SCALING LAND-BASED MITIGATION SOLUTIONS IN NEPAL

LMT PORTFOLIO AND NARRATIVE DEVELOPMENT

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1. Introduction

This report sets out a broad nation-wide transition scenario for the implementation of four land-based mitigation technologies and practices (LMTs) for the agriculture, forestry, and other land use sectors (AFOLU) sector in Nepal. This transition scenario is based on a number of pieces of research conducted in Nepal between June 2020 (when LANDMARC started) and the end of 2022:

First, we performed an initial scoping of key LMTs in the case study country, Nepal. The scoping exercise included a literature review and formal and informal meetings with relevant stakeholders. The scoping assessment resulted in a long list of broad portfolios of different LMTs that could be viable within Nepal.

Second, we whittled that long list down to a shortlist that contained only LMTs that would be the most relevant for the Nepalese context. We proposed and validated this LMT portfolio through a complementary (policy) literature review, stakeholder interviews (i.e., external validation by relevant country experts and stakeholders) and a workshop.

The workshop identified rice and forest management as two of the most important components of Nepal's LMT portfolio. It delivered a key message about the need for government policy for landbased mitigation technologies that aim to co-deliver improved environmental outcomes, increased soil fertility and enhanced well-being for farmers.

The interviews focussed on an in-depth understanding of LMTs at the local context. They revealed that Nepal does not yet have mechanism to define and identify peatland and that there is a growing policy concern about organic agriculture development in Nepal . The co-design process allowed insights us to remove peatland management from the portfolio and add organic agriculture. The scoping process and results are presented in section 2 of this report (steps 1 & 2).

Third, after the short-listed LMT portfolios were validated, we developed national scaling narratives or storylines for each LMT included in their portfolio. The assessments focus on climate risks, vulnerabilities as well as socio-economic co-benefits and trade-offs associated with upscaling LMTs in the case study countries. The analysis is based on a broad range of information/literature sources, and stakeholder consultations conducted. This process is supported through a risk and impact assessment (i.e., an online survey and workshops/seminars) conducted through LANDMARC tasks 4.1, 4.2 and 5.2. The results of this analysis are a set of LMT narratives which are presented in section 3 of this report.

The research steps are designed to enable an **analysis of the risks and (climate) impacts of scaling up land-based mitigation and negative emission solutions**. As such this report primarily contributes to objectives 2, 3 and 4 of the six LANDMARC key objectives (see Table 1).

Table 1: LANDMARC project objectives.

	Project key objectives
1	Determine the potential and effectiveness of LMTs in GHGs mitigation using Earth Observation (EO)
2	Improve climate resilience of LMT solutions at the local level for large-scale implementation
3	Assess the risks, co-benefits, and trade-offs of scaling up local LMTs nationally
4	Scaling up LMT solutions to the continental and global level to assess the effectiveness
5	Improve current methodologies to estimate emissions and removals for LMTs
6	LMT capacity building and develop new tools and services for decision making

While the results shown in this report represent a mostly qualitative storyline describing the context and impact of scaling up LMTs in a country context, they also enable project partners to proceed with the translation of the outcomes in a manner so that they can serve as direct model input.

Furthermore, these national-level assessments provide a testing ground and empirical basis for the continental, and global assessment of the realistic scaling potential of land-based mitigation and negative emission solutions implemented in Work Packages 6 and 7 of the LANDMARC project (***Objective 4***).

2. Scoping of land-based mitigation and negative emission solutions

2.1 Overview of the potential of LMTs in Nepal

2.1.1 Introduction

The net greenhouse gas (GHG) emissions of Nepal are estimated to be 31.99 MT Co^2-eq per year, equivalent to 0.06% of global emissions (MoPE, 2017). Table 2 shows the mitigation potential of different technologies and practices in Nepal's Agriculture, Forestry, and other Land Use (AFOLU) sectors. The top three potential land-use-based mitigation technologies (LMTs) are reforestation, forest management and rice management. Reliable and consistent data for the analysis of the mitigation potential from the land-use sector in Nepal is lacking. For example, data on upland and lowland rice at the national level are important for estimating the mitigation potential of the rice sector, but such information is not yet available (MoPE, 2017). As such, estimates for realistic potentials, additional costs, biomass impacts, and technology readiness levels (TRL) are not available.

Table 2: Mitigation potential of different technologies and practices in Nepal

LMT Category	LMT	Technical potential, Mt CO_{2e}/y
Negative emission practices-LAND MANAGEMENT	**Land-use (mix of measures)**	
	Reforestation/afforestation	23.23
	Forest management	2.44
	Rice management	2.43
	Peatland restoration	0.02
Total	**Total negative emissions of land management practices in Mton CO_2**	**28.12**

Source: Adapted from Griscom et al. (2017)

2.1.2 Technologies dependent on biomass/photosynthesis

A typical Nepalese farming household relies heavily on traditional biomass, mainly crop and forest residues, for energy resources. which accounts for up to 78% of their total household energy resources (CBS 2011).

Nepal's abundant forest resources and underutilised crop residues give Nepal means that there is a lot of potential for biomass-based negative emission technologies like, for example, Bioenergy with Carbon Capture and Storage (BECCS) and Biochar. However, these technologies are not addressed in Nepal's existing climate change policies.

BECCS

There is great potential for the use of BECCS feedstock in Nepal, with minimal impact on current residue and waste flows. For example, the abandonment of agricultural land is increasing every year, mainly in hilly and mountainous regions (Chaudhary et al., 2020). Plants grown on this abandoned land could be a good source of feedstock for BECCS. Despite this, there is yet to be any formal assessment of BECCS potential in Nepal.

Biochar

Studies on the application of biochar in Nepal are scant; limited to field trials only. But literature shows that biochar has tremendous potential to improve soil properties and soil productivity (Pandit et al., 2017a), whilst simultaneously addressing climate change mitigation. For example, a study of biochar using different crops in Nepal, Schmidt et al. (2017), found that the application of organic biochar based fertilizers increased crop yield by 123% (±76.7%) when compared with the same amount of organic fertilizer without bio-char. Similarly, another study showed that while there was no significant positive effect of biochar application in the first year, maize and mustard grain yield increased by 93% and 134% respectively in the following year (Pandit et al., 2018).

Biochar is particularly important for areas that have problems with acidic soil, as it increases soil PH (Pandit et al., 2017a). However, there is remains a lack evidence of biochar's effectiveness in the all the various soil types and cropping patterns that are found across the different agroecological regions of Nepal (Dahal et al., 2016). The cost effectiveness of biochar at the household level has also not been studied yet, which is essential for understanding its potential for large-scale implementation.

2.1.3 Land management practices

Forestry (Afforestation/reforestation, avoiding deforestation and forest management)

Historically Nepal has seen plenty of deforestation, for the purposes of converting forests to farmland and for the export of timber. The Nepalese government began trying to clamp down on these practicies in 1957, when it nationalised private forests. promulgated stricter laws for forest conservation, and expanded government forest offices to all districts (Gautam et al., 2004). However, these policies could not stop widespread deforestation, loss of bio-diversity and land degradation (Gautam et al., 2004).

In the 1970s, Nepal recognised the importance of communities in forest management, and initiated a community forestry program as a means of both protecting, and effectively utilizing, forests. Under this program, the government allocates a small area of forest land to the local community. Subsequently, a community forest user group (CFUGs) is responsible for the conservation, sustainable use and management of the forest and its products. The revenues from the community forest are spent on pro-poor activities and community forest development. This community forestry program has made Nepal one of the most successful countries in the world in forest management.

About 45% of farming households in Nepal are already members of a CFUG, covering about 1.8 million hectares of community forests (Nuberg et al., 2019). The community forest initiative successfully restored degraded forests, and has become a source of timber and firewood for the members of the user groups (Basnyat et al., 2020). In addition, studies suggest a substantial increase in the density of trees, biomass and carbon stock of trees in the community forests (CF), showing the important role of CF in carbon sequestration (Anup et al., 2018). Since 2015, Nepalese forest policy has acknowledged the important role of communities in forest management, and classified community-based forest management practices into six different types including: i) community forest; ii) leasehold forest; iii) collaborative forest; iv) buffer zone community forest; v) protected forest, and vi) religious forest.

Agroforestry

Agroforestry can improve the livelihoods of farming households, and simultaneously contributing bio-diversity conservation and removal of atmospheric carbon. Nepalese farmers traditionally practice agroforestry as a source for firewood, fodder, and timber. The type of agroforestry practiced depends on agro-ecological zones and altitudes. A common example of agroforestry practice in Eastern and Central hill regions is *Utis* – Cardamom agroforestry (Amatya et al., 2018). This traditional practice includes on-farm tree plantation, tree intercropping, plantation of fodder trees and an integrated farming system (Aryal et al., 2019). Based on surveys, agroforestry in Nepal can be divided into seven categories: i) Agri silviculture; ii) silvopastoral; iii) Agri-silvopastoral; iv) silvo-fishery; v) home gardens; vi) woodlots, and vi) shifting cultivation (Amatya et al., 2018).

Agriculture

The Agricultural sector in Nepal contributes about 40% of national gross domestic product and employs about two-thirds of the population (MoAD, 2014b). Using traditional knowledge and practices, mountain farmers in Nepal use farmyard manure made from forest litter, crop residues and animal manure, as their main source of fertilizer. However, the organic pools in agricultural soils are decreasing due to a shift to more intensive agriculture, bringing with it chemical fertilizers, soil erosion, excessive tillage and removal of crop residues (Dahal and Bajracharya, 2010; Sitaula et al., 2004).

Nepal has acknowledged climate friendly agriculture in its policies and programs for increasing agricultural production and combating climate change. Nepal's overarching agricultural policy – the Nepal Agriculture Development Strategy (2015-2035) (ADS) - aims to reduce emissions from agriculture and scale up carbon sequestration. Nepal has recently submitted its second Nationally Determined Contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), which aims to establish 200 climate-smart villages by 2030 (MoFE 2020). The NDC acknowledges promotion of intercropping, agroforestry, conservation tillage, livestock, and agricultural waste management, which are related to negative emission technologies in agriculture. It has also an ambitious target of increasing soil organic matter in agricultural soils to 3.95% by 2030. Since 1999, Nepal has been implementing a sustainable soil management program in 388 villages. This has been managed through its Agriculture, Forestry and Environment Committee (AFEC) (Shrestha Shiva, 2015; Subedi et al., 2017), which became very effective in participatory planning, resource mobilization, and agriculture service provision (Subedi et al., 2017). The major negative emission technologies in the agricultural sector are tillage and residue management, cover crops, crop rotation and rice management.

2.2 Determining the LMT scope for national-level simulation modelling

This section discusses the set of LMTs that we will study in detail in Nepal. Table 3 summarises the list of possible LMTs in Nepal and indicates those included in the short-list of the LMT portfolio. The main rationales for including the various LMTs in the national-level scaling simulation assessment are presented below.

Table 3: Long-listing of relevant LMTs

LMTs	Specification	Included in the national LANDMARC LMT portfolio
BECCS		N
Biochar		N
Wetlands	Peatland management	N
Cropland	No-tillage and reduced tillage	N
	Rice management (dry-seeded rice with no-till)	Y
	Agroforestry	Y

	Residue retention	N
	Crop rotation	N
	Organic farming	Y
	Cover cropping	N
Grassland	Grassland and range land management	N
Forest land	Avoided deforestation	N
	Afforestation/reforestation	N
	Forest management	Y

After scoping analysis of the LMTs presented for Nepal, we have shortlisted forest management, dry-seeded rice, agroforestry, and peatland management for further scenario scaling analysis in Nepal. The main rationales for this are presented below.

Forest management

Nepal has avoided deforestation and successfully managed forests through ambitious forest sector policies and stricter laws. Nepal is renowned for its success in community-based forest management at the national level. The country's Forest Policy 2015 aims to maintain at least 40% of total land as forests. In Nepal's second NDC this ambition was increased to 45% by 2030 (MoFE 2020).

Agroforestry

Various policies have aimed to develop agroforestry, as it is considered an opportunity for livelihood improvement, employment generation and food security. The forest policy of 2015 recognises the need for research and the extension of various agroforestry systems in Nepal. Similarly, the Forest Sector Strategy (2016-2025) aims to promote agroforestry in existing privately owned farmlands (MOFSC, 2016a) and agroforestry with species of multipurpose trees in the uncultivated agriculture lands (MoFE, 2019). The National Bio-diversity Strategy and Action Plan 2014 also envisaged promotion of agroforestry on public lands for the conservation of biodiversity. Government and several NGOs are promoting small scale private forests as a part of agroforestry systems. Recently, Nepal promulgated the National Agroforestry Policy 2019, which envisages agroforestry as a means of reducing pressure on forests and conserving environmental and biological diversity to develop climate resilience ecosystems.

Dry seeded rice

Rice crop plays a critical role in the food and nutrition security of smallholder farmers. It is a primary source of income and employment for the majority of farmers. It contributes about 20% of Nepal's agricultural GDP and 7% of national GDP (Joshi et al., 2020). Due to the importance of rice production, the Nepalese government has been formulating policies and programmes on increasing the rice production area, and increasing productivity, since the first five year plan of Nepal (1956-1961) (Bhandari et al., 2017). In terms of climate change mitigation, rice substantially contributes (over 17.%) towards methane emissions from the Nepalese agricultural sector (Joshi, 2016).

Dry seeding rice with no tillage is a climate friendly crop establishment method that can reduce methane emissions from rice fields and enhance carbon sequestration. Rice is dry seeded when primed (or pre-germinated) seeds are sown directly in zero-tillage or reduced tillage conditions. This replaces puddling, transplanting, and maintaining standing water. Although dry seeded rice is important for climate mitigation, this crop establishment method is also widely considered to be a means to increase production, reduce labour costs, and cut water consumption.

The rationale for excluding other LMTs from any further national scenario scaling analysis is provided below:

BECCS and Biochar

There are no policies or programs related to biochar and BECCS. The government has not acknowledged the potential for bio-energy crops to replace cereal crops, as it can threaten the food security of the country.

Reduced tillage, harvest residue management, crop rotation, cover cropping

These LMTs are directed at the enhancement of soil carbon sequestration and the improvement of soil properties. Nepal's second NDC includes these LMTs, however, a clear policy on the application of these LMTs is still lacking.

Peatland management

Nepal has been involved in the conservation of wetlands since the signing of the Ramsar Convention in 1987. Currently, about 5% of the total land is categorised as wetlands, covering 750,000 hectares. This includes nine Ramsar, wetland sites of international importance, covering 60,561 hectares (MoFE, 2018a). The Nepal Wetlands Policy has acknowledged the importance of wetlands in climate change mitigation and has focused on the sustainable conservation of wetlands (MoFSC, 2012). However, Nepal has already lost about 5.4% of its total wetland area due to the conversion to crop cultivation (MoFE, 2018a). Studies on Nepalese wetlands so far are scant, and mostly limited to species diversity and ecosystem services (MoFE, 2018a; Poudel, 2009). Among the wetlands, Nepal has not defined and classified wetlands to the level of peatland.

2.3 Discussion on short-listing of LMTs

2.3.1 Land-use change dynamics

Land-use change in Nepal is presented in Table . Forest dominates Nepalese land cover and is well distributed in the Terai, Siwalik, and Himalayan regions. Area under forest increased from 38% of the total land in late 1978/79 to about 40% in 2010, showing the effective efforts of Nepal on forest management and conservation practices. Handing over government-owned forests to local communities through community forestry started in the late 1970s. The size of the CF area increased from 0.048 million hectares in 1986 to 1.8 million hectares in 2010. Similarly, the area of grasslands decreased from 1.7 million hectares in 1990 to 1.3 million hectares 2010. The area under agriculture increased from 3.8 million hectare in 1990 to 4.0 million hectares in 2010. Rice production area has also risen from 1.4 million hectares in 2009/10 to 1.5 million hectares in 2018/19.

Competing land use

Use of agricultural land for urban growth is becoming a serious problem in Nepal. Currently, the proportion of built up areas to the total land area is very low, however, the rate is steadily increasing. Urban growth averaged 3.3% during 1989-1996, increasing to 12.61% during 2011-2016 period (Rimal et al., 2018). To avoid the rapid loss of cultivated areas, the Nepal Land Use Policy (NLUP) 2015 aims to discourage non-agricultural use of agricultural land, keeping land fallow and restricting widespread land fragmentation (MoLRM, 2015).

Table 4 Land use change in Nepal

SN	Types of land use, units	Historical land use (1960-2009)	Recent land use (2010-2019)
1	Agricultural land, million ha	3.75 (1990)	4.04 (2010)
2	Rice production area, million ha	1.41. (2009/10)	1.49 (2018/19)
3	Area under permanent crops, %	0.7 (1962/63)	6.7 (2011/12)
4	Area under temporary crops, %	92 (1961/62)	84.2 (2011/12)
5	Forest, %	38 (1978/79)	40.36 (2010/11)
6	Shrub, %	4.7 (1978/79)	4.4 (2010/11)
7	Built-up area, %	0.22 (1990)	0.34 (2010)
8	Grassland, million, ha	1.7 (1990)	1.26 (2010)
9	Area under community forest, million ha	0.048 (1986)	1.88 (2018)

10	Area under leasehold forest, million ha	0.007 (1998)	0.043 (2018)
11	Area under partnership forest, million ha	0.0067 (2008)	0.00734 (2018)

Source: Adapted from Nepal et al. (2020), Uddin et al. (2018), and MoAD (2020).

Nepal envisages the use of renewable energy technologies in the near future (MoFE, 2019) which can compete with other land uses. Nepal's second NDC aims to generate around 1500 MW of clean energy by 2030, from micro-hydro, solar, wind and bioenergy (MoFE, 2020). The potential of solar energy and wind energy in Nepal is 2100 MW and 3000MW respectively (Poudyal et al., 2019). However, until now, production from large scale solar, wind and bioenergy are very low. For example, Nepal's largest solar farm, Nuwakot Solar Power Station, produces about 1.5 MWh (as of June 2020), which will be increased to 25 MWh in the next few years. In the biomass sector, policy support is limited to energy from agricultural and forests residues. Nepalese policymakers have not considered bioenergy crops on dedicated cropland yet, due to its possible impact on the country's food security. There is a good opportunity for using abandoned agricultural lands and degraded lands for growing bioenergy crops, which will reduce the likelihood of biomass energy competing with other land uses.

2.3.2 Land management dynamics

In the past, land use planning in Nepal had focussed mainly on increasing agricultural productivity. The 8th Five Year Plan (1992/93-1996/97), became a major milestone in land use planning, as it acknowledged necessity of long-term planning to allocate areas for forestry, agriculture, and pastures. The 9th Five Year Plan (1997/98-2001/02) emphasized the utilisation of ecological variation and biodiversity. The National Land Use Policy (NLUP) 2013 aimed to protect agricultural lands to ensure food security. The NLUP was revised in 2015, with a focus on sustainable socioeconomic and ecological development by optimising the use of available land and land resources (MoLRM, 2015). NLUP 2015 classified 11 land use zones: i) agricultural; ii) residential; iii) commercial; iv) industrial; v) mines and minerals; vi) cultural and archaeological; vii) river and lake reservoir; viii) forest; ix) public use and open spaces; x) building materials (stone, sands, concrete), and xi) other zones as required.

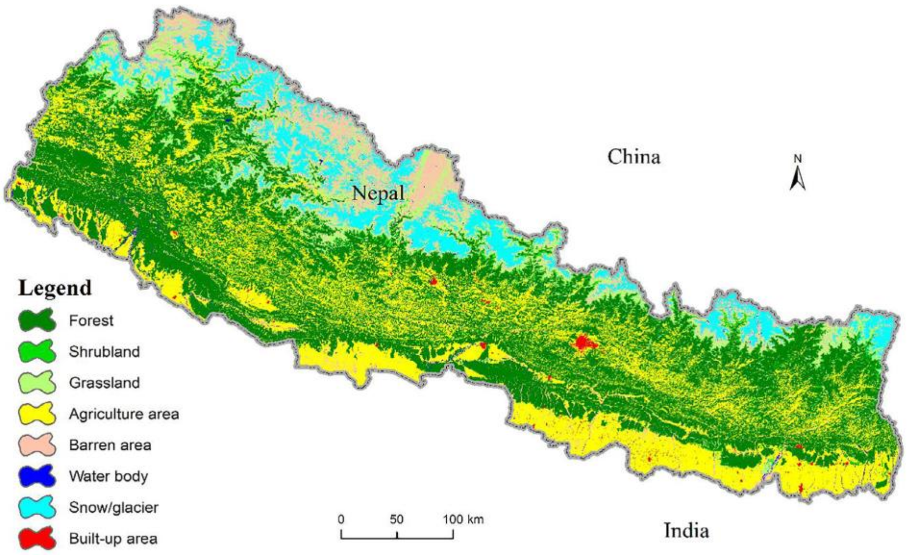

Figure 1 Land-use and land cover pattern in Nepal **Source: Nepal et al. (2020)**

Nepal's climate change policy envisages potential carbon sequestration by forests through: sustainable forest management; agroforestry development in degraded forest areas and riverbeds; and management of forest fires (MoFE, 2019). To implement its ambitious plan of forest conservation, and utilization, Nepal aims to attract funding from global initiatives that seek to reduce emissions from deforestation and degradation (REDD+). This will allow the sustainable management of 50% of Tarai (lowland) forests and 25% of mid hills and mountain forests (MoFE 2020). Nepal has increased forest cover in the past decades, through forest conservation policies that promotes the role of local communities for management and optimum utilization of forests.

The total carbon stock in Nepalese forest constitutes 1054.97 megatons (MoFSC, 2015b). In the forest carbon stock, tree components (live, dead standing, dead wood and below ground biomass), forest soil, and litter and debris constitute 61.53%, 37.80%, and 0.67% respectively. The soil organic carbon content was found to be higher with increasing altitude (MoFSC, 2015b). For example, soil organic matter in forests of physiographic units such as Terai, churia, middle mountain and high mountain were 33.66 t/ha, 31.44 t/ha, 54.33t/ha and 114.03 t/ha respectively (MoFSC, 2015b). A rough estimation shows that Nepal could receive between $20-86 million per year as an incentive from REDD+ initiatives for reducing deforestation and avoiding forest degradation (MoFSC, 2015a).

3. Co-design of LMT narratives

3.1 Introduction

The long and shortlisting were validated by means of both a literature review and stakeholder consultation. Although peatland management was included in the long listing, it was removed from the analysis after discussion with stakeholders, which revealed that it had limited potential in the Nepalese context. Among stakeholders there was a consensus that Nepal lacks a proper classification of wetland to the peatland level, and therefore there are no policies and programs on peatland yet. A workshop highlighted that, instead, organic production has much greater potential in Nepal, due to the possibility of planting export oriented crops including organic non-timber forest products (NTFPs), tea and coffee. As a result of increasing interest from stakeholders,, organic farming has been included in the shortlist of four LMTs that are considered for further analysis within the LANDMARC project. The following sections provide the qualitative narratives of the four LMTs for Nepal.

- Rice management (See section 0)
- Forestry (see section 0)
- Agroforestry (see section 1.4)
- Organic farming (see section 0)

3.2 Rice management: Dry seeded rice

3.2.1 Introduction

Rice is a staple food crop in Nepal. It is cultivated over 1.5 million hectares of land in different agroecological zones, with a production of 5.61 million tonnes per year (FAOSTAT), which is about half (51.6%) of total food grain production (MOAD 2017). Although Nepal has a very small share of global rice production and trade, it plays a significant role in food security and the economy of the country, contributing about one fifth of agricultural GDP (Joshi et al., 2020). Rice is not only a primary source of employment and income but also provides food and nutrition security for the majority of smallholder farmers.

Rice management is considered one of the critical mitigation options in agriculture (IPCC, 2019), which mainly comprise alternate wetting and drying, residue and tillage management, fertiliser management, the system of rice intensification and dry seeded rice. Among them, the dry seeded rice in no-till method is selected for this review, as it is one of the most efficient mitigation options by combining tillage, residue, and water management. No-tillage dry seeding rice involves sowing rice a depth of two to three centimetres directly in untilled soil, using a tractor-drawn seeder. This process replaces the traditional method of raising seedlings in nurseries and manually transplanting them in massively puddled soil. Direct planting of seeds avoids the costs associated with land preparation, nursery bed preparation and transplanting of the seedlings, and requires less labour and water. This crop establishment method is being promoted in Nepal and other Asian countries. Dry seeded rice could be an option for reducing methane emissions from rice fields, increasing organic content in the soil, and simultaneously increasing rice production.

3.2.2 Policy context

Nepal does not have a specific policy covering rice management. The recently submitted Second Nationally Determined Contribution (NDC) mentions that the organic content of agricultural soils will be increased from 2% to 3.5 % by 2030 (GoN 2020). Similarly, Climate Change Policy 2019 also does not mention rice management directly, but it acknowledges the use of climate-friendly technologies in agriculture (MOFE 2020). In the past, the Nepalese Government's National Rice Research Program, and Regional Agriculture Research Centre of National Agriculture Research Council (NARC) conducted on-station and farmer's field trails with dry seeded rice in the Sunsari and Dhanusha districts. Experts from Government and NGOs mentioned that dry seeded rice could be one of the best mitigation options - especially in the Terai (lowland) districts - because of increasing labour costs and water scarcity due to delay in monsoon onset. There is no separate funding for the rice management, however, farmers would be able to get some financial support to buy tractor and zero tiller through the district level agricultural knowledge centres. However, such support is not always available, and are difficult to obtain, in particular by small scale farmers.

3.2.3 Current land use and potential land-use competition

National-level data on the historic and current application of different rice management practices including dry seeded rice is not available. During the discussion, experts projected that despite its potential, very few farmers are currently adopting the dry seeded rice method. Farmers in the major rice-growing districts - including Sunsari, Jhapa and Morang, Bara, Parsa, Rautahat, Dhanusha, Chitwan, Kailali and Kanchanpur - are using the dry seeded rice method. Since the net economic return from rice farming is low, it is likely that other activities with high returns, such as commercial vegetable production and housing development, will increasingly displace rice cultivation in the future.

3.2.4 Climate risks & sensitivities

Unusually early rainfall in the rainy season can limit the use of seed drills in rice fields, restricting the use of this practice. In the wet season, sudden flooding due to high rainfall can decrease crop establishment if it takes place within a few days of seed planting. Farmers mentioned that due to unprecedented high rainfalls in the monsoon season, they prefer to dry seed rice mainly in the spring season rice, when there is very limited rainfall. Similarly, dry seeded rice plants are more vulnerable to damage in high wind conditions than transplanted rice, as the high plant density causes elongation of stems, thinner stem walls and small stem diameters (Wang et al., 2017).

3.2.5 Economic implications

Dry seeded rice can be economically beneficial when compared to transplanted rice. A study in Nepal by Dhakal et al. (2015) showed that the net benefit cost ratio of dry seeded rice was 2.2, compared to 1.6 for transplanted rice. A similar study in India, by Bhullar et al. (2018) found that net return from the dry seeded rice-wheat system was INR 5050 to 8100 per hectare greater than the transplanted rice-wheat system. While many previous studies show similar or greater yield in dry seeded rice methods than conventional rice, yield can vary widely (Kumar and Ladha, 2011) due to a lack of region-specific information on suitable varieties, appropriate soil textures, weed management, no-tillage method and management of residues. Therefore, when compared to conventional rice cultivation, dry seeded rice can be more prone to yield losses due to inappropriate management practices, unsuitable soil, weed infestations and climatic stresses (Xu et al., 2019). Dry seeding also attracts birds immediately after sowing, which may result in poor crop stand and a corresponding loss of yield.

3.2.6 Co-benefits and trade-offs

Co-benefits

Food security: Dry seeded rice increases food availability and nutritional benefit for farmers, and their families. Dry seeded rice requires the timely sowing of rice which increases the possibility of following crops, such as wheat, being planted on time, ensuring production at an optimum level (Kakumanu et al., 2018). Delayed planting of the following crops can, for example, reduce wheat yield by 60 kg per hectare per day (Hussain et al., 2012).

Economics: Dry seeded rice is important for farmers with low resources, as it can provide similar or greater yields as conventional rice with less input (Laing et al., 2018). This is increasingly important, as labour costs for rice production have tripled in recent years (Liu et al., 2014). Dry seeded rice can reduce the total labour required by up to 66%, while crop establishment costs can be reduced by 75%, depending on the season, location and management practices (Kumar and Ladha, 2011). The net return from dry seeded rice could be 1.49 as compared to 1.14 in conventional rice (Rana et al., 2014).

Environment: Dry seeded rice can reduce methane emissions and save freshwater. Methane emission reductions from dry seeded rice fields range from 33% to 37% (Pathak et al., 2013; Singh et al., 2009). Rice crops use about 24 to 30% of the world's freshwater resources, and increasing water scarcity is threatening the sustainability of irrigated rice production (Bouman et al., 2007). Studies show that 17 to 22 million hectares of irrigated rice production area in Asia will face water scarcity by 2025 (Tuong and Bouman, 2003). Dry seeded rice can reduce water consumption by 30 to 55%, which will have a positive impact on hydrology and water use at larger spatial scale levels (Pathak et al., 2011; Tabbal et al., 2002).

Soil quality: Untilled dry seeded rice helps to maintain crop residue on the soil surface, which can improve soil quality through enhanced nutrient recycling and soil organic carbon sequestration. When seed drilling with dry seeded rice, residues of previous crops are retained, adding organic matter that improves soil pH, soil organic carbon, nutrient content, and microbial activity. A study by Gupta Choudhury et al. (2014) shows that soil in dry seeded rice had a higher capability to hold the organic carbon in the surface (11.57 g Kg per soil aggregates), and increased water-stable macroaggregates by 51.13%.

Trade-offs

Methane and nitrous oxide (N_2O) are potent greenhouse gases and have an inverse relationship to each other when it comes to dry seeded rice. Methane emissions are substantially reduced when dry seeding rice; however, emissions of nitrous oxide can increase. Due to the aerobic condition of the soil, under moderate soil moisture conditions, and especially in the high nitrogenous fertiliser application areas, nitrification and denitrification processes produce nitrous oxide (Kumar and Ladha, 2011).

3.2.7 Risks associated with scaling up

Small farmers need financial support to adopt dry seeded rice techniques. Experts mentioned that the lack of government policy support for dry seeded rice means the pace of adoption by farmers is very slow. For example, farmers were not receiving grants or subsidies from the government, which are often needed for purchasing tractor-drawn seeding machines.

Water management of rice fields is a key aspect to consider as soil drainage and water retention capacity constrain the adoption of dry seeded rice at a large scale. This means dry seeded rice cannot be applied in Nepal’s lowland fields, as they have low or no drainage.

Lack of technical support for farmers also constrains dry seeding rice. Ideally, farmers should gain expertise in sowing and weed control techniques, which requires at least two years of continuous technical support. Weed control is more complicated with dry seeded rice than with other conventional methods, which can result in lower yields. Stakeholders reported lower yields of dry seeded rice, but this might be due to the inappropriate weed management. A lack of proper knowledge amongst farmers can result in poor crop establishment and high weed infestation. The resulting yield reduction deters farmers from adopting the technology.

3.2.8 Research gaps

Reliable data on the status of dry seeded rice and other rice management practices is limited, and explicit analysis of the mitigation potential of this technology at the national, regional, and global levels is still lacking. Moreover, dry seeded rice with no tillage can increase soil carbon sequestration. However, the role of no tillage dry seeded rice in carbon sequestration has been, as yet largely overlooked.

The performance of dry seeded rice depends on the set of management practices adopted by farmers, which may vary in different agro-ecological and socio-technological conditions. The development of complete sets of technological and management solutions, with a focus on the development of rice seeds optimised for dry seeded cultivation and weed management practices, would be crucial in the future. Similarly, the extant literature on dry seeded rice based on field experiments and documentation of farmers' opinions on the challenges of dry seeded rice technology is limited. Future research on understanding farmers' views is critical to guide external interventions to scale up the technology.

In Nepal, women play a vital role in rice cultivation, contributing about half of the required labour. Women are mainly responsible for sowing, transplanting, weeding, fertiliser application, harvesting, and seed storage, while men are responsible for land preparation and irrigation. No tillage dry seeded rice replaces rice nursery, land preparation, and transplanting. This can reduce the heavy drudgery on women, who may work as unpaid labour (Khan et al., 2016). Future research in changing gender dimensions of rice farming due to dry seeded rice would be very valuable.

3.3 Forestry

3.3.1 Introduction

Afforestation/reforestation and forest management are negative emission practices in forestry, which remove carbon from the atmosphere and store it safely above ground (in trees) and below ground (in living biomass, litter, and soil). In Nepal, forests are a source of fuelwood, timber, and fodder for the forest dependant households. This means the forestry sector plays an important role in the Nepalese economy. Existing forests in Nepal are divided into seven types: i) community forests; ii) collaborative forests; iii) leasehold forests; iv) private forests; v) religious forests; vi) protected forests, and vii) protected areas (Table 4). Among them, community-based forests (which includes both community forests and leasehold forests) are popular due to the resource contribution they make to poor households in rural areas.

3.3.2 Policy context

The Nepalese Forest Policy 2019, Nepal Climate Change Policy 2019, Second Nationally Determined Contribution (NDC) 2020, Forestry Sector Strategy (2016 -2025), National REDD+ Strategy (2018-2022), and the Community Forestry Development Guideline 2014 are the major national policies aiming to conserve forests and reduce the drivers of deforestation and forest degradation. Forest Policy 2019 aims to promote forest conservation, by securing incentives from global initiatives for reducing deforestation and degradation. Nepal Climate Change Policy 2019 focuses on sustainable forest management to increase forest carbon (MoFE, 2019). To avoid forest degradation and depletion, it also has provisions to reduce drought, wildfire, the spread of invasive alien species, forest pests and diseases. Similarly, Second Nationally Determined Contribution (NDC) 2020 aims to maintain 45% of the total area of the country under forest cover by 2030. Forestry Sector Strategy (2016 -2025) aims to enhance forest cover by at least 10% in the 10 years period 2015 to 2025 (MoFSC, 2016b).

Likewise, Community Forestry Development Guideline 2014 aims to conserve forests and improve livelihoods through the active participation of local communities and inclusion of marginalised communities and women. National REDD+ Strategy (2018-2022) aims to enhance the carbon and non-carbon benefits of forest ecosystems to the overall prosperity of the people (MoFE, 2018c). These policies are focused on forest and biodiversity conservation and are not favourable to commercial harvesting and the forest products trade.

At the central level, the Ministry of Forests and Environment (MoFE), formulate policies and plans, and coordinates and monitors forest management activities. The Department of Forests (DoF) plays an important role in drafting forests policy and negotiating with stakeholders. At the grassroots level, Community Forest User Groups (CFUGs) and the Collaborative Forest Management committee are the main sector stakeholders. The Federation of Community Forest Users Nepal (FECOFUN) which represents 22, 266 community forest user groups, the Association of Collaborative Forest Users Nepal (ACOFUN) and the Community-Based Forestry Supporter's Network, Nepal (COFSUN) are the key networks playing a direct role in the implementation of community and scientific forest management in Nepal. These networks of forest user groups have become a strong political force for forest conservation which advocate for protection of forest users' rights in the natural resource governance. Similarly, local governments are responsible for allocating finance at the local level and coordinating forestry programs.

The Nepalese Government provides support for community-based forest programs through its offices at regional and district levels. Attracting international funding for REDD+ programs to reduce emissions from deforestation and forest degradation has been a good opportunity for Nepal. Currently, Nepal has been implementing two REDD+ programs: the Forests for Prosperity Project and Emission Reduction Programme. The Nepalese Government received financial support for the Forests for Prosperity Project from the World Bank, for promoting the private sector in forests and improvement of private sector forests. Similarly, with support from the Forest Carbon Partnership Facility (FCPF) of the World Bank, the Emission Reduction Program aims to protect about 2.4 million hectares in the Terai region.

3.3.3 Current land use and potential land-use competition

Forest cover decreased from 6.40 million hectares in 1964 to 4.26 million hectares in 1994 – meaning Nepal lost 2.14 million hectares of forest to shrubland or other land use (MoFE, 2018b). Recent data shows that today forests cover about 5.96 million hectares, which is 40.36% of the total area of the country (FAO and UNEP, 2020). Most of the forests area are located in the middle mountain region (37.8%) followed by High mountain and High Himal (32.2%), Churia (23%) and Terai (6.9%) regions (DFRS, 2015). The total forest carbon stock in Nepal is around 1.05 million tonnes. Trees, forest soils, and litter and debris constitute 61.53%, 37.8%, and 0.67% of this amount respectively (DFRS, 2015).

The different types of forests, based on management regimes, are presented in Table 4. Altogether 2.90 million farming households in Nepal are already members of 22,266 CFUGs, covering 2.23 million hectares of forest. Similarly, 864,015 households are involved in 30 collaborative forests, covering 76,012 hectares. Leasehold forests are mostly focused on poor households, engaging 71,753 households in 43,317 hectares of forest. Many of the forests are managed by local communities, and the area covered by private forests is very low.

Table 4 Different types of forests in Nepal

SN	Type of forest	Number	Area, ha	Households
1	Community forest	22,266	2,237,670	2,907,871
2	Collaborative forest	30	76,012	864,015
3	Leasehold forest (pro-poor)	7,484	43,317	71,753
	Leasehold forest (commercial)	22	640	
4	Private forest	2458	2,360	
5	Religious forest	36	2,056	
6	Protected forest	10	190,809	
7	Proposed protected forest	6	137,833	
7	Protected areas	10	34,419	

Source (DoF, 2017)

Expansion of agriculture and infrastructure is the main land use developments that cause deforestation and forest degradation in Nepal (MoFSC, 2014). Expansion of infrastructure includes road construction, hydropower, mining, airports, urbanisation, resettlement, industrial area, and transmission lines. Similarly, agricultural activities that affect forest areas are squatter (Sukumbasi) settlements in forests, gradual encroachment of existing cultivators and shifting cultivation.

3.3.4 Climate risks & sensitivities

In general, climate risks factors to forests include drought and fires. Forest fires are becoming more common in Nepal, but do not receive much attention from policymakers, because there are very few human casualties from wilfrires. Wildfires mostly occur in government forests, and appear to be the result of deliberate attempts to increase the grass inside the forest, which means there is no long term and pervasive impact of forest fires. Forests are also affected by increasing river floods in the Terai region, and landslides in hills and mountain regions. The increase in river floods and landslides in the future could damage a large forest area in the long-term.

3.3.5 Economic implications

Estimates of the economic benefit from forest management vary widely. A study in Nepal showed that the net economic benefit from community forests ranged from $ 4,814 to $7,994 per community user group, which is $ 152 to $29 per hectare of forest (Pandit et al., 2017b). Similarly, K C et al. (2015) reported that the benefit-cost ratio of community forests is 3.04. A report on the benefit-cost of different types of forests in different physiographical regions (Table 5) suggests that the income from the collaborative forests is highest, followed by community forests in Terai, Siwaliks and Mid hills. The net annual benefit is lowest in protected forests. Similarly, annual implementation costs of forests are highest in community forests of in mid-hill regions, followed by community forests in Siwalks and Terai regions. Implementation cost is lowest in the protected forest. Annual changes in stored carbon are highest in community forests and lowest in collaborative forests.

Table 5 Annual costs and benefits from forest management and average annual change in carbon

Forest	*Annual forest management cost, USD/ha*	*Net annual benefit, USD/ha*	*Annual change in tonnes carbon per hectare*
Community Forest (Mid hills)	*31.56*	*211.44*	*1.96*
Community Forest (Siwaliks)	*26.26*	*228.74*	*1.84*
Community Forest (Terai)	*8.23*	*504.77*	*0.18*
Collaborative forest management	*7.56*	*1107.44*	*0.01*
Protected forest	*6.78*	*85.22*	*0.35*

Source (Rai et al., 2018)

3.3.6 Co-benefits and trade-offs

Co-benefits

Bio-diversity: Protecting or restoring high carbon forests is directly related to the conservation and promotion of biodiversity (Asbeck et al., 2021). However, some forests with high biodiversity might have low carbon sequestration potential (Buotte et al., 2020). Besides this, forests are important in restoring and conserving unprotected and degraded lands (Soto-Navarro et al., 2020).

Water quality: Forest cover is important in supplying watershed services. Studies suggest that an increase in forest cover is positively related to the quality of freshwater (Ovando and Brouwer, 2019; Price and Heberling, 2018).

Economic: In Nepal, forest management is related to the wellbeing of the local community and the wider society, as the livelihoods of most of Nepal's farmers depend on forests-based resources, including fodder, fuelwood, timber, and leaf litter. However, the benefit communities receive depends on the context of forest management. For example, community forest users can get timber to build new homes, and receive a quota for collecting fodder and fuelwood from dead trees, old trees, and branches. In collaborative forests, on the other hand, members can get much less fodder and fuelwood (25 – 35 %) (Rai et al., 2017), as it covers users from much larger areas. They also create jobs mainly for forest rangers(K C et al., 2015). Collaborative forests are much larger than community forests, which can create additional jobs for unskilled labours, accountants and technicians (GoN, 2016).

Social: Most forest management in Nepal, including the management of community forests, leasehold forests and collaborative forests is based on collective action, where each member contributes to the management of forests, including meetings, forest fencing and thinning. Community forestry is known for reducing gender and social gaps (Giri and Darnhofer, 2010), as they increase participation of marginalised communities - including women, Dalits and Indigenous groups - in decision making.

Trade-offs

Reduced biodiversity: Economic incentives for carbon sequestration through reforestation or afforestation programs can promote a monoculture of high-value trees, leading to negative impacts on biodiversity. Moreover, conflict with biodiversity aims can occur if the forest policies and programs choose trees with high carbon sequestration and high timber values, but with lower biodiversity value (Caparrós and Jacquemont, 2003). In Nepal, the probability of a reduction of biodiversity from forestry programs is low, as current programs mostly focus on forest conservation rather than achieving maximum economic benefits through commercial production and harvesting.

Threat to people's livelihoods: Too much emphasis on carbon sequestration and forest conservation can negatively affect local livelihood practices. In Nepal, the introduction of community forestry and protected forest areas after the 1970s curtailed local and Indigenous peoples' traditional practices of access to and control of the forests. As the access to forest resources were restricted, many transhumance herders could not continue their traditional practices (Banjade and Paudel, 2008).

3.3.7 Risks associated with scaling up

Since the inception of the concept of community forestry in the 1970s, the government is handing over forest areas to the local communities for forest management. Nepal has already promoted different forestry programs at the national level, including programs for community forests, collaborative forests, and leasehold forests. Experts mentioned that there is a high regulatory risk in forest management in Nepal. For example, Nepal's government introduced Forest Regulation 2079, which is being opposed by the Community Forest User Federation. The forest user committees say that with these new regulation, the Nepal government is centralizing control over the management and utilization of forest resources.

Interview with experts showed that private or family forests have not improved, as the current forest policy is not favourable for the trade of timber from the private forests due to legal and administrative constraints. Private forest owners need to go through a cumbersome process of documentation and contacting district forest offices for validation and verification of forest products and get the harvesting permit for selling forest products. In addition, they also need to pay royalties to the government. All these tedious processes are hindering the commercial trade of harvested woods from the private forests.

3.3.8 Research gaps

The selection of suitable tree species is important for establishing new forest planting areas, for increasing carbon and income from the harvested tress. However, the identification and recommendation of trees based on their suitability at the local micro-climatic level is lacking. Experts mentioned that there is a belief that forests protect against landslides. However, whole forests have been known to be pulled down during landslides as the actual load bearing capacity of Nepal's geographical structure is still unknown. Further research is needed, to understand load bearing capacity of forests in the local contexts.

Another understudied aspect of the Nepalese forest sector is the contribution of forests to carbon storage. Stakeholders pointed out that it is also important to have a local allometric equation to better estimate forest biomass, however, Nepal does not have this yet. There are also limited studies on how local communities can be involved in carbon accounting. Similarly, there are few studies on the value chain of the harvested wood products, and their impact on local livelihoods.

1.4 Agroforestry

3.4.1 Introduction

Agroforestry is a sustainable land management practice in which trees and crops are grown together. Agroforestry is a traditional practice in Nepal, as the planting of fruit and fodder trees in edges of terraces of croplands is commonly practised in the hill and mountain regions. Agroforestry can sequester significant amounts of carbon and simultaneously increase agricultural production, provide fodder and litter for livestock production, and fuelwood for household energy needs. In the Nepalese context, high-value non-timber forest products, mainly medicinal and aromatic plants, are also a component of agroforestry. Therefore, in the hills and mountain regions of Nepal, agroforestry is also considered a way of improving the livelihoods of small farmers.

3.4.2 Policy context

Several policies have acknowledged the contribution of agroforestry in agricultural households and fostered an enabling environment for agroforestry development. The Forest Act 1993 aims to promote agroforestry as a method of forest conservation and development. Similarly, the Forest Sector Strategy (2016-25) aims to promote agroforestry in barren lands and privately owned land. Nepal is the second country in the world to formulate a national agroforestry policy, the Agroforestry Policy (2019). Nepal's 20-year agriculture development plan, the Agriculture Development Strategy (2015-2035) recognises agroforestry as a tool for achieving environmental sustainability, increasing food security, and improving the livelihoods of resource-poor farmers. It envisages a pro-poor approach in agroforestry to restoring degraded lands and increasing productivity of low productive agricultural lands. Likewise, the Climate Change Policy 2019 has a provision for the promotion of agroforestry with multipurpose trees in abandoned agricultural land. Nepal's Second Nationally Determined Contribution 2020 has provision for agroforestry through afforestation or reforestation of public and private lands. Nepal's current 15th Five Year Development Plan (2019 – 2023) aims to promote agroforestry in barren and marginal lands of hill regions with multipurpose trees and high-value products. Recently, the Ministry of Forests and Environment (MoFE) published the Model Agroforestry Program Implementation Procedure 2021, which supports individual farmers or farmer groups to adopt agroforestry practice in plots of land larger than ten hectares. It does this by providing grants, saplings of medicinal plants, fodder trees, non-timber trees and multipurpose tree species in the marginal lands.

3.4.3 Current land use and potential land-use competition

There is no record of current land-use area or future projections for agroforestry. Since the Nepalese government has a strategy of utilising barren and marginalised lands, and degraded forests and land below electricity transmission lines (MoFE, 2021), there will be less competition with the existing forest and agricultural land. In recent years, since land abandonment is increasing in mountain regions (Chaudhary et al., 2018; DFRS, 2015), there is the potential of an increase in agroforestry in abandoned agricultural land.

3.4.4 Climate risks & sensitivities

Fires in the agroforestry plantations is not common in Nepal, since most of the forest fires are deliberate attempt by people living in the areas. However, extreme climatic events including drought, floods and hailstones are important climate risks that affect commercial agroforestry practices in Nepal. These extreme climatic events mainly affect agroforestry crops and small trees rather than large agroforestry trees. Hailstone is mostly common in the mid-hill region, while flooding affects terai (southern plain) region. While there is no reliable data, but stakeholders believe that the frequency and intensity of hailstone is increasing in the mid hills' regions.

3.4.5 Economic implications

The purpose of agroforestry is to maximise economic benefit from both agriculture and forest. Hence, much of the new agroforestry practices are focused on high-value products or medicinal plants. Neupane and Thapa (2001) found that higher benefit from sericulture-based agroforestry (USD 1582/ha) than the non-traditional system (USD 804/ha). The benefit-cost ratio was 2.5 in the agroforestry intervention as compared to 1.8 without intervention. Similarly, a study by Cedamon et al. (2019) found that different agroforestry practices can provide additional revenue. The study showed that if commercial harvesting of trees is allowed, revenue will be increased by EURi1 479 to 2,022 per farmer. Net economic return is focused more on market-oriented agroforestry practices such as tomato (EUR 12,245), cardamom (EUR 1,923), banana (EUR 1,813) , round chilli (EUR 1,201) and ginger (EUR 1,124) (Pandit et al., 2019).

3.4.6 Co-benefits and trade-offs

Co-benefits

Food security*:* Food security is an important function of agroforestry in Nepal. A study by Cedamon et al. (2019) showed that, among the different agroforestry practices, planting high yielding fodder trees for commercial goat production and market-oriented timber production are agroforestry interventions that increase food security for rural households. A similar study by (Pandit et al., 2019) showed that after the implementation of agroforestry projects the percentage of food sufficient households increased from 52 to 69.

Biodiversity: Agroforestry in farmland can be a solution for biodiversity conservation, providing a reservoir of genetic diversity for tree species. A study of traditional agroforestry practices in Nepal showed that the species diversity index is higher with medium and large landowners (Acharya, 2006). Also, the farmland of upper castes *Brahmin/Chettri* area has large species diversity than those of the lower caste *Dalit*s (Pokhrel et al., 2015).

Trade-offs

Financial: Selecting agroforestry systems with high carbon sequestration capacity could provide less return to the farmers (Middendorp et al., 2018; Tschora and Cherubini, 2020). Therefore, it is important to optimize the benefit for farmers and carbon sequestration capacity of agroforestry practices.

[1] 1€ = 131.55 NPR

3.4.7 Risks associated with scaling up

Nepal is globally 2nd in formulating national agroforestry policy for increasing the productivity of agriculture, forestry, and livestock sectors. However, Nepal lacks proper policy and therefore, subnational (provincial level) and local policies for aligning with national agroforestry policy is lacking. Farmer and private sector expect support and subsidies from the government due to the required high initial investments and technical support. But there is no there is no proper political commitment yet forming the main barriers for small farmers. There is also a lack of clear policy in agroforestry, in particular the commercial trade of the harvested wood from agroforestry, which limits the scaling of agroforestry at the national level.

Although Nepal has ample agroforestry policies, there is a lack of proper technical knowledge alongside transfer mechanisms to small farmers. Although there is a consensus that high-value crops or non-timber forest products in agroforestry systems are important in improving the livelihoods of small farmers, there is limited detailed analysis of such products, and without proper market development, they are less likely to be adopted by small farmers.

3.4.8 Research gaps

The size of the return from agroforestry practices is dependent on the type of trees and crops. However, the agro-ecological site-specific suitability of different agroforestry systems has not yet been studied in detail. Traditional or subsistence agroforestry systems, which includes home garden, crop with fodder trees, is widespread in Nepal, mainly in mid-hills and mountain regions. Economic analysis of market-oriented intervention approaches needed to be studied further. Only a few percentages of farmers are engaged in market-oriented agroforestry, including medicinal and high-value crops. Studies on successful cases of agroforestry need to be carried out, to guide and support the further promotion of agroforestry at the national level.

3.5 Organic Farming

3.5.1 Introduction

The development of organic agriculture was a response to the environmental pollution caused by intensive agriculture, which uses an excessive amount of mineral fertilisers and pesticides (Kwiatkowski et al., 2020). Growing consumer demand for organic farming has received attention from researchers, policymakers, environmental NGOs, and farmers in both developing and developed countries. At present, the market for organic produce is around 106 billion Euros, with organic production taking place in 187 countries, by 3.1 million producers over 35.1 million hectares (FiBL, 2021). Nowadays, although the impact of organic farming in climate change mitigation is contested (Leifeld et al., 2013), it is increasingly recognised as a major tool for climate change mitigation due to its huge capacity to store carbon in agricultural soil. Organic soil amendment increases carbon sequestration, enhances long term organic pools, reduces greenhouse gas emissions and improves the resilience of the agroecosystems (Tautges et al., 2019). In developing countries, including Nepal, organic farming is increasingly popular, as farmers can get premium prices, resulting in an improvement to their livelihoods (Karki et al., 2011).

3.5.2 Policy context

Organic agriculture in Nepal is well embedded in national agricultural policies. Several policies have acknowledged the potential of organic agriculture in the overall development of the agricultural sector in Nepal. The Agriculture Development Strategy (2015-2035) aims to promote organic branding for value addition and targets an increase of organic matter in agricultural soils to 4% by 2035 from a baseline of 1% in 2010 (MoAD, 2014a). Similarly, Nepal's Second Nationally Determined Contribution 2020 has a provision to promote soil organic matter to 3.5% by 2030. The current 15th Five Year Development Plan aims to increase the share of organic farming in agricultural trade by promoting the involvement of farmer groups, cooperatives and the private sector (NPC, 2020). Recently, Nepal's Ministry of Agricultural and Livestock Development (MoALD) formed a high-level committee with multiple stakeholders, including NGOs, the private sector, farmers, to formulate an organic agriculture strategy. The government also formed a high-level task force to develop a proposal for a holistic program to guide the development of organic farming at the national level.

At the regional level, the government of Karnali province recently declared its ambition to become the 'Organic Karnali Province'(GoKP, 2018). The Policy and Programme of the Government of Karnali Province for Fiscal Year 2018/19 states that support for organic food production and marketing will be initially promoted in five mountain districts and five other districts. For this, the Karnali province has a slogan, 'Increased organic farming for prosperous Karnali'. At the district level, the Ministry of Agriculture and Livestock Development (MoALD) provides grants for organic fertiliser, which is operated through Organic Fertiliser Subsidy Program Implementation Procedure 2019 (MoALD, 2019). MoALD is also implementing pilot programmes for organic farming in 12 districts (Gauchan et al., 2020).

3.5.3 Current land use and potential land-use competition

In much of the remote hill and mountain regions, chemical fertiliser and pesticides are not generally used. During a discussion with local experts, it was estimated that around 26% of farmland is organic in Nepal, which can be referred to as organic by default. However, the area under organic certification is very low. Currently, about 9,361 hectares of agricultural land is under certified organic production (FiBL, 2021), which is negligible in comparison to the total cropped area of 2.83 million hectares. Organic certification is mainly applied to export-oriented crops including organic tea, coffee, and high value aromatic and medicinal plant products. Due to the lack of awareness of the need for organic certification, and low technical capacity to certify and the expensive certification system, farmers usually do not opt for organic certification. There are no future projections for organic farming development in Nepal. Due to increased international and national consumer demand, and increased government interest in the promotion of organic production, organic production will be increased in future. However, the pace of increase in organic production will be low, as current policies favour conventional agriculture by providing subsidies and grants for inputs, including chemical fertilisers.

3.5.4 Climate risks & sensitivities

Similar to conventional farming, flood, drought and hailstones are important climate risks that affect crop production from organic farming. Experts mentioned that crop failure in organic farming due to these extreme climatic events deter farmers from adopting organic farming, as it can incur low returns. Experts mentioned that although it is difficult to highlight type of climate risks in the organic farming is increasing as the level of crop damage by the extreme climatic events such as high rainfall (floods).

3.5.5 Economic implications

Farmers can receive greater economic benefits from the organic farming in comparison to conventional farming; however, benefits vary widely depending on crop type and region. A study on organic tea in Nepal by Karki et al. (2011) found that observed economic benefit is one of the key reasons to switch to organic production. For example, a certified organic farmer can get a price that is 20% higher for fresh coffee and cherry when compared to non-certified smallholders in the conventional market (Kattel, 2017). Similarly, a study of rice farmers in Nepal showed that organic rice production has a benefit-cost ratio of 2.2 in organic rice production, as compared to 1.9 in conventional rice production (Sapkota et al., 2021). A similar study in carrot production found that the benefit-cost ratio was higher (1.52) for organic carrots than the conventional carrot (1.44) (Adhikari, 2009).

3.5.6 Co-benefits and trade-offs

Environmental co-benefits

Organic farming has a lower environmental impact than conventional farming. A meta-analysis of European research by Tuomisto et al. (2012) found that soil organic matter was 7% higher in organic farms than conventional farms. Also, it was found that the rate of nutrient losses including nitrogen leaching, ammonia, and nitrous oxide emission, were lower in organic farms. A similar meta-analysis by Rahmann (2011) showed higher biodiversity in organic farms than conventional farms. Likewise, energy consumption is much lower in organic farms (38%) as compared to conventional farms (Gündoğmuş, 2006; Koesling et al., 2017).

Trade-offs

Yield loss in organic farming is a major trade-off, that can reduce income of farmers. A meta-analysis by (Gong et al., 2022) to quantify the trade-offs between crop yield and biodiversity in conventional and organic farming showed that organic farming increased biodiversity by 23% but also decreased the yield. Similarly, Seufert et al. (2012) found that organic farming can have similar yields to conventional farming only if they follow good management practices.

3.5.7 Risks associated with scaling up

Despite Nepalese farmers showing increasing interest in organic farming, it is difficult to upscale at the national level due to the challenge of market development and lack of knowledge in soil nutrient management. Certified organic farming is not generally practiced due to the lack of infrastructure and markets. The government continues to provide subsidies for chemical fertilisers, which lowers prices. On the other hand, commercial production and trade of organic fertilisers are also not well developed and organic fertilisers are often expensive and are less reliable in quality. Moreover, internal markets for organic farming are growing, but are not well developed. People tend to buy organic foods by ‘trust’, as most of the products are not certified. While some farmers are receiving good returns due to direct selling, due to the involvement of several intermediaries, most farmers are not getting an appropriate premium price from the organic production except in export-oriented organic products.

3.5.8 Research gaps

Consultation with stakeholders showed that conventional farmers believe that switching to organic farming means incurring a loss. This is because there is not much local economic analysis of the process of switching to organic farming in different agro-climatic contexts of Nepal. A comparative study exploring the economic profitability of different organic products in different agro-ecological regions, with distinct market features, would be useful. Despite an increase in market demand for the export oriented organic crops including tea, coffee and herbs (Karki et al., 2011), detail studies on international marketing potential of these crops is limited.

4. Conclusions

We identified a portfolio of land-based mitigation technologies and practices (LMTs) in Nepal - forest management, agroforestry, organic farming and rice management. To better understand the realistic future impact of these LMTs on the economy, resource utilization and environment, scaling scenarios for these LMTs need to be optimized. The outcome depends on how Nepal translates these LMTs into policy, and how these polices are implemented in local and sub national levels.

During the interviews and workshop, the stakeholders pointed out that appropriate policy implementation and technical and financial support -- which are crucial for scaling up these technologies -- are lacking. Therefore, further research on better implementation of LMTs is needed to provide appropriate technical support to the farmers. Future strategies should include local capacity building for appropriate research and extension systems. Additionally, a financial incentive mechanism needs to be developed for the farmers and landowners as a reward for mitigation. If implemented sustainably, the LMT portfolio could be a best option for co-delivering improved climate mitigation, increased soil fertility and enhanced well-being of farmers and landowners.

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ANNEX III

OVERVIEW OF INPUT TABLES FOR SIMULATION MODELLING PER COUNTRY

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10.Nepal

10.1. Qualitative storylines by identifying measures and actions from interviews for each LMT scenario

Nepal LMT 1: Afforestation/reforestation and forest management

	1. Wishes of the future for the LMT: include timing	2. How to achieve the wishes • Who pays? • Who implements?	3. Target/Actions • Policies, strategies, projects
Scenario 1: "Fully green forests" (Ideal scenario) **Stakeholder representations:** Federal and provincial government, Indigenous and local community, NGOs, (provincial/national)	• All degraded forests reforested, full afforestation capacity achieved, completely avoid deforestation by 2050	• Government supports to restore and manage forests • Local communities manages forests • International carbon markets	• New forest policies by 2030 that promotes forest management and new forest development • Reducing ambiguity in national and federal government policies • Prevent forest encroachment and land use change • Strengthen institutional capacity
Scenario 2:"Midway ambition" **Stakeholder representations**: Provincial government, NGOs, communities	• Only half of degraded forest restored, half of the afforestation capacity achieved, but complete avoidance of deforestation by 2050	• Government grants • Local communities	• National campaign - One household one tree, one village one forest, one town one park • New regulation by 2030

Scenario 3: " Prosperity through forests" **Stakeholder representations**: Federal government, private companies	• Increasing in government revenue from forests • Policy shift from forest conservation to commercialisation of forest , that creating friction with the interests of local communities. • Only 25% of the target achieved by 2050	• Companies pay and implement	• Review of current forest policy started to lease large forests for private sector. • New regulation by 2030

Nepal LMT 2: Organic farming

	1. What are the wishes of the future for the LMT • include timing	2. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	3. Actions • policies, strategies, projects
Scenario 1: "Fully Organic Nepal" **Stakeholder representations:** Local farmer cooperatives, environmental NGOs, National and provincial governments	• Complete organic production by 2050 • Import substitution of inorganic fertilizers • Reduce extensive use of chemical fertilizers	• Government grants and subsidies • Contract farming from companies	• Pilot projects • New regulations by 2030 to promote organic farming and development of organic certification • Promote participatory guarantee system

Scenario 2: "Midway ambition" **Stakeholder representations**: Provincial government, industry,	• Convert most croplands to allow new business opportunities and protect environment by 2050	• Government subsidies • Voluntary carbon markets	• Pilot projects • Regulations by 2030
Scenario 3: "Fully Organic Karnali Province" **Stakeholder representation** **Provincial and local governments, farmer cooperatives, industries**	• Fully organic Karnali province • 25% of other provinces organic by 2040	• Government subsidy • Farmer cooperatives implement	• Karnali province bill of Organic agriculture bill 2018 • One local government one model organic farm • One cooperative one model agriculture, livestock and fisheries farm

Nepal LMT 3: Agroforestry

	4. What are the wishes of the future for the LMT • include timing	5. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	6. Actions • policies, strategies, projects
Scenario 1: "Fully agroforestry " **Stakeholder representations:** Local community, environmental NGOs, green party (provincial/national)	• Full scale market based agroforestry in all hill and mountain districts by 2050 • Community based agroforestry in restored bare forests and abandoned croplands • Export promotion for high value non-timber products	• Government grants and subsidies • Contract from companies • Voluntary carbon markets	• Regulations on agroforestry by 2030 • Amendment on existing agroforestry policy (2019), to encourage involvement of farmers in agroforestry by 2030 • Simplify private forestry registration system

Scenario 2: "Midway ambition" **Stakeholder representations**: Provincial government, industry,	• At least 50% of agroforestry in hill and mountain districts by 2050	• Government grants and subsidies • Voluntary carbon markets	• Regulations on agroforestry by 2030
Scenario 3: "Partial agroforestry" **Stakeholder representation:** Provincial government, local government, farmer cooperatives.	• Around 25% of agroforestry in hill and mountain districts by 2050	• Government grants and subsidies • Voluntary carbon markets	• Regulations on agroforestry by 2030

Nepal LMT 4: Improved rice managment

	7. What are the wishes of the future for the LMT • include timing	8. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	9. Actions • policies, strategies, projects
Scenario 1: "Complete climate friendly rice " **Stakeholder representations:** Local community, NGOs, provincial and national government)	• Improved rice management In all rice production by 2050 • Efficient fertilizer and water management in rice • Better water quality in rivers and aquifers • Reduced cost of production	• Government grants and subsidies for inputs (machinery and organic fertilizer and market development	• Regulation by 2030 • New environment friendly rice labeling • Research and knowledge transfer to manage problems related to improved rice management
Scenario 2: "Midway ambition" **Stakeholder representations**: Central and Provincial government, industry,	• 50% of total rice production new improved y management by 2050	• Government grants and subsidises • Farmer cooperatives and rice processers implement.	• New regulation by 2030 • Promotion of technology

Scenario 3: "Partial improved rice production " **Stakeholder representation** Provincial government, local government, farmer cooperatives.	• Only 25% of total rice production in new improved management by 2050	• Government grants and subsidises • Individual farmers and rice processers implement.	• New regulation by 2030

10.2. Quantitative storylines: pace of implementation for each LMT

	Current situation (baseline)	**SCEN-" High ambition " SH perspective:**		**SCEN-" Midway ambition " SH perspective:**		**SCEN-" Low ambition" SH perspective**	
Year	Now (provide sources)	2030 (change relative to the current situation) (provide sources)	2050 (change relative to the current situation) (provide sources)	2030 (change relative to the current situation) (provide sources)	2050 (change relative to the current situation) (provide sources)	2030	2050
LMT 1: Forestry (AF/RF and FM)	40.36% of total area of the country covered by forests (DFRS 2015).						
LMT 2: Organic farming	9,361 ha certified organic (FIBL,2021) But organic by default (non certified organic) could be upto 25% of the total production (interview)						
LMT 3:Agroforestry	Data not available						
LMT 4: Improved rice management	Data not available						