu 2008; Kassahun 2008; Deressa et al. 2008). Therefore, it is possible to conclude that not only the rainfall distribution that has changed but it has also become warmer in the last 60 years. Hence, there is already a great demand for improved seed which is more drought and pest resistant, and for seeds which mature faster as the rains have become more unpredictable and shorter in some places.

Today the forest covers is very low (less than 10%), so the soil has become more vulnerable to erosion. People cut down the forest to create more farmland and to harvest firewood for cooking. Population growth will put pressure on the already degraded soil, and marginal plots will be brought into use which worsens the situation (Mengistu 2008; Deressa et al. 2008; Mengistu and Mekuriaw 2014) (Table 1).

4 Implications of Climate Change in Food Security

A large body of literature demonstrates negative impacts of climate change on the agricultural sector in East Africa. Climate change affects agriculture and food production in complex ways. It affects food production directly through changes in agro-ecological conditions (e.g. changes in rainfall leading to drought or flooding, or warmer or cooler temperatures leading to changes in the length of growing season), and indirectly by affecting growth and distribution of incomes, and thus demand for agricultural products (Gregory et al. 2008).

Climate change is likely intensified high temperature and low precipitation in semi dry and dry areas, it is the most dramatic effects that will be felt by small holder and subsistence farmers (Mendelson and Dinar 2009). According to IPCC 5th report Climate change impacts in East Africa will increase risk of food insecurity and the breakdown of food systems, increase risks of loss of rural livelihoods and income due to insufficient access to drinking and irrigation water and reduced agricultural productivity, particularly for farmers and pastoralists with minimal capital in semi-arid regions. Risks due to extreme weather events leading to

Table 1 Sectoral impacts of climate change in Ethiopia

Sector	Potential impacts
Agriculture	Shortening of maturity period, crop failure and expanding crop diseases
Livestock	• Change in livestock feed availability and quality • Effect on animal health, growth and reproduction • Impact on forage crops quality and quantity • Change in distribution of diseases, decomposition rate, income and price • Contracting pastoral zones in many parts of the country
Forests	• Expansion of tropical dry forests, desertification • loss of indigenous species/expansion of toxic weeds
Water resources	• Decrease in river run-off and energy production • Flood and drought impacts
Health	• Expansion of malaria to highland areas • Threat from expanding endemic diseases and newly emerging varieties of human, plant and livestock diseases
Wildlife	• Shift in physiological response of individual organisms • Shift in species distribution and Shift in biomass over decades/centuries • Shift in genetic make-up of populations • Loss of key wetland stopover and breeding sites for threatening birds species • Out migration, of endemic and threatened species
Environment	Reduced productive capacity from degradation of forests, range and water recourses

Adapted from Mengistu and Mekuriaw (2014)

breakdown of infrastructure networks and critical services such as electricity, water supply, and health and emergency services are also linked to these areas of concern (IPCC 2013).

The overall effect of climate change on yields of major cereal crops in the African region is very likely to be negative, with strong regional variation (Niang et al. 2014). At even relatively low levels of warming of 1–2 °C, many unique natural systems are threatened and food productivity, human health and water resources could be negatively impacted in some regions. "Worst-case" projections (5th percentile) indicate losses of 27–32% for maize, sorghum, millet and groundnut for a warming of about 2 °C above pre-industrial levels by mid-century (Schlenker and Lobell 2010). The IPCC concludes that large-scale warming, of around 4 °C or above, will increase the likelihood of severe, pervasive and irreversible impacts to which it will be difficult to adapt.

Achieving food security and reducing poverty in the Ethiopia has been a major challenge for both governments and development agencies due to the result of many factors, some of which are: (1) land degradation or poor in nutrients; (2) the rapid population growth (3) the low and inappropriate use of technologies such as improved varieties, fertilizers, mechanization and irrigation that have stimulated agricultural development elsewhere in the world (Mekuriaw et al. 2008; Kassahun 2008). The agricultural sector employs between 85% of the active population and contributes close to 40 $ of the Gross Domestic Product (GDP), generates about

88% of the export earnings; and supplies around 73% of the raw material requirement of agro-based domestic industries (Gebreegziabher et al. 2011). Agriculture is a major source of food and plays a key role in generating surplus capital to speed up the country's socio-economic development and hence the prime contributing sector to food security. Yet, agriculture in degraded and semi-arid regions is a highly risky enterprise due to unreliable and variable rainfall. According to Zenebe et al. (2011) as the effects of climate change on agriculture become negative, incomes drop off considerably. At the end of 2050, because of climate change, average incomes will be reduced. In the no-total factor productivity -growth scenario model showed that, climate change a leads to a loss of some 30% of income, compared with the no-climate-change baseline (Gebreegziabher et al. 2011).

According to World Bank (2006), droughts and floods are very common phenomena in Ethiopia with significant events occurring every three to five years. Climate change is expected to exacerbate the problem of rainfall variability and associated drought and flood disasters in Ethiopia (Mesfin 1984; NMA 2006; World Bank 2006; Amsalu and Adem 2009; UN-ISDR 2010).

5 National Response Towards Climate Change: Adaptation and Mitigation Policies and Strategies

Ethiopian's anthropogenic GHG emissions contribution is marginal (only 0.3% of global total) (USAID 2015). Ethiopian's GHG profile showed that the agriculture sector contribute the highest (61%) followed by land use change (18%), energy (17%); (waste 3%) and only 1% from industrial processes and product use (USAID 2015) (Fig. 1). In its climate resilient green economy (CRGE), Ethiopia plans to cut its 2030 GHG emissions at 145 $MtCO_2e$ by 64% (225 $MtCO_2e$) reduction from

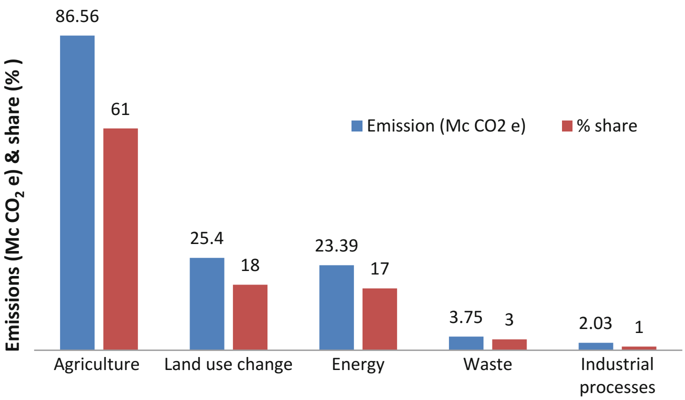

Fig. 1 Greenhouse gas emissions in Ethiopia; by sector. Adapted from (USAID 2015)

projected business as usual emission level by 2030. The reduction includes 130 $MtCO_2e$ from forestry, 90 $MtCO_2e$ from agriculture, 20, 10 and 5 $MtCO_2e$ from industry, transport and buildings, respectively(USAID 2015). Ethiopia has a potential to mitigate an estimated 2.76 billion tons of carbon through protection and sustainable management of forest resources (Moges et al. 2010).

To facilitate the country's response to climate change a comprehensive adaptation and mitigation mechanisms have been developed such as: CRGE strategy, GTP II, Sectoral GHGs Reduction Mechanism (SRM), National Disaster Risk Management and Strategy, National Adaptation Programme of Action (NAPA, now NAP), Sectoral/regional adaptation plans etc. Since 1992 many MEAs are signed and/or ratified. Ethiopia leads least developing countries group in the international climate negotiation agenda.

5.1 Current Policies on Environment and Climate Change

The Ethiopian government has recognized climate change as a threat to its national development. The country has signed most of the international environment conventions including those specifically focused on climate change: it ratified the UNFCCC in May 1994, UNCCD United Nations Convention to Combat Desertification in June 1997, and the Kyoto Protocol in February 2005. The country prepared a National Adaptation Programme of Action (NAPA) to fight the impacts of climate change and desertification (Amsalu and Gebremichael 2009). The program clearly states the urgency of taking practical adaptation and mitigation actions in many social and economic sectors (NMA 2006; Epsilon International 2011). CRGE (Climate Resilient Green Economy) strategy recommends the use of low carbon solutions to leapfrog other economic sectors while realizing the ambitions set out in the country's GTP. CRGE Present an overarching framework to marshal a coherent response to climate change, to generate both innovative thinking and a course of actions to meet the challenges associated with the transfer of climate-friendly technologies and finance for the construction of a climate resilient green economy in Ethiopia (NMA 2006; Epsilon International 2011).

GTP (Growth and Transformation Plan) recognized Climate change as a huge threat. It stipulates the country's ambitions to build a CRGE by 2030. The country has formulated a number of policies, strategies and action plans aimed at promoting Environmental protection, sustainable development and poverty reduction. However, lack of local specific focused policies and legislation were a serious impediment to deal with the adverse impacts of changes and variability in climate (Sintayehun 2008). Kassahun (2008) also stated, it is important and high time to take climate change issues into the country's policies, program and guidelines. However, the current policies, strategy and laws related to climate change and sustainable agriculture are adequate. But still they are not adequately incorporated into extension guidelines and manuals in a way that local farmers understand and participate in the implementation processes. Therefore, creating awareness about policies, strategies and implementation guidelines at all levels including agricultural extension workers and implementation of CSA (climate smart agriculture) is a key.

Despite the relatively high knowledge of the subject among policy-makers, and the prominent role being played by Ethiopia in international climate change negotiations, Ethiopia was still formulating its response in 2009 (Ayalew 2009). Ethiopia, on behalf of African continent plays a great role in climate change negotiations (COPs) which indicates that Africa as a whole and Ethiopians in particular are aware of the climate change impacts on global, regional and national scale. The efforts given to poverty alleviation and socio-economic development will be challenged by the impacts of a changing climate unless such issues are well integrated with adaptation plans (NMSA 2001). According to Deressa et al. (2008), since vulnerability to climate change in Ethiopia is highly related to poverty through loss of coping or adaptive capacity. Integrated rural development schemes can play a great role in reducing poverty and increasing adaptive capacity for dealing with climate change.

Yesuf et al. (2008) also suggested that farmers need timely information on predicted changes in climate in a readily accessible form to empower them to take appropriate steps to adjust their farming practices, such as adopting yield-enhancing adaptation strategies. The early warning system in the country is based on crop forecasts and assessments of food stocks, and deals mainly with preparedness for food emergency relief. In addition, efforts should also be made to reduce the risks of disasters, and extend access to credit markets and extension services in order to facilitate adaptation (Amsalu and Gebremichael 2009). However, the Government's response has been challenged by shortage of funds and lack of institutional capacity. Hence, the role of non-state actors and their contribution in enhancing local adaptive capacities is very crucial need to be encouraging (Amsalu and Adem 2009; Amsalu and Gebremichael 2009) and included in the plan.

5.2 *Ethiopia's Program of Adaptation to Climate Change (EPACC)*

EPACC (Ethiopian Program of Adaptation to Climate Change) strategy adequately understood climate change as a growing threat in Ethiopia and clearly elaborate the need to mainstream climate change in all spheres of development policy making and planning at all phases and stages of the planning and implementation process.

As a Party to the UNFCCC, Ethiopia is obliged by several articles of the convention to address climate change through the preparation of a national adaptation document and the integration of climate change into its sectoral development plans, policies and strategies. The NAPA, prepared in 2007, represented the first step in coordinating adaptation activities across government sectors, but was not intended to be a long-term strategy in itself. Ethiopia's NAPA projects are currently "on hold" whilst international adaptation funding mechanisms are under negotiation (Adem and Bewket 2011).

The former Federal Environmental Protection Authority and the present Ministry of Forest Environment and Climate Change (MFECC) of Ethiopia developed a separate work program for action on adaptation to climate change. The document interlinks climate change adaptation strongly with the economic development and physical survival of the country. The main objective of EPACC and CRGE is to create the foundation for a carbon-neutral and climate-resilient path towards sustainable development in the country. According to this programme, climate change will be implemented by inhabitants and farmers at local and district levels (NMA 2006 and Adem and Bewket 2011). The climate risks identified by EPACC are broadly in the areas of human, animal and crop diseases, land degradation, loss of biodiversity, decline in agricultural production, dwindling water supply, social inequality, urban waste accumulation, and displacement due to environmental stress and insecurity. The programme also identifies adaptation strategies and options in the various socioeconomic sectors including cloud seeding, crop and livestock insurance mechanisms, grain storage, societal reorganization, renewable energy, gender equality, factoring disability, climate change adaptation education, capacity building, research and development, and enhancing institutional capacity and the political momentum (NMA 2006). The program clearly explains the need to mainstream climate change in all spheres of development policy making and planning at all phases and stages of the planning and implementation process and the urgency of taking practical adaptation and mitigation actions in the various social and economic sectors.

5.3 Climate Resilient Green Economy (CRGE) of Ethiopia

Although international climate negotiations have made little progress, Ethiopia has started the race towards low-carbon development (LCD). LCD Plans have been developed and lay foundations for overall sustainable development planning of the country. In fact aggregate climate change mitigation commitments are still far apart from a level of ambition that effectively creates a realistic chance of limiting global warming to a maximum of 2 °C or possibly even lower. Many developing countries including Ethiopia seem to have already begun this process. In this regard, Ethiopia can be an example and tried to implement a new national strategic framework for a smooth transition to a climate resilient green economy by 2030. A climate resilient green economy is a long-term ambition of Ethiopia. The mission statement developed to facilitate the development of the Ethiopian CRGE strategy sets out a five step roadmap for moving towards a climate resilient low carbon economy. The roadmap identified the need for more work on Ethiopia's climate change institutions, monitoring and finance systems and sectorial and regional action plans. When combined, the work is expected to enable the EPA to draft a CRGE Strategy which will identify a clear path to the goal of a climate resilient green economy by 2030 (Adem and Bewket 2011). Building resilient means reducing the risk of becoming food insecure and increasing the adaptive capacity to cope with risks and respond to climate change (Gitz and Meybeck 2012).

Priority challenges and constraints for Addressing climate change impacts

Ethiopia faces a number of cross-cutting challenges and constraints in regard to climate change venerability assessment and adaptation and implementation. As noted in NAPA, these challenges include:

- Weak policy implementation and limited awareness
- Lack of research and development capacity to assess the impacts and consequences of climate change
- Lack of individuals with specialization in venerability and adaptation assessment in agriculture, water resources and health
- Limited skill capacity, facility, and technologies to provide accurate and timely weather and climate forecasts
- Weak institutional framework for dealing with climate change
- lack of coordination between research institutions and policy makers.

Addressing these capacity, institutional and coordination and needs will contribute to Ethiopians ability to continue to move forward effectively on implementation of adaptation that support long term climate-resilient green development.

5.4 Improving Smallholder Livelihood and Resilience Through Climate-Smart Agriculture (CSA)

Climate-smart Agriculture (CSA) is an approach that helps to guide actions needed to transform reorient agricultural system to effectively support development and ensure food security in the changing climate. CSA aims to tackle three main objectives: (1) increase agricultural production and income sustainability, (2) adapting and building resilience to climate change and (3) reduce and/or remove greenhouse gas emissions, where possible (IPCC 2013). CSA practices aimed at promoting efficient use of land, water and soil and other environmental resources. CSA promotes coordinated actions by farmers, researchers, private sectors, civil society and policy makers towards climate-resilient pathways through four main action areas: (1) Building evidence (2) increasing local institutional capacity and effectiveness (3) fostering coherence between climate and agricultural policies and (4) linking climate and agricultural financing (Fig. 2). CSA differs from 'business-as-usual' approaches by emphasizing the capacity to implement flexible, context-specific solution, supported by innovative policy and financing actions (Leslie et al. 2015; FAO 2016).

CSA emphasizes utilization of ecosystem service for agricultural systems to support productivity, adaptation and mitigation of climate change. CSA encourages integrated approaches (Leslie et al. 2015) for example:

- integrated crop, livestock, aquaculture and agroforestry systems;
- improved pest, water and nutrient management;

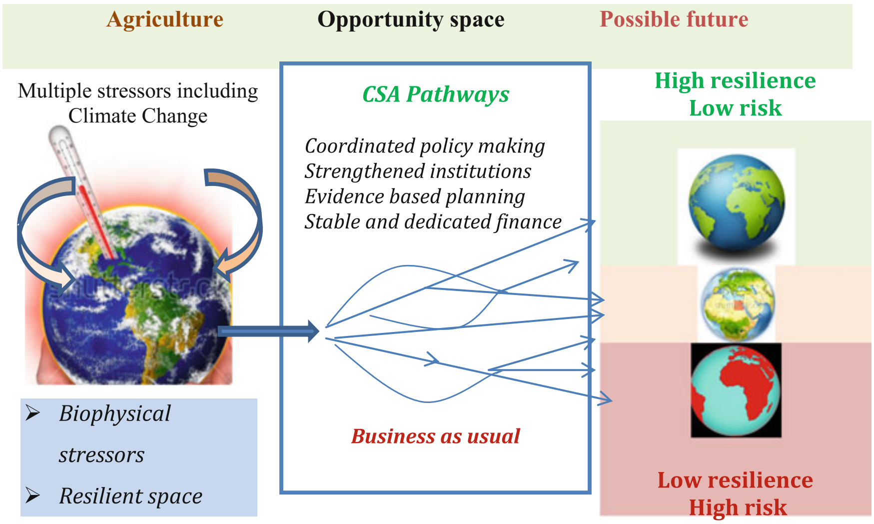

Fig. 2 Climate-resilient transformation pathways for agriculture. Adapted from ref. 4, © IPCC

- landscape approaches;
- improved grassland and forestry management;
- practices such as reduced tillage and use of adverse verities and breeds;
- integrating trees into agricultural systems;
- restoring degraded lands; improving the efficiency of water and nitrogen fertilizer use; and manure management, including the use of anaerobic bio-digesters.

All these integrated activities enhance soil quality and can generate high production. It also Enhances adaptation and mitigation benefits by regulating carbon oxygen and plant nutrient cycles leading to enhanced resilient to drought and flooding and to carbon sequestration (Leslie et al. 2015). Transformative change in agriculture can involve shifts in agricultural production (for example from crop to livestock) or source of livelihoods (increase resilient on non-farm income) (Leslie et al. 2015).

Transforming the current agricultural practice into CSA approach urgent actions from policy makers, public, private and civil society stakeholders at all levels is required in four areas: (i) building research based evidence and assessment tools; (ii) strengthening national, regional and local institutions (iii) developing coordinated and evidence- based policies and (iv) increasing finance institutional capacity and its effectiveness. The current evidence based research findings are inadequate, inaccessible to decision makers support effective decision making at the national, regional and local levels. Therefore the current research addressing climate change impacts on agriculture are not sufficient for national and local level planning. Research institutions should be coordinated to develop tools needed for evaluating the impact of climate change (both extreme events), adaptation and mitigation potential of different policies and technologies.

Challenges and opportunities for effective implementation of CSA in Ethiopia

The key challenges to implement CSA in Ethiopia are: weak implementing capacity on climate change adaptation and mitigation, lack of integration or coordination between federal and regional levels, public sector and civil society organizations, private sectors, and impacts of conventional agricultural practices such as open grazing and frequent ploughing. In spite of the above challenges the country has untapped opportunities to support the scale up of CSA in Ethiopia. These includes; Climate Resilient green economy (CRGE) strategy of Ethiopia, promotion of avoiding open and uncontrolled grazing by regional states, promotion of integrated watershed management to improve agricultural productivity, existence of extension and development agents to create climate related awareness and provide capacity building tanning at the local level. All these opportunities, in addition to NGOs, at the grass root level can promote climate smart agriculture activities in the country.

Improving smallholder livelihood and resilience, in the context of climate change, through climate-smart agriculture (CSA) includes improving farm level food security and productivity through the development of profitable and sustainable farming systems. This can be achieved through integrated and sustainable land and forest management program, integrated soil fertility management, small scale irrigation scams, integrating tree-food-crop livestock system, poultry, bee farming and animal fattening, soil and water conservation measures, rain and ground water harvesting practices. The existence of development agents and extension workers can start CSA practices if appropriate strategy, action plans and manuals are set in place.

6 Conclusion

Many studies convincing that climate change is real, that it will become worse, and that the poorest and most vulnerable people will be the worst affected. Agriculture completely dominates Ethiopia's economy and any climate-change impacts on agriculture will be considerable in the coming decades. Climate change affects agriculture and hence food security directly through changing agro-ecological conditions and indirectly by affecting growth and distribution of incomes. Environmental changes, such as changes in water availability and land cover, altered nitrogen availability and nutrient cycling, has increased concerns about achieving food security. These problems are further intensified by climate change. Shifts in rainfall and rise in temperature will bring major impacts in terms of crop and livestock feed yields, water availability, disease incidence and flood damage. CSA strategies for adaptation and mitigation options should be strengthen such as carbon-sequestration practices involving reduced tillage, increased crop cover, including agro-forestry, and use of improved rotation systems are needed. This transition to CSA will have to be improved by active adaptation policies on the part of the government and will surely need outside support. The countries Green Economy Policies and Strategies integrate the different sectors depending on water-rain fed and irrigated agriculture, livestock, fisheries, forestry, water and soil conservation and biodiversity protection activities. An integrated, evidence based and transformative approaches to addressing food and climate insecurity at all levels require coordination actions from national to local levels, from research to policies and investment and across private, public and civil society sectors to achieve the sale and rate of change required. With the right site specific practices, policies and investment's, the agriculture sector can move on to CSA pathways result in improved food security and decrease in poverty in the in the short term while contributing to reduce climate change as a treat to food security over a longer term.

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Comparative Study on Agriculture and Forestry Climate Change Adaptation Projects in Mongolia, the Philippines, and Timor Leste

Cynthia Juwita Ismail, Takeshi Takama, Ibnu Budiman and Michele Knight

Abstract The impacts of climate change, such as increasing temperature, erratic rainfall pattern, sea level rise, etc., are being increasingly reported. These impacts are destructive for human activities and thus the development and improvement of mitigation and adaptation strategies is a priority globally. In the least developed and developing countries, adequate adaptive capacities are required so to boost the resilience of communities towards the projected climate change projected. Moreover, activities of climate change adaptation not only provide solutions and strategies to deal with climate change, but also encourage sustainable development. This comparative study evaluates projects in three countries: Mongolia, The Philippines, and Timor Leste, by mapping and contrasting the factors that contribute to adaptive capacity and support sustainable development. A heuristic matrix was used to articulate the capacities that influenced the desired outcomes of each project. Some key components of adaptive capacity were identified in each context. The interaction of those components improved the generic and specific capacity at individual and system level then ultimately improved resilience towards climate change.

Keywords Adaptation · Climate change · Agriculture · Forestry
Water management · Sustainable development

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1 Introduction

The impacts and risks of climate change are already affecting many sectors crucial for human livelihoods including water resources and food security (UNFCCC 2014). Economically precarious communities, especially those in developing countries and rural localities, are considered the most vulnerable to negative climate change consequences (Hallegate et al. 2016). Adequate attention and proper measures should thus be given to climate change adaptation capacities to prepare communities for projected climate change impacts. As part of this, interventions that build capacity should ultimately support the sustainable development of the region.

Activities attempting to address the climate change impacts have been implemented worldwide, and are expected to be expanded and integrated to mutually promote both adaptation to climate change and sustainable development, yet the role of different capacity attributes promoted in these activities, not least their interaction in different contexts, is still poorly understood. UNFCCC (TEC-UNFCCC 2014) presented that agriculture represented the single most important sector in the economy of many low-income countries, and 75% of the world's population relies on the related activities. On the other hand, WorldBank (2013) highlighted that hundreds of millions of people around the world depend directly on forest resources for their income and livelihood, including many people living in extreme poverty. However, both sectors are under threats of climate variables (e.g. temperature, precipitation, radiation, and extreme weather events) which ultimately jeopardize the survival of people who rely on those sectors. IPCC (2007) added: "The inter-annual, monthly and daily distribution of climate variables affects a number of physical, chemical and biological processes that drive the productivity of agricultural, forestry and fisheries systems." IUFRO (2009) reported that human dimensions of adaptive capacity in subtropical and tropical forests are more variable due to constraints on access to capital, information and technology. Since the recent report of IPCC AR5 suggested the urgent efforts of adaptation, the establishment of adaptation strategies are crucial for both sectors (i.e. agriculture and forestry).

This study analysed adaptation projects as case studies at agriculture and forestry sector in three countries: Mongolia, Philippines, and Timor Leste. The idea of this study was to explore aspects that influence the success of increasing communities' adaptive capacities at the end of the projects by adopting a heuristic matrix developed by Eakin et al. (2014). This matrix can be an alternative way to evaluate the impacts of adaptation projects as a lesson learned in a more comprehensive way.

Monitoring and Evaluation (M&E) and Measuring, Reporting and Verification (MRV) for climate change adaptation receive increasing interest and attention at both political and operational levels. On the political side, the outcomes of Paris Agreement indicated an increasing focus on the national reporting of both future adaptation actions that have been implemented. On the other hand, the operational side tends to the scale of the financial resources flowing into climate adaptation, is likely to lead much stronger donor emphasis on documenting results and impacts in the future (Christiansen et al. 2016). Furthermore, M&E is crucial to capture the progress of the project whether sustainable development is achieved. In response to that, this study adopted qualitative analysis to evaluate the result of each case. The qualitative approach was selected to describe effectively the distinctive aspects and the contemporary phenomena of the project as they are unique cases and difficult to replicate. The qualitative approach is expected to reveal something about the case studies and contributes to a general understanding of the nature of this kind of activities.

2 Case Description

This study covered three adaptation projects in Mongolia, Timor Leste and the Philippines. These project activities aimed to improve the adaptation capacity and formulate the adaptation strategies at agriculture and forestry sector with the expectation of sustainable development stage is achieved. In Mongolia and Timor Leste case, the issues related to forestry management were highlighted, whereas the Philippines covered water management issues at agriculture sector. Improving adaptive capacity in the vulnerable areas are the focus of each project.

2.1 Mongolia Case

There were 7 vulnerable provinces (i.e. Tuv, Selenge, Khentii, Bulgan, Khuvsgul, Arkhangai and Uvurkhangai) selected as target areas aiming for improving livelihoods of rural communities through sustainable forest management and increasing apiculture. In those provinces, demographically, population densities are low and communities are usually dispersed and nomadic. Livelihood opportunities for local communities are limited by the short growing season and low yields for agricultural products. The communities consist mostly of herders with little access to non-herding income. The incidence of poverty generally increases with distance from municipal services and access to livelihood diversity. Thus, poverty in these areas is generally high—in 2012 (the baseline year of this project), according to World Bank assessments, more than 35% of the rural Mongolian population was considered impoverished following national standards. The 2006 Forest By-Laws, enacted in 2009, allow local communities to form community-based Forest User Groups (FUGs) to manage forest areas based on forest management plans approved by regional governments. To date, 1180 FUGs with about 26,000 members have been established, managing over 3 million ha of forest.

2.2 The Philippines

Lantapan, Bukidnon were selected as target areas to increase the adaptive capacity, especially capacity building of watershed management and up-land farming. Currently prolonged rains, impacts resulting from El Nino and La Nina, and early and delay onset of the rainy season have mainly negative impacts on crop yield, farm income, water and soil quality, and health of the farmers. Lantapan has an agricultural-based economy with 60% of the total labour force employed on bananas and pineapples plantations covering large tracks of land, and in commercial swine and poultry farms. Corn is the predominant crop, and is planted at higher elevations alongside coffee and other vegetables. Meanwhile, coffee is prevalent at the middle altitudes, with irrigated rice, and vegetables such as cabbage, tomatoes and potatoes being the other crops that are distributed within the watershed. Demographically, half of the population attended elementary school, a third entered high school, and slight less than 15% attained tertiary education. This limits their ability to seek non-farm employment in towns and cities. Many households live close to the poverty line. Thus, they seldom have the capital to start small, non-farm related scale business enterprises.

When the farmers are impacted by current climate hazards, they seek assistance from lending institutions for purchase of pesticides; local government units for provision of seeds, technical and financial assistance, and food subsidies/handouts; commercial plantations to seek additional employment; and local health centers and medicine men for the treatment of flue colds, coughs and fever. At times, the delay in the release of local budget can facilitate coping mechanisms, and other times constrain them, as there are challenges in arranging adjustments to budgets or to respond to climate variability and extreme events (e.g. to take on additional short-term staff), or results in a decrease in budgets.

2.3 Timor Leste Case

Climate data or forecasts is limited for Timor Leste, but climate change is predicted to cause hotter dry seasons, shorter and more unpredictable rainy seasons, more frequent extreme heavy rainfall and cyclone events and sea water intrusion. These natural disasters associated with droughts, floods, landslides and soil erosion, result in decreased capacity for agricultural production and damage to infrastructure. The country experiences a distinct 'hungry season' for up to four months of the year in many districts. In Timor Leste, a positive Indian Ocean Dipole equates to less rainfall, protracted dry seasons. During La Niña years above normal rainfall leads to increased flooding and landslides in Timor Leste, while El Niño years are associated with droughts. The most significant impact on the population during El Niño years is reduced ground water availability. Aileu is targeted as the project site. The communities are largely subsistence farmers who are very isolated, far from markets, little access to roads, have poor crop quality, low yields, poor food security, over reliance on maize and rice for income. The communities have a history of exploiting the natural resources of forest, and poor history of engagement with government. Education levels are extremely low across the project population, and lower for women than men. These baseline data put Aileu as the vulnerable area which requires proper adaptation measures.

3 Methodology

This study dealt with an evaluation on adaptation projects at agriculture and forestry sector in three countries: Mongolia, Philippines, and Timor Leste at agriculture and forestry sector. The data collection was done by qualitative approaches. The approach was conducted by site visit, observations and interview the respective stakeholders such as the project developer, the local government, and the impacted communities. Those was also complemented by reviewing the projects' final reports, and survey to the impacted communities (i.e. number of people, number of households). At the end of each project, Eakin et al. (2014) suggested a simple heuristic matrix to evaluate the impact of each project. This is a proper tool used to articulate the influential capacities that have led to the desired outcomes of a project. The capacities matrix consists of two dimensions: *generic capacity* and *specific capacity*, as illustrated in Table 1.

Table 1 The manifestation of different forms of capacity at different organizational levels

	Individual actor	System-level
Generic	• Income level and structure • Savings • Material assets • Health status • Education level • Population mobility • Participation in social organizations	• Economic productivity • Information infrastructure • Poverty levels • Economic and social inequality • Transparency in governance • Population-level education • Sanitation • Health care services • Built environment integrity
Specific	• Climatic information use • Protection of private property • Climate risk insurance • Adoption of technologies to reduce climate impacts • Cultural climate prediction • Traditional risk mitigation strategies	• Insurance provisioning systems • Early warning systems • Scenario development • Infrastructure investment • Disaster planning and compensation fund • Risk mitigation planning

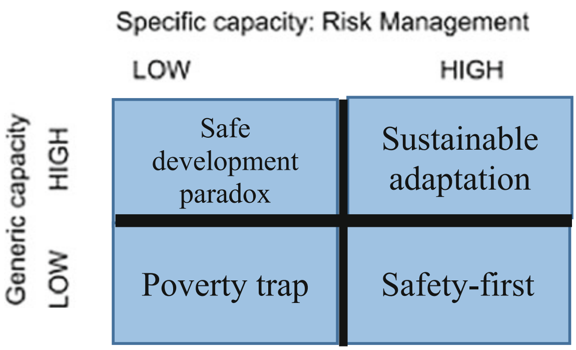
Source Eakin et al. (2014)

Generic capacity is related to capacities which are basic human development needs, while specific capacity is defined as tools and knowledge required to anticipate and effectively respond to climatic threats. Thus, generic capacity includes education level, health, mobility, livelihood, and security whilst specific capacity refers to the knowledge and system concerning adaptive procedure. Although project indicators on one project are not analogous to those of other communities', it is possible to draw out the essential aspects of generic and specific capacity profiles. The matrix also furcates these capacities for examination at individual actor and system level.

To evaluate the interaction between specific capacity and generic capacity, Eakin et al. (2014) suggested 4 classifications as shown in Fig. 1. Firstly, when both generic and specific capacity are at a low level, the target community is classified to be in a "poverty-trap". In this state, the targeted community suffers from intense stress that erodes human welfare and social structure that would otherwise support effective risk management. Secondly, if generic capacity is low whilst specific capacity is high, the society will be considered as a "safety-first" population. The circumstances of this community lead them to prioritize present day safety and security over investments in generic capacities that might enable future welfare gains. There are typically weak safety nets at the level of governance ("system-level") of "safety-first" communities. Furthermore, capacity to invest in assistance for household risk management, or build generic capacity, is lacking.

A further classification, the "safe development paradox" is defined when the target society has high generic capacity but low levels of specific capacity. It describes a society with a good level of education or health, but limited ability to cope with the risk and impacts of climate change. At the system-level of the "safe development paradox" community, there may well be very strong safety nets and public investments in risk management and programs to ensure socioeconomic stability. Lastly, characterized by high generic and specific capacity, there is the community enacting "sustainable adaptation". Communities in this domain are characterized by conditions that would most likely lead to a sustainable outcome and potentially, transformative adaptation. In this condition, generic and specific

Fig. 1 Capacities matrix



risk management is high at both individual and system-levels, and as such, development and adaptation policies are mutually reinforcing to the benefit of reduced overall vulnerability (Eakin et al. 2014).

3.1 Mongolia Case

The project has two approaches: the focus on protection and sustainable management of the forests and sustainable livelihoods for communities in proximity to forests. To execute the project, a field visit was conducted by World Vision Mongolia to hold focus group discussion and key informant interviews with respected community members and officials. Then, it was followed by a workshop to assess the priority environmental issues and the most important causes of those issues. The project supported 24 households (1.6% of the total number of beneficiaries) that had members with disability and some bee-keeping groups had active members who had disabilities. Furthermore, document report from the project were also conducted to evaluate the impact of the project.

3.2 Philippines Case

The overall goal of the project is to promote climate change adaptation by upland farmers and watershed management. To achieve this, the impacts of climate variability to crop yield, vulnerability and adaptation policies/strategies were assessed through a combination of one-on-one interviews with farmers and stakeholders, focus group discussions, workshops and review of literature. Results of the assessment were presented and validated during workshops. Then, capacity building activities were undertaken in the forms of magazine, video and other easy understanding media. Those are aimed for non-technical people to increase the level of awareness of farmers and stakeholders on climate variability, climate extreme and climate change. A pre-test of materials was performed before distributing to the project site. In addition, formal and informal training sessions for climate change 'champions', farmer groups, stakeholders and policy makers were held at the local level, and efforts were made to ensure that these were covered by the local media to attract more stakeholders involved.

3.3 Timor Leste Case

At the beginning of the project, meetings and visits created awareness and agreement for local leaders to implement and enforce "tara bandu" which is the local land law. In Timor Leste, tara bandu is enforced a strict local forest policy which prohibited cutting and burning of forests. Through the meetings (i.e. discussions, interviews), tara bandu was readopted and re-agreed to prohibit all burning, and limited and controlled wood harvesting. Stakeholders were able to advocate for more supportive arrangements for the management and utilization of natural forests. The project supported 46 people living with a disability (25 male and 21 female) to participate in training and project activities and were given priority access to agroforestry materials. Several assessments such as vulnerability assessment, participatory rural appraisal/PRA were performed.

4 Results

As result, Table 2 shows the overall outcome of projects in terms of adaptive capacity using the heuristic matrix suggested by Eakin et al. (2014). This result was based on the projects' final report, observation, interviews and survey. The logical view which lead to such results will be discussed in the next three sub-sections (i.e. Mongolia case, The Philippines case, and Timor Leste case).

Table 2 Project evaluation using a heuristic matrix suggested by Eakin et al. (2014)

No.	Location	Project name	Aim of the project	Status before project	Status after project
1.	Mongolia	Forest Protection and Enhanced Rural Livelihood Project (FPERLP)	To improve the livelihood of rural communities through sustainable forest management and increasing apiculture	Poverty-trap	Safety-first
2.	The Philippines	Mainstreaming climate change adaptation in watershed management and upland farming in the Philippines	To promote climate change adaptation by upland farmers and watershed management at the national and local levels in the Philippines	Safety-first	Safety-first
3.	Timor Leste	Building resilience to a changing climate and environment	Increased community and environmental resilience to climate change effects	Poverty-trap	Safety-first

4.1 Mongolia Case

4.1.1 Before the Project Implementation

Despite the potential to facilitate adaptation, most FUGs lack knowledge to establish forest inventories and management plans also capability on sustainably maintaining the forest- something the project attempted to address. On the other hand, the forest legislation constrains adaptation because they do not allow trees to be cut without a permit (permits being reserved for poorly regulated, private forest enterprises). Therefore, the climate vulnerability of local community members will be reduced by building the local community's capacity to protect, manage and create livelihoods from forests in an ecologically sustainable way. Given the situations mentioned before the project implementation, the community condition is categorized as "poverty-trap".

4.1.2 After the Project Implementation

The project increased community adaptive capacity by both increasing community's income by diversification of non-timber-forest-product livelihoods sources and improving awareness of environmental degradation and management. In terms of gender, there was no notable difference in vulnerability as it was not included in the scope of the project. Women's participation in the forest groups supported by the project was equal to men's, and women achieved slightly higher number of leadership roles than the men. The effort to diversify the livelihoods to non-timber-forest-production of the local community was assessed to have increased the specific capacity at both individual and system level shown in Table 4; as compared with the condition before the project implementation (Table 3). Specifically, diversifying the livelihood sources, at the generic level, reduced community reliance to exploit the primary resources and conditions required to profit solely from animal husbandry (livelihood diversification); while at specific capacity, it created new market opportunities, improved capacity to engage with market. Also, the mobility of community to urban areas as described in Table 3 was diminished. These outcomes may reduce the impact of climate change shocks and stressors. In addition, by explicitly educating community members

Table 3 The adaptive capacities at the beginning of the project in Mongolia case

	Individual actor	System-level
Generic	• Seasonal population mobility • Agrarian local knowledge and cultural appreciation for nature	• High population-level education rate
Specific	• Engaged in a livelihood activity (herding) • Some traditional use of forest resource	

Table 4 The adaptive capacities at the end of project of the project in Mongolia case

	Individual actor	System-level
Generic	• Social organization around resource management and markets • Increased awareness of environmental issues • Strengthened community and social cohesion through communal management and skills-transfer	• (Increased) economic productivity • Improved understanding of policies around sustainable forest management
Specific	• Engaged in an increased diversity of livelihood activities • Improved access/sustainable use of forest resources (across genders) • Improved capacity to engage with market • Improved community stewardship of forest resource	• New market opportunities and touchpoints • Improved DRR planning (specifically for bushfires)

around policy, environmental protection and livelihoods, as well as the links between these, the market economy activities related to forest resources have become molded. Overall, it was assessed that the project successfully improved the adaptive capacity from ‘poverty trap" to "safety-first" community.

4.2 The Philippines Case

4.2.1 Before the Project Implementation

Considering the knowledge about climate change mitigation and access to funding, the state of the community is at "safety-first" where generic adaptation capacity is moderate at both individual and system levels, and specific adaptation capacity is relatively high. In the short-term, specific adaptation capacity is needed on the use of climate change information both at the individual actor and system level.

4.2.2 After the Project Implementation

The project found that the main factor related to vulnerability is low level of education that limits their ability to seek non-farm employment in towns and cities (Pulhin et al. 2016). Although the project has provided interactive education for non-technical people, it was claimed that there was no significant change in terms of adaptive capacity (Table 5) because the same table was produced at the end of project implementation. It was suggested that the development of insurance systems and the uptake on risk insurance should be introduced to alleviate food security

Table 5 The adaptive capacities before and after the implementation of the project in Philippines case

	Individual actor	System-level
Generic	• Population mobility • Participation in social organizations	• Economic productivity • Information infrastructure • Partnership strategies
Specific	• Climatic information use • Adoption of technologies • Traditional risk mitigation activities	• Risk assessment • Early warning system • Infrastructure investment • Risk mitigation/contingency plans • Disaster compensation/assistance funds • Recovery plans

issues during extreme climatic events in the short-term. In the long-term, climate scenario development and the analysis of positive and negative impact of climate change will help to inform development planning in the region. Additional investments in increasing education levels is required to improve incomes and ability of the community to find alternative employment that is less climate sensitive. Nevertheless, the project succeeded in identifying the impacts of current climate hazards on the local people, identifying their current coping mechanisms and raising their awareness of climate change. Overall, this project did not successfully improve the adaptive capacity of the respective communities, the safety-first condition.

4.3 Timor Leste Case

4.3.1 Before the Project Implementation

The condition of the community is categorized at "poverty trap" because of low capacity in generic and specific. For instance, low education level, lack of government support and social infrastructure are yet established in Aileu. On the other hand, climate change is hastening the decimation of the natural resource base, notably water, agricultural and forest resources.

4.3.2 After the Project Implementation

The project has significantly achieved its goal of increasing community and environmental resilience to climate change effects. The very significant reported decline in the incidence of burning is no doubt influenced by increased government messaging in this area, and in particular local level regulations promoted through tara bandu. A reduction in burning will greatly contribute to climate resilience. At the community level in the project area raising climate change awareness appears to have been effective. There are 76% of respondents claimed to know what climate

Table 6 The adaptive capacities at the beginning of the project in Timor Leste

	Individual actor	System-level
Generic	• Agrarian local knowledge • Tara bandu tradition	
Specific	• Some traditional use of forest resource in desperate times	

Table 7 The adaptive capacities at the end of the project in Timor Leste

	Individual actor	System-level
Generic	• Increased awareness of environmental issues • Improved understanding of prohibitions and rights around sustainable forest management • Decrease in destructive practices (specifically slash and burn)	
Specific	• Engaged in an increased diversity of livelihood activities • Improved community stewardship of forest resource	• Strengthened adherence to forest law (due to tara bandu governance)

change was but perhaps more notable was the rate of awareness on potential climate change impacts on agriculture with up to 84% of those aware of climate change able to describe at least one impact consistent with the general science. There was a reasonably high level of knowledge of suitable measures to mitigate climate change impacts. The improvement made by this project is shown in Table 7 when it is compared with the conditions before the project activity, shown in Table 6. Overall, the project successfully improved the adaptive capacity from "poverty trap" to "safety first" although mostly at individual level.

5 Discussion

A difference was ultimately observed for each project, and moreover differently affected the adaptive capacity of each target community. Herein, we will attempt to explain the interaction of adaptive capacities of each project that influence the outcome and subsequently provide comparative study especially in agriculture and forestry activity.

To further analyze factors that affect the success of each of the projects, this study highlighted the aspects to be evaluated including data availability, the importance of inception and participatory analysis, the education level of the target community, technology and knowledge transfer, policy and government support, and financial measures.

5.1 The Importance of Data Availability and Participatory Analysis

All cases suggest that inception and participatory analysis are significant to ascertain the success of a project (Pulhin et al. 2016; World Vision Mongolia 2015; World Vision Timor Leste 2016; Smit and Walden 2006). Likewise the development projects, data availability is significant in adaptation projects (Patwardhan 2003). For instance, the project proponent in the Philippines did assessment to picture the condition in the targeted areas by interviewing the respective stakeholders prior to assess climate vulnerability and impacts including the adaptation strategies (Pulhin et al. 2016). Understanding that the education of the community is low, then increasing the education level and awareness becomes crucial in the project.

5.2 Education Level, Technology and Knowledge Transfer

All cases imply that sufficient education level of local communities is crucial to assure the outcome of the project. The three cases described the education level of local communities are considerably low and various methods had been conducted to increase the awareness, knowledge and adaptive capacity (Pulhin et al. 2016; World Vision Mongolia 2015; World Vision Timor Leste 2016). However, the cases did not success in providing their adaptation strategies at the end of the projects because of the lack of knowledge and further need of capacity building. This illustrates the importance of education level in determining the pace of project implementation before proceeding to formulating the adaptation strategies. Therefore, an intensive and comprehensive capacity building is necessary as it was implemented intensively in the Philippines case and Mongolia. Focus Group Discussion, visual materials (e.g. book, video) and workshop could be options (Pulhin et al. 2016). In addition, high education level stimulates a good social organization that may contribute significantly on improvement at system-level (Williams et al. 2015). Having adequate education level also accelerates skill and knowledge transfer from one community to another.

According to the project report in the Philippines case, although the improvement is noticeable, it could have been better if the education level is not low (mentioned at the previous section). This implies capacity is necessary to ensure the enhancement of adaptive capacity occurs mutually at both individual and to an extent, at system level. Despite, the Philippines case study provides also a good example of a successful method to increase awareness and knowledge about climate change. As part of this project, the project team endeavored to use various media to increase the capacity at individual level based on familiar local means of communication, for example, all media used local dialect and easily-understood language for non-technical people to describe climate change and the importance of adaptive capacity (Pulhin et al. 2009).

Technology transfer is also considered plays important role in enhancing adaptive capacity of a community. Establishing improved pathways of technology transfer from the level of individual actor to system-level in the case of the Timor Leste project would improve specific capacity at both individual level and governance (system-level). The absence of this aspect, inhibits the enhancement of adaptive capacity as shown in Table 7.

5.3 Policy and Government Support

Policy is regarded as a notable attribute influencing the success of all projects in this study. This is in line with mainstream literature that attests institutional barriers are the most frequently reported barriers to climate change adaptation (Biesbroek et al. 2013; Brooks and Adger 2015). Governments have an important role in this context. They can help by creating an attractive environment for research, development and demonstration (RD&D) and safeguarding the drivers of innovation.

Well-designed targeted technology policies on both the supply and demand sides are a fundamental ingredient in a strategy to accelerate innovation. While the specific combination of policy measures will depend on country circumstances, it is important in all cases to construct the appropriate framework to allow breakthroughs to happen (IEA 2011). First and foremost, local and national responses to climate change need to be well coordinated. This ensures coherence of local and national action, while clearly acknowledging differences in the mandates of cities and national governments. City and sub-national regional leaders are generally best suited to design strategies to address their infrastructure needs, land use, geography, and economic profiles. Together they could work closer together to develop and exchange information about possible policy responses, to experiment with new solutions, to share experience and broaden and replicate successful initiatives especially in dealing with climate change. Mongolia is an illustrative case where inhibitory policy hindered the outcomes of the project. In Mongolia, the inhibitory forest legislation constrained adaptation so that adaptation was only realized at the individual level (Table 4).

Conversely, the case in Timor Leste is an example where amending policy to address the risk of climate change positively impacted adaptive capacity at the system level. This suggests that appropriate policy makes a significant contribution to adaptive capacity at system-level. Referring to Tables 6 and 7, at the beginning of the project, adaptive capacity at system level was absent. After readopting the local law of tara bandu, specific capacity at system-level was strengthened.

Furthermore, the Timor Leste case demonstrated government backing of favorable policy and/or governance contributes to development at both capacities, generic and specific, as well as at individual and system levels. Moreover, a supportive policy can facilitate the involvement of other stakeholders such as NGOs and local development agencies to contribute actively to accelerate project implementation to achieve its goals (Adger et al. 2011). Notably, such support expands the opportunities of partnership. These engagement principles are also suggested in

Timor Leste, where engagement is needed at the system-level to better support the individual actor, for example both in the improvement of forestry and agricultural industry to the development of markets that support sustainable forest management and ecological agriculture (World Vision 2016).

5.4 Financial Measures

Adaptation requires sufficient and sustained funding so that countries can plan for and implement adaptation activities. Indeed, the Intergovernmental Panel on Climate Change (IPCC) identifies economic wealth as a principal determinant of adaptive capacity (IPCC 2001). Central governments, in turn, can set out the broad goals and frameworks to encourage action in the right areas; they can also provide needed funding or other incentives for city initiatives. The costs of adaptation in cities will account for a significant proportion of this average, largely because of the expense required to adapt (or, in the case of many low- and middle-income countries, build new and resilient) infrastructure and services for densely populated areas. UNFCCC estimates that adapting infrastructure worldwide could require US$8–30 billion in 2030, one-third of which would be for low- and middle-income countries (UNFCCC 2007).

Most of the projects-those in Mongolia, Philippines, and Timor Leste, were precluded from being able to fully enhance community adaptive capacity to a sustainable state because of funding availability; e.g. lack of access to financial measures such as insurance, grants, markets or loans. Ultimately, the government plays a crucial role in mobilizing funds towards sustainable development at local, sub-national and national levels.

An example of an integrated financial measure is the Philippines case. When the farmers are impacted by current climate hazards, they are able to seek assistance from lending institutions for purchase of agricultural inputs; local government units for provision of technical and financial assistance, and food subsidies/handouts; commercial plantations to seek additional employment; and local health centers and medicine men for the treatment of flu, colds, coughs and fever. In addition, the development of insurance systems and the uptake of suitable risk insurance in the Philippines, may further alleviate food security issues during extreme climatic events in the short-term.

This measure does not effectively adapt the community to climate risk over the longer term however, nor provide the community with adequate and consistent financial reserve to support future-oriented adaptation activities (funding is aimed at recovering losses and responding to immediate needs). Additional investments to increase education levels would improve incomes and the ability of the community to find alternative employment options that are more advantageous, in accordance with the risk highlighted in climate scenarios. Unfortunately, the delayed release of the project budget hindered the project implementation. This implies that a sustainable and integrated funding is required to properly support projects building resilience to climate change.

In terms of progressing the requirements of sustainable development unmet at the project close, targeted monitoring data and strategies could promote follow-on projects. Funding is a need for all developing countries to develop and implement national adaptation plans and for these to exist at all levels: local, sub-national and national. This was found to be an important to support progress towards and perpetuation of sustainable development across the projects.

6 Conclusion

The analysis performed above identified the following attributes that contribute to improve adaptive capacity: data availability, the importance of inception and participatory analysis, the education level of community target, technology and knowledge transfer, policy and government support, and financial measures. How these attributes may change the generic and specific capacity at individual and system level was discussed.

We conclude from this analysis that the success of a project is contingent on meeting the following steps to ensure the formulation of effective adaptation strategies:

1. Strong scientific data basis for decision making
2. A pre-assessment on the vulnerability of climate change at local context including inception and participatory analysis
3. Education, training and public awareness on adaptation; including the establishment of pathways of technology transfer
4. Funding security
5. Project Evaluation and Monitoring to support follow-on projects in the future.

This study also reveals the complex interaction between project attributes. Notably, the presence of policy and government support is considered to give significant enhancement in generic and specific capacity at individual and system level. Likewise, both the analysis of positive and negative impacts of climate change through climate scenario development and the establishment of apprised pathways of technology transfer, will help informing and sustaining the development planning and innovation in the regions. It is these relationships and their interactions that determine the ultimate outcomes of adaptation activities. By doing so, it will be more likely to be implemented in a way that is effective, efficient and equitable. Furthermore, sustainable development stage is expected to achieve by implementing the suggested strategies above.

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Perceiving, Raising Awareness and Policy Action to Address Pollinator Decline in Nigeria

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Abstract Insect pollinators contribute to agricultural crop yield and beekeeping provides a major source of livelihoods for farmers in Nigeria. This study developed two survey questionnaires and collected data from beekeepers, researchers and government officials to generate quantitative indicators for the purpose of description as a guide to action. Evaluation and characterization of colony bee loses by beekeepers were assessed. The surveys conducted between October 2015 and March 2016 consisted of questions related to: the importance of pollinators, including managed honeybees (*Apis mellifera*), in agriculture and observations on factors associated with pollinator declines; and management of bee mortality. Evaluation and characterization of colony bee loses by beekeepers in Osun State was conducted. Responses were received from 31 beekeepers and 20 policy makers and researchers. 81% of beekeepers reported a reduction in number of colonies. The results inform policy action on pollinator benefits for increasing crop yield and helping smallholder farmers adapt to a decline in insect pollinators. This study emphasizes pollination and insect pollinators as drivers of agricultural crop production with a view to providing guidance for sustainable management of pollinators and achievement of green growth objectives.

Keywords Insect pollinators · Colony bee loses · Bee keepers
Policy makers · Crop yield

1 Introduction

Animal pollination, mainly performed by bees, is an important ecosystem service with almost 90% of flowering plants and 75% of the world's most common crops benefiting from animal flower visitation (Klein et al. 2007; Ollerton et al. 2011).

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As the majority of the world's staple foods are wind- or passively self-pollinated (wheat, corn, rice), or are vegetatively propagated (potatoes), their production does not depend on and increase with animal pollinators (insects, birds, and bats). These crops account for 65% of global food production, leaving as much as 35% depending on pollinating animals (Klein et al. 2007). In Nigeria, crops that require pollination by bees and the crop's natural pollinators include: Mango, Runner beans, Guava, Pear, Cowpea, Tomato, Grape, Onion, Okra, Oil palm and Cashew. Currently, the main conservation strategy at present is to promote pollinators through establishment of protected areas. Pollination is the transfer of pollen from the stamen, or the male component of a flower, to the pistil, or the female part. The pollen grain reaches the ovary via the stigma to fertilize the ovules which produce the seeds and fruit. Several types of vectors may ensure fertilization of a flower: wind, water, and animals, especially insects. There is increasing evidence of a global decline in insect pollinators that threatens the reproductive cycle of many plants and may reduce the quality and quantity of fruit and seeds, many of which are of nutritional and medicinal importance to humans. Identification of appropriate actions is needed, especially given the uncertainty posed by gaps in both scientific knowledge and effective policy interventions. Insect pollinators, comprising both managed (e.g. honeybee *Apis mellifera*) and wild populations (species that exist as non-managed wild populations including wild *Apis* spp.), have become a focus of global scientific, political and media attention because of their apparent decline and the perceived impact of such declines on crop production (Cameron et al. 2011; Kerr et al. 2015). Pollinator declines are a consequence of multiple environmental pressures, e.g. habitat transformation and fragmentation, loss of floral resources, pesticides, pests and diseases, and climate change (Potts et al. 2010; Vanbergen 2013). Similar environmental pressures are faced in Nigeria where there is a high demand for pollination services. The fact that almost half the data on pollinator decline from recent studies comes from only five countries, with only 4% of the data from the continent of Africa (Archer et al. 2014), highlight the lack of information.

Despite the perceptions of global honeybee decline, long-term global data indicate an increase in managed honeybees (Aizen et al. 2008; Aizen and Harder 2009), except in the USA. However, agricultural demand could outstrip supply of managed honeybees (Aizen and Harder 2009) and greater demand for high value fruit and nut crops may further increase demand for pollination services (Gallai et al. 2009; Breeze et al. 2014). This demand implies that pollination services may experience constraints even without a dramatic decline in honeybees and highlights the need for effective strategies to safeguard reliable pollination services for agriculture. Such strategies could include: improved health of managed honeybees; identifying possible substitutes for managed honeybees (Corbet et al. 1991; Potts et al. 2011); increasing and diversifying the suite of wild pollinators where possible (Corbet et al. 1991); and increasing the effectiveness of wild pollinators (Brittain et al. 2013). The latter includes conserving suitable food sources and nesting habitat for wild pollinators within the agricultural matrix and raises the question: 'Is management to secure biodiversity benefits more rewarding for crop production than management less favourable to biodiversity?' If so, then strategies to improve pollination services need to be aligned with strategies to conserve biodiversity in agricultural landscapes (Ghazoul 2013). Another way to examine the likelihood or proximity of a pollination crisis is to examine delivery of pollination services. Although global honey bee stocks have increased by ~45%, demand has risen more than supply, for the fraction of global crops that require animal pollination has tripled over the same time period (Smith et al. 2013), making food production more dependent on pollinators than before. It has also emerged that the majority of crop pollination, at a global scale, is delivered by wild pollinators rather than honey bees. Yields correlate better with wild pollinator's abundance than with abundance of honey bees (Breeze et al. 2011; Garibaldi et al. 2013; Mallinger and Gratton 2014); hence increasing honey bee numbers alone is unlikely to provide a complete solution to the increasing demand for pollination. Reliance on a single species is also a risky strategy (Kearns et al. 1998). While Aizen et al. (2008) concluded from a global analysis of changing crop yields over time that there was not yet any clear evidence that a shortage of pollinators was reducing yield, a subsequent analysis of the same data set by Garibaldi et al. (2011) shows that yields of pollinator-dependent crops are more variable, and have increased less than crops that do not benefit from pollinators, to the extent that a shortage of pollinators is reducing the stability of agricultural food production. In a meta-analysis of 29 studies on diverse crops and contrasting biomes, Garibaldi et al. (2011) found that wild pollinator visitation and yields generally drop with increasing distance from natural areas, suggesting that yields on some farms are already impacted by inadequate pollination.

1.1 Nigeria Agricultural Transformation Agenda

The agricultural transformation agenda of the Federal Ministry of Agriculture and Rural Development is the pillar of Nigeria's current agricultural policy. The Agricultural sector is an important segment of the economy with high potentials for employment generation, food security and poverty reduction. Low productivity in Nigeria over the years has been largely attributed to low fertilizer and improved seed utilization and inadequate government expenditure and the inability to compete with others. The vision in the transformation strategy is to achieve a hunger-free Nigeria through an agricultural sector that drives income growth, accelerates achievement of food and nutritional security, generates employment and transforms Nigeria into a leading player in global food markets to grow wealth for millions of farmers. Transformation action plan for some priority agricultural commodities is focused in the six geopolitical zones of the country. The commodities are rice, cassava, sorghum, cocoa cotton, maize, dairy, beef, leather, poultry, oil palm, fisheries as well as agricultural extension. These are carried out through the value chains of each of the commodities while recognizing roles of the actors/stakeholders along the nodes of the chain, inputs requirements in achieving production targets, constraints faced and expected output. The main target is to grow the agricultural sector through the various commodities and also to generate employment opportunities. Pollination and pollinators as drivers of agricultural crop production yield was not emphasized in the agricultural transformation agenda policy with a view to providing guidance for sustainable management of pollinators.

Objectives:

(a) Assess honey bee colony population abundance in study area.
(b) Identify targeted activities and methods to manage and mitigate changes in pollinator abundance.
(c) Development of best pollinator management strategy.

2 Methods

2.1 Study Area

Osun State is an inland State in South-Western Nigeria with capital is Osogbo. Its situated in the tropical rainforest zone. It covers an area of approximately 14,875 km^2 and lies between latitude 7° 30′N and longitude 4° 30′E. Its boundaries are: Ogun State to the South; Kwara State to the North; Oyo State to the West; and Ekiti and Ondo State to the East. The State was selected due to the beekeeper's being well organized under the Federation of Beekeepers Association in Nigeria (FEBKAN), Osun State branch.

2.2 Data Collection

Evaluation and characterization of colony bee loses by beekeepers in Osun State, Nigeria, using a detailed questionnaire. A survey on insect pollination management was conducted among researchers and policy makers. Information was collected using interviews and two survey questionnaires for beekeepers (Annex 1), policy makers and researchers (Annex 2). The questions used for the beekeeper survey is adapted from the colony loss monitoring questionnaire (Van der Zee et al. 2013) for beekeepers in Osun State. Beekeeper assessments were based on production colony information between October 2014 and September 2015. The survey consisted of 22 major questions with some questions further divided into subparts. Although the majority of questions were intended to generate yes/no responses, several questions were multiple-choice or were open-ended to provide respondents with an opportunity to enter their own responses and supporting references. Thirty one (Kevan 2001) participating beekeepers returned their completed surveys to the author out of a total of thirty five beekeepers indicating 89% response rate. Data were excluded from the loss rate analysis if the essential questions about colony losses were not answered. Where necessary, translation was required in the indigenous language. Participant knowledge, expectations, experience through spoken or written forms were obtained. Transcripts were analyzed to provide salient information, including potential trends in responses. Participants for the pollination management survey included government officials (Corbet et al. 1991), researchers and agricultural scientists (Aizen et al. 2008). After survey results were collected, they were entered into a spread sheet and frequency of response tables calculated.

3 Results and Discussion

Overall, the Nigerian honeybee populations in the study area have not exhibited significant losses (number of dead bees in production colonies), probably because of the relatively unmanaged state of African honeybees and the fact that they are indigenous. However, the fairly recent advent of environmental change (Climate change) globally and in Nigeria suggests that our bees are now more vulnerable and stressed than was previously the case. There is need to ensure that we are tackling all the issues that place pressure on honeybees, because in so doing we will hopefully also ensure the survival of some of the other lesser-known pollinators.

3.1 Beekeeper's Survey

In this study, 31 beekeepers (89% of the total number of beekeepers in Osun State) participated out of a total number of 35 beekeepers. The summary beekeepers response received from respondents is presented in Annex 3.

3.2 Policy Maker's Survey

This study developed a questionnaire and collected information from researchers and government officials to generate policy indicators related to pollination and pollinators for the purpose of description as a guide to action. The summary policy survey response received from respondents is presented in Annex 4 (researchers) and Annex 5 (government officials).

3.3 Beekeeper's Survey Response

In relation to production colonies during a one year period (October 2014–September 2015), beekeepers reported a loss of production colonies without dead bees in the hive. However, only 3% of beekeepers reported loss of production colonies due to queen challenges (queen less or drone-laying queen). 9% of beekeepers reported a reduction in total production colony numbers due to uniting/merging. A majority of beekeepers (48%) that responded were ignorant of the cause of the death of their colonies while others attributed the cause to starvation (3%), poor queens (6%) and disease (6%) and other unknown factors (12%). The beekeepers unanimously agreed that origin of queens were through rearing by their colonies. Most beekeepers did not have to provide a new queen (94%) nor were their colonies treated with a product for disease condition (97%). Most beekeepers (97%) reported that their colonies were neither contracted for pollination services nor moved for honey production. Due to a large proportion of small holder farmers in Osun State, bee movement for crop pollination is not practiced presently. This is in contrast with large-scale agricultural production systems such as almonds, apples, melons and other cucurbits where large fields provide limited edges where wild pollinators may nest (Chagnon 2008). Beekeepers replaced on average, 47% of combs in the majority of production colonies and majority (81%) did not use any supplemental sugar feed while others used honey (19%), Beet sugar (6%) and inverted beet sugar (3%). Colony disturbance reported by beekeepers were mainly by ants, humans (theft), rats and squirrels.

3.4 Honey Bee Colony Population Abundance in Study Area

All beekeepers reported a reduction in production colonies without dead bees in the hive. All local identified stressors—climate change, habitat loss, disease, diets, and pesticides- which were observed not to act in isolation. Inadvertently making bees more susceptible to population inhibiting pressures, and driving honey bee colony losses and declines of managed bees in the study area.

3.5 Researchers and Government Officials Survey Response

Information from researchers and Government officials indicates that population abundance trends in honey bee and other pollinator populations have largely not been documented in Nigeria. A majority of respondents, researchers (75%) and Government officials (83%) were not aware or uncertain of active in-country pollination research on various native and non-native pollinators. This implies that there is an urgent need for special funding for pollination research. A majority of respondents for both researchers and Government official's (75%) were not aware or uncertain on the role of managed bees in pollinating major crops. This implies that there is need to create incentives and increase awareness for farmers to increase crop productivity with managed bees. All respondents (100%) were either not aware or uncertain if honey bee population declines have been documented in Nigeria. This is largely because there have not been large scale studies on honey bee abundance and distribution. There is need for a country wide bee abundance assessment. All respondents (100%) were either not aware or uncertain if other non-honey bee pollinator populations have been documented. Abundance in other non-honey bee pollinator populations has been documented. However, information on non-honey bee pollinator population variations over time is limited. There is need for further studies on non-honey bee pollinators of major crops. When asked if any Ministry has a formal insect pollination policy, a large percentage of the respondents, researchers (87%) and Government officials (92%) were not aware of any policy. An outcome from the survey indicates that there is no formal insect pollination policy by the Ministry of Agriculture. When asked if the Federal Ministry of Agriculture has conducted cross-ministerial work, with any other Ministry, incorporating insect pollination into national policies and programs, a large percentage of respondents, researchers (87%) and Government officials (100%) were not aware or expressed uncertainty. However, a general insect pest control policy is available for crop protection in Nigeria. There is need for incorporating insect pollination and pollinators into national policies and programs.

3.6 Perception of the Importance of Honey Bee Pollination Service by Policy Makers

The perception of policy makers surveyed were very low (75%) as most were not aware or uncertain on the role of managed bees in pollinating major crops. This is attributable to fragmentary information on the benefits of pollinators and pollination services and the need for broad policies to aid their conservation in other to boost crop production.

3.7 Risks to Pollination Decline that Deserve Future Study

Pollination is the transfer of pollen from the stamen, or the male component of a flower, to the pistil, or the female part. The pollen grain reaches the ovary via the stigma to fertilize the ovules which produce the seeds and fruit. A pollinating species is termed "wild" when its habitat is located in a natural environment or an environment with no human interference. A “native pollinator” refers to a species originating in, associated with, and established in a given habitat over a long period. Introduced (managed) pollinators refer to species in which reproduction and survival are controlled by man (Chagnon 2008). Over the past two decades, there has been considerable concern globally over the apparent reduction in populations of pollinators of all kinds. Several research projects, publications and public awareness campaigns have focused on determining the possible causes of decline in introduced pollinator numbers, particularly among honey bees. Some of the causes include.

3.8 Pesticides

Pesticides constitute a major threat to pollinators. It has been known for some time that the use of pesticides to control agricultural pests can have a negative impact on honey bee colonies (Johansen and Mayer 1990). For decades, there have been massive losses in bee colonies wherever agriculture and beekeeping have co-existed. Losses in bee numbers are often the result of poor handling and application procedures for pesticides or else failure to follow the recommendations printed on the label. Even when the instructions are closely followed, the pesticide will inevitably constitute a serious risk for all the pollinators, regardless of whether they are wild or introduced. Pesticides are potentially able to harm a large number of pollinating species and even to eliminate a certain number of populations of species occurring in an ecosystem (Nabhan and Buchmann 1997). The presence and abundance of suitable floral resources in an environment are therefore extremely important factors. A relatively new class of widely used systemic insecticides, the neonicotinoids, is highly toxic to insects, including bees, at very low concentrations. The group includes imidacloprid, thiamethoxam, clothianidine and several other compounds which are widely used to coat seeds. These compounds can be taken up via the roots and then carried by the sap to all parts of the plant as it grows. This ensures protection against root pests but also against insects attacking the aerial portions of the plant. Since they are active until the flowering stage, they can be picked up by pollinators in the pollen and nectar. Pesticide use in Nigeria has been on the increase over the decades (Asogwa and Dongo 2009). It has been estimated that about 125,000–130,000 metric tons of pesticides are applied every year in Nigeria (Ikemefuna 1998). There is currently a Pesticides Registration Regulations arising from the Drugs and Related Products (Act 19 of 1993). It is well established that the improper use of agricultural pesticides negatively affects development of honey bee colonies. Pesticides should be reduced or completely eliminated. Standard guidelines and label instructions should be correctly applied.

3.9 Transgenic Crops (GMOs)

Transgenic plants were developed specifically to reduce some of the undesirable and involuntary effects of pesticides. There are concerns, however, about potential impacts the direct effects of insecticide proteins in the pollen may have on non-targeted species, including some pollinators (Losey et al. 1999). These concerns focus on the lack of information on the lethal threshold of transgenic insecticide proteins and the sublethal effects of the proteins on the physiological and reproductive behavior of the insects feeding on them. Published results suggest that the impacts of transgenic plants on bees should be examined case by case and depend on the portion of the plant that is ingested (Malone and Pham-Delègue 2001). In Nigeria, no method has been developed to assess the impact of genetically modified organisms on pollinators under natural conditions.

3.10 Fragmentation and Habitat Loss

Fragmentation and habitat loss are two types of disruption that have been recognized as important factors in loss of biodiversity on a local as well as global scale. Habitat loss refers to the loss of a natural environment arising from a primary succession, i.e., a natural landscape. Fragmentation of a habitat refers to the break-up of a habitat into fragments that are often too small to ensure the viability of populations of all species. Pollinators and pollination-dependent plants are not protected from this type of disruption (Kevan 2001). In Nigeria, the traditional land tenure system in Nigeria coupled with increasing population encourages land fragmentation with attendant consequences for agricultural productivity and pollinator loss. Beekeepers in Osun State, observed that major challenges include pressures due to reduction in native vegetation area and indiscriminate pesticide use. Land fragmentation has severe consequences for agricultural development; it leads to scattering of plots, little incentive for improvements, lack of security of tenure, restricted scale of operations (Idowu and Oladebo 1999). In spite of these associated costs, land fragmentation is still persistent and wide spread in Nigerian agricultural practice. Land fragmentation practices not only reduce natural and semi-natural habitats, they also cause loss of diversity among cultivated plants, further impoverishing the range of floral resources available to the natural pollinators in the area. Habitat fragmentation and loss affect pollinators in two ways. First, they reduce the availability of the range of plants capable of meeting all food needs throughout a season (Kearns and Inouye 1997). Loss of access to resources could increase competition among local species for the limited resources. Secondly, habitat loss could also disrupt nesting among a number of bee species that dig their nests in burrows.

3.11 Climate Change

According to some specialists, behavioral changes linked to the species' physiology have already been observed in some pollinators. Over the past two decades, British butterflies have made their first appearance of the season earlier and earlier and the peak period has also been brought forward. Similar changes have also been observed in California's butterflies (Forister and Shapiro 2003). The average period for the first flight of 16 species studied tended to occur earlier. An average difference of 24 days for four of them represented a statistically significant trend. On the other hand, seven species tended to appear later in the season. Different species of pollinators are consequently going to react differently to climate change, which will affect the diversity and abundance of their populations in varying degrees. In terms of physiology, some factors like the photoperiod and temperature exert a control on endocrine activity and can modify fertility, the mode and rate of reproduction as well as the rate of development. These physiological reactions may differ from one species to the next. The underlying causes for changes within a pollinator community are therefore highly variable. Climate change and variability from 1961 to 2010 and projections up to 2050 and its impacts on the oil palm leaf miner—*Coelaenomenodera elaeidis* in Edo State, Nigeria has been evaluated (Aneni et al. 2015). Currently, honey bee farmers in Nigeria, have observed low yield and the crystallized honey combs in their hives (Centre for Bee Research and Development (CEBRAD) 2016) which has been attributed to increased rainfall intensity (scarcity period for honey bee activity) (Oyerinde et al. 2014). Information gathered from this study indicates that there are limited published studies on pollinators and climate change interaction in Nigeria. However, it can largely be deduced from other insect studies that climate change would have an impact on insect pollinators in Nigeria.

4 Conclusion

4.1 Recommendations and Proposed Actions

The clear message of this study is that pollination is a key factor in agricultural productivity and pollinators are essential in providing this service. Fears over pollinators and pollination services continue to build up in the scientific and public space. Therefore, there is the need to enhance local data for understanding the status and trends of pollinators to sustainably manage pollination services. All stakeholders need to ensure that pollination is well understood as a key limiting factor in agricultural productivity and that steps are taken to manage it in sustainable ways that maintain populations of pollinators and their habitats.

4.2 Pollinator Gap Analysis

There is mismatch between government and local understanding of the problem of pollination service loss and governance priorities. This points out that while larger institutions can form the pillar for wider activities, practical measures need to be adapted to facilitate rather than hinder local farmers. The insect pollination gap analysis highlighting strengths and challenges in Nigeria is presented Table 1.

4.3 Pollinator Management

Pollinator management practices have been identified, to conserve and manage pollinator populations. These practices not only benefit pollination ecosystem services, but contribute to crop diversity (biodiversity), soil health and reduced pesticide use. They include.

4.3.1 Reduced Pesticide Usage

Pest control practices such as Integrated Pest Management that enhances natural pest controls reduce or eliminate the use of pesticides. At the same time, this greatly benefits pollinators which may be heavily impacted by pesticides.

Table 1 Strengths and challenges in the management of insect pollination in Nigeria

Factors	Strengths	Challenges
Insect pollinators of major crops	Insect pollinators of major crops identified	Inadequate capacity for appropriate management of the pollinators
Potential drivers of pollinator decline	Potential drivers of pollinator decline defined	Limited knowledge on drivers of pollinator decline
Policy on pollinator management	Progress in the development of national policies on agriculture	Pollinators not taken into account in existing national policies
Coordination, collaboration and partnership	Formal and informal structures for collaboration of relevant sectors exist	Lack of mechanisms for coordination and collaboration among relevant sectors
Human resource capacity on pollinator management	National training institutions available	Inadequate human resource for pollinator management
Surveillance capacity for pollinators	Relevant government institutions available	Surveillance systems for pollinator monitoring generally absent
Laboratory capacity for testing pollinator pesticide lethal and sub-lethal levels	Reference laboratories that deal with most chemicals identified as being of major public concern to pollinators available	Inadequate laboratory equipment and essential reagents

4.3.2 Maintaining Hedgerows and Floral Diversity

Hedgerows provide habitat and forage resources for bees, and by diversifying the floral resources, insect pollinators are encouraged to remain on-site even in the following year. This also contributes to biodiversity conservation.

4.4 Proposed Actions

(a) Pollinators of major crops in Nigeria

- Develop regulations, guidelines and tools for the safe management of insect pollinators

(b) Legislation and policy

- Develop comprehensive policies for an integrated approach to insect pollinators management using a life-cycle approach

(c) Coordination, collaboration and partnership

- Implement inter-sectoral coordination mechanisms for the safe management of insect pollinators
- National multi-sectoral task forces that deal with issues related to crops and the environment to include insect pollinators on their agenda

(d) Human resource capacity

- Develop training packages on pollinators that can be used to upgrade the capacity and capability of farmers

(e) Surveillance capacity

- Enhance surveillance capacity for monitoring insect pollinators that could have impact on agricultural production
- Foster inter-sectoral collaboration in the sharing of information and surveillance data

(f) Laboratory capacity

- Develop at the minimum capability for laboratory analysis of lethal and sub-lethal pesticide levels in insect pollinators.

Further scientific research is needed to inform policy decisions that are underpinned by sound scientific basis. These include:

1. Quantifying the abundance of pollinators in Nigeria and the risks associated with the loss of pollination services.
2. Determine the economic value of pollinators for key crops.

3. Establish the conservation status of insect pollinators.
4. Investigate the drivers of pollinator loss.
5. Investigate honeybee forage resources under global change scenarios (land use change or climate change).
6. Detailed research on threats to honeybees in Nigeria.
7. Research alternative species of pollinators (other than the honeybee) for potential managed pollination.
8. More standardized monitoring and documentation of the occurrence and abundance of pollinators are needed to enable comprehensive assessment of pollinator trends.
9. Developing excellence in pollinator taxonomy.
12. Identification of native pollinators for agricultural production.
11. Studying plant-pollinator relationships.
12. Protecting foraging sites and restoring degraded habitats.
13. Studies of pesticide impact and pathogens of wild insect pollinators.
14. Using the honey bee as a bio-indicator.

4.5 Priority Actions

The Sustainable Development Goals recognizes that biodiversity and ecosystem services can play a role in poverty alleviation, and the need to integrate ecosystem services such as pollination into food production. Priority actions include:

– Dissemination of this report to all relevant stakeholders.
– In-depth on-site evaluation of pollinator numbers and diversity in selected states based on the findings of this report.
– Elaboration of a country 2017–2020 strategy for management of pollinators to address the issues and challenges identified in this report.
– Development where and as necessary on the capacities required for pollinator management.
– Development of a comprehensive training package for public agricultural professionals on pollinator management, working in close collaboration with relevant stakeholders.
– Provision of technical support to research institutions for the implementation, monitoring and evaluation of the 2017–2020 country strategy after it is developed.

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Annex 1: Essential Beekeeper Information and Mortality Quantification

Respondent Information: *Please fill out this Sect.*

1. How many production colonies did you have on October 1st 2014?
   In the next questions you are asked for numbers of colonies lost. Please consider a colony as lost if it is dead, or reduced to a few hundred bees, or alive but with unsolvable queen problems
2. How many of your production colonies were lost between October 1st 2014 and September 30th 2015
3. How many of your production colonies were lost between October 1st 2014 and September 30th 2015 without dead bees in the hive or in the apiary (bee yard)?
4. How many of the production colonies were lost between October 1st 2014 and September 30th 2015 because of queen problems (queenless or drone-laying queen)?
   Please answer the next 2 questions only if you bought, sold, united or split colonies between October 1st 2014 and September 30th 2015
5. Between October 1st 2014 and September 30th 2015;
   What was the reduction in total production colony numbers due to uniting/merging?*
   *eg two colonies united/merged together = loss of one colony
6. How many production colonies did you have on September 30th 2015?
   Identification of Possible Risk Factors (If any)
   In the next question, please TICK the alternatives that best answers your situation (you may tick more than one)
7. To what do you attribute the major cause of the death colonies in your operation (If observed)?
   Don't know…..
   Starvation……..
   oor queens…..
   Disease…………
   Others…………..
   The next question is about the origin of your queens. Please choose the items which describe your situation (you may tick more than one box).
8. What is the origin of your queens?
   (a) Reared by the colony it self
   (b) Reared from one of your own selected queens
   (c) Acquired from a queen breeder
   (d) Acquired for a queen breeder outside Nigeria
   The next question is about queen problems, please don't include normal requeening (e.g. when the queen is old) in your answer.

9. In how many of your colonies did you have to provide a new queen because of queen problems last year?
10. In what months and year have you treated your colonies with a product for disease condition during the period October 2014–September 2015?
11. How many of your colonies were contracted for pollination services last year?
12. How many of your colonies were moved for honey production last year? Please choose the honey flow sources in the next question, which best describe your situation
13. What percentage of combs did you replace in the majority of your production colonies last year?
14. If you gave your colonies a supplemental sugar feed last year, what product was used

    (a) Honey
    (b) Beet Sugar
    (c) Inverted Beet Sugar Syrup
    (d) High Fructose Corn Syrup (HFCS)
    (e) Other product, namely

15. Have your colonies suffered any disturbance by

    (a) Mice/rats
    (b) Ants
    (c) Squirrels
    (d) Humans (vandalism, robbery)
    (e) Other

Annex 2: Insect Pollination Management Survey

Respondent Information: *Please fill out this section.*
Name:
Phone number:
Email address:
Age: <21 21–30 31–40 41–50 >50
Gender:

1. Are you aware of research that has been conducted on the relative proportions of crops
   pollinated by various native and non-native pollinators?
   ___Yes ___No ___Uncertain
   If yes, please provide a reference.
2. Do managed bees pollinate major crops in Nigeria?
   ___Yes ___No ___Uncertain
   If yes, please list if known

3. Have declines in honey bee populations been documented in Nigeria?
   ___Yes ___No ___Uncertain
   If yes, please provide a reference.
4. Have declines in other pollinator (non-honey bee) populations been documented in Nigeria?
   _ __Yes ___No ___Uncertain
   If yes, please provide a reference for the study or survey.
5. Please describe your expertise
   ___Agricultural policy
   ___scientist
   ___research
   ___Other (*please specify*)____
   ____

   Insect pollination in National-Level Policies and Programmes
6. To the extent of your knowledge, which, if any, Ministries have a formal insect pollination policy, or include insect pollination considerations within their national-level policies and/or programmes?

Ministry	Yes	No	Unsure
Agriculture			
Water Resources			
Environment			
Science and Technology			
Lands and Housing			
Education			
Other			
Other			

   Please provide any further information: ___________________________________
   ____

7. To the extent of your knowledge, Has the Federal Ministry of Agriculture conducted cross-ministerial work, with any other Ministry, incorporating insect pollination into national policies and programs?
   Yes________No________Unsure________
   If yes, with which Ministry or Ministries? ____________________________
   ____
   Please provide any further information: _________________________________
   ____
   ____
   ____
   ____
   ____

Do you have a colleague whom the bearer should contact for this survey? Please provide their information below.

Name: ____

Position: ____

Contact Information: ____

Thank you for taking time to complete this questionnaire. The information will help prioritize research efforts on topics of benefit for insect pollination, beekeepers and agricultural productivity.

Annex 3: Summary Bee Keeper's Response B

A	B														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	2670	0	0	0	0	–	–	A	75	0	0	0	25%	ABE	ABD
2	20	0	0	0	15	20	–	A	0	0	0	0	–	A	AB
3	12	4	4	–	–	8	–	A	0	0	0	0	–	0	ABD
4	10	3	3	–	–	7	A	A	0	0	0	0	–	0	AD
5	14	4	4	–	–	10	A	A	0	0	0	0	–	0	B
6	44	4	4	–	–	40	A	A	0	0	0	0	–	0	B
7	5	1	0	–	–	–	E	A	0	0	0	0	–	0	AB
8	12	4	4	–	–	8	E	A	0	0	0	0	–	0	D
9	15	3	3	–	–	12	A	A	0	0	0	0	60%	0	AD
10	24	5	2	0	0	20	BCDE	A	0	0	0	0	2%	AC	AD
11	40	10	5	–	–	30	A	A	0	0	0	0	–	A	D
12	4	1	1	–	–	3	A	A	0	0	0	0	–	0	D
13	27	8	4	–	–	27	–	A	0	0	0	0	–	0	D
14	82	6	2	–	46	82	E	A	0	0	0	0	–	0	BD
15	14	6	4	–	–	8	A	A	0	0	0	0	–	0	D
16	9	2	2	–	–	7	A	–	0	0	0	0	55%	0	B
17	15	6	6	–	–	9	A	A	0	0	0	0	55%	0	AB
18	18	18	17	–	–	1	–	A	0	0	0	0	–	0	D
19	20	2	2	–	–	18	A	A	0	0	0	0	60%	0	D
20	300	5	10	–	55	210	D	A	5	June & July	8	150	–	A	ABD
21	40	–	–	–	–	–	A	A	0	0	0	0	–	0	AB
22	10	–	–	–	–	10	–	A	0	0	0	0	60%	0	B
23	22	–	–	–	–	20	–	A	0	0	0	0	–	A	AE
24	100	–	–	–	–	100	A	A & B	0	0	0	0	–	B	BC
25	20	3	–	1	0	–	C	A	0	0	0	0	–	0	BC
26	43	15	15	–	–	28	A	A	0	0	0	0	–	0	B

(continued)

(continued)

A	B														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
27	5	1	1	–	–	–	A	A	0	0	0	0	55%	0	B
28	35	10	10	–	–	25	A	A	0	0	0	0	–	0	B
29	30	10	10	–	–	20	–	A	0	0	0	0	–	0	E
30	17	2	2	–	–	15	A	A	0	0	0	0	–	0	B
31	53	9	9	–	–	44	–	A	0	0	0	0	–	0	ABC

A - Respondents
B - Response to questions (Annex 1)

Annex 4: Summary Response for Researchers

Questions	Yes	No	Uncertain
Are you aware of research that has been conducted on the relative proportions of crops pollinated by various native and non-native pollinators?	2	2	4
Do managed bees pollinate major crops in Nigeria?	2	2	4
Have declines in honey bee populations been documented in Nigeria?	0	1	7
Have declines in other pollinator (non-honey bee) populations been documented in Nigeria?	0	1	7
To the extent of your knowledge, which, if any, Ministries have a formal insect pollination policy, or include insect pollination considerations within their national-level policies and/or programmes?	1	3	4
To the extent of your knowledge, Has the Federal Ministry of Agriculture conducted cross-ministerial work, with any other Ministry, incorporating insect pollination into national policies and programs?	0	2	5

Annex 5: Summary Response for Government Officials

Questions	Yes	No	Uncertain
Are you aware of research that has been conducted on the relative proportions of crops pollinated by various native and non-native pollinators?	2	4	6
Do managed bees pollinate major crops in Nigeria?	3	2	7
Have declines in honey bee populations been documented in Nigeria?	0	2	10

(continued)

(continued)

Questions	Yes	No	Uncertain
Have declines in other pollinator (non-honey bee) populations been documented in Nigeria?	0	3	9
To the extent of your knowledge, which, if any, Ministries have a formal insect pollination policy, or include insect pollination considerations within their national-level policies and/or programmes?	1	7	4
To the extent of your knowledge, Has the Federal Ministry of Agriculture conducted cross-ministerial work, with any other Ministry, incorporating insect pollination into national policies and programs?	0	5	7

Glossary

Beekeeping
The husbandry of bees, especially honeybees (the genus Apis) but can be applied to other bees.

Biodiversity
Short for "Biological diversity" which is the variety of life on Earth. The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part; this includes diversity within species, between species and of ecosystems.

Diversity
The condition of having or comprising differing elements or qualities (peoples, organisms, methodologies, organizations, viewpoints, etc.).

Drivers, direct
Drivers (both natural and anthropogenic) that operate directly on nature (sometimes also called pressures).

Drivers, indirect
Drivers, that operates by altering the level or rate of change of one or more direct drivers.

Drivers, institutions and governance and other indirect
The way in which societies organize themselves. They are the underlying causes of environmental change that are external (exogenous) to the ecosystem in question.

Drivers, natural direct
Direct drivers that are not the result of human activities and are beyond human control.

Economic value
A measure of the benefit provided by a good or service to an economic agent (e.g. buyer or seller). It is not necessarily the same as market value. It is generally measured by units of currency, and can be interpreted to mean the maximum amount of money a specific actor is willing and able to accept or pay for the good or service.

Ecosystem
A community of living organisms (plants, animals, fungi and microbes) in conjunction with the nonliving components of their environment (such as energy, air, water and mineral soil), all interact as a system.
Ecosystem services
A service that is provided by an ecosystem as an intrinsic property of its functionality (e.g. pollination, nutrient cycling, Nitrogen fixation, fruit and seed dispersal). The benefits (and occasionally disbenefits) that people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as flood and disease control; and cultural services such as recreation and sense of place. In the original definition of the Millennium Ecosystem Assessment the concept of "ecosystem goods and services" is synonymous with ecosystem services. Other approaches distinguish "final ecosystem services" that directly deliver welfare gains and/or losses to people through goods from this general term that includes the whole pathway from ecological processes through to final ecosystem services, goods and values to humans.
Farm
An area of land, a holding of any size from a small plot or garden (fractions of a hectare) to several thousand hectares, that is devoted primarily to agriculture or an area of water that is devoted primarily to aquaculture, to produce food, fibre, or fuel. A farm may be owned and operated by an individual, family, community, corporation or a company, may produce one to many types of produce.
Field
In agriculture, it is a defined area of cleared enclosed land used for cultivation or pasture.
Flowering plant
Plants that are characterized by producing flowers, even if inconspicuous. They are collectively called angiosperms and include most plants grown for food and fibre.
Food Security
The World Food Summit of 1996 defined food security as existing "when all people at all times have access to sufficient, safe, nutritious food to maintain a healthy and active life".
Global
Pertaining to the whole world.
Governance
All processes of governing, whether undertaken by a government, market or network, whether over a family, tribe, formal or informal organization or territory and whether through laws, norms, power or language. It relates to the processes of interaction and decision-making among the actors involved in a collective problem that lead to the creation, reinforcement, or reproduction of social norms and institutions.
Habitat fragmentation
A general term describing the set of processes by which habitat loss results in the division of continuous habitats into a greater number of smaller patches of lesser

total and isolated from each other by a matrix of dissimilar habitats. Habitat fragmentation may occur through natural processes (e.g. forest and grassland fires, flooding) and through human activities (forestry, agriculture, urbanization).

Insecticide

A substance that kills insects. Insecticides may be synthetic chemicals, natural chemicals, or biological agents.

Introduced pollinator

A pollinator species living outside its native distributional range.

Invasive species

A species, that once it has been introduced outside its native distributional range, has a tendency to spread over space without direct human assistance.

IPM (integrated pest management)

It is a broadly based approach that integrates various practices for economic control of pests (q.v.). IPM aims to suppress pest populations below the economic injury level (EIL) (i.e. to below the level that the costs of further control outweigh the benefits derived). It involves careful consideration of all available pest control techniques and then integration of appropriate measures to discourage development of pest populations while keeping pesticides and other interventions to economically justifiable levels with minimal risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms.

Mitigation

Lessening the force or intensity of something that can result in disbenefits.

National

Pertaining to a nation state or people who define themselves as a nation. A nation can be thought of as a large number of people associated with a particular territory and who are sufficiently conscious of their unity to seek or to possess a government peculiarly its own.

Native pollinator

A pollinator species living in an area where it evolved, or dispersed without human intervention.

Parasite

An organism that lives on or within another organism of a different species (the host) from which it obtains nourishment and to which it causes harm.

Pest

An animal, plant, fungus, or other organism that thrives in places where it is not wanted by people, e.g. in fields, with livestock, in forests, gardens, etc.

Pollination

The transfer of pollen from an anther to a stigma. Pollination may occur within flowers of the same plant, between flowers of the same plant, or between flowers of different plants (or combinations thereof). Although pollination is a precursor to plant sexual reproduction, it does not assure same.

Pollinator
An agent that transports pollen. Such agents may be animals of many kinds or physical (wind or water), or both.
Pollinator decline
Decrease in abundance or diversity, or both, of pollinators.
Uncertainty
Any situation in which the current state of knowledge is such that (1) the order or nature of things is unknown, (2) the consequences, extent, or magnitude of circumstances, conditions, or events is unpredictable, and (3) credible probabilities to possible outcomes cannot be assigned.

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Promoting Circular Economy Through Sustainable Agriculture in Hidalgo: Recycling of Agro-Industrial Waste for Production of High Nutritional Native Mushrooms

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Abstract The effect of climate change on agriculture and its implications on food security are demanding topics. It is crucial to convert the existing methods of food production into a more sustainable, resilient and productive agriculture. Reduction of food loss and waste will improve the efficiency of the food system, and simultaneously it will reduce the pressure put on natural resources and diminish the greenhouse gases emissions. This project aims to assess the potential use of agribusiness waste as a substrate for cultivation of *Pleurotus* spp., in order to contribute to the development of a more sustainable agriculture practices while promoting local development. The principles of Circular Economy are being applied to the most representative lignocellulosic waste of the Hidalgo State: pecan nutshell (PS), agave bagasse (AB), pine needles (PN), tamal leaves (TL) and coffee pulp (CP). It was studied the potential of these wasted plant material as substrates to grow mushrooms, of ten native *Pleurotus* spp. strains, with high nutritional value (seven *Pleurotus ostreatus* strains, one *Pleurotus eryngii* strain, one *Pleurotus*

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djamor strain and one *Pleurotus opuntiae* strain). In order to evaluate the different waste usefulness in mushroom's growth, radial growth rate of the ten strains was assessed. Generally, the agave bagasse substrate promoted the highest growth rate. All *Pleurotus* spp. strains had slowest growth in control medium, PDA, due to the lack of lignocellulosic compounds.

Keywords Agro-industrial waste · Circular economy · *Pleurotus* spp Sustainable agriculture

1 Introduction

Food security, sustainable development and poverty eradication are goals largely threatened by climate change, a global situation chiefly caused by the greenhouse gas emissions produced by human activities (FAO 2017). On the other hand, climate change is responsible for changes in function and composition of ecosystems, including agroecosystems. Consequently, agricultural practices have also been adapted to conditions resulted from climate change, seeking for alternatives for sufficient food production (FAO 2017).

It is expected that by 2050, the global population will be 50% larger than at present. Hence, to achieve the desired global political and social stability, further increases in agricultural yields are essential. Nevertheless, those yield increases are often based on the simplification of agroecosystems caused by the intensification of agricultural practices, which may affect important ecosystem functions via the loss of biodiversity. For example plant growth, pest control, pollination and decomposition processes. Together with global climate change and over-population, new challenging targets and refreshing prospects are expected from industrial and environmental biotechnology, in terms of impact, mitigation and adaptation strategies. The impacts of such environmental and societal pressures reflect on agriculture, land-use and water supply and, consequently, on the availability of food, energy and fresh water. Adaptation strategies may rely on the exploitation of alternative food products. Contributions to mitigation of the stressors can arise in the form of new or improved biomass conversion and renewable energies, carbon and greenhouse gas sequestration measures, and more effective waste management options (Orgiazzi et al. 2016).

Agribusiness activities produce tons of waste that can be valued by assigning them to other purposes; those byproducts can be used to produce other products with social, economic, or environmental value (Saval 2012). In fact, the use of natural resources should cause the least possible environmental impacts. To minimize those impacts, waste must not be immediately considered as waste, but as a potential source of essential environmental services (Smil 1999; Santana-Méridas et al. 2012).

Sustainability as a concept integrates social development, economic growth and environmental care (Roseland 2000). Considering this point of view, environmental care must provide knowledge regarding species interaction.

The United Nations Environment Programme (UNEP 1995) estimated that low-income countries burn approximately 25% of all waste. Considerable amounts of unused lignocellulosic by–products are available in tropical and subtropical areas. These by–products are left to rot in the field or incinerated. Nevertheless, their use as nutrient essential sources for fungal (e.g. *Pleurotus* genus) biomass growing, a bioconversion process, offers an opportunity to contribute to circular economy (Akyuz and Kirbag 2009; Madigan et al 1997). In fact, mushroom cultivation using locally available technologies may be a solution to convert these inedible wastes into a highly valued edible biomass (Tesfaw et al. 2015).

Annually, Mexico produces nearly 3,901,146.63 ton of lignocellulosic matter. Every kilogram of burned lignocellulosic matter releases 2 kg of carbon dioxide (CO_2). This gas, among many other greenhouse gases, is responsible for most of the impact on Earth's climate (Chauhan et al. 2005). It is known that carbon dioxide is the most potent switch controlling the greenhouse effect, and that CO_2 abundance determines the amount of water vapor in the atmosphere, making it responsible for more than 60% of the greenhouse effect.

Diverse Mexican industries (e.g. production of coffee, tequila, pecan nut, and woodcutting) produce ton of lignocellulosic by-products. Most of them are discarded or burned, generating carbon dioxide and nitrous oxide emissions, both substances contributing to greenhouse effect.

In order to avoid those source of greenhouse gases emissions, some strategies were proposed to break the chain of linear economy and start implementing circular economy systems, based on optimization of stocks and the flow of materials, energy and waste, in order to use resources more efficiently (MacArthur 2013; Bicket et al. 2014).

2 Pecan Nutshell (*Carya Illinoinensis*)

Mexico is the second world producer of pecan nut, generating over 79,000 ton (Camacho 2012). In 2012, the State of Hidalgo produced 2,751.05 ton of nuts, of which 97.9% was pecan nut (Fig. 1). In 2014, production increased to 2,929.92 ton (SIAP, 2014). Current practices exploit only ~50% of the product's weight, the other ~50% is nutshell (Frusso 2007), reaching 1,346.63 ton in 2012. This kind of by–product is usually wasted, harming the environment. For example, in the municipality of Atotonilco el Grande, nutshell is discarded with trash, disposed over public grounds, hindering the growth of local vegetation (Fig. 2), or burned, releasing two kilograms of CO_2 for each kilogram of lignocellulosic matter. Nevertheless, this waste has bioactive products such as poly and monomeric phenols and its potential as biofungicide was already mentioned (Santana-Méridas et al. 2012).

Fig. 1 A vending stall for pecan nut in Tula de Allende, Hidalgo, Mexico

3 Agave Bagasse (*Agave Tequilana* Weber)

Blue agave, *Agave tequilana*, is widely cultivated through Mexico for tequila production, a traditional a spirituous drink, made from the plant's "heart". Yearly, 100,000 ton of agave bagasse (Fig. 3), a type of lignocellulosic waste, was generated during tequila production, which was mostly used as compost (Abreu-Sherrer 2013; Saucedo-Luna et al. 2010). This type of bagasse contains cellulose, hemicellulose and lignin at 65, 5.5 and 17%, respectively (Quintana-Vega, 2014). Approximately 232,000 ton of agave was processed in 2016, providing a total of 93,000 ton of bagasse (El informador, 2016).

*3.1 Pine Needles (*Pinus Pseudostrobus*)*

Pine needles are scarcely used for craftsmanship (Fig. 4). In the forest, pine needles take a long time to decompose, prevent the sun to reach ground plants, increase soil acidity, and are highly inflammable, representing an important fire threat (Córdova-Ordóñez 2009). There are big volumes of pine needles in the forests in the State of Hidalgo, without any law or rule currently controlling its management.

Fig. 2 Pecan nutshell discarded in Atotonilco el Grande, Hidalgo, Mexico

3.2 Tamale Leaves

For Mexicans, maize (or corn) is an important part of daily life, ubiquitous in traditions and cultural roots. One of the most important crops in the country, maize is also integrated into Mexican identity. Even nowadays, despite one third of the production is being exported due to internal economy, maize harvesting is still a cultural symbol in rural communities, since food security relies on it. In 2014, Mexico reached the sixth place in global production of corn, with 23,273,256.54 ton (SIAP 2014), from which 70,000 ton were corn husk, also known as "totomoxtle" (Fig. 5). A minimal amount of this waste is used for construction, ornamental, or gastronomic purposes. Regarding cuisine, corn husks are used for

Fig. 3 Residual fiber, commonly known as bagasse, after agave juice extraction, Rudio Distiller, Jalisco, Mexico

Fig. 4 Pine needle residues accumulated near a residential hill in Tulancingo, Hidalgo, Mexico

wrapping tamales, a traditional dish. However, once consumed, the tamale leaf, is discarded once again. The tamale leaves contains 78.86% cellulose (Prado–Martínez 2012).

Fig. 5 Tamale leaves (corn husks) discarded in a dumpster at Tulancingo, Hidalgo, Mexico

3.3 Coffee Pulp

Coffee pulp is a by-product of the production of coffee beans (Fig. 6). Pulp represents approximately 40% of the weight in coffee cherries (Olivares et al. 1990). During 2016–2017 México produced 9,342,000 ton of coffee, also generating 3,736,800 ton of pulp. Coffee pulp contains 63% cellulose, 2.3% hemicellulose, and

Fig. 6 Coffee pulp piled at the countryside, Hidalgo, Mexico

17.5% lignin (Murthy and Naidu, 2012). Furthermore, coffee pulp has bioactive compounds as caffeine and chlorogenic acid, having also been pointed out its allelopathic characteristics (Santana-Méridas et al. 2012).

The main goal of this work was to evaluate the potential use of the most representative lignocellulosic waste of the Hidalgo State (pecan nutshell, agave bagasse, pine needles, tamal leaves, and coffee pulp) as substrates for cultivation of ten native strains of *Pleurotus* spp. with high nutritional value, in order to contribute to a more sustainable agriculture and promote local development applying the Circular Economy principles.

4 Materials and Methods

4.1 Pleurotus *Strains Propagation and Storage*

The ten native *Pleurotus* strains (seven strains of *Pleurotus ostreatus*, one of *Pleurotus eryngii,* one of *Pleurotus djamor* and one of *Pleurotus opuntiae*) used in this study were obtained from the Instituto de Ciencias Básicas e Ingeniería (ICBI) of Universidad Autónoma del Estado de Hidalgo (UAEH) collection. Mycelium from each strain was inoculated in Petri dishes with potato dextrose agar (PDA) culture medium for propagation and storage. Firstly, culture media was prepared and sterilized in Erlenmeyer flasks for 15 min, at 15 lb/in^2 and 121 °C, in an autoclave. After being distributed through Petri dishes, PDA was inoculated with fungi strain samples, and Petri dishes were incubated at 21 ± 2 °C, for 21 days before being used. Each used strain was also stored in Petri dishes, at 4 °C.

4.2 Lignocellulosic Waste Selection and Preparation to Be Used as Pleurotus *Strains Growth Substrate*

The waste selection criteria to be used as substrate for mushroom growth were based on those previously pointed out by Saval (2012). The main waste component: (a) should be usable as solid state fermentation (SSF) substrate for saprophytic mushrooms grow; (b) should have local and sufficient availability; (c) should not have other applications or uses competing with the intended process; (d) should not require extra treatment to be use or, if necessary, should be simple and cheap.

Based on these criteria the selected waste studied as potential mushroom growth substrate were: pecan nutshell (PS), *Agave tequilana* bagasse (AB), *Pinus pseudostrobus* needle (PN), tamale leaf (TL), and coffee pulp (CP).

Pecan nutshells were kindly provided by a nut processing company from the region of the Biosphere Reservation "Barranca de metztitlán"; *Agave tequilana* bagasse was provided by a company from Tequila, Jalisco; *Pinus pseudostrobus* needles were collected from the ICAp garden in Tulancingo; tamale leaves were offered by the ICAp cafeteria in Tulancingo. Coffee pulp was provided by coffee producers from Huejutla de Reyes, Hidalgo.

Before being used in growth mushroom experiments, these waste were firstly pulverized, using a manual mill and then sieved through a 35 mesh.

4.3 Evaluation of Lignocellulosic Waste as Pleurotus *Spp. Strains Growth Substrates*

To study the potential cultivation use of the five previously referred most Hidalgo State, representative lignocellulosic waste as substrates for ten native *Pleurotus* spp. strains, it was used the following described methodology.

For each individual waste (treatment), firstly, 25 g of waste prepared as substrate (as described above) were added for each liter of prepared PDA growth medium. PDA medium without any added waste was used as control.

Ten groups of Petri dishes for each of the five waste prepared culture growth media and control were separated and labeled for each of the 10 *Pleurotus* strains: six *P. ostreatus* strains, labeled as PL10, Leb, Gris, B2, BPR2 and P07; one *Pleurotus* sp. strain native of the Tlanchinol region, labeled as PT; one *P. eryngii* strain, labeled as PE; one *P. opuntiae* strain, labeled as PM1; and *P. djamor* labeled as SMR.

The center of each Petri dish was inoculated with a micelial area of 1 mm^2. Then, three straight lines (A, B, C) were drawn, at 60°, intersecting at the inoculation center (Imtiaj et al. 2009). Petri dishes were incubated at 25 °C, in absolute darkness. Radial mycelium growth rate on solid media was measured daily, for 21 days. Growth was measured as the mean of mycelium extension over lines A, B, C (Fig. 7). Growth rate was measured over a distance of 80 mm covered by

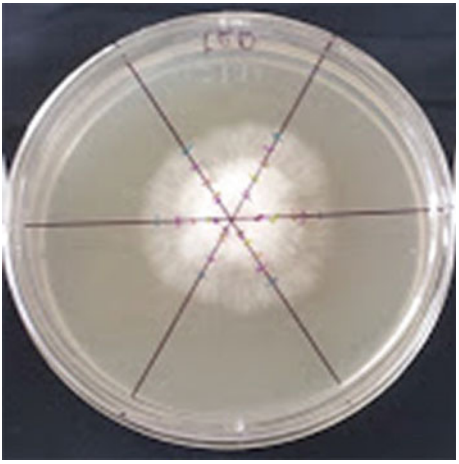

Fig. 7 Petri dish prepared for mycelium growth measurement

mycelia, divided by mean days of invasion. Five replicates were made for each treatment and control.

4.4 Data Analysis

First, the assumptions of independence, normality and homoscedasticity were tested for the studied variables. Secondly, given that the data structure comply with normality criteria, ANOVA was used to evaluate a mycelial growth rate, which were represented in terms of mean ± standard error of the realized tests. Significant differences between formulations were determined by paired student-t test (LSD) with $\alpha = 0.05$.

5 Results and Discussion

5.1 *Evaluation of Lignocellulosic Waste* as Pleurotus *Spp. Strains Growth Substrates*

A general view of the experiment can be seen in Fig. 8.

The growth rate for every combination of strains in each waste substrate is analyzed. It is evident that the best result was obtained in the medium with AB waste as substrate, and being the control medium, PDA, where the lowest growth was registered (Fig. 9).

This study showed that all mushroom strains grew slower in control, PDA media, than in any of the waste treatment media (Fig. 10). Strains PL10, Leb, Gris, B2, BPR3, P07, PE, and SMR grew faster in *Agave tequilana* bagasse (AB) substrate medium, while strains PT and PM1 grew faster in *Pinus pseudostrobus* needle (PN) substrate medium (Fig. 10).

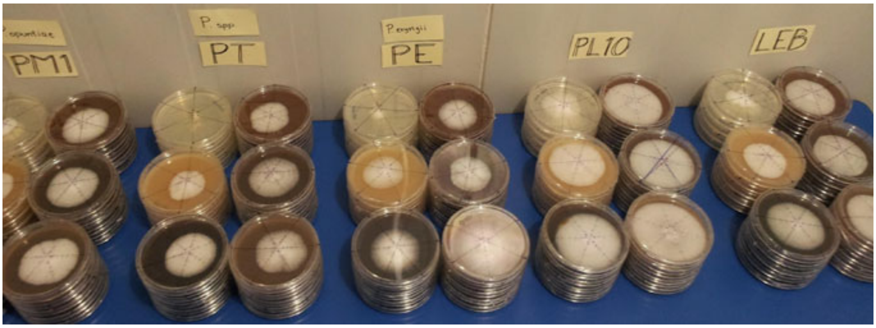

Fig. 8 Petri dishes grouped by mushroom strains, for mycelium growth measurement in six different waste media

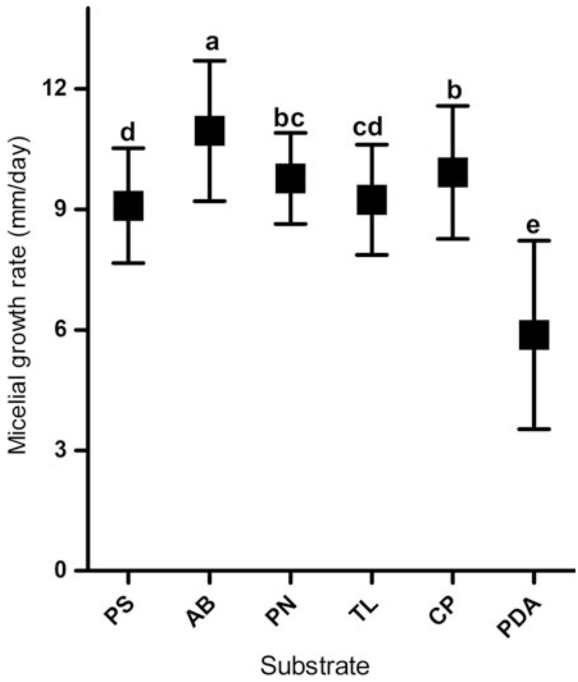

Fig. 9 Mycelium growth rate of the 10 *Pleurotus* strains studied using different waste substrates. PS—pecan nutshell; AB - *Agave tequilana* bagasse; PN—*Pinus pseudostrobus* needle; TL—tamale leaf; CP—coffee pulp; PDA—Control. Letters above boxes group data by statistically different means ($P < 0.05$)

A significant difference of growth was found between PDA and the other five substrates in strains Leb (7–9 days in AB, CP, PS, PN and TL; <21 days in PDA), P07 (8–11 days in AB, PN, CP, PS and TL; <21 days in PDA), PT (10–12 days in PN, PS, AB, TL y CP; <21 days in PDA), and PE (8–11 days in AB, PS, PN, CP and TL; <21 days in PDA).

The results suggest that growth can be stimulated by the addition of lignocellulosic waste as SSF substrates to growth medium. Gris strain showed similar growth rates in all treatments (7 days in AB and CP; 8 days in PS, PN and TL; 9 days in PDA). This could be explained by a complete domestication of the Gris strain, adapting it to commercial growth media, or because the strain is not affected by these studied lignocellulosic substrates.

Agave bagasse can be considered the best substrate, in combination with PDA growth media, for mycelium production in Petri dishes. Nevertheless, since bagasse must be acquired outside the Hidalgo State, a better option could be the use of pine needles, as this waste is easily obtained and it is a low cost option. Tamale leaf can be considered a second option, as it requires collecting and separating trash, with an intermediate washing step. Moreover, pecan nutshell and coffee pulp can be considered as good options in regions where they are easily acquired. Besides that, the SSF is able to produce bioactive compounds from agricultural waste (Santana-Méridas et al. 2012).

The results showed that it is possible to use the studied lignocellulosic waste as substrates to add to PDA, for mycelium producing in Petri dishes, at a quick rate. It

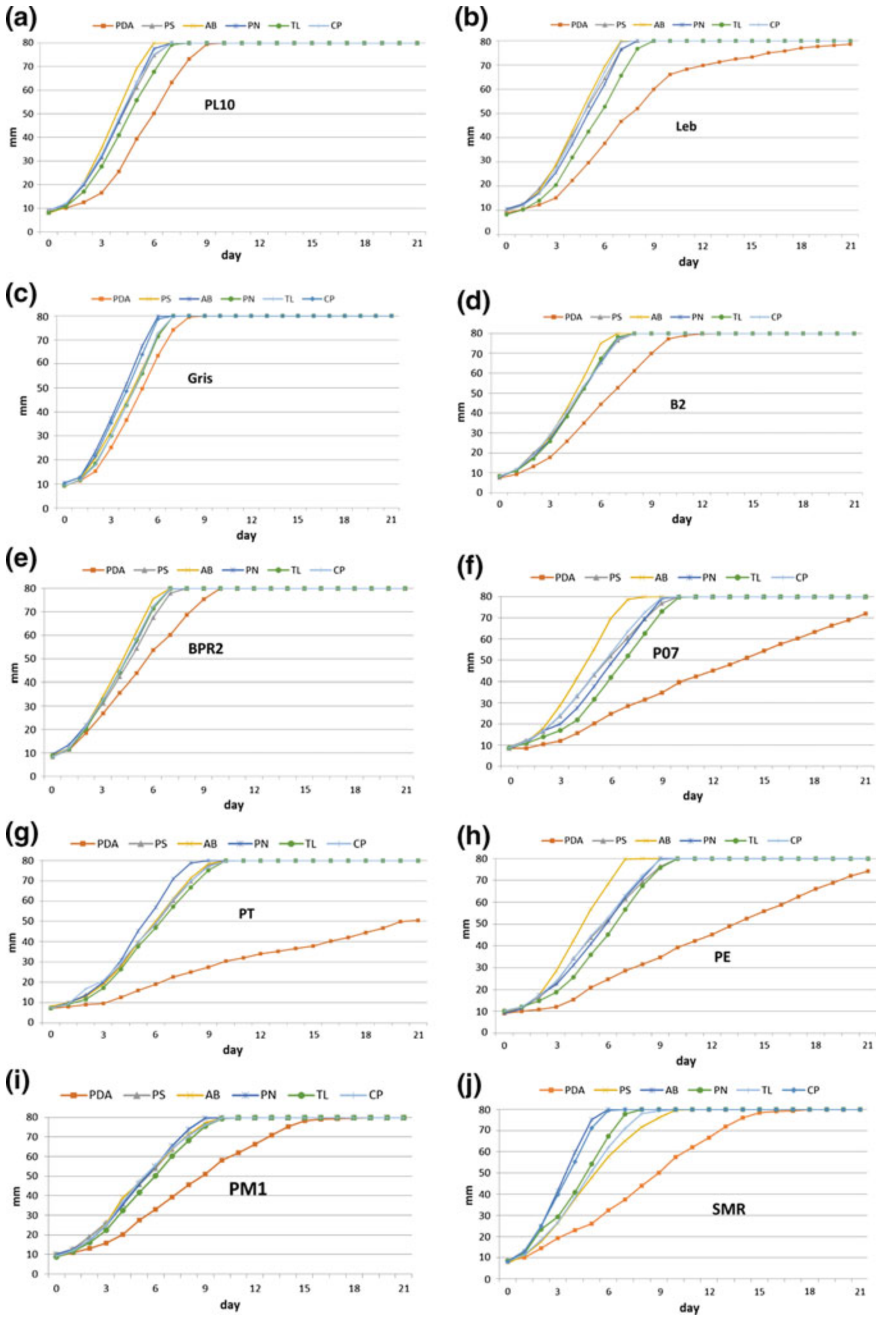

Fig. 10 Mycelium radial growth (mm) for all the mushroom strains cultivated under different waste substrates. **a** PL10 strain; **b** Leb strain; **c** Gris strain; **d** B2 strain; **e** BPR2 strain; **f** P07 strain; **g** PT strain; **h** PE strain; **i** PM1 strain; and **j** SMR strain

seems that for Gris strain growing, there is no need to add lignocellulosic substrates, PDA media is enough. On the other hand, the growth of PT and PM1 strains, both recently isolated from natural sources, is better when lignocellulosic compounds are added to PDA culture medium. Thus, it is possible to grow recently isolated strains under a laboratory setting using growth media complemented with lignocellulosic matter.

Thus, in this study it is pointed out a sustainable method for production of a high economic and healthy food product, contributing to boost Circular Economy at local level, enhancing simultaneously plant growth which will sequester carbon dioxide.

There is already a case of success in Mexico, at Las Vigas de Ramírez, in Veracruz State. A group of farmer women are producing edible mushrooms using agro-industrial waste (Mata et al. 2013).

Moreover, the microorganisms as SSF play a very important role in climate change, as there is a bioconversion of lignocellulosic waste, contributing to food production and simultaneously to CO_2, CH_4 and nitrogen, consumption, stabilizing climate change impacts (Chatzipavlidis et al. 2013).

In the future, it is very likely that new microbial strains will be developed offering a potential solution to problems related to food shortage. Besides that, taking into account the controversies that exist around the application of biotechnology in agriculture, there is a strong pressure and incentive to use natural biodiversity to meet the ever-growing consumer demands for such products in our increasingly environmentally focused society (Orgiazzi et al. 2016).

6 Conclusion

The five studied waste can be considered as sustainable alternatives to be used as growth media additives for *Pleurotus* spp. production, as this high nutritional value mushroom genus has high adaptability to grow on lignocellulosic materials.

Therefore, the use of lignocellulosic waste in this type of mycelium production can prevent the greenhouse gas emissions which will be produced by incineration of this kind of waste. Besides that, the removal of waste from the natural environment allows other plant species to grow, increasing CO_2 fixation and increase microorganism's biodiversity.

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People and Parks: On the Relationship Between Community Development and Nature Conservation Amid Climate Change in South-Eastern Zimbabwe

Wedzerai Chiedza Mandudzo

Abstract Wildlife conservation is a topic that has captured public imagination in both developed and developing nations. This is evident by the creation and establishment of protected areas such as national parks and trans-boundary protected areas. In addition to their fundamental role of protecting natural resources, protected areas largely have the vital task of supporting tourism and socio-economic development of local communities. However, with the establishment of protected areas, the concept of communities' dependence on natural resources has been ignored and protection of biodiversity taken precedence. Consequently, the prioritization of conservation over livelihoods has led to the widespread notion that conservation is a threat to development. Conservationists, on the other hand, assert that the onslaught of development is dependent on the same resources it threatens. This study evaluates the relationship between community development and nature conservation efforts among the Chitsa community and Gonarezhou National Park (GNP) in South-Eastern Zimbabwe amid climate change. In order to achieve the aim of the study, critical ethnography was employed, and utilized semi-structured interviews, focus group discussions and life histories as data collection methods. Findings of the study reveal that nature conservation and community development have long represented contrasts in both research and practice. Of significance are imbalances that favour analyses and prioritization of nature conservation over community development outcomes supported by natural resources in resource dependent communities. It appears that nature conservation focuses on the strict protection of natural resources and ignores aspects of social and political processes involved in it hence it limits the people's ability too adapt to climate change.

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1 Introduction

Throughout the world, biodiversity conservation has attracted much attention in many countries. This is evident by the creation and continued establishment of protected areas such as national parks and trans-boundary protected areas; Zimbabwe is no exception to this. Since the dawn of mankind, a number of communities have lived adjacent to or within protected areas and rely on natural resources for various purposes such as food, trade, medicine and building materials. However, with the establishment of protected areas, the theory of communities' dependence on natural resources has been disregarded and the protection of biodiversity has become dominant. Consequently, the prioritization of conservation over livelihoods has led to the widespread notion that conservation is a threat to development (Colchester 2004; Boonzaaier and Wilson 2011; Van der Duim 2011). Conservationists, on the other hand, assert that the onslaught of development is dependent on the same resources it threatens (Miller et al. 2011; Dowie 2009). Accordingly, community development and nature conservation ideologies have been presented as distant cousins.

With the establishment of protected areas, human occupancy in parks was seen as a hindrance to conservation (Nelson 2008; Sanderson and Redford 2003). Nevertheless, considering the interconnection between human population and environment, separating conservation and community development was and is not feasible (Van der Duim 2011; Colchester 2004). These poor results can be attributed to top down approaches have been adopted by conservationists and the exclusion of indigenous communities in decision-making, management and utilization of natural resources within their locale. The question of whether community development and nature conservation are compatible has been a focus of debates on sustainable development and biodiversity conservation in the South (Duffy 2000; Neumann 1998). Environmentalists assume that community development is not compatible with conservation; this stems from the idea that objectives of community development and nature conservation are different. According to the United Nations Conference on Environment and Development UNCED held in Rio de Janeiro in 1992 there is a shift on how natural resources are viewed and valued between developed (Northern Hemisphere) and less developed (Southern hemisphere) nations. Developed nations' leaders assumed that development in its forms is not compatible with conservation and less developed nations' leaders argued that conservation is a luxury unaffordable to them since it prevents development. These differences also help explain the 'blame game' in development-conservation nexus. Besides increasing interest to link conservation with the lives of communities living in or adjacent to protected areas, little attempt has been made to assess the link between these two dichotomies (Coria and Calfucura 2012; Van der Duim 2011).

The herein presented study sought to:

2 Objectives

1. To examine and describe the history of both Chitsa community and Gonarezhou National Park in order to identify the key factors that shaped the interaction between "people and parks" in Gonarezhou national park.
2. To identify the power relations that shapes the relationship and alleged conflict between the Chitsa community, the Gonarezhou Park's management, the Zimbabwean Government and other stakeholders

3 Background to the Study

Compatibility of community development and nature conservation in Zimbabwe is an area that has not been prioritized. Yet, the interrelationship between wildlife and human population is so intricate. The socio-economic well-being of humans depends on good management of wildlife, their ability to adapt to climatic changes and other natural resources in national parks of the world and vice versa (Burnham 2000; Colchester 2004; Gandiwa et al. 2011; Romero et al. 2012; Diam et al. 2012). This means that protected areas have long been realized as the most important means of conserving wildlife and biodiversity but they are characterized by tension between wilderness preservation, tourism, climate change adaptation and community development. Balancing community development, rural livelihoods and nature conservation is one of the greatest challenges being faced in Africa in the 21st century (Van der Duim 2011; Boonzaaier and Wilson 2011).

In as much as it is acknowledged that poverty and biodiversity loss are linked and should be treated together, there is a huge debate about the success of community based approaches to conservation (Adams et al. 2004). This debate stems from the fact that realization of strategies and objectives of community development, conservation and tourism leads to interference between wildlife and human populations living within or adjacent to such parks. Mombeshora and Le Bel (2009) asserts that history of most national parks are characterized by conflicts between local communities and institutions that are trying to bring the concepts of community development and nature conservation to fruition. The causes of these conflicts can be attributed to the establishment of these parks based on American romanticism whereby indigenous people were not consulted. This has caused problems in the implementation of conservation strategies, utilization and management of natural resources.

The other problem that surrounds the relationship of conservation and development is that both concepts are used in different ways and they depict different meanings (Campbell et al. 2010; Miller et al. 2011). The conflict between these two emanates from the "general conservationist view" that large conservation areas such as transfrontier parks should embody the notion of "wilderness", that is, an area in which, except for employees and tourists, humans should be absent (Twyman

2001). However, while conservationists try to preserve and protect natural resources, development practitioners on the other hand vye for the sustainable use of these resources by indigenous communities. This diverge can also be attributed to the lack of harmony between community development and conservation (Miller et al. 2011; Brandon 2002; Schwartzman et al. 2000).

In Zimbabwe one of the strategies that have been adopted as a bridge between conservation and development is Communal Areas Management Program for Indigenous Resources (CAMPFIRE). CAMPFIRE was established in 1989 under the direction and sponsorship of Zimbabwe s Department of National Parks And Wildlife Management (Logan and Moseley 2002; Frost and Bond 2008). However, it was noted to have failed due to political situation in Zimbabwe, withdrawal by donors and the imbalance of CAMPFIRE objectives between ecology and poverty eradication (Wolmer 2003; Logan and Moseley 2002). This study is important in the body of knowledge because it provides an insight into the realities of the interaction between wildlife and people in Gonarezhou National Park given that there is a community residing inside the park (Chitsa community). The study sought to understand if community development can be a panacea for conservation and conservation a panacea for community development. An assessment was done on whether conservation-community development initiatives are not money making initiatives under the guise of nature conservation, community development and tourism. The quest for an understanding of the nature of interconnectedness of everything in conservation and development attracted attention. The investigation on the gaps between community development and conservation and possible solutions to marry them into practice lies at the bottom of this research.

3.1 Setting the Research in Context: Origins of GNP and Chitsa Community Interactions

Pre-colonial Africa has often been depicted as a land of "*uncivilized warring savages in loin cloths and spears with no knowledge of the environment or insight into its sustainable use*" (DeGeorges and Kevin 2008; Van der Duim 2011). During this period, it was believed that Europeans were required with their 'modern' wildlife practices and administrative structures to bring about conservation and sustainable use of natural resources. It can, however, be argued that colonialism and independence have hindered the evolution of traditional resource management systems, ignored them and in some instances, killed them (DeGeorges and Kevin 2008). Understanding the history of the establishment of GNP and its interaction with indigenous people in South-Eastern Zimbabwe helps in sparking debate and revolutionizing the community development and nature conservation thinking relationship in the 21st century.

GNP has beautiful scenery that is interspaced with numerous rivers, the largest of which are Mwenezi, Runde and Save. There are also several kopjes that cap the

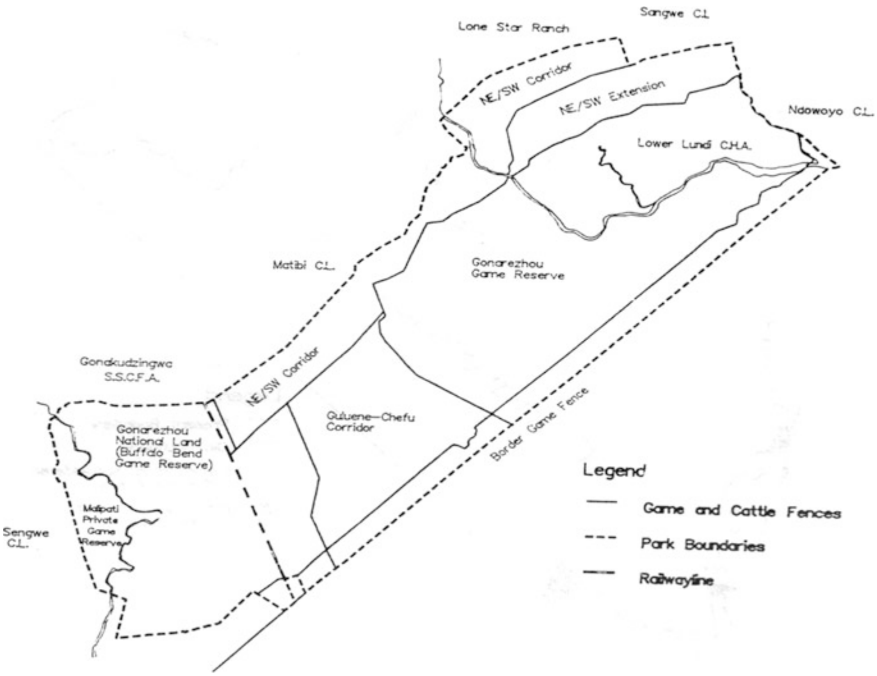

Fig. 1 GNP former land demarcations (Mugadza and Mandizodza 2006)

beauty of the park. Wolmer (2007) stated that 'humans and their changing environments are reciprocally inscribed in cosmological ideas and cultural indulgence: the forest is the people, in the same way that ancestors can be, in a sense, extensions of the living. Therefore, like the rest of Zimbabwean people, the Chitsa people regard nature and themselves as inseparable. Figure 1 shows the locality of Gonarezhou Park and adjacent Shangaan communal lands.

GNP was created from the land that historically belonged to the Shangaan people. As noted above, the Shangaan people in Chipinge and Chiredzi districts are segments of a larger group who were the major occupants of the South-Eastern Lowlands of Zimbabwe in pre-colonial times. The advent of colonialism brought forced removal and concentration of settlements in native reserves as land was taken by the government for conservation purposes. As GNP was being created, the Chitsa people were also affected by these land expropriations (Murombedzi 2003). Between 1890 and 1933, the area belonging to the Chitsa people at the confluence of Runde and Save Rivers was a fragment of the controlled hunting area. In these areas, the hunting of wild animals for food or sport was prohibited unless permission was sought and granted by the responsible authorities (Mombeshora and Le Bel 2009). Victoria Publicity Association strongly campaigned for the game reserve on the basis that it would stimulate tourism in the province (Wolmer 2007). They were strongly supported by the Umtali Publicity Association, who figured that the game reserve would attract tourists to the town of Mutare.

In 1934, a parliamentary verdict proclaimed Gonarezhou Game Reserve amid opposition from white cattle ranchers, who feared that it would lead to the spread of the tsetse fly and endanger the cattle industry (Scoones et al. 2012; Murombedzi 2003; Mombeshora and Le Bel 2009). Smallholder farmers also resisted the establishment of game reserves, especially since this would entail their relocation from areas designated for game reserves. Frontier disputes between the indigenous people and the Department of National Parks still transpire to this day, with pre-colonial and colonial land claims designated for national parks being reasserted in many areas (Murombedzi 2003). Furthermore, the establishment of these game reserves was not without cost. Numerous numbers of Africans were displaced by the new game reserves and relocated into the already crowded reserves. Thus, for instance, the proclamation of the Gonarezhou Game Reserve in 1934 led to the displacement of 1500 households who were relocated in the overcrowded Matibi 2 reserve in Natural Region 5 (Scoones et al. 2012; Murombedzi 2003; Mombeshora and Le Bel 2009; Tarutira 1988). One can deduce from the above that nature conservation and tourism reduced community access to natural resources; according to Dzingirai, “disenfranchisement at large”.

In a bid to control tsetse flies, Gonarezhou Game Reserve was de-proclaimed (Mombeshora and Le Bel 2009; Wolmer 2007). The Chitsa community land was originally not part of the game reserve, but by 1956 the settlement was included in Gonarezhou. Redrawing of the game reserve boundaries also led to redrawing of chieftaincies (Scoones et al. 2012; Murombedzi 2003; Mombeshora and Le Bel 2009). Chief Chitsa, who had previously tried to fight inclusion of his area in the reserve, was relegated to a mere headman under Chief Tshovani (Mombeshora and Le Bel 2009). Following this, a game fence was erected along Chiwonja hills which separated Seven Jack (the area where the Chitsa community now lives) and Gonarezhou Game Reserve. In 1962, yet again, the Chitsa people were forcibly removed to the Seven Jack area to pave the way for another tsetse control procedure (Mombeshora and Le Bel 2009; Wolmer 2007). Consequently, Sangwe Communal Land was identified as a resettlement area for the Chitsa. The resettlement in the Ndali area was agreed upon on the basis that once the tsetse control program was completed, they would return to their land (Lan 1985). In the interim, boreholes were drilled by the government in the area, but the Seven Jack area was rented to Lone Star Ranch as a cattle grazing area (Wolmer 2003). This led to a veterinary cattle fence with iron poles being erected in 1974 around the disputed land. With the intensification of the liberation war struggle in the 1970s, Sangwe communal land people were moved into keeps (protected villages). Consequently in 1975 Gonarezhou was officially proclaimed a national park and the Seven Jack area which the Chitsa people claim as theirs was integrated into the park (Lan 1985; Mombeshora and Le Bel 2009).

After independence, the state wanted to transform the population living in chiefdoms into citizens who would participate in election of their leaders. Notwithstanding these determinations, Tshovani and Chitsa continued to operate as guardians of customary law (Mombeshora and Le Bel 2009; Wolmer 2007). The Zimbabwean government reverted to praising the role of chiefs in rural areas, mainly because of their vote broking role for the ruling party. Chiefs were given cars, electrification of their rural homes and paid high salaries by the government. Headman Chitsa invaded GNP in 2000 as a means of escalating his claim to the lost chieftainship, status and privileges (Murombedzi 2003; Tawuyanago and Makwara 2011).

Headman Chitsa was able to stake his land claim through a local alliance with a local councillor, war veterans and a sympathetic provincial governor who directed farm invasions (Tavuyanago and Makwara 2011; Mombeshora and Le Bel 2009). The invasion was then formalised during 2000 as the Department of Agricultural, Technical and Extension Services (Agritex) pegged the area and ten villages were laid out. With the approval of the provincial governor, the district administrator issued Chitsa people with endorsed documents to reside, cultivate and keep livestock in the park (Wolmer 2003; Mombeshora and Le Bel 2009; Wolmer 2007). Meanwhile the Ministry of Environment and Tourism and the Department of National Parks and Wildlife Management under which GNP falls did not have knowledge and consent of what was happening.

The South-Eastern Lowveld has been struck by a number of droughts in recent decades, most notably in 1982–1984, 1991–1992 and since 2001 (Wolmer 2007). Its communal areas are very remote as evidenced by poor access and limited infrastructure. The area is accessible through dust roads that go through big, uninhabited ranches. Cyclone Eline of January 2000 brought severe flooding and the washing away of numerous bridges, which worsened the inaccessibility of the area (Tavuyanago and Makwara 2011; Mombeshora and Le Bel 2009). The events between GNP and the Chitsa community show how inharmonious their history is. The question that comes to one's mind after being presented with such history is: can a land reform programme alone provide a solution to the strained relationship between community development and nature conservation in the South-Eastern marginal community of Zimbabwe?

Land and natural resources are not the only important factors to livelihoods nor are they always the most important ones (Wolmer 2003). As Scoones et al. (2012) notes, political, media, and academic commentary has been attracted by the publicity surrounding Zimbabwean land reform. Despite official declarations and guarantees that such areas will remain untouched, people have invaded them. From the history of GNP and the Chitsa community presented above, it can be concluded that the application of exotic conservation approaches in cultural areas ignores community knowledge (Pikirayi 2011). However, the question that remains is: did Chitsa people invade GNP solely as a way of acclaiming lost chieftaincy, or there are more reasons to the invasion?

4 Overview of the Research Methods

A qualitative research approach was adopted for the study, since the evaluation of development and conservation was to be studied in the natural context and could not be quantified ordinarily. The researcher was attracted to critical ethnography because this approach is apprehensible to inequalities within societies and focuses on advocacy for positive social change (Madison 2012: 5; Asher and Miller 2011; Bernard 2006: 342). It looks at how basic issues of social structure, power relationships and cultural practices influence human behaviour (Manias and Street 2001: 235) and it is influential in revealing embedded values and practices that are not obvious to people (Thomas 1993). De Vos (2011) acknowledges that in an effort to gain a better understanding of the phenomenon being studied, qualitative research is essential. Critical ethnography has been deduced as a modernization of orthodox ethnography which seeks empowerment and freedom. It gained momentum after mainstream ethnography was criticised for ignoring issues of empowerment and freedom of the researched. This research was not merely a study of socially marginal communities, but it also sought to help in the achievement of emancipatory goals, negate exploitive influences that lead to unnecessary social domination of groups. Consequently, critical ethnography was the most appropriate method of inquiry suitable for understanding and interpreting how the various participants construct realities of the world around them. In an effort to remain 'scientific' while simultaneously practising critique, the following data collection tools were employed: participant observation, life histories, semi-structured interviews and FGD (Fig. 2).

5 Reflections and Realities of Development-Conservation Nexus

5.1 The Historical Background of the Chitsa Community and the Establishment of Gonarezhou National Park

To obtain first hand historical facts about the community and establishment of GNP (Gonarezhou National Park), the researcher visited the local chief, Chitsa, who narrated the clan's life history recounting from the arrival of Munhumutapa in the ninth century to the arrival of the Chitsa people in the 17th century (1695) to the arrival of Europeans in the 19th century (1838). According to his narration, Chief Chitsa pointed out that original occupants of the area they are occupying were the Bushmen. Chief Chitsa indicated that people within the South-Eastern Lowveld are clustered around chiefs and headmen. In this particular area, there are two chiefs,

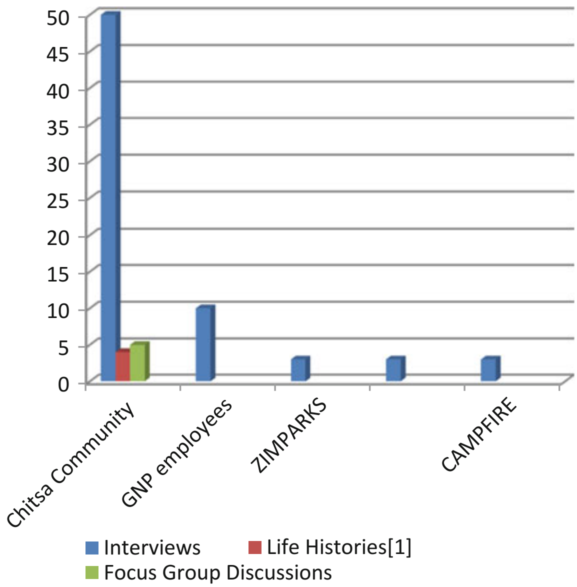

Fig. 2 Participant demographics, 2012

namely Chitsa (officially recognised as a headman) and Tshovani. Chitsa people came into Zimbabwe from Mozambique,[1] settling at the confluence of Runde and Save Rivers during the late 19th century (Wolmer 2007). Ever since they settled in this area they have lived side by side with wildlife. The aspect of living side by side with wildlife concurs with DeGeorges and Reilly's (2008) assertion that in Africa, human beings and wildlife have co-existed since the advent of humankind.

> We the Machangana (Shangaan) people of the South-Eastern Lowveld of Zimbabwe are the proud owners of a unique and vibrant social Xichangana culture.

Xichangana is the correct term if referring to the language. Machangana is a plural form of muchangana, referring to the people. Chief Chitsa mentioned that in the pre-colonial period, his community consisted of a hierarchy of land communities that nested one within another, and membership of these communities depended on acceptance by traditional governance authorities. Governance of natural resources like land and its related resources (wildlife included) were regulated by this structure and hence it functioned as a social control device.

However, the advent of colonialism in the 20th century had a serious negative impact on traditional governance of resources. Chief Chitsa acknowledged that communities were re-defined and they cut natural and cultural systems. Accordingly, between 1890 and 1933, their area was declared by the then Rhodesian government as a controlled hunting area. People lost access and control over natural resources within the area. In an attempt to conserve wildlife, in 1934 a

[1]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

ministerial decree proclaimed Gonarezhou Game Reserve out of Shangaan land. 1500 families were displaced and resettled in Matibi Nature Reserve to pave way for the newly established reserve.[2] During the early 1950s, the boundaries of the Gonarezhou Nature Reserve were redrawn and this time the Chitsa people's land was incorporated in the Reserve.[3] Once again, the Chitsa people were evicted from the confluence and this time resettled in an area called Seven Jack, which is near the Sangwe communal area situated in the southern part of GNP.[4] To make sure that the Chitsa people who had previously shown resistance would not attempt to encroach onto the reserve, the government erected a fence along the Chivonja hills to separate Seven Jack from the game reserve.[5]

In 1962, yet again, the government displaced the Chitsa people from Seven Jack to facilitate another tsetse control.[6] This displacement led to their resettlement in the Ndali area. During this stay, they assumed that once the tsetse control was over they would return to the Seven Jack. However, Chief Chitsa complained that this remained wishful thinking because the area was leased as a grazing area by the government to the Lone Star Ranch, now called Malilangwe Trust Conservancy.[7] To make sure that the Chitsa people would not 'illegally' settle in this area, the government erected a veterinary fence with iron poles around the Seven Jack area in 1974 (Mombeshora and Le Bel 2009). With the intensification of the war of liberation, the Chitsa people in the Sangwe area were moved into 'keeps'[8] just like any other people. It is apparent from the above account that in the eyes of government and colonial conservationists, human population was a hindrance and disturbance to 'natural' or nature conservation. These narrations, while preliminary, suggest an aspect of deep-rooted bitterness towards displacement and disempowerment of communities. It is justifiable then to note that during this time development and conservation had an inverse relationship, because for conservation objectives to be achieved, human presence in the reserve was prohibited. What further complicates the relationship between development and conservation here is the fact that people regarded land, together with other natural resources, as a source of ontological

[2]Chitsa, J., Kuruveli, J. & Musainge, R. Chitsa Community (Life Histories, 29 January 2013).

[3]Redrawing of reserve boundaries was accompanied with redrawing of chieftaincies and people were scattered. Those who resisted where either abolished or demoted. Chief Chitsa acknowledged that he was demoted because he resisted the inclusion of his land into park (Mombeshora and Le Bel 2009).

[4]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

[5]This fence is the one Chief Chitsa acknowledges as the official boundary to this day.

[6]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

[7]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

[8]Keeps are protected villages where ordinary citizens were put in during the liberation war struggle in Zimbabwe. Villagers were forcibly removed from their homes to these protected areas which in actual sense were nothing more than concentration camps in inhumane conditions. They were approximately 100 acres and surrounded by a high chain- link fence with barbed wire at the top (Zimbabwe Bulletin 1977).

origin, so displacement for them was unacceptable. This is justified by the continued occupation by Chitsa people in the GNP to this day.

The Reserve, in 1975, was subsequently gazetted as GNP by the government and this encompassed the Seven Jack area that belonged to the Chitsa people. After independence, Chief Chitsa and Comrade (Cde) Phikilele, a local Shangaan war veteran leader, teamed up and led an invasion on the portion of the park[9] (160 km^2) which they had always believed to be theirs, despite proclamations by the government (Scoones et al. 2012: 17). Consequently, 750 households were established in the park and they cleared some land for the purpose of farming. Occupants started farming cotton as well as sorghum and they managed to secure contracts with Delta Breweries, a Zimbabwean beverage manufacturer, for supplying sorghum. However, as the local people settled in the park, non-indigenous people, especially war veterans from outside the area, came and settled there as well.[10] Currently, there are ten villages with approximately 1500 households inside the park.

In a bid to legalise the invasion, the government, through the Department of Agricultural, Technical and Extension Services (Agritex), pegged the area and ten villages were formally laid out. As presented above, this pegging was supported by the provincial governor (Wolmer 2003; Mombeshora and Le Bel 2009: 2610; Wolmer 2007). Respondents from the ZIMParks said the pegging of plots in the park took place without permission of the Ministry of Environment and Tourism and the Zimbabwe Parks Wildlife Management Authority under which GNP falls.[11] The government drilled boreholes and deployed teachers to schools that were built by local people with mud and poles. While all this took place, the Ministry of Environment, conservationists and park authorities were not happy with this development and continued to vie for the eviction of the Chitsa people. As narrated above, it is significant that the reoccupation of the park, resistance by conservation actors and legalisation by the government goes beyond nature conservation and local economic development. This reveals how development and conservation are political processes in Zimbabwe.

The present historical findings are significant in at least two respects, namely, contested land and competing land uses. As shown in the above account, the land use contest emerges from forced displacements and land repossession complexity. While the land the Chitsa people claim to be theirs is officially a segment of GNP, this debate heightens an already complex relationship between development and conservation. As mentioned previously, spiritual associations between people and land through certain activities and practices connects them in a sensitive and complex web of meanings, responsibilities and reciprocities. This finding, though preliminary, suggests that when knowledge is expressed in a spiritual or social manner, scientists often find it challenging to acknowledge its relevance to NRM.

[9]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

[10]Chadenga, R. Harare (Interview, 10 December 2012).

[11]Chadenga, R., Sibanda, T. & Mapfumo Harare (Personal communication, 7 February 2013).

It can be concluded from the above that colonial and post-colonial NRM laws dispossessed local people of their customary rights over natural resources. There is a long-standing denial of local economic development through free access and use of natural resources, coupled with the enactment of official law transferring property to states, notably through imported legal concepts such as *terra nullius* (nobody's land). This highly politicised nature of community development and nature conservation increases the complexity of local economic development, nature protection, conflicts and resistance between development and conservation camps. As evidenced above, local history contributes to the understanding of development and conservation relationship in South-Eastern Lowveld.

5.2 Power Relations

Having examined the historical background of the interaction between the Chitsa community and GNP, the researcher saw it as imperative to examine how power relations shape the association between community development and nature conservation. The nature of power relations between the Zimbabwean Government, Chitsa community and other actors involved in the development, nature conservation and use of natural resources have proved to have a major bearing on the nature of the relationship between community development and nature conservation in the South-Eastern Lowveld of Zimbabwe. The effect, hostility and interference in the implementation of community development and nature conservation initiatives greatly influence the nature of the relationship and lead to unintended outcomes and possibly even to conflicts. Findings on how power relations affect the relationship between community development and nature conservation have been subcategorized into local traditional leadership, power relations between local traditional leadership, local government departments and central government.

5.3 Local Traditional Leadership

As noted earlier (Chief Chitsa Pers.comm, December 2012), people within the Chitsa community are under the traditional institutions of governance, which are chiefs and headmen. The two chiefs in this area, Tshovani and Chitsa, are embroiled in a dispute over local leadership. These two are from the same descendant named Zari, who had several sons. Amongst his sons were Mihingo and Tshovani.[12] The current Chief Chitsa is a descendant of Mihingo and Chief Tshovani is descendant of Tshovani (Mombeshora and Le Bel 2009: 2608). The genealogy is presented in Fig. 3 (Mombeshora and Le Bel 2009: 2608) below.

[12]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

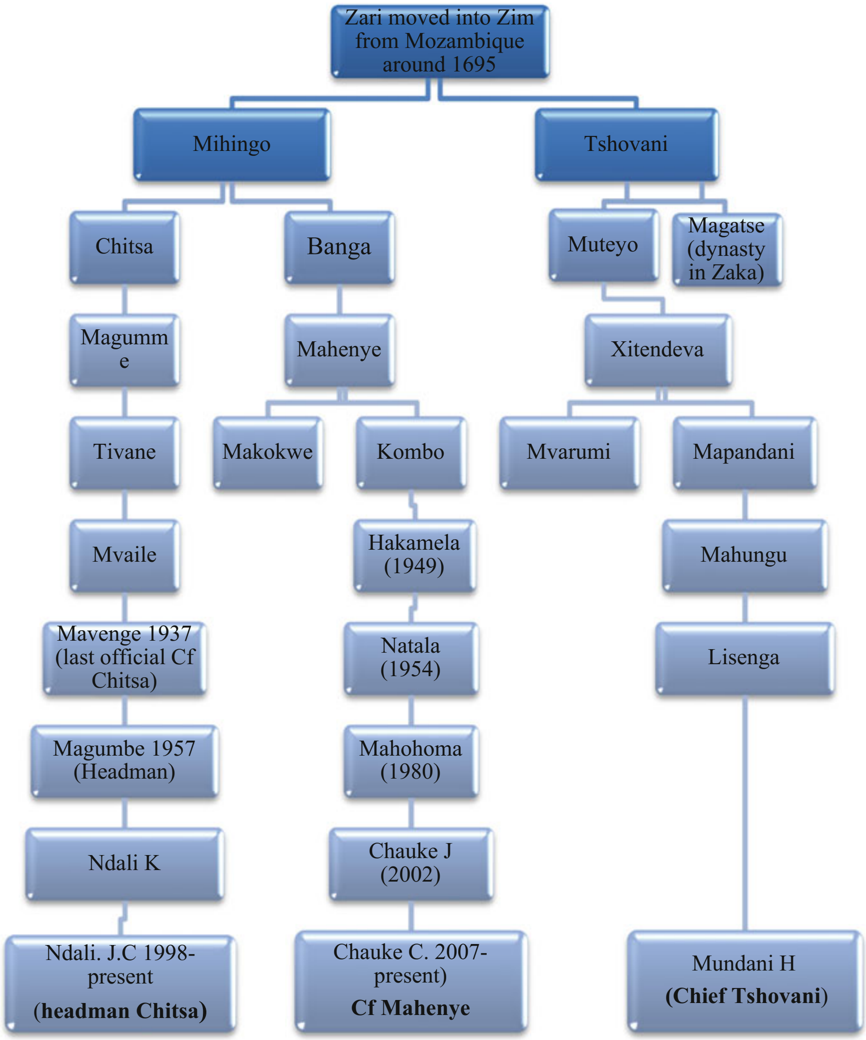

Fig. 3 Shangaan royal hierarchy in South-Eastern Zimbabwe (Chief Chitsa Pers. comm, December 2012; Mombeshora and Le Bel 2009: 2608)

Chief Chitsa, in justifying his chieftaincy, said Mihingo, from whom he is a descendant, was more senior than Tshovani, his brother, and therefore, he is the rightful chief of the area. He considers himself as the senior in the current royal hierarchy. He argued that being considered as the headman is mockery and a farce of uprightness that calls for correction. On the other hand, his rival, Chief Tshovani, acknowledged coming from the same descendant (Zari), but argued that the current royal status should be maintained as it is. Chief Chitsa traced the injustice of royal hierarchy to colonial times. He said when their ancestors came to reside in this place from Mozambique in approximately 1695 the area was total wilderness with no occupants, apart from wildlife. They then lived in the area harmoniously with wildlife. The coming of Europeans and proclamation of Gonarezhou Game Reserve impacted on their lives negatively. There were recurrent displacements of the Chitsa people, all in the name of tsetse control and paving way for the National Park.[13]

When the then Chief Chitsa (Mavenge) resisted these displacements and inclusion of his land into the National Park, he was demoted to a mere headman and Tshovani, who is believed to be loyal to the government, was rewarded with more people, since the Chitsa people now were placed under his chiefdom.[14] Chief Tshovani, who is allied to the provincial governor, lives in an upgraded modern house that is electrified and has been given partnership in the Save Valley Conservancy (SVC).[15] Seven chiefs in the South-Eastern Lowveld are benefitting from SVC: Chief Nhema, Mr Ranganai Bwawanda of Zaka, Chief Tshovani (Mr Felix Mundau of Chiredzi), Chief Gudo (Mr Mavivi Karukai of Chiredzi) and Chief Msikavanhu (Mr Vusani Mutumebvi of Chipinge), Chief Budzi of Bikita, Chief Chamutsa of Buhera and Chief Mutema of Chipinge.[16] As this last point indicates, Chief Chitsa has been excluded from benefitting from the SVC. Apparent from this account is how historical events and power struggles still shape and determine the nature of the relationship between development and conservation. Colonial land division and apportionment policies have left a deep imprint on present day patterns of land tenure and settlement in the South-Eastern Lowveld. Despite its exploratory nature, the study offers some insights into how chieftainship power struggles between local traditional leadership threatens development and conservation.

The above finding reflects the sentiments of local traditional leadership in the face of power struggles. As asserted by Mombeshora and Le Bel (2009: 2608), these arguments are to be positioned within wider background of colonial ruling and the deviations it brought about on indigenous people. Colonialism brought the concept of nature conservation through protected areas which led to displacements and concentration of people in communal land. Consequently, due to mixing and a concentration of people in certain areas, local power struggles between traditional leaders erupted there. Ignoring these local traditional leadership struggle realities, achievement of development and conservation objectives remains wishful thinking as chiefs continue influencing their people to embark on activities that show their powers while complicating the relationship between development and conservation.

[13]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

[14]Chitsa, J. & Kuruveli, J. Chitsa community (Personal communication, 26 May 2013).

[15]The Save Valley Conservancy is situated in the South eastern Lowveld of Zimbabwe. It is one of the largest conservancies in the world and covers approximately 845,044 acres (342,123 km^2). Historically, this area was predominantly used for cattle ranching. A massive drought served as a catalyst to change overall land use from cattle ranching to conservation in 1991 (Wolmer 2003: 3).

[16]Chitsa, J. Ndali Business Community (Life History, 10 December 2012).

5.4 The Nature of Power Relations Between Traditional Leadership, Central Government and Local Government Departments

As mentioned earlier, the particular study area is embedded in a land conflict with the government. The major communities demanding their land back are the Chitsa, Ndali and Chibemenene. Respondents of villages 1 to 10 in the GNP blamed the government for initially allowing them to stay in the park and subsequently, reneging on this promise.[17] The chief and other community members agreed that the government allowed them to stay in the park mainly for political reasons during the 2008 parliamentary and presidential elections. The chief said the then ZANU PF (Zimbabwe African National Union Patriotic Front) national chairman visited them in the park in 2007 and made assurances that the government would not remove them from their ancestral lands, but once the elections were over, they no longer cared about the Chitsa people.

> …..They assured us that we will stay in the park for good now that elections are over they want to chase us just like that……[18]

> …if Smith's administration achieved robbing our land an Act (legislation) why can't the government revise the same Act so that we can repossess our ancestral land? We don't want the entire of Gonarezhou but just a strip….[19]

Whilst the government tried to facilitate conservation by relocating the Chitsa people, the villagers resisted, claiming that they are the rightful owners of the land. In 2010 the government deferred, resettling the Chitsa people citing unavailability of funds. Conservationists who participated in this study said that after resettling in the park, the community started to cut down trees rampantly and pull down the fence, implying that they were likely to move further into the park.[20] Community members were given an opportunity to justify why they were pulling down the fence in a Focus Group Discussion. They indicated that the erection of the GNP fence was done by the government without consulting indigenous people. Therefore, they do not recognize the boundary. Very strong opinions pointed out that the fence has separated them from their ancestors and therefore, they will not respect this boundary. Musainge of Village 9 had this to say:

> Since they erected this new fence we have observed drastic changes in our lives, our land have become unproductive, we did not receive any rain last year and our children have all left. These are revealing signs that all is not well in the spiritual world.

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[17]Hahlani, C., Kunene, J., Kunene, F., Masivamele, F. & Musainge, R. Ndali Business Centre (FGD, 6 May 2013).

[18]Phikilele, Y. Village 1, (Personal communication, 17 February January 2013).

[19]Chitsa, J. Chitsa community (Personal communication, 20 January 2013).

[20]Chadenga, R. Jongoni, S. & Ncube D Harare (Personal communication, 27 January 2013).

One can read from the above account that national parks have remained to protect the wilderness form of conservation which view indigenous people as obstacles to effective protection of biodiversity. However, anthropologically, humans and their environment have proved to be inseparable; thus, nature and environment are socially produced. This finding concurs with that of West and Brockington (2006: 613) that different power plays between development and conservation brings out the social effects of protected areas on people. An implication of this finding is that social structures, cultural values, power plays and individual behaviours are embedded within environmental services, and therefore cannot be ignored if successful conservation of development is to be achieved.

The provincial governor emphasized that it is impossible to move the Chitsa people because they are just claiming their land. To him, occupation in the park does not interfere with any NRM effort within the park. He indicated that their resettlement is history as the government could not secure funds to relocate and compensate them.[21] However, a representative within the Ministry of Environment and NRM said the government explained to the Chitsa people the importance of the park locally, nationally and regionally. Of cognitive importance to the responsible ministry is the contribution of the park to economic growth through tourism. The representative reiterated that the South-Eastern Lowveld is seen and should be maintained as a wilderness landscape.[22] It can be deduced from the above that in the eyes of conservationists, wildlife preservation has priority over people. Government, through representation by conservation actors and political leaders, views conservation as having top priority over resource access and use by indigenous people.[23] Be that as it may, development actors and community members agreed that the economic contribution of the park is realized more at national level than locally. Therefore, development actors deemed it difficult to support conservation efforts while the ‘first people’ are not directly benefitting from it.

While the community members blamed the erection of the fence for separating them from wildlife and adding to the misfortunes in their lives, high profile participants within the Ministry of Environment and NRM said the ministry is opposed to the invasion. Dr Chadenga voiced his opinion that villagers should be resettled elsewhere because they are invading the Gonarezhou sanctuary and it is not good for tourism.[24] These sentiments expressed by respondents support the second research objective, namely that of ‘identifying key issues in the GNP’s engagement with the Chitsa people who are living in the park’. Linked to the current relationship of development and conservation in the South-Eastern Lowveld is the epistemological differences between the two: origins, objectives, theory and practice. It can be deduced from the above that indigenous people claim that their lives are shaped and revolve around their history, culture, traditions and land tenure. It appears as

[21]Local Government Representative, Masvingo (Personal communication, 10 May 2013).

[22]Chadenga, R. Harare (Interview, 10 December 2012).

[23]Chadenga, R., Sibanda, T. & Mapfumo Harare (Personal communication, 7 February 2013).

[24]Chadenga, R. Harare (Personal Communication, 7 February 2013).

though development and conservation have different origins and thus, it is difficult to harmonise them. Due to their different origins, they are rooted in different operational frameworks in which development on one hand seeks to exercise equity, sustainability and self-reliance, and conservation on the other stresses maximising revenue generation whilst preserving wildlife. Caught in between these two discourses are the indigenous people.

One of the government officials interviewed said that in Zimbabwe, land for wildlife conservation should be solely used for preservation of wildlife rather than crop production; therefore, farmers allocated land under land reform program should practice wildlife conservancy.[25] This implies that conservationists are of the opinion that the practice of crop production, which is the Chitsa people's source of food security, is incompatible with stipulated land use in the area. On the other hand, community development actors object to the above mentioned view, saying that all land was declared as farming land. Consequently, people given land in the respective areas should practice crop farming regardless of "land use" options available in the areas.[26] In concurrence with the findings of Romero et al. (2012), the difference in the origins, actors and power play between conservation and development makes the two incompatible. These reflective opinion differences depict how land use has important implications for the livelihoods of resource users. Just as in much of rural Africa, land is of crucial importance to economies and societies, constituting the main livelihood basis for a large portion of the Chitsa population (Cotula 2007: 6). In this context, changes in land tenure systems bring about winners and losers. As land competition increases between wildlife conservation and crop production, resource access and use become more complicated.

The research also revealed a constricted relationship between local leadership, government departments and the central government. The local traditional leadership accused the government of not attending to their needs. The locals said they had to beg the government to build schools and clinics for them.[27] Chief Chitsa complained that the government viewed the community as a homogeneous entity, ignoring the diversity within the community, and this has led to problems of differential access to resources and benefits. He emphasized that the government assumed his rival, Chief Tshovani, has the ordinary people's interests at heart, but the reality is that people from outside have been allocated land in the park and other indigenous people continue staying in the unproductive communal area. This finding provides evidence with respect to Wassermann and Kriel's (1997: 67) erroneous assumptions of community development. This view concurs with Deville

[25]Sibanda, T. Harare (Personal communication, 8 March 2013).

[26]Mutumbi, A., Hove, C., Kubvakacha, P. & Muzari, T. Harare (Personal communication, 8 March 2013).

[27]Chitsa, J., Phikelele, H., Kuruveli, J., Hahlani, C., Kunene, J., Kunene, F., Masivamele, K. & Musainge, R. Chitsa community (Personal communication, February 2013).

in Cotula's (2007: 36) assertion that in customary systems, access to land and resources are an integral part of social relationships. Customary systems are alliance-based and rely on a number of principles. These usually include predominance of first occupants and access to resources linked to lineage membership.

6 Conclusions, Recommendations of the Study

Community development and nature conservation efforts which in turn influence adaptation capacity are not sufficiently recognized and managed in GNP. In the first instance, IKS, and roles and responsibilities for all stakeholders should be incorporated in strategies for both development and conservation. A knowledge base for nature conservation, rural livelihoods and community development seems disjointed, uncoordinated and rigid, and thus community development and nature conservation have a complex, but inseparable relationship. The pressure on natural resources is intense because of the inharmonious relationship that exists between community development and nature conservation. Consequently, this threatens the natural attractiveness of the park, sustainable use and management of resources, security of livelihoods by indigenous people, and facilitation of community development and nature conservation. The reality of minimal, if any, dividends returning to the community from tourism and hunting have been caused by lack of knowledge and ability to manage how these can simultaneously contribute to community development and nature conservation.

Although the study revealed the existence of a positive relationship between the Chitsa community and GNP, to conclude that community development and nature conservation can act as a panacea (remedies) for each other is rather unjustified, given the complex relationship revealed in the study. Evidence from the study indicates that pre-existing historical configurations influence long- term evolution of conservation and development. History has been shown to be influential in shaping up the current relationship between development and conservation in Zimbabwe's South-Eastern Lowveld. In particular, history is important because the line of movement, direction and flow of previous resource dependency cycles shape the current interaction of people and the park in this community. As asserted by Brennan (2009: 3), local culture has proved to be the basis for development and it serves to promote the use of local identity and management of resources. It mobilizes local population's way of behaviour. At the heart of the strand of the debate surrounding Africa's development and conservation relationship is history and culture. This study argues that history and culture embrace every attempt and activity of man in his life mentally, physically or spiritually, and therefore nature conservation needs to acknowledge and accommodate indigenous cultures.

The evaluation of development and conservation in the South-Eastern Lowveld points out two positions. Firstly, there is the claim that people live in harmony with natural resources and do not threaten nature conservation. As asserted by Orlove and Brush (1996: 335), this claim emanates from a long history of the presence of people in protected areas, rich knowledge in IKS, specific management practices based on IKS, and religious beliefs and ritual practices. These claims prove that indigenous people are committed to conservation. However, this is easily attacked by conservationists, who lack recognition that indigenous knowledge has a place in nature conservation.

Secondly, as illustrated by Sherman et al. (2011: 98), bureaucratic arrangements of government structures make the involvement of indigenous people in nature conservation difficult. As presented in above, the decentralized nature of NRM retained powers in the hands of the government. Communities have no governance and decision-making powers. Therefore, CAMPFIRE has failed to harmonise development and conservation in this resource dependent community. The study has shown discrepancies between theory and the practice of the devolution of powers in NRM to the lowest level of structures (community). The theory of CAMPFIRE has the potential to harmonise conservation and development efforts. However, in practice, these principles are rarely adoptable in resource-dependent communities (Dzingirai 2004; Frost and Bond 2008).

The study also recommends effective stakeholder analysis and engagement on the relationship between community development and nature conservation. It proposes promotion of effective dialogue between key stakeholders which have been identified as ZIMParks, Chitsa community, GNP employees, development actors, traditional leadership, the Department of Community Development and the government. The involvement of stakeholders in both development and conservation efforts/projects will instil ownership of the projects and thereby facilitate sustainability of those efforts through empowerment and capacity building. It is presumed that stakeholder analysis, consultation and engagement create harmonization of the relationship between development and conservation. Subsequently, through engagement, acknowledgement of GNP as containing multiple cultural activities of different groups who use and protect those natural resources will be achieved. In turn, interests and priorities of different stakeholders will be shaped in a participatory and inclusive model of the park management that will provide the underpinning for sharing different cultural approaches regarding resource values and benefits. In particular, as mentioned in the previous sections, current forms of participation do not support the needs, benefits and rights of indigenous people. The proposed effective stakeholder analysis, consultation and engagement on NRM has the potential of creating space in which local, national and global values relating to both community development and nature conservation can be expressed. It involves rethinking how natural resources within GNP can provide both benefits to the Chitsa community's development and support national conservation purposes at the same time.

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Environmental Assets and Carbon Markets: Could It Be Amazônia's New *Belle Époque*?

Thiago Lima Klautau de Araújo, Amadeu M. V. M. Soares and Ulisses M. Azeiteiro

Abstract The Carbon and the Environmental Assets Markets are not regulated in Brazil. They are pointed out by experts and activists as sustainable alternatives of wealth generation and forest valuation. But will they be enough to make Amazônia able to experience once again a time of economic prosperity related to environmental preservation, just like in the *Belle Époque* (the golden time of Amazônia, supported by the rubber extraction)? This paper intends to discuss several issues—currently ignored—about the subject, considering historical, legal, social, environmental, economic and political backgrounds. Besides those contexts, there is an assessment of the public policies, current studies on regulation, and legislative trends about the environmental issues, the Carbon and the Environmental Assets Markets. Several inconsistencies/weaknesses were found in the legal system and if they are not properly considered, they might threaten the success of those markets and/or even preclude the social and economic return for the local populations, especially from Amazônia, in a possible future regulation. Without due care, instead of becoming an alternative of environmental preservation with economic development and decrease in social and regional inequalities, they may become another example of financial conglomerates income concentration, at the expense of the region.

Keywords Amazônia · Law and economics · Public policies · Environmental assets · Carbon markets

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1 Introduction

The last century (particularly in its second half) has presented a major dilemma to Brazil: economic growth or environmental conservation? Up until recent years, undoubtedly, the unsustainable and irresponsible economic growth prevailed over biodiversity issues, environmental and social affairs (Pinho et al. 2014), or even over justice and fraternity among the states of Federation, existing values in the successive Brazilian Constitutions. Amazônia, a long and uncharted territory, has been characterized by the most perverse government interventions. Not properly planned and truly ignoring the reality of the region, it were based on the eagerness for economic "progress" and began a process of social and environmental degradation (Klautau de Araújo 1995), land conflicts and political disputes.[1]

Initially fueled by Juscelino Kubistchek's developmental policies in the 1950s, followed by national integration initiatives of the military dictatorship[2] (Paulino 2014), and, finally, leading to the disregard from the governments after the redemocratization, Amazônia faces, nowadays, a real environmental, social and economic disruption. However, it was one of the richest and most important regions in Brazil between the second half of the 19th century and the first half of the 20th century. More recently, increased attention was therefore paid to the process of environmental, social and economic degradation of the region, which shelters the most relevant and significative storehouses of the planet's biodiversity

Despite several isolated initiatives, not only governmental ones, but also, and, mainly, from the civil society and international organizations, the social and environmental situation[3] from Amazônia continues to deteriorate. The inefficient work by the successive governments and the environmental agencies can be pointed out, as well as the incoherence and weaknesses of the Brazilian Legal System—from the Constitution to other assorted regulatory provisions—the failure of the environmental education policies, illegal practices, forest exploration with predatory economic activities (for instance: mining, logging, agriculture and cattle) and the extreme poverty of the populations from the region are considered to be some of the major determinants that contribute to aggravate the situation.

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[1]Which triggered, for instance, several break-up states projects and a popular referendum on the division of Pará State in three other ones (Pará, Carajás e Tapajós), in 2011, that was rejected, above all, by the dissenting vote of the people who live in the metropolitan zone of the capital of the state, Belém. In the affected areas by the creation of the new states, the votes in favor of the division were more than 90%.

[2]Both have proved disastrous because not only the proposals were not achieved (creation of transport infrastructures, road links to urban centers of other regions, creation of agrarian settlements, among other initial intentions), but it also created several economic and social problems that had never existed before.

[3]An increase is observed not only in the number of conflicts, but also in the violence rate. Despite the fact that the North Region has a small population if compared to other Brazilian areas, it sees a serious increase of the violence rate, much faster than the more populated regions (FBSP and IPEA 2016).

In addition to the aforementioned elements of that disrupted context, the existing political resistance regarding the elaboration of appropriate public policies to environmental preservation[4] is noticeable.

The political forces from Amazônia are considered to be tiny if compared to the ones from South and Southeast states.[5] Therefore, there is no political pressure or bargaining power[6] since the representation is clearly small and fragmented among the recognizable opponents, including those who are against the environmental actions because, according to their point of view, they would hinder the economic growth.

To make things worse, Amazônia has the largest mineral province of the planet, located in the state of Pará, with significant production of iron ore, gold, bauxite (and its by-products alumina and aluminum), nickel, copper, kaolin, among others. That exploration results in environmental and/or social damage, without financial compensation. This is because, according to Article 155, §2°, X, of the Constitution of the Federative Republic of Brazil from 1988 (CF/88), the products intended for export cannot be taxed by the states. In other words, the ICMS (tax over operations related to the circulation of goods and interstate and intercity transport and communication services), main state tax in Brazil, cannot be charged by the states on the mineral extraction activity to export, which corresponds almost entirely to the total of the mineral exploitation. There is, also, oil and natural gas production in Amazonas state and it is likely that there are oil stocks on the Pará's Coast.

For those reasons, several political agents are still convinced that the environmental preservation, especially in Amazônia, is a strong obstacle to the Brazilian

[4]The already low level of funding for fighting against deforestation had been reduced in 72% between 2010 and 2014 (Leite 2015) and in 2017, there was a reduction of more than 50% in the Ministry of the Environment's budget—from 911 million (Ministério da Fazenda 2017), to R$ 446 million (Gesisky 2017; Moutinho and Guerra 2017). Meanwhile, the Federal Government has provided R$ 190.25 billion to the Agricultural and livestock plan 2017/2018, more than the R$ 185 billion available for the 2016/2017 Plan (Peduzzi 2017). The amounts invested in the agricultural plan represent more than 426 times the current budget of the Ministry of the Environment, which is the responsible for the federal environmental monitoring of the whole country, not only of the Amazônia.

[5]The North Region, that corresponds to almost the total of the Brazilian Legal Amazônia, has seven states, representing 45.25% of the national territory (IBGE 2016); however, it relies only on 65 of the 513 parliamentarians from the House of Representatives, since the population is proportionately represented, but this number is outdated and does not match the actual population—Amazônia would have more deputies if the division of places was updated. Nowadays, only the state of São Paulo has more than 70 representatives, 5 more than all states from the North Region together.

[6]Weinstein (1993), describing the negative fall in the prices of rubber latex in the international market, during the first decades from the 20th century, demonstrates that the lack of political power from the North Region is an old problem in Brazil: "(…) It is essential to consider the political component of the economic obstacles from the region. Since it needs political support at the national level, the elite of Amazônia failed many times in offering support to programs that intended to combat the devastating effects of price fluctuations. Moreover, their appeals for emergency assistance right after the collapse were largely ignored".

economic growth. Nevertheless, it is necessary to highlight that the environmental preservation may be an important complement of the economic growth and development of the region—and vice versa—like the one we have seen in the past, in the most relevant moments of Amazônia history.

This paper intends, therefore, to discuss about alternatives for Amazônia's development, the context of the current laws, the terms for establishing markets and the challenges for doing so. Despite the fact that the Carbon Market is the fashionable one, we comprehend that it is, in the context of Amazônia, just one of many renewable and non-predatory possibilities of rational use from the existing natural resources in that region. Due to those reasons, as we shall debate it later, we suggest the regulation, also, of the Environmental Assets Market (and the Carbon capture, obviously, is one of them), so that there can be established the maximum use of Amazônia potential, with the environmental preservation, climate context improvement and development for the region and its local populations.

2 Amazônia, the *Belle Époque* and the Environmental Assets

The Environmental Assets, some of the greatest Amazon riches, have fundamental importance to the sustainable development[7] of the region. As a matter of fact, the history of Amazônia shows two examples in which the economic growth was directly associated to the use of those environmental assets without forest damage: at the beginning of the colonization in that region, with the so-called backland drugs; and with the latex exploration, also called "rubber boom", divided into two phases, one during the 19th century and the other one during the 20th century.

The backland drugs were the main reason of Amazônia colonization, since Portugal could not control the Indian spices route, it then attempted to use Amazônia products as substitutes, among them, the cocoa, *pau-cravo* and achiote; that led to the cities and villages foundation in order to control the territory and the transit of foreigners in Amazônia. Belém, the capital of Pará, was founded and expanded in that context of monitoring, due to its geographic location and strategic importance, seen as one of the main entry doors for Amazônia (Cardoso 2015).

The rubber cycle, in turn, consisted in the exploitation of latex from Amazônia rubber tree *Hevea brasiliensis*. Its widespread use in the industry for a variety of purposes and its exclusiveness of production in the states in Brazil's North Region would promptly bring prosperity to the region and then enrich it, fact that made Belém one of the main (if not the main) financial center of the country in the second

[7] Based upon the economic growth, environmental preservation and improvement of the social conditions.

half of 19th century, not only due to the wealth brought by the rubber, but also due to its strategic proximity to Europe and the United States of America.[8]

All that abundance culminated in the building of imposing palaces, houses, parks, avenues, hotels, theaters, cities planning, development of significative infrastructure works like ports, railroads, public illumination, electricity, trams, among other various ventures that took the latest technologies to Amazônia. Clearly, all things worked and were built with European influence,[9] especially from Paris, hence the designation used for that period: *Belle Époque*, being Belém affectionately nicknamed as "Paris n'America".[10] The sumptuousness of the buildings and the ingenuity of the urban solutions were really impressive, especially if we consider the logistical and geographical challenges still found up to the present. Undoubtedly, it was Amazônia's Golden Era.

The first rubber cycle ended at the beginning of the 20th century because British Government Officials smuggled rubber trees seeds and established huge plantations in Malaysia (Garfield 2009), where did not exist the plagues that blocked the development of large fields of rubber trees in Amazônia, so they could reduce the costs of production and it led the Amazonian rubber plantations to the decline, followed up by their abandonment, since they were more expensive, with tricky logistic lines and more time-consuming collection and distribution, regarding the dispersed trees throughout the forest.[11]

However, the Malaysia rubber plantations were under the Nazis' control during the World War II, which led to three situations: the shortage of material, the consequent rise in latex price in the international market and the weakening of the Allies' armies (and their economies) due to the lack of this essential raw material for the industry. Hence, the rubber exploitation in Amazônia restarted, with shorter duration at that time, but brought fresh air to the economy of the region.[12]

There was, over those periods of time, an unmistaken direct relation between the produced wealth and the forest preservation.[13] Naturally, on account of the indigenous labor (during the backland drugs period) and the use of slave labor or

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[8]The geographic importance of Belém was demonstrated, for instance, by the air links to Europe and to the USA, which were set up from Belém and not from São Paulo.

[9]With particular situations like, for example, rich families from Belém used to have the laundry done in Paris (Weinstein 1993) and the use of large and warm clothing in a region where the temperatures remain constantly above 30 °C during the whole year.

[10]Curiously, that is the name of a traditional store, which still works at the same place since 1900 in a building in the downtown of Belém.

[11]Regarding the existing problems in Amazônia for the wealth coming from the latex transition to a more industrialized economy—as it did not turn out to be, see Weinstein (1993).

[12]For more details on the relationship between Brazil and the USA, due to the importance of Amazônia for producing rubber latex during the World War II and the immigrating and economic impact to the region, see Garfield (2009, 2010).

[13]Different from other events in the Brazilian history, as in Pau Brasil exploitation (*Caesalpinia echinata*), that almost made that specie disappear, or as in the economic situation of Amazônia itself, which has been destroyed for soy-plantation, cattle breeding and timber extraction.

slave-like terms or even low wages (in latex production),[14] it is not possible to talk about sustainable development, since the social component was not covered, especially because those practices were common and legal at that time. However, despite the reprehensible and inadmissible practices related to social and labor terms, the mentioned times demonstrate that the maximum use of the Amazon potentials can occur not only with activities that do not deforest the region, but also can quite possibly be a complement to combat environmental degradation.

3 The Negative Change in the Amazônia Path

Despite the clear propensity of the region in considering a non-predatory use of the environmental assets,[15] the economic, political and infrastructural models applied in Amazônia since the 1950s did not consider basic cultural, natural and social characteristics of the place. That caused serious damage to the environment and to the society (Klautau de Araújo 1995, 2014; Paulino 2014). The Brazilian governments imposed solutions previously used in other states which were successful, but that, obviously, did not work in Amazônia because its environmental features demanded—and still demand—carefully conceived and personalized choices.[16]

Therefore, it was ignored the necessity to treat unequals unequally to achieve justice—Aristotle's thought plentifully discussed over the years.[17] Thus, there was no participation of the local populations in the definition of laws and public policies

[14]Weinstein (1993) states that it was the main reason behind the economic decline in Amazônia with the rubber price collapse, if compared to São Paulo, which also suffered from the coffee crisis effects, but it became industrialized: with no internal market of products, based upon wage labor, Amazônia did not have other options besides the latex extraction. That excessive dependency on a single product, without establishing a productive market, led it to its economic ruin.

[15]The proof lies in the fact that the richest period of time of the region history was based in a renewable and non-predatory product, with almost no deforestation, and without serious environmental impacts. On the other hand, currently the environmental degradation is noticeable, either because of mining, livestock or logging activities, while the population remains miserable.

[16]Amazônia is unique and, therefore, different from other Brazilian realities. The soil type, the rivers dimensions, the features of the weather are, sometimes, impossible challenges to solve traditionally. Examples of failed initiatives that did not take into account those elements are several: Madeira-Mamoré railway, which was not concluded due to project problems that brought a huge distress initially and due to the death of several workers who developed tropical diseases; Balbina hydroelectric, in the state of Amazonas, which has a reservoir similar to the one of Tucuruí hydroelectric power plant, in Pará, but that has about 3,3% of the energy produced in Tucuruí; the roads BR-163 (Cuiabá-Santarém) and BR-230 (Transamazônica) with no completion until nowadays, besides many other examples.

[17]The debate on the topic has begun with Aristóteles, who considered it in the "*Nicomachaen Ethics*", especially in Chaps. 4 and 5 of its 5th book. Still on that, there are works like the "*Discours sur l'origine et les fondements de l'inégalité parmi les hommes*" by Jean-Jacques Rousseau, e "*A Theory of Justice*", by John Rawls. In the Brazilian context, it is important to mention "Oração aos Moços" (Addressing the Young), by Rui Barbosa.

to Amazônia, or in their corresponding implementation and monitoring.[18] The region was treated merely as a new border for changing problems from the main urban centers of the country and also seen as a solution for housing the farmers who did not have lands in other regions.[19]

Under the slogan of national integration, with a development-oriented policy, the government of Juscelino Kubitschek promoted roads construction without proper planning, intending to connect the North Region with the whole country and with the new federal capital. In continuity, the military governments built more roads[20] and started a disordered landholding colonization process, under the motto "land without men for men without lands", and arguing that the settlement of the area could protect the national territory, safeguarding the national sovereignty. However, the attempt of landholding colonization without any support by the public agencies, lacking adequate infrastructure and even no researches on the soil types of the region[21] demonstrated that it was not an attempt to solve the Brazilian agrarian problem (taking into account that, until the present moment, the Land Reform in Brazil has not been enacted), but it was a political way to keep the popular pressure

[18]Until these days, the effective popular participation is a huge democratic challenge, even in developed regions. In Amazônia, it is particularly difficult, and there are studies and proposals with possible replication, as the one carried out by Folhes et al. (2015). However, it is necessary to emphasize that Amazônia is diversified and that not all designed models for it will have the same effects in different zones. Moreover, the participation model has to be defined properly and planned along with the community, considering each case specifically (Klautau de Araújo and Lima 1997a, b).

[19]Wolford (2016) points out some notes about the used strategies by the military governments for Colonization in Amazônia: "INCRA was created on July 9, 1970, as an autonomous agency tied to the Ministry of Agriculture (Decree-Law 1110, Article 4, July 9, 1970). The military government in power at the time created the agency to oversee the colonization and settlement of Brazil's vast and "underpopulated" northwestern frontier. The march westward was expected to fulfill Brazil's promise as a developed, modern nation, which meant extinguishing peasant protests in the Northeast and dealing with the presumed threat of communist guerrillas known to be hiding out in the Amazon rain forest (Martins 1984, 41; Bunker 1985). Colonization was also a means of combating external influence; the slogan "*integrar para não entregar*" (integrate to avoid delivering [the Amazon to foreigners]) was part of the substantial publicity campaign that accompanied frontier development (Reel 2010, 36). In the early 1970s, Brazilian theaters showed films weekly documenting the bulldozers and trucks cutting through the jungle to build new highways (Drosdoff 1986, 60–74). (…) Buttressed by a sense of manifest destiny, INCRA employees moved west to settle "men without land in a land without men," carving out thousands of 100-hectare plots, building houses and towns, and leading markets into relatively untapped regions of the Amazon rain forest (Hecht and Cockburn 1989, 108)".

[20]Including two that have left a trail of unprecedented environmental destruction: the Transamazônica and the Cuiabá-Santarém roads, already mentioned in the footnote 16.

[21]"The endless soil fertility of Amazônia, announced by natives and visitors of the region, has proven to be one of the several legends fostered by the luxurious and thick forests from the region. As a matter of fact, the soil of Amazônia highland, like the tropical soil in general, is thin and with nutrients easily exhausted as soon as the forest cover exposes it to the rain. After that, only the intense fertilizer application will facilitate the growing/cultivation. Regarding the small part of Amazônia surface classified as alluvial plain, that is less susceptible to leaching and hardening than the 'dry land', but can also burn out under intensive cultivation" (Weinstein 1993).

away. At no time, any of the plans or government interventions had considered the social-environmental aspects or eventual externalities that ended up occurring.[22] Concerning the national security, the argument has also fallen down because the Amazônia frontiers are still opened for the trafficking of arms, drugs, animals, human organs and people. The increase in population did not bring any benefits, neither to the region, nor to the local populations or even to the immigrants. Moreover, there was a worsening of the social conditions and deforestation.

The roads construction is also linked to the migratory flows towards the surrounding regions, where people would be attracted by the promise of economic development and jobs, since the landholding colonization programs had failed. The population growth with no basic structures like health, education, security, sanitation and other State services has set up a complex socioenvironmental context. The successful options have been marked by binding together both society and the governments, searching for a broader integrated understanding of the local situation,[23] instead of isolated mitigation measures, as it has commonly been done.

Another important aspect to be highlighted is that the built roads did not work as an alternative to the existing railroads, but rather as substitutes. Nowadays, the road transport corresponds to 61.1% of the transport of goods and to 95% of the transport of people (CNT; SEST; SENAT 2016). The concentration of cargo and people transportation in the road model, apart from being more expensive and polluting, is also slower.[24] It partly explains the difficulties in creating a local productive chain for Amazônia goods: the distance from major consumer centers of the country in addition to the lack of faster, safe and cheaper transport alternatives have reduced the interest of investments in that region. The establishment of companies could certainly contribute for generating jobs, income, local technology and for promoting a closer interaction between the populations and the production of non-predatory items derived from the forest, which arouses an increasing interest to conserving the environment. That would be an interesting option for adding value and regional development around its main potential: the forest; nowadays, nearly all Amazônia's products are exploited to be manufactured in other states or

[22]Even though the described facts have occurred during the military dictatorship time, lack of concern about Amazônia features still remains, and the governments, successively, keep on ignoring the basic aspects of the region context. Recently, for example, school buses were donated to Afuá city, in Marajó archipelago, Pará; but in Afuá, known as "Marajoara Venice", there are no streets, since all its buildings are on stilts and there are lowland soils and floodplains in which the use of motor vehicles is forbidden (Meirelles Filho 2015).

[23]As in Paragominas, State of Pará, where with strong participation from the mayor, managers and society, the context of social and environmental degradation of the city was changed, and Paragominas is an interesting example to be examined. See more in Klautau de Araújo (2014).

[24]And, if we consider the terrible road construction, especially in Amazônia, the numbers are more negative: due to the bad quality of the pavement, more than 77,488 million liters of diesel fuel are spent unnecessarily every year, which represents 2.07 $MtCO_2$ of additional emissions (CNT; SEST; SENAT 2016).

countries, leaving so little or nothing to the local people, leading to an understandable declining interest in environmental issues in the face of the current poverty.

4 Environmental Assets: A "New" Hope for Sustainable Development in Amazônia

Considering that context, the environmental assets can be decisive elements for changing the socioenvironmental situation. As we have already mentioned in this paper, the creation of productive chains for Amazônia products could lead to the economic and social development of the region. Fostering the Environmental Assets and considering the possibility of using them as an enhancing instrument for the forest are widely discussed alternatives (Ministério do Meio Ambiente 2016; Birdsall et al. 2014; CGD 2015; Seymour and Busch 2016), even before the consolidation of the use of that terminology.[25]

Amazônia is rich in environmental assets of all kinds,[26] and if is made the most of that potential, with the local populations engagement, the possibilities for the sustainable wealth generation in that region are feasible. For instance, by addressing some infrastructure issues, it is possible to develop the ecotourism, an alternative that remains unexplored in the area, or expand the food, pharmaceutical and cosmetics industry[27] which use the regional products.[28] Everything depends on the way that the environmental assets and their possible markets are regulated, conceived and defined, as well as the underlying issues discussed up to this point.

[25]The sociologist José Mariano Klautau de Araújo started to debate about the need of the Environmental Assets sustainable use in Amazônia since the 1970s, when the projects for national integration and settlement were at the top. His discussions, subsequently published on books and papers, added to the Socioenvironmental Method, written by him, are interesting points of reference to understand the historical and institutional background of public policies for Amazônia since the 1950s until nowadays. The Socioenvironmental Method was the pedagogical foundation for Escola Bosque, an initiative awarded internationally and that can be read in much more details in Klautau de Araújo and Lima (1997a, b, c), Klautau de Araújo (2016) and Lima (2013).

[26]As it can be seen in more depth in Seymour and Busch (2016), according to the different types of environmental assets classified by the authors.

[27]A huge Brazilian cosmetics company was accused of using, without permission, traditional knowledge from herb medicine women from the Ver-o-Peso market, in Belém (Weis 2006; Soares 2016); after a great controversy, there was then a refund for that (Soares 2016), and a soap and essential oils factory from that company was opened in the metropolitan region, in 2014 (Kafruni 2014).

[28]Products like açaí, cupuaçu, cumaru, camapu, among other fruits, plants, herbs and seeds derived from Amazônia have awakened a great international interest due to their nutritional, aesthetic and therapeutic properties. However, the most part of those products, with rare exceptions, is collected in the region, and the end products are produced somewhere else, with no return to the local people.

5 Current Legal Brazilian Situation Concerning the Carbon Market, Environmental Assets, Mitigation and Adaptation to Climate Change

The Brazilian environmental laws are dispersed, confusing, bureaucratic and complicated to deal with, due to their gaps, shortcomings and lack of regulation (Klautau de Araújo 2014, 2016). The few existing legal devices regarding the Environmental Assets trading, including the carbon, or related to the climate change are in that same direction, as well as the current legislative proposals and public policies.

As the main legal basis for that issue, the Law 12187/2009 (National Policy on the Climate Change), in spite of being recognized as an important legislative framework (Milaré 2014; Lopes et al. 2015; Pinheiro Pedro et al. 2015) comes up a bit short of the expected. In its art. 4º, VII, it is established the fostering to the development of the Brazilian Emissions Reduction Market, which would open the national Carbon Market and would contribute to the clearer participation of Brazil in the international market, but it does not mention how that aim would be reached (nor even the Decree 7390/2010, which regulates parts of the above-mentioned law).

In the art. 9º, the Law 12187/2009 grants carbon credits (here mentioned in a broad sense) of legal nature of securities and requires them to be traded in the stock exchange,[29] being the Securities Exchange Commission (Comissão de Valores Mobiiários—CVM) the responsible for monitoring it; however, the CVM disagrees with the classification established by the National Policy on Climate Change.[30] Since the articles 4º, VIII and 9º are too superficial and were not regulated by the mentioned decree, the Carbon Market has not yet been satisfactorily implemented

[29]In this context, the BM&F Bovespa.

[30]The problem in this case was the legal system inconsistency. That was because the Law 6385/76, about the securities, has a strict list in its art. 2º. Therefore, the Securities and Exchange Commission expressed its opinion, asserting that “Carbon Credits are securities issued by an organization associated with the United Nations which represent no-emission of certain amount of gas that cause global warming. The CVM discusses matters related to the carbon credits and why they must not be considered derivatives or collective investment securities—**thus, they are not securities, but assets and they are marketed to reach the targets of carbon emission reduction or aiming the investment. In addition, The CVM understands that it would be inconvenient to classify the carbon credits as securities through the edition of the law regarding the arrangement of those instruments**. The Securities and Exchange Commission also discusses the features of some financial products derived from the carbon credits, that, depending on their characteristics, might be defined as securities. The assessment of each financial product will be done by the Securities and Exchange Commission” *[highlighted by us]* (CVM 2009). Although that issue may appear to be a simple detail, it may be decisive in the future concerning the tax matters, fundraising from the Carbon Market and the legal certainty/validity of the contracts. More than that, by failing to amend the Law 6385/76 or to consult the Securities and Exchange Commission about the legal nature of an obligation modality that would be ruled by that institution shows the regulator’s negligence and weakens the applicability of the law.

in Brazil[31] because it is not as significant as it could be and it does not offer sufficient legal guarantees to the investors. Last but not least, the art. 12 establishes voluntary reduction from 36.1% to 38.9% based on the projected emissions until 2020,[32] but it does not say how it should be done either,[33] not even mentioning the metrics to be used to verify the results.

Therefore, if there is no commitment to the targets, no solid legal basis to create the Carbon Market, to reduce the emissions, to implement concrete measures to be taken by the public authorities, the Law 12187/2009 and the Decree 7390/2010 seem to be only intentions that the federal government may not be interested in putting in practice.[34]

Regarding other aspects of combat, mitigation or adaptation to climate change, there are: Law 12114/2009, which creates the National Fund on Climate Change, regulated by the Decree 7343/2010; Law 11284/2006, which is "about the public forest management for sustainable production; it establishes, on the basis of Ministry for the Environment, the Brazilian Forestry Service; it creates the National Forest Development Fund", among other measures, as well as its regulatory Decrees 6063/2007 and 7167/2010; the Decree 6527/2008, which is about Fundo Amazônia; the Decree 8576/2015, which "establishes the National Commission to Reduce the Greenhouse Gas Emissions Resulting from Deforestation and Environmental Degradation, Forest Carbon Stocks Conservation, Sustainable Forest Management and Enhancement of Forest Carbon Stocks—REDD+"; Some of the Forest Code provisions (Law 12651/2012),[35] especially the Article 41, which

[31]Although Brazil holds 5% of the world's Carbon Market, while 20% was expected initially (Brasil 2012).

[32]That, according to the art. 6° of the Decree 7390/2010, means to reduce between 1168 million of tonCO_2eq and 1259 million of tonCO_2eq of emissions.

[33]The art. 6°, §1 of Decree 7390/2010 lists ten actions to be taken to make feasible the accomplishment of the goal, being foreseen and implemented by sectorial plans.

[34]Lopes et al. (2015) and Pinheiro Pedro et al. (2015) emphasize the importance of the Law 12187/2009 to the establishment, at first, of a voluntary market and of a mandatory one later, after adopting the compulsory measures of emissions reduction. Nevertheless, we understand that the enactment of the above mentioned law was only an attempt of political response to the national and international pressures/expectations and not a practical step indeed. The Brazilian legal experience in the last decades demonstrates that law enactments without regulation (or their ineffective regulation) has been a strategy of the governments in order to avoid the responsibility of polemic or complex issues (Klautau de Araújo 2014, 2016). Due to that, we believe that a norm with inconsistencies, omissions and inaccuracies is not able to substantiate a whole system of combating measures, mitigation and adaptation to climate change.

[35]One of the legislative provisions of the Forestry Code is the Environmental Reserve Quota (CRA), that consists in a portion of non-deforested land which exceeds the law requirements. It may be considered as an Environmental Asset because it may be negotiated with other landowners who have not fulfilled the minimal legal size of vegetation in their areas. It is provisioned by the articles 44 to 50 of the law 12651/2012. There is a recent study developed by Brito (2017) about more efficient regulations of that legal institute so that there is not an excess supply, pulling down the prices and inhibiting the restoration of the areas, taking Pará state as a reference for additional regulation to the recommended by the Forestry Code.

is about the Environmental Assets. Also, there are two National Congress Bills, in progress: the 212/2011 draft legislation, which intends to set up the "national system of reducing emissions from deforestation and forest degradation, conservation, sustainable forest management, maintenance and enhancement of forest carbon stocks (REDD+)",[36] and the 95/2012 draft legislation, which intends "to determine the securities trading in the Brazilian Emissions Reduction Market related to the avoided greenhouse gas emissions verified in indigenous lands must be previously authorized by FUNAI".

5.1 Legislative Trends

As previously observed, there were several laws and regulations concerning environmental and climate change issues and there are new ones already being planned. In other words, there is a tendency for legal provisions and sparse regulations that makes the legal system tricky. That tends to decrease the efficiency of implementation, the legal compliance and laws inspection, as well as to difficult the citizens' understanding on the Law field, if compared to the issues that are arranged in codes or in few and concise laws (Klautau de Araújo 2016). Milaré (2014) claims that the codification of the environmental issues can give legal security to the area, and we may infer that the same would happen if applied to the Environmental Assets Market. The same way that the environmental issues have been regulated, it became very difficult for citizens to participate in the elaboration, enforcement and, mainly, monitoring of the laws, since they do not know the technical terms, do not have resources or even because there is such a complex bureaucracy involved (Klautau de Araújo 2014).

Besides the regulation issues and the scattered laws, there is a worrying trend to weaken the federal environmental norms, despite the increase in deforestation. The text of the new Forest Code ended up confirming irregular deforestation before 2008.[37] In May 2017, the House of Representatives and the Senate ratified two provisional measures that reduced in 597 thousand hectares Pará and Santa Catarina states preserved areas. 587 thousand hectares of this reduction were only in the

[36]Although there is not any law project about it, we should consider the ENREDD+, the "REDD strategy development" planned by the Ministry of the Environment (Ministério do Meio Ambiente 2016).

[37]Legal devices like the articles 61-A, §§ 5° e 6°, 67, 68, among others from the new Forestry Code, reduce or leave behind the demand for reforestation of the Legal Reserve (minimum of native vegetation to be kept on the estate) or Permanent Protection Area (vegetation surrounding rivers and sources, for example) for several contexts, which means relaxation of the environmental rules and legalization of the irregular situations. The message to be understood is that the environmental rules may be not followed, since, at any time, there will be tolerance of validations of the illegalities in the name of the economic issues.

Jamanxim National Forest and in the Jamanxim National Park, located in Pará (Maisonnave 2017a, b).[38]

A data entry carried out by WWF indicates that bills in course in Congress reduce the protection of approximately 80,000 km^2[39] (Maisonnave 2017a).There is, also, another Law Draft (3729/2004), with 18 included projects, in course, that aims to relax the environmental license regulations, which has been pushed through to be approved (Miranda 2017).

The most recent environmental debate was derived from the edition of Decree 9142, from August 22, 2017, which extinguished The National Reserve of Copper and Associates (Renca)—an area between Pará and Amapá states with a forest area over 4 million hectares—and opened part of the reserve to mining. It had a great impact and the Government edited a new Decree (9147, from August, 28,2017) revoking the previous one, remaining the extinction, but addressing few points in detail which had been contested in Decree 9142; The Government and some experts say that the reserve has already been occupied by illegal loggers and miners, who extract the Brazilian resources avoiding taxes and polluting the rivers, also exposing fish and watercourses to mercury contamination, promoting deforestation, and the mining regulation would control the impact of those activities (Schreiber 2017). However, the polemic persisted throughout, the public opinion was overwhelmingly against the reserve extinction and, shortly after, the Federal Justice decided to suspend the Decree. There was another suspension order by the Supreme Court that determined the government to clarify the issue in 10 days. For those reasons, the Ministry of Mines and Energy (MME) published a Directive on September 5th, 2017, suspending the legal effects of the Decree 9147 during 120 days in order to broaden the discussion on the subject (G1 2017). On September 25th, 2017, the President decided to revoke the extinction of Renca, with the Decree 9159. The Ministry of Mines and Energy published a note affirming that: "(…) The country needs to grow and generate jobs, attract investments to the mineral sector, including to exploit the economic potential of the region. The MME reaffirms its commitment and of the entire government to the preservation of the environment, with the safeguards provided for in the environmental protection and preservation legislation, and that the debate on the subject must be taken up at a later time and must be extended to more people in the most democratic way possible" (Ministério de Minas e Energia 2017). It seems that the results of this story are far away, especially if we consider that the environmental question is, apparently, being used as an exchange for political power and support.

[38]However, after extreme national and international pressure, the President Michel Temer has gone back on his own proposal and has vetoed provisional measures 756 e 758, that established the reduction of the area. In a new twist, the Government sent a proposed law to the National Congress, reducing once again the area of Jamanxim National Forest, not in 486,000 hectares, but now in 349,000 hectares, that will be protected areas, with a few restrictions, if the project is approved (G1 PA 2017).

[39]Near Portugal's territory dimension, which has a little bit more than 90,000 km², including its islands.

Nowadays, as it can be seen, there is an overall weakening trend—rather than a strengthening one—of the Brazilian environmental legislation. Added to that, there are international uncertainties related to the success or to the failure of the countries cooperation against climate change,[40] endangering the Carbon and the Environmental Assets Markets in Brazil. Without a mandatory setting of a limit of emissions and a legal system efficient for punishing irregularities,[41] there will scarcely be any interest or economic feasibility of the markets. Moreover, regarding the Environmental Assets Market, directly affects the very existence of the assets to be traded.

6 Technical Challenges and Possible Distribution Models Originated from the Carbon and Environmental Assets Markets

6.1 Challenges—Not So New as They Seem

The economic development of Amazônia through activities linked to the regional vocation and to the sustainable management of the existing environmental resources is fundamental to equalize the social and environment preservation issues (Klautau de Araújo 1995, 2016). That is because Amazônia, currently, does not have the least necessary structure of transports, health, basic sanitation and education, with a few alternatives of decent livelihood remaining to the populations of its remote areas, who end up preying on the environment in exchange for some living, specifically (but not only limited to) cutting down the forest illegally for selling timber; with no guarantees for human dignity to the local populations, it is impossible to demand their support to the government against environmental degradation, or even expect that they worry about preserving Amazônia (Klautau de Araújo 2016). That situation fits within Paul A. Samuelson's argument (1976) about Economics of Forestry and the extinction of certain animal species.[42]

[40]Especially after the withdrawal of the United States from Paris Treaty. It is early to analyze the impacts and consequences of that decision, even with the response of leaders in the European Union and China reaffirming their commitment to the international agreement (Lusa 2017; Gomes 2017).

[41]The bureaucracy, the low values charged by the fines, added to the almost endless possibility of lodging an appeal create a sense of impunity and, at times, is more profitable to do something illegal and then pay or contest the possible fines (Klautau de Araújo 2016).

[42]"When people in a poor society are given a choice between staying alive in lessened misery or increasing the probability that certain species of flora and fauna will not go extinct, it is understandable that they may reveal a preference for the former choice. Once a society achieves certain average levels of well-being and affluence, it is reasonable to suppose that citizens will democratically decide to forego some calories and marginal private consumption enjoyments in favor of helping to preserve certain forms of life threatened by extinction." (Samuelson 1976).

The current policies of forest preservation are not only based upon a confusing and flawed system, but also transform the forests in a source of expenses, not of possible income, since the environmental protection is not well regarded by the governments (Klautau de Araújo 2016). Some environmental assets, like the Carbon Market—which generates wealth through the simple preservation of environmental areas—can change this context, adding value to the forest as heritage sites to be preserved not only due to its ecological, climate and biodiversity aspects, but also due to its inherent social and economic potential.

The environmental issue is not—and it has never been—into Brazilian political focus. In a particularly troubled moment for the Federal Public Management, with discussions and debates on electoral, political, labor and social security reforms and so many corruption scandals, the concern with the environment is far from being a priority. Another relevant aspect is the continuous disinvestment in the environmental monitoring sector, which has worsened over recent years (Klautau de Araújo 2016). Arousing the economic interests in maintaining the green areas is a way to bridge the gap between the environmental issues and legislators and governments.

Therefore, despite the existing limitations to the Environmental Assets, they are considered to be, in Amazônia context, the most feasible alternative at the moment, since they offer the possibility to generate wealth, income, employment, life conditions with dignity to the local populations and, simultaneously, the forest preservation. However, in the Brazilian case, despite all the problems pointed out by some scholars, the Environmental Assets, particularly the Carbon Market, do not face great difficulties in the international scenery or even in terms of long-term economic viability, but in the legal system. Maybe this is the most significant barrier for the implementation of a comprehensive policy focused on the sustained use of those resources.

The Brazilian legal system is extremely confusing and disconnected, making the procedures too bureaucratic, long and difficult. For instance, the first practical difficulty in the implementation of a Carbon Market in Brazil would be a more precise definition of land ownership. Odd as that may seem, there is no consensus on the exact public land delimitation and dimension for each one of the federal entities, setting judicial disputes among the states[43] and between The State and private individuals. One of the reasons for that is the lack of clarity (and/or regulation) of the art. 20, I to XI and §2º, and art. 26 of the 1988 Federal Constitution, as well as the art. 16 of the Transitory Constitutional Disposition Act.[44] Added to it, the Land Reform in Brazil has not been enacted, fact that brings legal uncertainty,

[43]Acre and Amazonas are disputing a 12,000 km², while Mato Grosso contests for 22,000 km² with Pará, and Ceará complains about 2821 km^2 with Piauí (Mariani et al. 2016).

[44]Referring to the public land ownership.

which gives ground to frauds against individual and state patrimonies.[45] Lastly, the lack of data links among registries makes the system even less reliable.

Defining public and individual land ownership in Brazil is essential to make the most out of the Environmental Assets potential, but in particular to make the Carbon Market feasible for the national territory. Without knowing which areas belong to whom, it is not possible to estimate neither how much land each market player (especially the public bodies) has for carbon absorption, nor how many tons might be absorbed. Moreover, without solving this problem several judicial disputes may occur focusing the money raised in market, leading purchasers' migration to other markets.

Although it is a complicating factor and that certainly will bring many practical difficulties and legal disputes over the years, that issue does not block the Brazilian Carbon Market from being implemented.[46] The purchasers, naturally, will seek for agents appropriately settled and they will select those who will remain or will leave the market. Something to worry about is that Brazil, until this moment, was not able to carry out structural adjustment reforms and any regulation arranged will only be a slight repair over a confusing and inconsistent legal system.

It is necessary to remember that the 1988 Federal Constitution—as has dealt with the public land ownership—established the environmental protection in a general way, regarding as a joint competence the environmental protection, air pollution combating, forest, flora and fauna preservation to the Member States, to Federal District and to the municipalities,[47,48] Added to that, there is a constitutional determination on the preservation of the environment contained in Art. 225[49] from CF/88, and its paragraphs, in which the expression "Public Power" is used in the broadest sense of the term. It means that all power spheres are responsible, conformity with their respective competences, for the environmental protection.

[45]Without the Agrarian Reform and a standardization of the securities, all proofs of ownership modalities are accepted, if the necessary requirements at the time of the alleged purchase are met. It happens that, if there is no control of the registers, it is possible, for example, to have a land title document from the sixteenth century validated. That is one of the reasons why a very common fraudulent practice in Brazil used to be the document forgery, putting the papers inside drawers with crickets, because their secretion would make them appear older than they actually are. That practice was called "grilagem", a nickname given, nowadays, to all kinds of fraudulent attempts of land regulation.

[46]Especially because it already exists, but it is not based on laws, as we will confirm later in this paper.

[47]Art. 23, VI and VII of the 1988 Federal Constitution.

[48]There is also legislative concurrent competence/authority to the Union, states and Federal District, regarding "forest, hunting, fishing, fauna, conservation of nature, soil and natural resources preservation, protection of the environment and pollution control", according to the art. 24, VI from 1988 Federal Constitution.

[49]"Art. 225. Everyone has the right to an ecologically balanced environment, which is an asset of common use and essential to a healthy quality of life, and both Governments and community shall have the duty to defend and preserve it for present and future generations."

The legislative intent was good: by expanding the number of the responsible ones for monitoring, the efficiency of surveillance would increase. But the results did not meet the expectations and the attempt to generically share the responsibility for the environmental monitoring caused the opposite effect.[50]

As we have already mentioned, in theory, if the Carbon Market, generates revenues, instead of being a burden for the State budget, the forest would be a source of income which would increase the interest for its conservation.[51] What happens is that the collection of taxes and revenues is strongly controlled by the Federal Government, but the charges of environmental monitoring belong to everyone.

If there is not any system restructuring of the environmental agencies and the clear liabilities establishment, the problem will remain unsolved, despite the influx in revenue of the Carbon Market.[52]

Another reason why the regulation must be a careful process is that the sale of carbon credits is, all in all, an offset, since it keeps a reduced economic activity in order to preserve the forests. Nowadays, the Brazilian cities that present the lowest human development indicators are located in Amazônia. Brazil shows extremely serious regional disparities and the Environmental Assets sustainable exploitation is one of the few available alternatives to reduce the disparities without further aggravating environmental degradation.[53]

Therefore, we point out four possibilities of collecting and distributing revenues from Carbon Market—or, why not, from the Environmental Assets market?—if the Brazilian regulation is possibly established.

[50]In another study (Klautau de Araújo 2016), by the use of the game theory and an adaptation of one game, it was pointed out that when all the constitutional powers are generically shared it is likely that none of the agencies act. That is because all tasks might be shared, but not the budgets. Without a clear division of competences and tasks, it is almost impossible to demand an agency responsibility in case of default since it is stated that you cannot blame a single absent agency for the unsuccessful public policies when other agencies did not act either.

[51]Not only for public entities, but also for individuals. The Carbon Market is an alternative for obtaining economic income from preserved areas required by law inside the states, as the Legal Reserve, which currently are unpaid. Concerning that, the then-Senator and current foreign minister Aloysio Nunes stated that: “the Carbon Market would be a stimulus for the grower to maintain his legal reserve, so that he can generate income from that. It would fulfill our goals not only internationally, but also inside Brazil, implementing an important law, welcome by the whole world, that is the Forestry Code law” (Altafin 2016).

[52]In the discussions on this topic, this point was also raised by Senator Jorge Viana: “who can trade the carbon absorption in the forests? Is that the country and in a centralized manner? Or are the states, which are guardians of the forests? There is almost no regulation of it. It is a new market, not widely-known, which is part of climate change” (Altafin 2016).

[53]The areas with higher biodiversity in Brazil are those in which the people have lower incomes and little provision of public services (Kageyama 2009; Klautau de Araújo 2016).

6.2 Possible Methods for Collecting and Distributing Revenues

6.2.1 Federal Government Revenue Collection and Distribution of the Total Value or a Portion of It Proportionally

That hypothesis would consist of the Carbon Market values centralized in the hands of Federal Government and further distribution proportionally among the States and cities.

In this model, the Federal Government would be the only entity of public power able to make trades—as it is already seen, for example, in the capital market. There are strong chances to adopt that option, since it is about repeating the existing practices in which the power is centered at the Federal level and the sharings are distributed in a standard way, taking into account the region of the federative entity and the income *per capita*.[54] However, with that regulation form neither the regional inequalities in Brazil will be reduced, nor the forest conservation will be encouraged. This is because in the distribution according to the previous criteria, the states with the highest capacity to absorb Carbon[55] will have to divide the main compensation for maintaining their forest area. However, all the conservation burden will remain individualized. Therefore, a scenario of strong regional differences is eternalized, enhancing those differences, due to the fact that the forest conservation duty is imposed (involving costs and the forgoing of tax revenues) in exchange for specified economic benefits that will be shared.

We could consider a possible comparison between that model and the regulation of royalty payments related to oil and natural gas exploration, ruled by the Laws 9478/97, 12351/2010 and 12858/2013. There is a share of the royalties aimed at the producing states and cities and a shared aimed at the Federal Government and other non-producers, what may seem unfair at first. But the oil exploration creates a lot of jobs and attracts investments, which is the opposite of the Carbon Market: you pay for the forest maintenance by using credits derived from the option of not making economic activities. Moreover, the oil and the places where the exploration is more common belong to the Federal Government, according to the Article 20 V, VI e IX of the 1988 Federal Constitution. The states, the Federal District and the municipalities are allowed to participate in the results of those resources exploration or

[54]As it is used, for instance, in the division of the State Participation Fund (FPE) and in the Municipalities Participation Fund (FPM). For further details, read: art. 159 of the 1988 Federal Constitution; art. 34, §2°, I, II and III of the Transitory Constitutional Disposition Act; the arts. 90, 91 e 92 of the Law 5172/66 (National Tax Code); and the Complementary Laws 62/89 and 91/2001.

[55]Consequently, with less economic activity, lower GDP (gross domestic product) growth, and higher monitoring costs and forest conservation.

they can be compensated by the exploration itself if it takes place in their area, according to the §2° of the forementioned article, but the property is still of the Federal Government. That is why that analogy is not valid, considering that in the Carbon Market the land ownership to be conserved for CO_2 capture is assured, and it may belong to the Federal Government, to the states, to the Federal District, to the cities or even to individuals.

Thus, that model is unwelcome because it would disregard the individual capacity of Carbon absorption and the negotiation of federative entities and individuals in the Market. It also would increase the regional inequalities by not compensating economic activity decrease (or little maintenance) of the states where there are preservation areas.

6.2.2 Federal Government Revenue Collection and Distribution Among the Entities in Their Proper Quotas

In this system there is a similarity between what happens in the capital market and the previous model, the only one entity of public power able to operate in the Carbon Market would be the Federal Government, but the difference is the way of sharing the funds after raising them. Sharing without regarding the proportional criteria of population, location of the states and per capita income, but considering the actual results of environmental preservation and carbon absorption, there would be a more effective offset for the carbon absorption and a greater economic interest of the states and the Federal Government in the environment preservation. Therefore, this option could be more fitting and fairer that the first one.

In order to distribute the amount collected by the Federal Government in the Carbon Market to the states and the cities, there are two options: carbon trading assignment of rights of the federal entities to the federal government and payment for the proper quotas[56] or the royalties payment of the Union to the states and cities regarding their preserved areas, in a similar system of the Financial Compensation for the Exploration of Mineral Resources (CFEM).[57]

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[56]What, in practice, would work as though the Union had bought the carbon credits from the states and cities and had resold them in the market with its own credits.

[57]This system is regulated by the law 7990/89 and 8001/90 and distribute the royalties obtained with mining as it follows: 65% to the cities where the production occurs (and to the Federal District, if applicable), 15% to the states (or the Federal District) where the production occurs, 15% to the cities and to the Federal District affected by the mining activity, and 10% divided between Federal Agencies. Observe that, different from the oil royalties, only the producer states and cities (and those which are not producers, but are directly affected by mining infrastructures) receive a financial compensation.

The bureaucracy involved, however, is the problem of the last modality because it gives grounds for corruption[58] due to the excessive centralization of powers of some agencies and political players.[59]

Besides those difficulties, there are also complications in budget planning of the states and the cities in the context of this model. That is because depending on the Union transfer of resources, it is not entirely clear when and how much will be available in the states and cities coffers.[60] Due to all these uncertainties and to the insistence on imposing a model of powers centralization, we believe that this alternative would not fit properly within the Brazilian context, especially regarding Amazônia sustainable development.

6.2.3 Linking of Earnings for Sustainable Development Projects in the Region

There are strong indications that this hypothesis could be confirmed, maybe, as a complementary manner to others, especially because it has already been used in the regulamentation of the oil royalties, but to a fund for Education and Health. It would be interesting to use part of the revenue obtained by the Union through Carbon Market as an investment for environmental preservation, for sustainable development of regions with rich biodiversity and natural resources as well as for restoring degraded areas. Here, that possible regulation is attractive because it qualifies the purpose of those obtained values, otherwise, there would be common revenues.

Thus, the repetitive discourse which affirms that the environmental preservation sucks resources dry and that it blocks the economic growth is not valid, and with this alternative, this narrative loses its meaning, because providing funds to the country may boost the economy and safeguarding part of revenue to invest in environmental recovery and protection makes the system self-contained. By promoting sustainable development, apart from social conditions improvements, there is a chance for Brazil to develop economically, heading towards a more

[58]In 2016, a serious corruption scheme was uncovered involving the National Department of Mineral Production (DNPM), dismantled by the Federal Police, through Operação Timóteo, in 11 states and the Federal District (G1 DF 2016; Affonso et al. 2016). This department is responsible for collecting and distributing the mining royalties in Brazil and handled approximately R$ 1.6 billion in 2015. In this specific case, the corruption scheme was related to the amounts which would be allocated directly to municipalities.

[59]Klautau de Araújo (2016) points out that one of the biggest problems of the public policies implementation process in Brazil is the centralization in the planning and decision-making processes and the dispersion of the implementation. In that context, the situation is similar: the concentration of power in few agents attracts strong political interest, makes the proper use of the money difficult and increases the possible deviations from ethical conduct.

[60]The event at the National Department of Mineral Production had to do with it: there were late payments and the agents from the department received bribes (concealed by law and consultancy offices) in order to speed up the money deposits and to increase the values.

environmentally friendly production with a strong focus on the rational and conscious use of the natural resources. The path towards an environmentally friendly economy is neither about loss of competitiveness nor about impoverishment,[61] but it needs more investments and also a paradigm shift in the relationship between State and society, as well between those and the nature.

However, for the same reasons presented in the previous alternative, there are strong evidences that it would be a failure as the main model. That would happen because the resource centralization in a single fund, besides leading to the greed of malicious public managers,[62] will also lead to the problem of over-centralization pointed out by Klautau de Araújo (2016). More than that, it is important that the environmental assets can be seen as attractive business opportunities, as well as income generation and job creation opportunities. The advantage of using them in a coordinated manner is that they can complement each other. That means it is possible to generate wealth, for instance, through ecotourism or adventure tourism, extraction and cultivation of medicinal herbs, flowers and fruits from Amazônia, to achieve the carbon absorption and to sell securities on the Market, all those things by using the same area. The allocation of revenue to a single fund (even though if it would be only the public one) obtained from a specific environmental asset would reduce the flexible usage of sustainable environmental assets and mutually complementary. Consequently, their competitiveness and attractiveness for the private sector would also be reduced.

Specifically in the case of Amazônia, the community and individuals deep involvement will be necessary since the area to be monitored is very large, the governments do not have sufficient means to be present throughout the territory (even if they had, the costs would be extremely high), and the current methods are more repressive than preventive.[63] Moreover, the failures in implementing public policies in Amazônia in previous experiences, as we have already discussed in this paper have demonstrated the need for understanding, agreement, contribution and

[61]If we analyze the examples of the developed countries, the technology, the productive processes, the entrepreneurial dynamics, the environmental awareness and planning are more connected to the success of the economy than to the plenty of natural resources. Japan, for instance, relies on few natural resources, has a rough ground, hard to be used, besides being a group of islands, what would make its development difficult. However, despite all those facts, it is one of the most developed economies, a balanced society and with low level of poverty.

[62]Even though the study of Public Administration in Law courses, most of the times, recommends to consider corruption in the spheres of government as an exception, not as a rule, the Brazilian experience shows us that the reality is different and that the current political system has many examples of a corrupt governance. There are denouncements against all the political spectra and against almost all political parties. Therefore, the planning of alternatives to the country must be designed in a way that the flaws may be minimized and the public funds may be protected.

[63]The satellite surveillance, inspection activities, among others, intend to punish the responsible for the environment damage, what is valid, but if the damage has already been done, the environmental restoration is hard, even with the modern procedures of reforestation, due to the maintenance of ecological balance and biodiversity, it is best to keep the original wood instead of reforesting a cleared area.

participation of local populations in the decision-making and executive process. Without that, it is almost impossible to think about monitoring and managing such a large and difficult access area like Amazônia.

6.2.4 License for Individuals and Public Entities to Operate Freely in the Market

For the given reasons in the previous topic, the participation of the local people and of all the federative entities is necessary for finding solutions to the environmental issue. There are many doubts concerning the possible ways of arousing the interest. By allowing a broad participation of public and private entities in those markets, increasing their profitability with the natural resources conservation and biodiversity, there is a clear valorization of the forest and growing interest of the individuals in taking part in the initiatives for conservation.

Thus, the model we believe to be the most interesting for implementing the Carbon Market in Brazil is a hybrid model of collection, distribution and allocation of the obtained revenue, in which all the federative entities and individuals could freely participate, making their rights, duties and obligations clear, (topic that will be discussed further in this paper), also considering some part of the revenue allocated to a supervisory, monitoring, conservation and reforestation fund.

7 Practical Challenges

Besides all the technical challenges, in order to design a management model of the Environmental Assets that work efficiently and to make the Carbon and the Environmental Assets Markets reach the goals of economic and social sustainability, it is necessary to regard some practical challenges, namely: fostering an economic interest for conservation and maintenance of forests; designing a regulation system appropriate for the reality and accessible to the interested people, in which there is an understanding of the protected legal assets importance, the duties, obligations and rights of the parties involved in this market, whether they are small rural landowners or major corporations; and the strengthening of the educational system, especially the environmental education.

The first challenge is to find ways that make the Environmental Assets viable sustenance alternatives so that the local people cease predatory practices and become interested in maintaining and preserving the forests. In addition, engage them in the sense of not allowing third parties to make predatory activities. It means to make the local populations and the State partners in the monitoring of forests and ecosystems. It is necessary to note that the Environmental Assets may be economically attractive, as stated above in this paper, because it is possible to combine the exploitation of several environmental assets simultaneously, increasing their profitability.

The second challenge is to communicate effectively with those populations, making them access, in a real and not fictious way, the legal documents and legal regulations about the issue.[64]

It is not appropriate to use a very technical language (as it has been used) with terminologies which people do not know and can barely understand. Most of the times, it is necessary to have appropriate knowledge of the field in order to communicate with the people responsible for the studies and the regulation projects. For this reason, on behalf of honesty, transparency and good faith of the decision-making processes and enforcement proceedings, the communication must be improved. A context in which the regulation of a sector is not understood by almost any of the interested parties is an enabling environment for the spread of corrupt practices and vested interests that do not fit the exercise of citizenship and democracy.

The third one is the implementation of a qualified education system for the populations. That is the key component to make children, teenagers, young people and future generations environmentally aware, even for those who are not inserted into the forest reality, so that they will be able to help in the environment preservation.

If some of those things (especially the communication with the population) fail, the effectiveness and efficiency of that action as a sustainable way to Amazônia and other Brazilian biomes that are endangered will possibly be reduced, since the three presented components complement each other. Nevertheless, the tackling of those issues depend on a regulation system suited for the specificities of Brazil and its regions in order to arrange the Carbon and Environmental Assets Markets as economic development alternatives, not only as simple chances of some groups to make money out of the natural resources that are of interest to the society.

Especially because the Carbon and Environmental Assets Markets are not going to save Amazônia—or the world, but they are sustainable alternatives for economic diversification and natural resource use. Overly concentrating investments and to pay attention exclusively to that possibility is risky and reckless. Doing that is like

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[64]A brief comment on the popular participation and interaction effectiveness is welcome: they are possible only if there is an open, transparent and accessible language. The overuse of technical terms, jargons, acronyms and abbreviations makes the documents reading unpleasant and sets up a bar for any person who is not in the limited circle of "specialists". Even the Law or Environmental field professionals who are unfamiliar with the Carbon Market and the Environmental Assets experience serious difficulties when dealing with this topic due to the language unnecessarily tight, the challenge is greater to, for instance, a person from Amazônia countryside with poor education and with no access to public services, a very common profile found in the local community (brought about by the indifference of the governments). In order to make those people—who have so much to contribute to the understanding and preservation of their areas—participate in the debate, clarity, respect and transparency from the specialists are demanded and they may learn a lot about Amazônia with its natives. Unfortunately, until the present moment, frequently, the decision-making processes and the explanations of open initiatives to the participation of local people are not arranged in that way, resembling an accession model in which the "knowledge" is taken to the people; there is no dialogue, there is no participation.

getting back to *Belle Époque* but for bad reasons: that excessive economic dependency on the rubber led Amazônia to chaos with a decrease in that product prices in the international market.[65] If the Carbon and the Environmental Assets markets are not used as an instrument for the region to find two ways of sustainable development, the same past negative outcome may happen once again.[66] But the consequences may be even worse: without appropriate rules, a steep rise of the values may lead to a land purchase race,[67] fact that would evict or marginalize the local populations,[68] and that would increase risks to fraud for obtaining land.

All those issues cannot be dropped off the market regulation proposal, but the studies have been mostly carried out focusing the market functioning. That, over the years, can become a problem, since the external or secondary issues and the interaction of market and its surroundings is essential for its development.

The manner the legal regulation will be arranged may mean the success or the failure of this alternative and the real participation, or not, of the local people. According to what present proposals and studies establish, there are few chances for this effective participation. Most of the suggested forms are based upon existing models in other countries, what can lead to the great financial conglomerates, once more, profiting from Amazônia. That is, obviously, a failed path, designed to failure in few years. Since they do not have local connections, after taking profits on the

[65]Weinstein (1993), regarding the *Belle Époque* period, highlights that: "The fast growth of the main port of the area established a market for some few local industries; it promoted, also, the development of public works and of municipal improvements that transformed Belém in one of the most impressive capitals of state of Brazil. However, it seems to have created an interest larger in non-productive activities, such as the real estate speculation and the import of luxury goods‶. That concentration of activities, which made the collapse of the rubber cycle even worse, with no alternative economic sectors was due to the close monitoring of the rubber elite on the poorest population that was involved in the productive chain and that acted against any development that could transform the extractive economy (Weinstein 1993).

[66]That is the reason why we also understand that international donations for preservation funds, such as the donation of US$ 1 Billion from Norway to the Amazônia Fund—assessed by some scholars (Birdsall et al. 2014)—is not as beneficial as it sounds. This is because the donation of values from other countries is a one-off aid, which causes dependence on the outside, without generating value for the forest, and without causing the necessary cultural change on the value of living forest for the local populations. Governments may need money to keep the forests preserved. However, people living in these places need sustainable alternatives to avoid predating the forest, living with dignity and helping to preserve the environment. An Environmental Assets Market can provide this; international donations, no. Donations without other supports (scientific, medical or technological) may cause dependence of the poor countries, and it may hinder their development (Deaton 2017).

[67]There are, also, bills that seek to allow the purchase of lands for foreigners, almost without limits (Estadão Conteúdo 2017). The content of the proposals does not include that permission when the biomes demand Legal Reserve of 80%, that it is the case of Amazônia, but for being just of a project, that provision can be dropped easily.

[68]As it was seen in the areas where there was mining, for instance, or huge agricultural projects. The population was no longer the owner of the lands and experienced living on activities related to the flow of people attracted by the area. However, that flow of people brought violence, overload of the facilities and of the public services, marginalizing the local populations.

situation or, maybe, if there is not any interest, those huge companies will leave the region, creating a big social and economic empty hole.[69] Thus, what was conceived for this opportunity will not be designed and required: a model of sustainable development, with the decrease of social disparities in Amazônia and in the rest of the country, and at the same time, the forest preservation, an issue of international interest.

8 Conclusions

In this paper, we have tried to discuss several issues related to the Environmental Assets and Carbon Markets as sustainable alternatives for Amazônia (if regulated), in a multi and interdisciplinary perspective. Considering all the gathered data and data analysis, as well as the authors' professional and personal experience, we believe that the environmental issue, in Brazil, is not properly regulated and ruled. Moreover, the success of those markets establishment and their potential of social and economic transformation in the region will depend upon the way the regulamentation will be arranged. It is a valuable and unique opportunity and perhaps the last chance to preserve and value Amazônia Forest. However, if its regulamentation is not well arranged, there is a risk of concentrating, even more, the riches of the region in the hands of large corporations, making, once more, the local people helpless.

Also, we have raised the issue of the Carbon Market as a relevant alternative but not the only one available to Amazônia. We have suggested the Environmental Assets Market regulation, so that there will possibly be a coordinated, intelligent and systematic valorization towards the social, economic and environmental development of the region, free from the dependency of a single activity. That all hinges upon the participation of local people and on the manner the subject will be regulated.

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[69]Such as that seen in the second rubber cycle, in Fordlândia project (Pará), in the exploration of manganese at Serra do Navio (Amapá), amongst other examples.

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