Resilient and Low Carbon Agriculture in Lao PDR

Priorities for a Green Transition

Agriculture and Food Global Practice

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Acronyms and Abbreviations

ADB	Asian Development Bank
ADS	Agriculture Development Strategy
AEZ	Agro-Ecological Zoning
AFOLU	Agriculture, Forests, and Other Land Use
APB	Agriculture Promotion Bank
AWD	Alternate Wetting and Dying
BAU	Business-as-Usual
Bio-CF	Biocarbon Fund
CAWA	Climate Adaptation in Wetland Areas in the Lao PDR Project
CC	Climate Change
CCKP	Climate Change Knowledge Portal
CIAT	The International Center for Tropical Agriculture
CMIP	Coupled Model Intercomparison Project
CO_2	Carbon Dioxide
CORDEX-CORE	Coordinated Regional Climate Downscaling Experiment - Coordinated Output for Regional Evaluation
CRED	Climate Resilient Extension Development
CSA	Climate Smart Agriculture
DaLAM	Department of Agricultural Land Allocation and Management
DCC	Department of Climate Change
DEPC	Department of Environment and Pollution Control
DLF	Department of Livestock and Fisheries
DMC	Direct Seeding Mulch-Based Cropping
DMH	Department of Meteorology and Hydrology
DOA	Department of Agriculture
DOE	Department of Environment
DOF	Department of Forestry
DOPC	Department of Planning and Cooperation
DPF	Department of Planning and Finance
EPR	Lao Emissions Reduction Program
ER	Emissions Reductions
ESLRP	Enhancing Systematic Land Registration Project
EU	European Union
EUDR	EU Regulation on Deforestation-Free Products
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FABLE	Food, Agriculture, Biodiversity, Land Use, and Energy
FCIP	Forest Carbon Partnership Facility
FSC	Forest Stewardship Council
GAP	Good Agriculture Practice
GDP	Gross Domestic Product
GEF	Global Environmental Facility

GFLL	Governance Forests Landscapes and Livelihoods
GHG	Greenhouse Gas
GGGI	Global Green Growth Institute
GIZ	German Agency for International Cooperation
GSAF	Green and Sustainable Agriculture Framework
ha	Hectare
I-GFSS	Implementation of Governance Forest Landscapes and Livelihoods
IFAD	International Fund for Agriculture Development
IPCC	Intergovernmental Panel on Climate Change
IREP	Institute of Renewable Energy Promotion
ISIMIP	Inter Sectoral Impact Model Intercomparison Project
$ktCO_2e$	Kilotonnes of Carbon Dioxide Equivalent
LACP	Lao Agriculture Competitiveness Project
LaCSA	Laos Climate Service for Agriculture
Lao PDR	Lao People's Democratic Republic
LLL	Lao Landscapes and Livelihoods Project
LRIMS	Land Resources Information Management System
LT-LDES	Long-Term Low Emission Development Strategy
LURAS	Lao Upland Rural Advisory Service
MAF	Ministry of Agriculture and Forestry
MNB	Molasses Nutrients Blocks
MDER	Minimum Daily Energy Requirement
MIF	Microfinance Institutions
MONRE	Ministry of Natural Resources and Environment
MRV	Monitoring, Reporting and Verification
$MtCO_2e$	Million Tonnes of Carbon Dioxide Equivalent
NAFRI	National Agriculture, Forestry and Research Institute
NBB	Nayobay Bank
NDC	Nationally Determined Contribution
NDMC	National Disaster Management Committee
NGGS	National Green Growth Strategy
NPL	Non-Performing Loans
NSEDP	National Socio-Economic Development Plan
OA	Organic Agriculture
O&M	Operation and Maintenance
PIP	Public Investment Plan
PPP	Public Private Partnership
RAI	Responsible Agriculture Investment
RCP	Representative Concentration Pathway
REDD+	Reducing Emissions from Deforestation and Forest Degradation
SAMIS	Strengthening Agro-climatic Monitoring and Information System Project
SCU	Savings and Credits Unions
SCALE	Scaling Climate Action by Lowering Emissions
SDC	Swiss Agency for Development and Cooperation

SNV	Netherlands Development Organization
SMEs	Small and Medium Enterprises
SOC	Soil Organic Carbon
SPS	Sanitary and Phytosanitary
SRI	System of Rice Intensification
SRIWMP	Sustainable rural infrastructure and watershed Management Project
TCAF	Transformative Carbon Asset Facility
UNDP	United Nations Development Programme
UNFCCC	United Nations Framework Convention on Climate Change
VNSAT	Vietnam Sustainable Agricultural Transformation
WCS	Wildlife Conservation Society
WUAs	Water User Associations
WUGs	Water User Groups

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Executive Summary

The objective of this report is to fill knowledge gaps and lay a foundation for a green transition of the Lao agriculture sector through identifying technology options and enabling environments required to transform to more productive, resilient, and low-carbon agriculture. The report uses a combination of literature review and modelling to generate analytical evidence and identify key climate-smart agriculture (CSA) technologies to boost productivity, mitigate and adapt to climate hazards, and achieve valuable greenhouse gas (GHG) mitigation Co-Benefits. It also details the costs and benefits of adoption of green technologies, and explores financing options, institutional and policy actions, and incentives needed to drive the transition. Below is a summary of the report.

Current trends in Lao agriculture necessitate a green transition.

Laos' agriculture plays an important role in the country's economy and contributed to GDP and employment at levels above the regional East Asia average of 11.5% for GDP and 25% for employment between 2015-2019. Also, the sector is a leading contributor to rising farm incomes and poverty reduction in the country, providing employment and livelihoods for 94% of poor households, most of who rely solely on agricultural income. Amid a shift to more commercial production, and the tendency to grow more cash crops for export, rice production for domestic consumption still dominates Lao agriculture. Livestock production is mainly smallholder-driven and is steadily increasing.

Laos' agricultural sector challenges include vulnerability to climate hazards, deforestation, biodiversity loss and soil degradation, insufficient irrigation systems, low crop and livestock productivity, and low inputs use. Climate hazards have been known to result in losses in farmer livelihoods and average annual damage in the magnitude of about $159 million. Unsustainable crop expansion (e.g., cassava) is a source of land degradation and natural capital depletion. Shifting cultivation is the main form of land opening for agriculture production, practiced by 70% of farmers and resulting in deforestation, environmental degradation, and increased greenhouse gas (GHG) emissions. 85.6 percent of national GHG emissions come from Agriculture, Forestry, and Other Land Use (AFOLU). Since the early 2000s, forest conversion to farmland has been the dominant source of GHG emissions accounting for about 61% of AFOLU emissions.

There is need for the transition of the agriculture sector onto a more productive, resilient, low carbon and sustainable path. National policies, strategies, and plans, such as the Agriculture Development Strategy (ADS) to 2025 and Vision to 2030, the 9th Five Year National Socio-Economic Development Plan 2021-2025 (NSEDP), the National Green Growth Strategy (NGGS), and the Green and Sustainable Agriculture Framework (GSAF) to 2030, were developed to integrate climate resilience and low carbon and sustainable agriculture in national activities. In its Nationally Determined Contribution (NDC) to the UNFCCC the country has set an ambitious target to reduce its GHG emissions in 2030 by 60% compared to the Business as usual (BAU) scenario. The short-term adaptation target in agriculture for the year 2025 is to mainstream climate change adaptation in sectoral strategies and action plans. Long-term adaptation objectives are to promote climate resilience in farming systems and agriculture infrastructure and promote appropriate technologies for climate change adaptation.

While several ministries are active in promoting climate resilience, public sector investment in low-carbon technology is still extremely low. Investments in climate-smart and green agriculture come primarily from the international development community and focus more on climate change adaptation and resilience.

Private sector does not actively engage smallholder farmers and a more conducive environment is needed to boost investments. Government has limited fiscal space to support investment in climate smart technologies, and the adoption readiness of technologies and practices in the country is limited as demonstrated by low adoption of good agriculture practice (GAP).

Lao agriculture is already vulnerable to climate hazards, which will be exacerbated by climate change.

Laos is highly exposed to flooding, including riverine and flash flooding. The south is more affected than the north, which has remained more stable in terms of rainfall or with only slight increases. The country has already observed temperature and precipitation increases and climate change will lead to chronically heat stressed farming environments, increased rainfall intensities with augmented incidence of extreme river flows and associated flooding risks. Changes in the spatial distribution of precipitation and a relative increase in the number of dry days are projected in the future (2030s and 2050s). Southern provinces, with higher population density, and where most rainfed cropland is located are the most exposed to future climate risks.

Climate change is projected to lower agricultural productivity and affect value addition.

Heavy rains, heat stress, typhoons and flooding will affect rice production, but growing rice will still be possible in most parts of the country. Projected warmer temperatures and delays in the onset of the rainy seasons are expected to decrease maize yields. Cassava, a climate-resilient crop due to its stable performance under low soil fertility and water availability, will be moderately impacted by climate change. Extreme weather events will have detrimental effects on coffee production resulting in low and unstable yields and low-quality coffee beans. Banana production will be negatively affected by climate change, but suitability could increase in central and northern provinces. Increasing temperatures will have detrimental effects on livestock through heat stress, diseases, and pastures loss.

Agricultural value chains are exposed to climate hazards particularly through weak post-harvest storage and processing infrastructure. Traditional post-harvest handling methods like sun drying of rice will increase exposure to extreme weather events and can lead to grain quality degradation. Climate change will entail that bananas quickly ripen under elevated temperatures, causing quality and shelf-life reduction. High temperatures and relative humidity will cause mold and mycotoxin spread during coffee storage, while heavy rainfall and flooding events will cause the rewetting of dried coffee beans. The oxidative deterioration of cassava in the post-harvest phase cause changes in the root color and could be worsened by increases in the relative humidity conditions. Extreme heavy rainfall and flooding will also cause road infrastructure damage, with negative impact on farmers' market access.

Agriculture will continue to be an important contributor to GHG emissions and environmental change.

Under the business-as-usual pathway, based on current policies and the continuation of current production trends, internal and external demand for crop and livestock products can drive a production increase of 65% by 2050. As a response, the increase in agricultural production will lead to significant land use changes: cropland area may increase by 26%, driven by expansion in the production of cassava, coffee, vegetables, and maize, at the expense of the forest area. Agriculture sector GHG emissions will continue growing until 2050, primarily driven by livestock expansion and expansion of cash crop production. Annual crop blue water consumptive use will increase 1.4 times. Net GHG emissions from the AFOLU sector will however decrease assuming that positive actions on forest protection and regeneration are undertaken.

Adopting climate-resilient technologies and practices is an opportunity to improve farming efficiency and productivity, raise farmer incomes, adapt to climate change, and lower the sector's GHG emissions and other environmental impacts.

The report identifies feasible and scalable climate smart technologies for Laos (*table ES1*). The adoption of climate smart technologies (5 were tested in this study) can decrease GHG emissions from the AFOLU sector by -108.5 Mt CO_2e in 2050 compared to the BAU scenario. It is estimated that 65% of the avoided emissions will come from reduced deforestation (land use change-LUC), driven by the implementation of climate smart technologies. Applying climate smart technologies will also generate productivity gains. By 2050 rice productivity can be 13% higher, maize productivity 20% higher, cassava productivity 13% higher, coffee productivity 3% higher, and vegetables 34% higher. The application of climate smart technologies and practices will thus have triple win benefits (enhanced resilience, mitigation, and physical/economic productivity). In addition, evidence from this study shows that adopting climate smart technologies is more profitable than the continued application of conventional farming methods (*table ES1*). Net margins can be 3-121% higher for crops, 126% higher for livestock relative to conventional agriculture practice. Interventions at the post-harvest stage could lead to increase in net income of farmers by 30–50%.

Table ES1: Green and resilient improved technologies feasible and scalable in Laos, and their estimated productivity, adaptation, mitigation, and economic benefit.

Improved technology	**Climate-smart cropland production in rainfed areas**	**Sustainable intensification in irrigated areas**	**Climate-resilient livestock production**	**Climate-smart interventions at post-harvest stages**	**Weather-informed agricultural advisory services**
Crops	Cassava; coffee; maize; vegetables	Paddy	Cattle	Cassava; coffee; maize; vegetables; paddy	Cassava; coffee; maize vegetables; paddy
Description of the improved technology	Intercropping & crop rotation, cover-cropping, organic fertilization & mulching, use of climate resilient varieties, and agroforestry, Integrated land/soil management (e.g. minimum tillage and direct seeding), organic fertilization, crop residue management	Improved water management; SRI; cultivar change; alternate wetting and drying (AWD); Climate-proofed irrigation system and water reservoirs.	Breed improvement (crossbreeding); Improved feeding quality (e.g. MNB)	Artificial drying using flatbed dryers; large-scale solar greenhouse dryer; small-scale local storage, processing, solar dryers, and grading facilities; hermetic storage-metal silos, steel net and wire mesh storage bins; improved crop storage bags;	Flooding monitoring and control systems. Training agricultural extension services and farmers Weather-informed agricultural advisory services, early warning systems for extreme weather events, and crop insurance schemes.
Adaptation benefits	Resilience to pests and diseases; Reduced soil erosion; Reduced death of young seedlings from drought; Resilience to soil erosion, and nutrient leaching; Resilience to heavy rainfall events and increasing temperatures;	Reduced drought impacts on hydrology, and yield losses; Lower heavy rainfall, flooding, storms, impacts on soil erosion; Reduced damage to agricultural land and water resources; Reduced damage to irrigation	Resilience of fodder production and grazing pastures to droughts, floods: Climate-proofed pastures against heavy rainfall and floods; Resilience to extreme temperatures; Resilience to weather-related diseases.	Resilience of storage and transportation to drought and floods; Reduced risk of mycotoxin growth, fungi, mold contamination, and pest attacks; Reduced risk of quick fruit ripening; Reduced quality and shelf-life, grain losses, from heavy rainfall	Resilience to weather-related pests and diseases: Reduced risk of fungi, mold contamination during storage and processing due to high temperatures and relative humidity; Reduced soil erosion and nutrient leaching; Reduced death of young seedlings from drought events.

	Resilience to drought and floods.	network and infrastructure.		events and increasing temperatures.	
Mitigation potential (emissions reduction *relative to conventional)*	Emission abatement due to the avoided cropland expansion - 246 tCO_2e/ha of avoided deforestation [1] Agroecological practices also increase carbon sequestration and decrease emissions from synthetic fertilizer use.	Emission abatement through avoided CH4 emissions: -0.9 of tCH4/ha in irrigated areas, -1.2 tCH4/ha in rainfed areas [2] Emission abatement due to avoided rice land expansion -246 tCO_2e/ha of avoided deforestation [3]	Emission abatement through reduced enteric fermentation: -470kgCO_2e per MNB per cattle [4] Crossbreeding may lead to higher emissions factors per cattle (higher manure quantity, higher feed requirements)	Reduction in emissions through reduced food loss and waste	N/A
Physical productivity *(Yield increase relative to conventional)*	Corn: + 20% kg/ha Coffee: + 3% kg/ha Cassava: +13% kg/ha Vegetables: + 34% kg/ha	Paddy rice: +13% kg/ha	+ 80% tons of beef/TLU +18% liters of milk/head	Reduced post-harvest losses by 3-7% compared with traditional practices. Reduction of 120.000 tons of rice losses per year	N/A
Economic productivity (*income increase relative to conventional)*	*Gross margin:* Corn: + 21% $/ha Coffee: +121% $/ha Cassava: +14% $/ha Vegetables: +34% $/ha *Net margin:* Corn: +64% $/ha Coffee: +96% $/ha Cassava: +3% $/ha Vegetables: +54% $/ha	*Gross margin:* +14% $/ha *Net margin:* +9% $/ha	*Gross margin:* +105% $/ha *Net margin:* +126% $/ha	Increased net income by 30–50% compared with traditional practices	N/A

There are barriers to the adoption and implementation of climate smart technologies.

Despite the productivity and climate benefits, the adoption of resilient and low carbon technology and climate-smart practices in Laos is partly limited by the following barriers:

i. low farmers' access to agricultural inputs such as fertilizers and improved seeds and suboptimal performance and failure of irrigation schemes, restricting the implementation of CSA practices;
ii. weak knowledge and capacity for commercial livestock rearing, limiting the potential of improved livestock management;
iii. inadequate production and market infrastructure, impeding development of and access to domestic and regional agricultural markets, thus reducing income opportunities and incentives to invest in new practices or diversify production;
iv. mismatch between policy makers, local administrators, and farmers about the perceived value of forest land, which can continue to impede actions to reduce forest encroachments and land degradation;

[1] FABLE approach from FAO data.
[2] Footnote 152
[3] Footnote 152
[4] Windsor, PA., Hill, J. (2022). Provision of High-Quality Molasses Blocks to Improve Productivity and Address Greenhouse Gas Emissions from Smallholder Cattle and Buffalo: Studies from Lao PDR. *Animals*. 12(23):3319. doi:10.3390/ani12233319

v. weak financial management skills and business orientation of the smallholders, which limit their reliability as borrowers;
vi. insufficient public resources invested in research and development, which reduce opportunities for demonstration of new technologies, and the potential of the extension services to successfully disseminate the necessary knowledge for developing CSA systems.

In addition, even if the adoption of climate-smart technologies is more profitable than the continued application of conventional methods, on-farm implementation costs exist, including higher costs of labor and inputs (e.g., improved seeds, fertilizers), establishment and maintenance costs (e.g. to plant trees under agro-forestry systems). Supplementary (off-farm) costs of the transitioning to climate smart technologies include (public) costs to generate and disseminate knowledge and for capacity building. Such investments – comprising infrastructure and equipment, knowledge material and training of extension staff, monitoring and evaluation – represent a critical cost that the government will have to bear. There are however societal benefits, at the farm and landscape scale, which include reduced GHG emissions and enhanced carbon storage in soils and biomass (mitigation), enhanced soil fertility, water storage, agricultural ecosystem resilience, resource-use efficiency. Such benefits, if appropriately monetized, could represent a source of financial resources and reduce the costs of transition.

There is a critical shortage of finance for green technology in the country as the public purse is heavily burdened by other development priorities, and private sector players consider agriculture a risky area of investment. Therefore, there is need to take advantage of all available opportunities to finance the transition towards resilient and low carbon agriculture in Laos. This includes taking advantage of the a growing international climate finance landscape, repurposing available public resources towards more impactful and multi-purpose climate-smart interventions, improving access to finance for smallholder farmers and SMEs through de-risking the sector to make it more attractive to private players, supporting the development of green financial products and services, and taking advantage of the policy framework for sustainable agriculture finance in Laos and the nascent green finance and sustainable finance market in the country.

This report recommends the following actions to prepare the country for a resilient and low carbon transition over the next decade.

Table ES2 Summary of Recommendations (Urgency: M-Medium; S-Short-term; L-Long-term)

	Recommendation	Urgency	Responsible
	Investments in climate-smart technologies		
1	Expand irrigation services and ensure sustainability through a return-on-investment focused approach and tracking economic performance.	M	DOI
2	Establish a program for variety improvement and multiplication for select strategic crops like rice, through leveraging partnerships.	M	DOA
3	Expand the roll out of GAP building on lessons from on-going and past projects	S	DAEC/DOA/NAFRI
4	Establish a program on sustainable livestock commercialization focused on animal health and nutrition.	L	DLF
	Institutional strengthening		

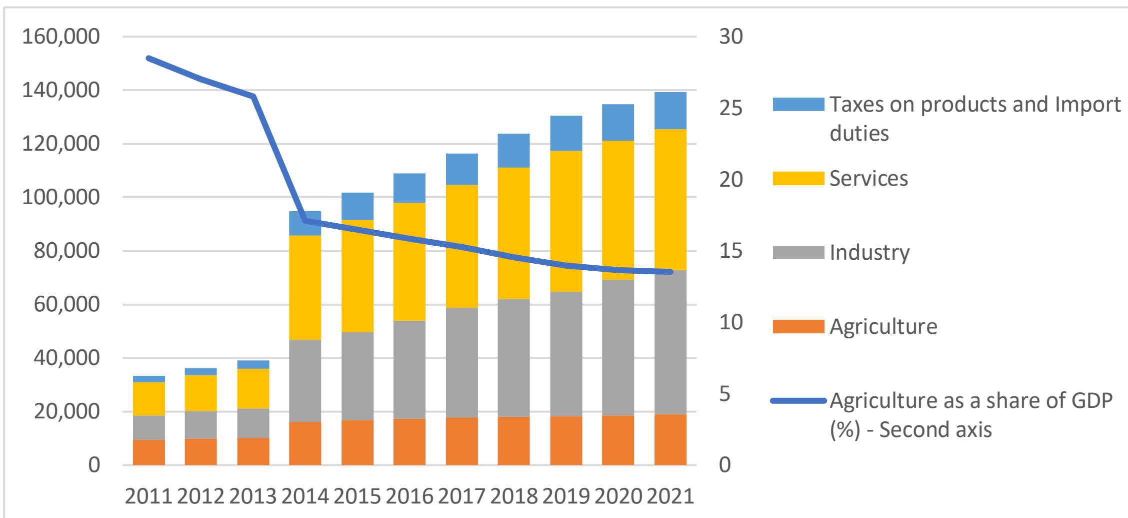
5	Repurpose public funding towards R&D through outcome-oriented allocations of research grants.	M	DOPC/NAFRI/ MOF
6	Reform the extension services to support more pluralistic services including private sector and NGOs.	M	DAEC/NAFRI/DOA
7	Introduce a program for improving the operation and sustainability of irrigation schemes through strengthening cohesion and capacities of WUAs, and WUGs.	S	DOI
8	Build the capacity of MAF on climate finance access through local, regional, and international learning exchanges to raise awareness and build experience.	S	DOPC
9	Develop an MRV system for tracking impacts of climate smart technologies on GHG emissions and other key agricultural indicators.	M	MAF/MONRE
	Policy and regulation		
10	Develop marketing procedures and product standards for climate-friendly/green and safe products for select value chains to meet demand from local and export markets like China and EU.	M	MAF/MOIC
11	Apply a dual approach of empowering local administrators to enforce forest protection and land use regulations and incentives to farmers for sustainable land management.	M	DaLAM/DOF/MAF DLM/MONRE
12	Improve land use monitoring to track forest encroachment by completing the Forest and Land Use Zoning (FLUZ) exercise.	M	DaLAM/DOF DLM/MONRE
	Finance and incentives		
13	De-risk commercial lending to farmers through organizing farmers and investing in farmer financial literacy.	S	MAF/MOF
14	Pilot a cooperative program with commercial lenders for financial services for smallholder farmers, including technical assistance on developing and implementing tailored financial products which suit farmer's needs.	S	MAF
15	Establish a framework for implementing agriculture insurance products for farmers based on international and regional good practice.	M	MAF/NDRC/MOF
16	Provide incentives to private sector to support technology transfer and to agro-business to enter sustainable business partnerships with farmers.	L	MAF/MOIC

Chapter 1: Current Trends in Lao Agriculture and Necessity of a Green Transition

1.1 Agriculture sector trends

Laos' agriculture sector has been undergoing structural change but is still an important contributor to the GDP growth and employment. The agriculture sector grew by 3% per year over the last decade, while the overall economy grew by 7-8%. Its contribution to GDP declined from 30% to 13% during the 2010-2021 period (Figure 1) and its contribution to employment declined from 70% to 64% during the 2010-2019 period. Despite such changes, agriculture plays an important role in the country's economy. The contribution to GDP and employment between 2015-2019 was above the regional average of 11.5% and 25% respectively[5].

Figure 1. Changes in contribution of the agriculture to the economy in Laos



Value of GDP (billion kip) and share of agriculture sector in GDP in Laos (%)

Source: Bank of the Lao PDR (2021).

The agriculture sector has been a leading contributor to rising farm incomes and poverty reduction. Agriculture provides employment and livelihoods for 94% of poor households, most of who rely solely on agricultural income[6]. Poverty in the country declined from 24.6% to 18.3% during the 2013-2019 period, driven by a rise in farm incomes and average crop sales.[7]

Amid a shift to more commercial production, and the tendency to grow more cash crops, rice production for domestic consumption still dominates Lao agriculture. Since the 1990s, efforts have been made to move the sector from production for self-consumption to market-orientation with a focus on cash crops. Rice, the staple crop, is grown on about 1 million ha (72% of the country's agricultural land) and 62% of farming households are involved in rice production. Rice productivity however has been stable over the

[5] Bank of the Lao PDR (2021). Annual Report 2012-2021. *www.bol.gov.la/en/annualreports*
[6] Lao Statistic Bureau (2021). The 3rd Lao Census of Agriculture 2019/2020. Ministry of Planning and Investment, Vientiane, Laos
[7] World Bank (2020). Lao People's Democratic Republic Poverty Assessment 2020: Catching Up and Falling Behind. World Bank, Washington, DC. http://hdl.handle.net/10986/34528

past years. Its production averages 3.8 million tons per year[8], 96% of which is consumed domestically. The remainder is mainly exported in the region, with Vietnam and China accounting for about 9% and 73% of the total milled rice export volume in 2020[9] respectively. Although rice productivity is high in Laos (about 4.1 t/ha), it is still lower than in neighboring countries like Vietnam and China, indicating potential for higher productivity (*Table 1*).

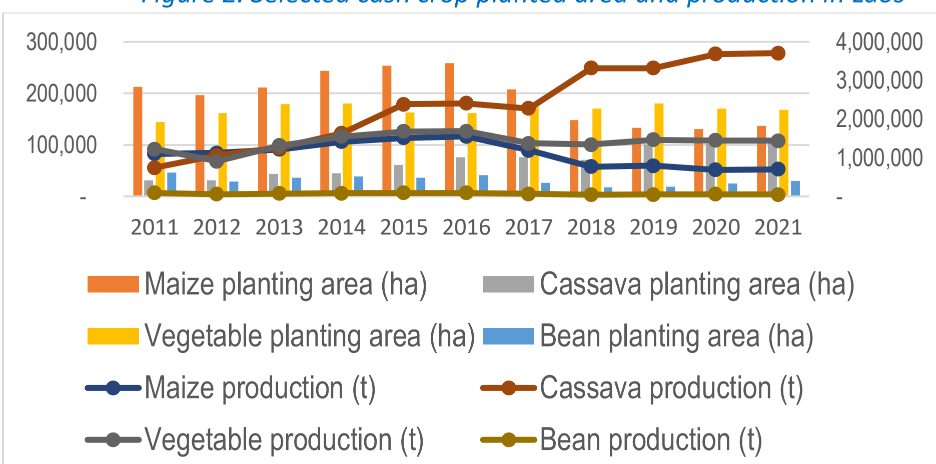
Table 1: Lao agriculture productivity relative to other countries in the region

Country	**Average crop productivity, 2017-2021 (Kg/ha)**				**Livestock stock, 2021 (n. heads)**	
	Rice	Maize	Cassava	Coffee	Cattle	Pig
Laos	4,106	5,661	32,800	96	2,258,176	4,468,192
China	7,030	6,228	16,000	152	60,522,044	454,807,281
Thailand	2,983	4,464	21,200	32	4,627,914	7,743,876
Vietnam	4,792	4,792	19,400	135	6,365,300	23,533,400

Source: FAOSTAT.

Cassava production has been increasing in recent years. *Figure 2* shows that maize has been quickly replaced by cassava in terms of area (production), decreasing from 212,105 ha (1,096,235 tons) in 2011 to 137,287 ha (703,953 tons) in 2021. Farmers have adjusted cropping patterns in response to market demand for raw cassava for bio-ethanol production in China, Thailand, and Vietnam and domestic demand for flour. Cassava has become a major source of income for smallholder farmers, who benefited from relatively high farm gate prices, with a net annual income of about 30 million kip ($1,695) per ha[10]. Cassava yields in Laos are much higher than among regional neighbors (Table 1).

Figure 2. Selected cash crop planted area and production in Laos

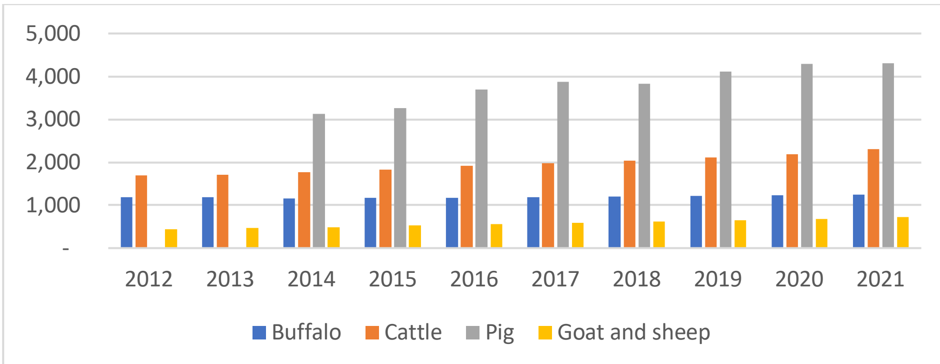


Sources: Ministry of Agriculture and Forestry (MAF), 2012-2022

[8] FAO (2022). Rapid Assessment on the Impact of the 2022 Financial Crisis on Food Security and Livelihoods in Laos
[9] IRRI (2021). Draft Lao Rice Export Promotion Strategy, Ministry of Agriculture and Forestry and Ministry of Industry and Commerce, Laos
[10] Such amount has essentially doubled in dollar value in the past two years, driven by the boom in regional demand. However, other factors may have contributed to this, e.g. the ongoing Ukraine war and the global shortage of biofuel and animal feed precursors previously exported from Ukraine, might have pushed up the cassava price so steeply. However, there are not studies available on this and further investigation is required.

Smallholder livestock production is steadily increasing. The number of households rearing livestock increased by 36% between 2012 and 2022, and livestock population increased by 29% (*Figure 3*). However, absolute herd numbers are lower than other countries in the region (Table 1). During 2015-2020, livestock production for domestic consumption amounted to 210,800 tons of meat; 38,600 tons of eggs; 123,000 tons of farmed fish; and 64,000 tons of wild fish and various aquatic animals[11]. Cattle rearing plays an important role in small family farms. Despite government efforts to develop commercial-scale livestock farms[12], smallholders own 98% of the cattle heads on the country, and consider cattle a major capital reserve.

Figure 3. Number of livestock in Laos, 2012-2021 (000 heads)



Source: MAF (2022)

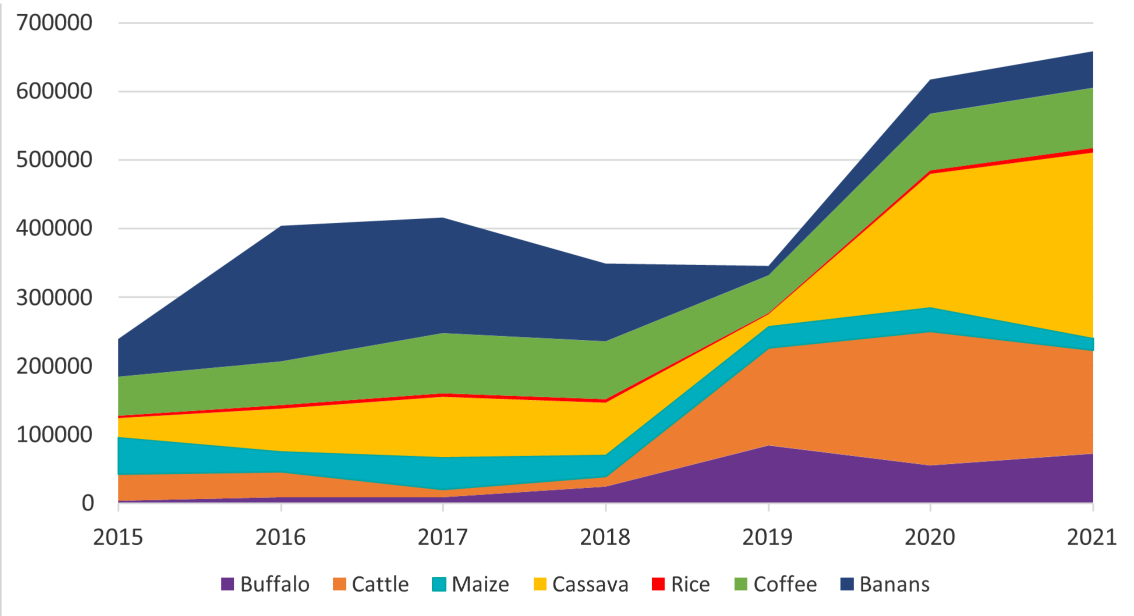
Agriculture sector exports are growing and represent more than one-fifth of Laos exports. The estimated agriculture sector growth of 2.3% in 2021 was driven by expanded production and exports of cassava, banana, rubber, and coffee[13], offsetting a contraction in other commodities like fruits, maize, and live animal exports (*Figure 4*). The export growth of these four main agricultural products accounted for about 72% of total agricultural exports in 2021, due to growing demand in Thailand, China, Vietnam, and South Korea. Of the $900 million of agricultural products exported in 2021, over 80% were exported to China.

The Lao government aims to increase the production of cash crops as part of its commercialization agenda. Coffee, vegetables, and bananas are important commercial crops in the country. Coffee production has significantly increased in the last 20 years, particularly in northern and southern provinces. Coffee is one of the top five export earners in the country, contributing about 1.1% of the total export value or $64.3 million in 2019[14]. In 2020, the European Union (EU) alone imported €29 million worth of coffee and tea from Laos.[15] The government aims to increase coffee production to 1 million tons by 2025 to take advantage of the promising opportunity for Laos coffee from the growing global demand for high-grade specialty and "sustainable" coffee. However, yields of coffee are lower than China and Vietnam

[11] Ministry of Agriculture and Forestry (2021). *Agricultural Development Strategy to 2025 and Vision to 2030 (Revised) DRAFT* 2021.
[12] Napasirth, P. and Napasirth, V. (2018). Current situation and prospects for beef production in Lao People's Democratic Republic — A review. Asian-Australas J Anim Sci; 31(7): 961–967.
[13] World Bank (2022). Developing the Agribusiness Potential in the Laos-China Railway Corridor – Opportunities and Challenges
[14] Phimmavong, S., Tek, N.M, Rodney, J.K, Chanhsamone, P., and Boonthavy, D. (2023) Impact of the coronavirus pandemic on financial returns of smallholder coffee plantations in Lao PDR. *Agroforestry Systems* 97, no. 4 (2023): 533-548.
[15] International trade center (2021). Story: Lao farmers reaching for global organic coffee markets, 20 June 2021. https://intracen.org/news-and-events/news/story-lao-farmers-reaching-for-global-organic-coffee-markets

(Table 1), and exporters and processers are unable to source volumes of sustainable coffee to meet market demand.

Figure 4. Main agricultural and livestock export products, Laos ($ thousand)



Source: Authors' elaboration on FAOSTAT data

The major destinations for Laos' agricultural exports are regional neighbors, China, Thailand and Vietnam, and the EU is a major global trading partner. Most agriculture exports reach the regional market. China, Thailand, and Vietnam account for more than 90% of such exports and demand an increasing quantity of agricultural products. in 2020 alone, export towards those countries increased by 37% (China), 51% (Thailand), and above 100% (Vietnam)[16]. The EU is Laos' fourth largest trading partner (in 2020, agricultural products accounted for 8% of total exports to the EU)[17].

1.2. Pressures towards a resilient, low carbon and green transition

Agriculture expansion, deforestation, soil degradation, and greenhouse gas emissions

Agriculture production expansion and commercialization have raised household incomes, but have contributed to deforestation, biodiversity loss and soil degradation. The total harvested area in Laos increased by 124% between 1990-2020. Cash crop plantations increased from 17,700 to 320,000 ha between 1992-2006[18]. Thousands of acres of forest have been cleared under contract farming schemes and planted with annual or perennial crops (maize, cassava, sugarcane, rubber, coffee). Shifting cultivation is the main form of land opening for agriculture production, accounting for 33% of land use over the past 30 years[19] and practiced by 70% of farmers. Such practice results in deforestation and

[16] World Bank (2022). Developing the Agribusiness Potential in the Laos-China Railway Corridor: Opportunities and Challenges. Lao PDR

[17] Thipphavong, V. Vanhnalat, B. Vidavong, C and Bodshisane, S. (2022). The Export Potential of Laos Agri-Food to the EU Market. Food Security Policy Research, Capacity, and Influence (PRCI)

[18] Keoka, K., Bouahom, B., Hett, C. and Harari, N., (no date). Policies, strategies, processes, and frameworks for scaling up sustainable land management in Lao PDR. NAFRI Policy Brief.

[19] Chen, S., Olofsson, P., Saphangthong, T., and Woodcock, C. (2023). Monitoring shifting cultivation in Laos with Landsat time series. Remote Sensing of Environment 288 (2023) 113507, ScienceDirect – www.elsevier.com/locate/rse

environmental degradation[20]. Many fields, previously recovered under fallow, have increasingly been converted to crop production. The repeated harvesting of monoculture crops on cleared land has also degraded soils, through accelerated erosion, especially in the mountainous regions.

Laos has lost over 4 million hectares of forest cover, equivalent to a 21% decrease in tree cover since 2000[21]. Between 2015-2019, deforestation in the Production Forest Areas of three provinces alone (Champasak, Khammuane, Oudomxay) caused the loss of over 10,000 ha of natural forest[22]. In addition to the expansion of agriculture, the clearing of forest land for hydropower projects, mining sites, and other infrastructure development, urbanization, resettlement, and illegal logging are other main drivers of deforestation. However, cash crop production, especially cassava still ranks first among the causes of deforestation in many provinces [23].

An increasing number of farmers is cultivating cassava in the central and southern region and opening virgin land (*Figure 5*). The area used to produce cassava has increased more than 5-fold over the past two decades. The average cassava yield in Laos is higher than other countries in the region, averaging about 33 tons/ha[24], because farmers tend to grow cassava on virgin soils more than what happens in other countries. The provinces of Xayaburi (34 tons/ha), Bolikhamxay (31 tons/ha), and Champassak (60 tons/ha) show the highest productivity[25]. Farmers who engage in cassava farming have limited resources and make a minimal investment in farm inputs to improve soil quality. Cassava production is causing soil degradation and soil nutrient depletion[26]. This forces farmers to regularly search for new land to maintain high yields, thereby leading to forest encroachment. Forest encroachment and environmental damage is more severe for cassava farmers in upland areas with abundant virgin land (Box 1).

There has been a growth in land use for coffee plantations accompanied by negative environmental impacts. Coffee plantation have grown on the Bolaven Plateau, in southern Laos (Champassak, Attapeu, and Sekong provinces), and the northern upland in Luang Prabang and Phongsaly (*Figure 5*) up to the current area of 90,000 ha, largely owned by smallholders (the average area grown being 1–2 ha per farm[27]). Smallholding coffee production is inefficient, product quality is poor, and yields are lower than those recorded in competitor countries at regional (like Vietnam) or international level. Rapid coffee plantation expansion has been based on unsustainable farming practices, especially natural forest clearing and monocropping[28]. This is a concern given that Laos aims to enter the specialty and sustainable coffee

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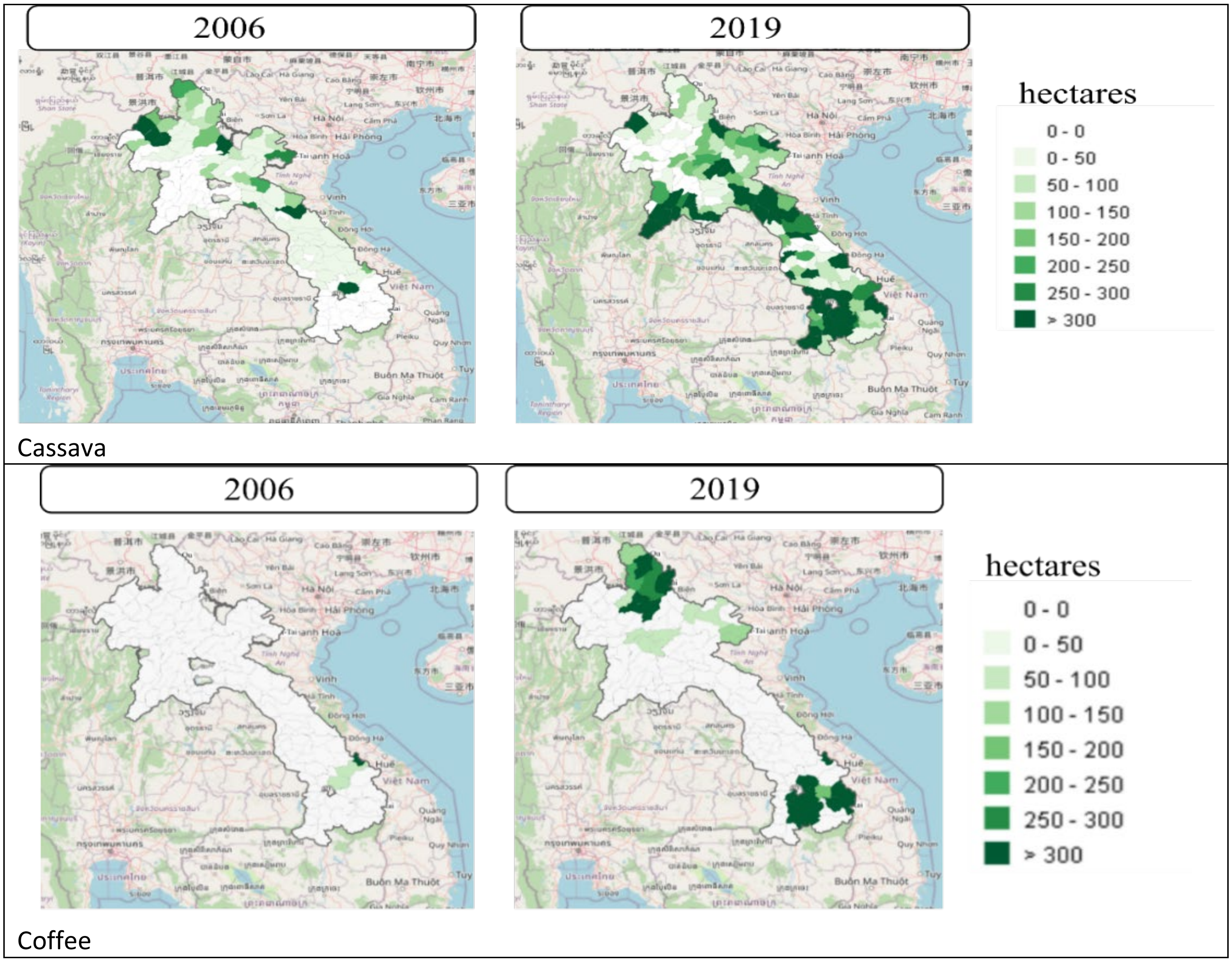
[20] Doi, T., Totsu, K. and Higashi, S. (2013). Nature and Our Future: The Mekong Basin and Japan. A Missui & Co., Ltd. Environment Fund support project. Mekong Watch - http://www.mekongwatch.org/platform/bp/english.pdf
[21] Global Forest Watch – Dashboards for Laos - https://www.globalforestwatch.org/
[22] Daviau, Steeve. (2022). Study on Forest Encroachment on Production Forest Areas (PFAs) under SUFORD-SU (2015-2019) – Drivers and Response. Lao PDR
[23]Daviau, Steeve. (2022). Study on Forest Encroachment on Production Forest Areas (PFAs) under SUFORD-SU (2015-2019) – Drivers and Response. Lao PDR
[24] Souvannavong, P. (2021). Value Chain Analysis of Cassava in Lao PDR. Australasian Agribusiness Perspectives 2021, Volume 24, Paper 13, ISSN:2209-6612
[25] "Lao PDR – ACIAR Cassava Value Chain and Livelihood Program," accessed March 9, 2023, https://research.aciar.gov.au/cassavavaluechains/lao-pdr/index.html.
[26] Chua Fung, M., Youbee, L., Oudthachit, S., Khanthavong, P., Veneklaas, EJ., Malik, I. (2020). Potassium Fertilization is Required to Sustain Cassava Yield and Soil Fertility. Agronomy 2020, 10, 1103; doi:10.3390/agronomy10081103 (www.mdpi.com/journal/agronomy). Howeler, R.H. (2014). Sustainable Soil and Crop Management of Cassava in Asia. In A Reference Manual; International Center for Tropical Agriculture (CIAT): Colombia
[27]Footnote 10
[28]Footnote 10.

market, yet there are increasingly stricter sustainability standards of key markets like the EU, which demands deforestation-free commodity value chains.

Figure 5. Number of hectares under coffee cultivation by province



Source: Authors, based on SAMIS project

Box 1 The unsustainable path of cassava production in Laos

1. ***Inadequate knowledge and access to advanced technologies, high-yielding varieties, and improved agronomy is limiting cassava yields***. There is minimal research and development on how to effectively manage pests, diseases, varietal choices, and farming practices. Coupled with few incentives for farmers to adopt good management practices, cassava production is being practiced with unsustainable methods like monocropping.

2. ***Cassava is grown in unsuitable areas and systems, leading to soils' over-mining and constant search [29] of more virgin land[30].*** This has negative consequences in terms of long-term soil erosion, land degradation, and deforestation. Without inputs, a deforested plot can give maximum three harvests, after which new land is to be found. However, the land left behind is often converted to rubber, which then provides a longer-term income, but requires higher upfront capital investment and is rarely suitable for smallholders. This is pushing the forest encroachment frontier forward.

3. ***The export of fresh cassava roots, without value addition, is an important risk source***. Given the increasing competition from neighboring countries, this could determine progressively declining returns to farmers and force them to expand further into virgin lands to compensate the losses through an increase in the quantity produced.

Issues	Impacts	Reference
Knowledge of appropriate agronomic practices (e.g. soil/land management)	Limiting potential yield and leads to land degradation	[31], [32], [33]
Varietal choice and knowledge of cassava main pests and diseases and their transmission mode	Limiting potential yield and decreasing quality	[34], [35]
Low mechanization	Increase in manual labor	[36]
Low market access		[37]
Monocropping	Decrease in cassava yields	[38]

Source: Authors

Land availability for agriculture use in Laos is in competition with forest land. The master plan for national land allocates 4.5 million hectares (19% of total land) to agriculture and 16.5 million hectares (70% of total) to forest land. Agricultural land comprises 2 million hectares (44%) for rice production, 1 million hectare (22%) for cash crops, 0.8 million hectares (18%) for fruit trees, and 0.7 million hectares (16%) for grazing land[39]. The 2019 forestry law foresees government incentives and control mechanism

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[30] Soukkhamthat, T. and Wong, G.Y (2016). Technical Efficiency Analysis of Small-Scale Cassava Farming in Lao PDR. ResearchGate, DOI:10.37801/ajad2016.13.1.2 - https://www.researchgate.net/publication/311614622

[31] FAO (2022). Exploring Cassava Futures: Building Cassava Climate Resilient Pathways in Lao PDR. CC2809EN/1/11.22, CC BY-NC-SA 3.0 IGO license - https://www.fao.org/3/cc2809en/cc2809en.pdf

[32] Footnote 25

[33] FAO (2022). Exploring Cassava Futures: Building Cassava Climate Resilient Pathways in Lao PDR. CC2809EN/1/11.22, CC BY-NC-SA 3.0 IGO license - https://www.fao.org/3/cc2809en/cc2809en.pdf

[34] FAO (2022). Exploring Cassava Futures: Building Cassava Climate Resilient Pathways in Lao PDR. CC2809EN/1/11.22, CC BY-NC-SA 3.0 IGO license - https://www.fao.org/3/cc2809en/cc2809en.pdf

[35] Souvannavong.P, (2021). Value Chain Analysis of Cassava in Lao PDR, *Australasian Agribusiness Perspectives* 24, no. 13.

[36] Footnote 25

[37] Footnote 25

[38] Footnote 25

[39] MAF (2021). Draft Agricultural Land Management and Development Strategy to 2040. Ministry of Agriculture and Forestry. Vientiane.

to protect forest land. However, as indicated above, agricultural land is not managed sustainably and often encroaches forest land. Yet, there is no clear protection and mitigation in place at local level against deforestation from cash crop expansion. The often-conflicting key targets for forestry and agriculture are reported in *Table 2*.

Table 2.Key National Target to be achieved by 2025 for the Forestry and Agriculture Sector

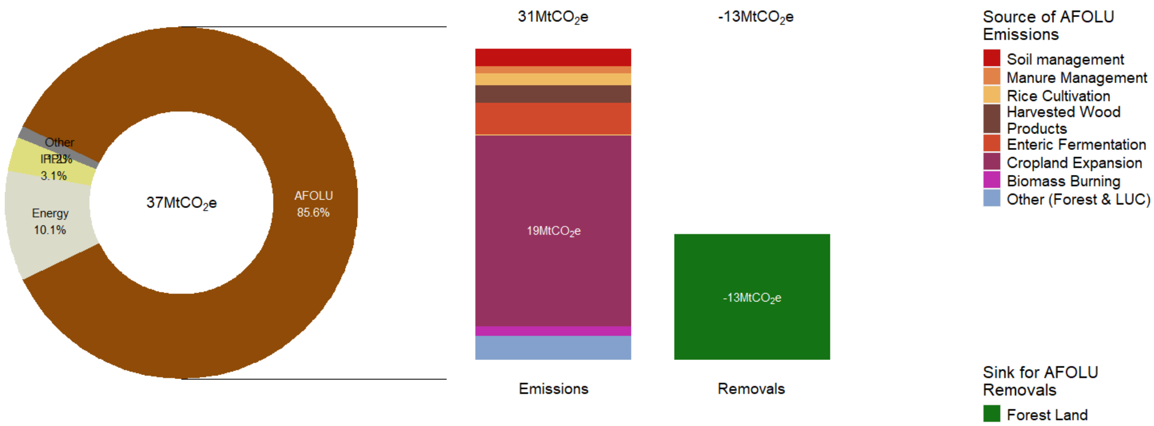
Key targets to be achieved by 2025 for the forestry sector	**Key targets to be achieved by 2025 for the agriculture sector**
Forests and forest lands cover 70% by 2030	Paddy rice production 900,000-950,000 ha or 3.5-4 million tons/year
Upgrade 5 preserved forest to 5 national parks - Conservation forest (NPA, National Park, World Heritage) 4.7 million ha	Food crop production (261,710 ha) - Tubers 11,678 ha by 2025 or 134, tons/year - Sweet corn 29,080 ha or 223,720 tons/year - Vegetables 188,200 ha or 1,462,000 tons/year - Fruits 32,752 ha or 307,900 tons/year
- Protection forest 8.2 million ha - Production forest 3.1 million ha - Rehabilitate forest 1.8 million ha - Plantation 501,000 ha	Commercial crops (410,706 ha) and livestock/fish - Coffee 96,094 ha or 175,500 tons/year - Maize 138,716 ha or 636,900 tons/year - Cassava 108,460 ha or 636,900 tons/year - Sugarcane 32,872 ha or 1.6 million tons/year - Banana 24,830 ha or 735,580 tons/year - Tea 14,000 tons/year - Watermelon 8,036 ha or 150,140 tons/year - Legumes (soybeans, green beans, peanuts, red beans) 28,206 ha or 74,750 tons/year - Sweet potato 6,364 ha or 131,220 tons - 250,000 Cattle for export to China or 50,000 cows/year

Source: MAF (2021). The 9th Five-Year Agriculture, Forestry, and Rural Development Plan 2021-2025

Since the early 2000s, forest conversion to farmland has been the dominant source of greenhouse gas emissions (GHGs). The country was a net carbon sink (-104.6 $MtCO_2e$) in 1990 and became a net emitter (+41.8 $MtCO_2e$) in 2000. In 2014 national emissions amounted at 36.8 $MtCO_2e$, of which: 85.6% were from Agriculture, Forestry, and Other Land Use (AFOLU); 10.1% from energy; 3.1% from Industrial Processes and Product Use (IPPU); and 1.2% from other industries (waste management). Within the AFOLU sector sources of emissions included: forest conversion to farmland (19.3 $MtCO_2e$ or 61% of total AFOLU emissions); livestock through enteric fermentation and manure (3.97 $MtCO_2e$ or 13% of AFOLU emissions); nitrous oxide (N_2O) from soil management (5.5%); methane (CH_4) from biomass burning (3%). Rice production contributed approximately 1.15 $MtCO_2e$ (3%) as N_2O and CH_4 emissions. Removals from forests amounted at 12.6 $MtCO_2e$ (*Figure 6*). Although growing, per capita GHG emissions for Laos (5.5 ton per capita) are lower that the world average of 6.5 ton per capita[40].

[40] World Resources Institute (2022). *Climate Watch Historical GHG Emissions*. (GWP-100 AR4). https://www.climatewatchdata.org/ghg-emissions

Figure 6. Historical share of GHG emissions from Agriculture, Forestry, and Other Land Use (AFOLU) to total AFOLU emissions and removals by source in 2014



Source: Adapted from First Biennial Update Report of Lao PDR to the UNFCCC, 2020.

Water access, management, and use

Water access is a limiting factor to agriculture expansion. The country's vast water resources are primarily consumed by agriculture (93%)[41]. Water is generally available and usually sufficiently abundant for a monsoon rice crop in the wet season, with supplementary irrigation practiced during dry spells or critical stages of crop growth. However, Laos lacks sufficient irrigation, especially for dry season cropping. Only 333,400 ha (15% of agricultural land) are equipped with irrigation[42].

Existing irrigation infrastructure is old and unfit to provide required levels of water services[43]. Irrigation system design in the country focuses on meeting crop water requirements for rice production. These schemes are ill-suited to meet the irrigation service standards required for a more diversified cropping strategy. Ageing infrastructure partly completed irrigation schemes, delipidated canals and diversions, and inadequate operation of infrastructure result in significant water losses and inefficiencies. In addition, floods repeatedly cause extensive damage to irrigation infrastructure, especially in southern and central regions. This is an important as it relates to the ongoing changes in the Mekong mainstream; the reduced wet season flows; the redistribution of water-dry season flows because of substantial increases in basin storage for hydropower energy development; and the shifts in floods and extreme events due to climate change.

With damaged and inefficient infrastructure, and low margins from rice production, most smallholders are unwilling or unable to pay even modest irrigation service fees (ISFs). This is particularly so in cases where timely water supply cannot be guaranteed and where irrigation service standards are low[44]. Consequently, some schemes are characterized by insufficient operation and maintenance capacity

[41] Government of Lao PDR (2020). *First Biennial Update Report of Lao PDR (BUR 1)*
[42] FAOSTAT data, 2020
[43] Statistical information on irrigation is available at the WB's PDNA report (2019) and in the agriculture statistic year books 2019.
[44] However, in some areas, farmers show significant willingness to invest in on-farm irrigation where returns are good (i.e., for non-rice crops), e.g., substantial investments by farmers have been made in the Vientiane Plain (storage filled from groundwater; pressurized distribution/sprinkler) for higher value crops that serve the local market).

especially of the water user groups (WUGs) and high operating costs with consequent unreliable water supply for agriculture production. In many lowland schemes, irrigation service fees are insufficient to cover the electricity costs of pumping, and many schemes have accumulated substantial debt. It has been estimated that an electricity bill from irrigation of over $150 million has not been paid[45]. This has led to chronic suboptimal performance and economic failures of irrigation schemes [46], resulting in the need for further investments[47]. Such issues have important social transfer implications since irrigation water remains critical to allow for one annual harvest of rice for subsistence and food security.

Energy access and use for agriculture production

Most farmers in Laos access electricity but it is costly and often limits farm operations. In 2021, 95% of total households in Laos accessed electricity[48]. The main energy resources for electricity generation include hydropower (81%), coal-fired plants (17%), renewable sources like solar and biomass (only 2%)[49]. The assessment of the Economic and Social Commission for Asia and the Pacific observed that agriculture consumes a small amount of energy, compared to other sectors, due to high costs and the limited capacity of farmers to afford. Farmers using gasoline and electricity to pump water always have high electricity bills[50]. For example, farmers in Attapeu province reported that during the dry rice season from November 2018 to 2019, when there was a natural disaster, hydroelectricity for 40 hectares of rice crops cost more than 28 million kip. For the dry season, farmers paid 600,000–700,000 kip per hectare[51]. As a result, many farmers avoided working on their rice fields in the dry season. Of-grid green energy solutions like solar have not been widely adopted by farmers because of the high investment costs for establishment and maintenance[52].

Access to improved technology and management

Adoption of advanced machinery is improving, but adoption readiness of technology is limited by cost. The use of simple mechanization options in agriculture is increasing, albeit still in its infancy. Technology spills from across borders are leading to a rapid increase in machine technology use. Tractors are replacing buffaloes for preparing land in lowland rice. In Savannakhet and Champassak, around 75% of households use two-wheel tractors for land preparation, although 21% still use only draught animal power [53]. Farmers who do not have tractors have access to rental services. However, other machinery (e.g., transplanters, drill seeders, and harvesters) is less common, having been introduced only recently and on limited areas[54]. Besides, most smallholder farmers cannot afford the costs of buying or renting farming machinery.

[45] Brunner, J., Carew-Reid, J., Glemet, R., McCartney, M.P. and Riddell, P., 2019. Measuring, understanding, and adapting to nexus trade-offs in the Sekong, Sesan and Srepok Transboundary River Basins.
[46] ADB (2018). Agriculture, natural resources, and rural development sector assessment, strategy, and roadmap
[47] Inthakesone, B., and Syphoxay, P. (2021). Public Investment on Irrigation and Poverty Alleviation in Rural Laos. Journal of Risk and Financial Management 14: 352. https://doi.org/10.3390/jrfm14080352
[48] Lao Statistic Bureau (2021). Lao Statistical Information Service website https://laosis.lsb.gov.la/tblInfo/TblInfoList.do?rootId=2101000&menuId=2101101&lang=en&keyword=&searchType=undefined
[49] Ministry of Energy and Mines. Vientiane Time, August 17, 2022, www.vientianetimes.org.la/freeContent/FreeConten158_Govtto.php
[50] Vientiane Time, June 20, 2019 - https://www.vientianetimes.org.la/sub-new/Development/Development_Solar.php
[51] The Economic and Social Commission for Asia and the Pacific (2021). Energy Transition Pathways for the 2030 Agenda: SDG 7 Roadmap for Lao PDR
[52] Hartung. H and Pluschke.L (2018). The benefits and risks of solar powered irrigation – a global overview. FAO
[53] Newby, J., Manivong, V., and Cramb, R., (2020). Economic Constraints to the Intensifcation of Rainfed Lowland Rice in Laos.
[54] Manivong, V., and Cramb, R. (2020). From subsistence to commercial rice production in Laos, Chapter Open Access in the White Gold: The commercialization of rice farming in the Lower Mekong Basin. https://link.springer.com/chapter/10.1007/978-981-15-0998-8_5

Smallholder farmers' use of improved seeds has led to an increase in rice and cassava productivity, however, adoption rate of improved varieties in cassava production has been relatively low. The adoption of improved varieties has been the most important factor in achieving significant productivity gains in crop production since the 1990s, especially for rice and cassava. In 1990, 95% of all lowland rice was grown on traditional low-yielding varieties. By the early 2000s, 70-80% of the lowland rice growing areas were covered by improved rice varieties. High yielding varieties have led to increases in rice yields from 2 t/ha in 1990 to 4.2 t/ha in 2017[55] and in cassava yields from 13.7 t/ha to 32.7 t/ha over the period 1996 to 2016. However, many cassava farmers cannot benefit from such productivity gains because of their limited adoption of the improved varieties[56]. Adoption of improved cassava varieties in the country is one of the lowest in East Asia (about 43% of cassava planted is represented by local varieties[57]) and the improved high yielding varieties are mostly obtained from other countries in the region (Thailand, Vietnam, and China), and are not easily accessible to farmers[58].

Despite widespread efforts to promote Good Agriculture Practices (GAPs) and Organic Agriculture (OA), adoption of GAPs has been low. The MAF (2015) Agriculture Development Strategy 2025 and Vision 2030 plan aim to achieve organic certification on a total cultivated area of around 34,377 ha by the year 2025. This goal was revised to 15,000 ha for OA and 10,000 ha for GAPs by 2030. Data available show that by the year 2021, 13,082 ha have been certified under OA and 103 ha under GAPs. The slow progress on the adoption of GAPs is due to the lack of technical capacity and awareness of the producers, and limited access to the use of agricultural inputs such as fertilizers**.** Laos' agriculture is characterized by the lowest synthetic fertilizers and agrochemicals use in Southeast Asia (0.03 kg/ha over the 2010–15 period) and a significant use of organic fertilizers. This is considered an opportunity to raise profitability in the growing organic food production and market[59]. However, farmers require approximately 2 million tons of fertilizer annually, but the country only produces 30% of that amount[60]. The most common practice is applying organic fertilizer, such as rice husk and animal manure, with limited quantities of chemical fertilizers. Local companies produce and sell organic fertilizer from composted animal manure and rice straw but at a relatively high price.

Crop residue burning remains a common practice, contributing to pollution and greenhouse gas emissions (GHGs). It is common practice that paddy rice is harvested by cutting the plant close to the gearheads and leaving most of the straw in the field for grazing animals. Towards the end of the dry season, fields and the remaining crop residue are burned to add ash to the soil, destroy weeds and control pests and pathogens in crops. Crop residue burning is an important source of air pollution contributing to air quality degradation and greenhouse gas emissions. It is also a risky practice for forest fires[61]. However,

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[55] Manivong, V., & Cramb, R. (2020). From subsistence to commercial rice production in Laos. *White gold: The commercialisation of rice farming in the lower Mekong Basin*, 103-119.

[56] Maung.A and Howeler.R (2022). Current situation and future prospects of cassava in Lao PDR. https://www.researchgate.net/publication/363852231_CURRENT_SITUATION_AND_FUTURE_PROSPECTS_OF_CASSAVA_IN_LAO_PDR

[57] Ricardo Labarta1, Tesfamicheal Wossen and Dung Phuong Le The Adoption of Improved Cassava Varieties in South and Southeast Asia. The 9th ASAE International Conference: Transformation in agricultural and food economy in Asia 11-13 January 2017 Bangkok, Thailand

[58] In 2023 the CGIAR has started piloting in Laos a manual to increase cassava productivity. https://alliancebioversityciat.org/publications-data?search_api_fulltext=Lao%20PDR&f%5B0%5D=year%3A2023

[59] World Bank (2021). Northern Lao PDR Regional Economic Corridor and Connectivity Project. Project Information Document.

[60] The Laotian time (2022). Laos to produce more fertilizer and animal feed amid supply chain turmoil

[61] Wildfires spread from residue burning have been increasing but there is no detailed study of the magnitude of the environmental damage, or health damage. After the fires, most area is likely to be converted to cassava (e.g. in eastern Savannakhet, Khammouane and Bolikhamxay). There is the need to further investigate this encroachment.

farmers favor such practice due to its perceived benefits, including savings in the costs, and labor needed for straw management. Enhanced crop residue management e.g., through mulch and compost, is not much practiced.

Unsustainable livestock production

Most smallholders practice traditional animal husbandry techniques, with little or no investments in improved livestock rearing, or commercialization. Livestock productivity in Laos is strongly constrained by natural forage quantity and quality. Animals are grazed freely on roadsides and meagre grassland. Studies show that the quantity and quality of natural pasture in Laos is low, and that local grass species are of low nutritional value.[62] Livestock is grazed freely in paddy rice fields after harvesting since rice straw is the most abundant feed resource for ruminants. However, rice straw is low in protein, so it cannot support nutrient requirements for the increased performance of ruminants.[63] There is little room for boosting livestock productivity with prevailing practices. While there are many known techniques to improve livestock productivity, such as treating rice straw with urea or alkaline, molasses nutrient blocks, silage production, and forage production, they have not been implemented much in the country. Sociocultural norms related to livestock ownership, particularly for large ruminants, limit the potential for commercialization since animals are mostly kept as a store of value.

Climate hazards

Laos faces extremely high exposure to floods and severe storms, with important economic implications. The country is highly exposed to flooding including riverine and flash flooding, which also brings with it associated issues like landslides[64]. The south is more affected than the north, which has remained more stable in terms of rainfall or with only slight increases. Since the mid-1960s, the country has experienced about 25 significant flood events, ranging in magnitude[65]. On average, floods and storms affect about 200,000 people per year with injuries and deaths[66]. Average annual damage from flooding amounts at about US$159 million[67]. Over the last decades, floods affected more than 9 million people, with annual expected economic losses ranging 2.8- 3.6% of GDP[68]. As an example, extreme flooding affected over 350,000 people in 2013, and the most recent major flood event in 2018 affected over 600,000 people, with 64 deaths and the destruction of farms and microenterprises along with disruptions to social services[69]. The six most flood-affected provinces are Attapeu, Champassak, Khammuane, Savannakhet, Vientiane, and Bolikhamxay[70]. Severe storms are also associated with high economic impacts. Typhoon Bebinca in 2018 resulted in an estimated total damage of approximately $371 million, or about 2.1% of the country's GDP, affected about 1 million people (Figure 7), and more than 100,000 ha of rice.

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[62] Napasirth, P., and Napasirth, V. (2018). Current situation and future prospects for beef production in Lao People's Democratic Republic — A review. Asian-Australas J Anim Sci; 31(7): 961–967.

[63] Footnote 56.

[64] The World Bank Group and the Asia Development Bank (2021). Climate Risk Country Profile: Lao PDR

[65] Center for Excellence in Disaster Management (2017). Lao PDR Disaster Management Reference Handbook 2017 - Lao People's Democratic Republic (the) | ReliefWeb," May 25, 2018, https://reliefweb.int/report/lao-peoples-democratic-republic/lao-pdr-disaster-management-reference-handbook-2017.

[66] Government of Lao PDR (2022). Second National Communication to the UNFCCC. .

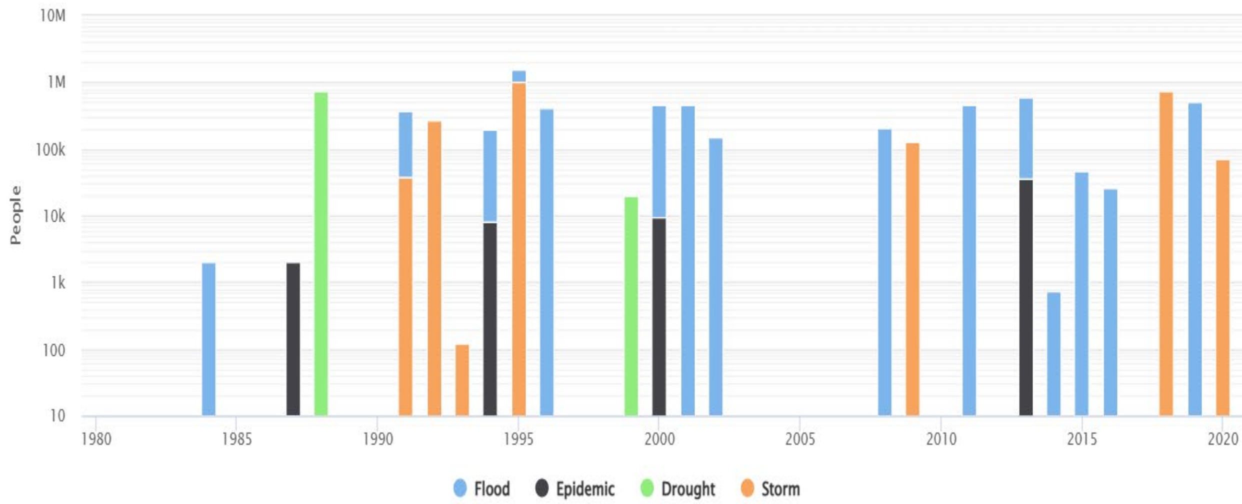
[67] Government of Lao PDR (2021). *National Strategy on Climate Change of the Lao PDR Vision to the Year 2050, Strategy and Programs of Actions to the Year 2030*.

[68] Government of Lao PDR (2018). *Post-Disaster Needs Assessment (PDNA): 2018 Floods Lao PDR*.; 2018.

[69] "Recovery and Resilience in Lao PDR," Text/HTML, World Bank, accessed March 3, 2023, https://www.worldbank.org/en/news/feature/2019/04/09/recovery-and-resilience-in-lao-pdr.

[70] Sutton, William R.; Srivastava, Jitendra P.; Rosegrant, Mark W.; Koo, Jawoo; and Robertson, Ricky. 2019. Striking a balance: Managing El Niño and La Niña in Lao PDR's agriculture. Washington, DC: World Bank. http://hdl.handle.net/10986/31520

Figure 7. Natural hazard events and people affected in Laos



Source: World Bank (2021). Climate Risk Country Profile for Lao PDR

The country is also susceptible to droughts, although at a much lower risk than floods and storms. It faces an annual median probability of severe meteorological drought of around 4%[71]. Drought exposure varies according to region. The least affected parts of the country are the highlands along the border to Vietnam. The central and southern parts of the country, particularly Attapeu, Saravane, Champasak, Khammuane, and Savannakhet provinces, experience the highest level of climate stress from droughts. In 1988–1989, severe droughts associated with El Niño caused about US$40 million loss in agricultural production, with national production declining by about a third. The droughts affected around 1 million people (8). Approximately 188,000 households are at risk of food insecurity due to droughts.[72]

1.3 Policies, investments, and finance for a green transition in agriculture

Laos is committed to further promoting investments in low-carbon sectors to achieve the 2030 goals for Sustainable Development and the objectives of the Paris Agreement. National policies, strategies, and plans, such as the Agriculture Development Strategy (ADS) to 2025 and Vision to 2030, the 9th Five Year National Socio-Economic Development Plan 2021-2025 (NSEDP), and the National Green Growth Strategy (NGGS) 2018-2030, were developed to integrate climate resilience and low carbon initiatives in national activities. The Green and Sustainable Agriculture Framework (GSAF) to 2030, which was developed in 2021 provides guidance in selecting priorities and strategic directions for the development of programs and activities in green and sustainable agricultural production. It is seen as key to operationalizing the National Green Growth Strategy and the Agriculture Development Strategy, through facilitating the formulation and implementation of coherent policy, programs, and investments in green and sustainable agriculture. However, clear action/investment plans for the operationalization of green and sustainable agriculture have not been developed. Annex 1a provides more information on the key policies and strategies for green and sustainable agriculture in Laos.

Laos' Nationally Determined Contribution (NDC) to the UNFCCC indicates the targets for achieving emissions reductions in the energy and AFOLU sectors and the adaptation objectives. The country has an ambitious target to reduce its GHG emissions in 2030 by 60% compared to the Business as usual (BAU)

[71] WBG Climate Change Knowledge Portal (2019). Interactive Climate Indicator Dashboard. URL: https://climatedata.worldbank.org/CRMePortal/web/water/land-use-/-watershed-management?country=LAO&period=2080-2099.
[72] Ministry of Natural Resources and Environment (2016). *National Biodiversity Strategy and Action Plan for Lao PDR 2016-2025*.

scenario[73]. This will require concerted effort across all key emitting sectors including agriculture, forest, and other land uses (AFOLU), and energy. To address the gap in dry season electricity shortage, the government has vowed to diversify energy sources by emphasizing more investment in the renewable energy (from solar, wind, and biomass sources), together with the promotion of energy efficiency. A conditional target in the agriculture sector is the development of 50,000 hectares of improved water management practices in lowland rice cultivation, to reduce annual emissions by 0.13 $MtCO_2e$ between 2020 and 2030. For adaptation, the short-term target in agriculture for the year 2025 is to mainstream climate change adaptation in sectoral strategies and action plans. Long-term adaptation objectives are to promote climate resilience in farming systems and agriculture infrastructure and promote appropriate technologies for climate change adaptation, including nature-based and circular economy solutions.

Some progress has been made towards advancing national targets for resilient and climate-smart agriculture in Laos, but more is still needed to implement actions and accurately track progress in forests and agriculture. On forestry, official data indicates that Laos has made advances towards meeting the targets to increase forest cover and reduce deforestation and forest degradation**.** For instance, records show that 62% of the target 70% forest covered territory has been achieved. However, methods and approaches to tracking progress may need to be improved to arrive at more accurate estimates of progress. For agriculture, areas under organic agriculture have increase substantially, while progress on GAP coverage has been very limited (see section 1.2 for explanation). There is also little progress made in meeting other agriculture related targets or limited information on progress as summarized in Table 3.

Several ministries are active in implementing climate resilience toward low-carbon outcomes but are poorly coordinated and lack information on climate smart agriculture. Under the ministry of agriculture and forestry (MAF), various technical departments promote low-carbon agriculture transition technologies. However, the different departments of MAF have several challenges, which include a lack of information and databases to track investments in and impacts of resilient and low carbon agriculture (see Annex 1b). Under ministry of natural resources and environment (MONRE), the Department of Climate Change (DCC), the Department of Meteorology and Hydrology (DMH), and the Department of Environment and Pollution Control (DEPC) mainly support the implementation of climate actions. However, coordination and information sharing among these technical departments and ministries are not yet systematic.

Table 3. Main targets concerning Green Agriculture in Laos[74, 75]

Resilient and sustainable agriculture targets in Laos	Achievements and remarks
Global Targets	
Reducing emissions below 70 tons of CO_2e per $millions of GDP by 2030	In 2020, emissions reached 83.3 tons of CO_2e per $millions of GDP (Green Growth strategy).
Reducing emissions below 0.6 tons of CO_2e per capita per year by 2025 and 1.2 tons of CO_2e per capita per year by 2030	In 2014, emissions reached 5.5 tons of CO_2e per capita (BUR 2020, World Bank population data).
Targets concerning forestry	

[73] The Government of Lao PDR (2021). Nationally Determined Contributions (NDC). Available online at https://unfccc.int/sites/default/files/NDC/2022-06/NDC%202020%20of%20Lao%20PDR%20%28English%29%2C%2009%20April%202021%20%281%29.pdf, accessed on 27 April 2023
[74] MAF (2015). Agriculture Development Strategy 2025 and Vision 2030
[75] The Government of Lao PDR (2021). First Nationally Determined Contribution (Updated Submission)

Covering 70% of the territory by forests by 2020 (16.58 million ha)[76] (postpone to 2030). Also: • 4,7 million ha of conservation forest • 8,2 million ha of protection forest • 3,1 million ha of production forest	According to official data, in 2020, 62% of the territory was covered by forest. However, most of the area falling in the 'forest' category includes rubber trees which have replaced natural forests because of the encroachment pattern of deforestation driven by crop expansion But, even accounting for rubber, 62% forest cover is probably an overestimation[77].
Planting 500,000 ha of forests by 2020[78]	Between 2016 and 2020, 555,000 ha were planted.
Restoring of degraded forest area of 2,500,000 ha by 2030 [79]	463,618 ha were restored by 2015. Forest restoration has different strategies based on three forest categories: production, protection, and conservation forests. The main strategy for restoration of degraded production forests seems to be the establishment of tree plantations for commercial timber production. Eucalyptus is the common species[80]. However, the logging ban on natural timber ongoing since 2013 reduced options for investing in forest restoration through establishment of tree plantations[81].
Reaching 50% of the protection and conservation forests well-prevented and managed by 2030[82]	Reduction of illegal forest logging through law enforcement enhancement. The logging and export bans (2013 and 2015) contributed to a slowdown in illegal logging for a few years. However, recent data show growing wood export into Vietnam[83].
Targets concerning agriculture	Challenges to implement resilient and low carbon agriculture include poor coordination with other key ministries, low capacity of technical staff and institutions, lack of data and information, poor knowledge, and limited incentives for farmers, also due to the lack of funding
Promoting conservation agriculture, integrated agriculture, and climate smart agriculture	Launched a series of programs
Reducing of slash and burnt agricultural practices by 15% by 2030	
Adopting better livestock feeding and manure management practices	Launched a series of programs
Restoring degraded soils	
Establishing 50,000 hectares of adjusted water management practices in lowland rice	

[76] The Government of Laos (2021). Nationally Determined Contribution 2021 - https://unfccc.int/sites/default/files/NDC/2022-06/NDC%202020%20of%20Lao%20PDR%20%28English%29%2C%2009%20April%202021%20%281%29.pdf ; National Assembly Resolution No. 098/NA on the National Land Allocation Plan with version to 2030.

[77] It is worth to notice here that the Lao Landscapes and Livelihoods (LLL) Project (https://projects.worldbank.org/en/projects-operations/project-detail/P170559) is conducting a Forest and Land use Zoning exercise to independently assess the actual good forest cover within the designated state forestlands. The results are expected in 2024.

[78] Government of Lao PDR (2020). *First Biennial Update Report of Lao PDR (BUR 1*). It is still unclear if the 500,000 ha refers to the old target (achieved) or to a new 500,000 in addition to it to reach a total of 1M ha by 2030 (personal communication).

[79] MAF (2021). Draft Revised Agriculture Development Strategy to 2025 and Vision to 2030

[80] There are 600,000ha currently set aside for commercial tree plantations. However, such area has not been demarcated and the concession process is lengthy and unclear. It is estimated that 10% of such area is currently under plantation arrangements (personal communication).

[81] The LLL project is conducting a survey on the restoration potential with the analysis of Permanent Sample Plots (PSPs). This analysis is expected to be completed in 2023 (personal communication).

[82] Footnote 73

[83] Illegal logging seems to have re-started, possibly caused by the economic crisis. Renovated sawmills in Savannakhet (near the Vietnamese border) can be observed and reports from district officers corroborate that despite the logging and export bans on natural wood, harvesting has re-commenced (personal communication).

cultivation to reduce emissions by 128 kt CO_2e per year[84]	
Area under organic agriculture (ha), 15,000ha by 2030[85]	13,082 ha certified for organic agriculture
Area under good agricultural practices (ha), 10,000ha by 2030[86]	103ha certified for GAP
Irrigated area (ha), 916,366ha by 2030[87]	Total harvested irrigated crop area (full control irrigation) in 2020 amounting at 439,000 ha (FAOSTAT data)

Source: Authors

Public sector investment in resilient and low-carbon technology is still very low and investments largely go to irrigation development. The government does not have the budget necessary to support agriculture related activities. On average, the agriculture sector receives around LAK 40 billion (or $4.9 million) per year from the government budget. This ends up being used mainly for irrigation maintenance and improvement (*Table 4*)[88], especially when severe natural disasters occur. The public budget leaves little to no room for public goods like research and development, demonstration of new technologies, and extension services, which are all vital for the implementation of resilient and low carbon technologies. Although limited, the government provides some subsidies such as small grants integrated into the activities of development projects, subsidized loans, and capacity building as part of the extension services to support resilient agriculture. The Ministry of Finance and the Bank of Laos are also developing a mechanism and policy to promote green financing scheme for small and medium enterprises.

Table 4. Public investment plan for agriculture sector in Laos (million)

	2019	2020	2021
Total PIP in agriculture sector	43,647 kip ($5.35)	37,236 kip ($4.57)	47,625 kip ($5.80)
PIP for infrastructure construction and improvement	29,786 kip ($3.65)	25,393 kip ($3.15)	7,099 kip ($0.86)
PIP for technical enhancement	11,861 kip ($1.45)	11,343 kip ($1.39)	1,236 kip ($0.15)

Source: Authors. Note: $1= 8,150 kip *(in 2019 and in 2020), 8,200* kip *(in 2021)*

The government has made other efforts to support the agriculture sector through providing subsidized loans, guarantees, or interest rate subsidies for farmers. A fund for small and medium enterprises (SME), including those operating in the agriculture (crop and livestock) sector, was established in 2010 and funded by the Government but is limited in scale[89]. It foresees a lending rate of 3% per year for enterprises operating in four priority sectors, including agriculture[90]. The government has established a Credit Guarantee Facility (CGF), as an instrument to help increase access to finance for businesses that do not have enough collateral and provide more incentive for banks to consider providing credit to risky sector like agriculture as well. The government is also a shareholder of the only two commercial banks operating in the farming sector (Agriculture Promotion Bank (APB) and Nayobay Bank (NBB)), with APB as the most critical financial provider for the agriculture sector. Approximately 80% of its loan portfolio is directly to

[84] The Government of Lao PDR (2021). Nationally Determined Contribution 2021 https://unfccc.int/sites/default/files/NDC/2022-06/NDC 2020 of Lao PDR (English), 09 April 2021 (1).pdf
[85] Footnote 73
[86] Footnote 73
[87] Footnote 73
[88] MPI (2019, 2020, 2021). Public Investment Plan for Agriculture Sector for 2019-2021
[89] DOSMEP (2023). SMEs Fund. Retrieved from https://dosmep.org/sme-fund-2/sme-fund/.
[90] There has not been any replicate of such SME Fund dedicated to the agricultural sector.

farmers and 20% to Micro, Small and Medium size Enterprises (MSMEs)[91]. Nevertheless, it has been plagued by a high level of Non-Performing Loans (NPL), due to the 'one-size-fits-all' financial products and is not used by farmers to finance inputs for annual crops because of the annual to monthly repayments it prefers to lower transaction costs.

The private sector should play an important role in financing green technology in the country but does not actively engage smallholder farmers. The Ease of Doing Business report ranks the country at 154 of 190 countries in 2020[92] indicating unconducive environment for private investments. Commercial bank credit in 2021 was US$8,958 million, of which only 7.6% was allocated to the agriculture sector (*Figure 8*). Only 14% of smallholder farmers have access to traditional banking credit[93], and only 2% receive loans from the 73 microfinance institutions operating in the country [94] (Figure 8). Lending to small scale agro-processors by commercial banks is also limited. The reluctance of commercial banks to extend credit to the agriculture sector stems from various factors, including: (i) the inherent risk associated with agricultural activities, including unpredictable weather conditions, vulnerability to pests and diseases, and fluctuating market prices and the ability of borrowers in the sector to generate consistent income and repay loans[95]; (ii) farmers keep inadequate financial records limiting the possibility to assess their creditworthiness; (iii) insufficient collateral options for smallholders, mostly due to lack of land titles for farm activities (only 11% of farmland possess a land title that can be used as collateral) and the absence of other forms of collateral[96]. On the other hand, where farmers have access to commercial bank lending, credit access procedures are too complex for the farmers and loans are ill-adapted to the farmers' needs.

With a limited national budget and private sector financing, Laos is highly dependent on the international development community to finance climate action in agriculture. The role of multilateral and bilateral development organizations in climate action is outsized, yet also tending to be lop-sided in favor of adaptation action and less on climate mitigation or reduction of the environmental externalities caused by agriculture. Annex 1c shows some recent projects in green and sustainable agriculture in Laos. The country will need to maximize all forms of financing possible to drive more action in resilient and low carbon agriculture.

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[91] The loan products include subsidized loan, group loan and individual loan. The interest rates for short-term (term ≤1 year) is 9-10.5%, e.g., chicken raising, for medium-term is 9.3-11.3% for medium-term (1< term ≤3 years), e.g., livestock and for long-term (3< term ≤5 years) is 10-12%. Group loan is a group of farmers who set up a group to produce agricultural product with equally responsibility over the loan on voluntary basis to borrow from APB. The member of the group includes 3 to 5 borrowers with 1 head of group designated to manage repayments; loan size capped at 30 million kip. No formal collateral required, simply a group guarantee. Individual loans have average loan size is 30 million kip. 'Golden land title' required as collateral. Loan size capped at 70% of land value.

[92] World Bank, May 2019, https://archive.doingbusiness.org/en/rankings

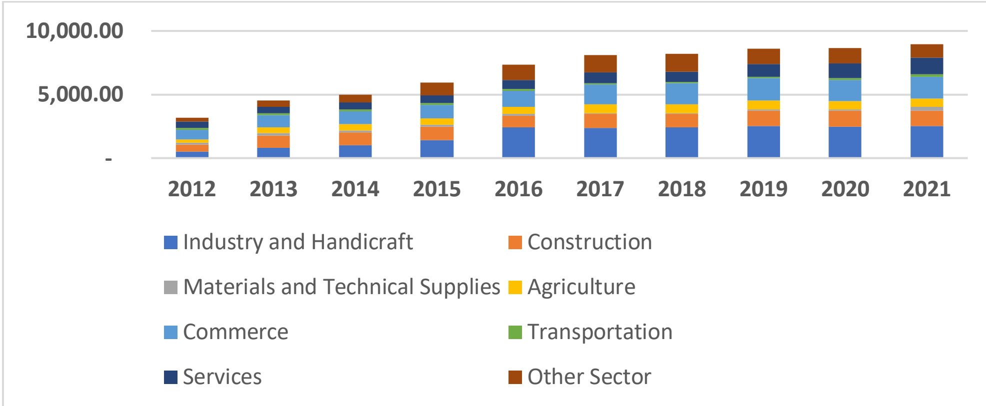
[93] MAF (2020). Agriculture census 2019/2020.

[94] Bank of the Lao PDR website https://www.bol.gov.la/en/Money_and_Banking

[95] Wongpit, P., & Sisapangthong, V. (2022). Willingness to pay of rice farmers in Lao PDR on agriculture insurance. Thammasat Review of Economic and Social Policy, 8(1), 49-66.

[96] Wongpit, P., Inthakesone, B., Sisengnam, K., Insisiengmai, S., Bounphakaisone, S. (2018). Farmers access to credit. Building and Evidence Base for Policy Fomulation in the Agriculture and Rural Development Sector in Lao PDR, National Agriculture and Forestry Research Institute.

Figure 8. Commercial bank credit in Laos (million $)



Source: Bank of the Lao PDR (2023). Annual Report2012-2021[97]

[97] Bank of Lao PDR (2023). Annual Report 2012-2021 of Bank of the Lao PDR (www.bol.gov.la/en/annualreports)

Chapter 2: Coping with Climate Risk through Green and Resilient Improved Technologies

2.1 Climate risks and vulnerabilities

Future climate hazards

Climate change will lead to chronically heat stressed farming environments. Laos has already observed temperature increases, with most areas experiencing an increase in maximum and minimum temperatures of 1.2 °C since 1850. Climate models[98]project an increase of up to 2°C in the 2050s and 4.1°C by the 2090s compared to the 1986–2005 baseline, under the highest emissions pathway (RCP8.5). This reduces to 1.2°C in the 2050s under the lowest emissions pathway (RCP2.6). These translates into a projected country mean annual temperature of 28 °C (±1 °C) in 2100 under RCP8.5 compared to 24.5 °C (±1 °C) under RCP2.6. The highest increase in temperatures is projected to occur during the hottest months of April and May. The increase in temperature will also lead to an increase in the number of days with maximum temperature above 35°C (moving from approximately 40 days to 50–110 days by the end of the century and depending on the emissions pathway and climate model).

Intense rainfall events will increase in frequency while global warming will increase the incidence of extreme river flows and associated flooding risks. Laos has already experienced precipitation increases in some parts of the country, particularly in southern provinces. Most ensemble models also suggest that future climates will have increased annual precipitation rates. Uncertainty in precipitation trends remains high, as reflected in a wide range of model estimates. However, a comparison of multiple modelling projects shows that there is reasonable confidence that the country will experience an increase in heavy rainfall events in the future (*Table 5*). Studies show that East Asia would face an increased frequency of occurrence of extreme river flow caused by global warming (what would historically have been a 1 in 100-year flow, could easily become a 1 in 50-year or 1 in a 25-year event in the region[99]).

The country could experience changes in the spatial distribution of precipitation. Certain areas will receive more rain while others receive less. For example, northern provinces are expected to receive less rain (< 1500 mm cumulative annual mean) compared to 1990-1999 baseline by 2050. Additionally, climate model projections indicate that the country could see a relative increase in the number of dry days. The potential shifts in timing of monsoon will also present important challenges to farming. Early monsoon arrival can cause flood damage while late monsoon arrival can lead to water stress. Uncertain timing and changes in rainfall patterns also highlight the need for improved water management and irrigation services in the country. Although some models indicate a reduction in total rainfall in Laos, the probability of future average decrease in rainfall is low (Table 6).

[98] The World Bank Group and the Asian Development Bank (2021). Climate Change Country Profile: Lao PDR https://climateknowledgeportal.worldbank.org/sites/default/files/2021-06/15505-Lao%20PDR%20Country%20Profile-WEB.pdf

[99] Homero, P. et al., (2018). Global Implications of 1.5 °C and 2 °C Warmer Worlds on Extreme River Flows, *Environmental Research Letters* 13, no. 9 (August 2018): 094003, https://doi.org/10.1088/1748-9326/aad985.

Table 5. Projections of average temperature change (°C) for different seasons (3-monthly time slices), time horizons and emissions pathways, showing the median estimates of the full CCKP model ensemble and the 10th and 90th percentiles in brackets.

Scenario	2040–2059		2080–2099	
	Jun–Aug	Dec–Feb	Jun–Aug	Dec–Feb
RCP2.6	1.0 (0.2, 2.4)	1.2 (–0.4, 2.5)	1.1 (0.1, 2.3)	1.3 (–0.1, 2.6)
RCP4.5	1.5 (0.5, 2.8)	1.4 (–0.3, 2.7)	1.9 (0.9, 3.4)	1.9 (0.3, 3.6)
RCP6.0	1.3 (0.3, 2.6)	1.0 (–0.5, 2.0)	2.5 (1.3, 4.0)	2.1 (0.4, 3.8)
RCP8.5	1.7 (0.6, 3.2)	2.0 (0.3, 3.4)	3.7 (2.4, 5.8)	3.9 (1.6, 6.2)

Source: The World Bank Group and The Asian Development Bank (2021).

Table 6. Climate hazards identified based on the CCKP ensemble[100], the results of SAMIS[101](Box 3. System of Rice Intensification (SRI)), IPCC Interactive Atlas[102] and CORDEX-CORE[103] models.

Hazard	Source	Agreement	Confidence	Impact
Increase in mean temperature	CCKP-CMIP5	High	High	Increase in evapotranspiration which must be met by an increase in water supply
	SAMIS	(No information)		
	CMIP6	High		
	CORDEX-CORE	High		
Increase in number of days with maximum temperature above 35 °C	CCKP-CMIP5	(No information)	High	Suppression of ovary fertilization and grain filling process
	SAMIS	(No information)		
	CMIP6	High		
	CORDEX-CORE	High		
Reduction in precipitation	CCKP-CMIP5	(No information)	Low	Reduction in yield, crop failure
	SAMIS	Medium		
	CMIP6	Low		
	CORDEX-CORE	Low		
Increase in heavy rainfall events	CCKP	Medium	Medium	Anoxia, damage to seeds and seedlings, soil erosion
	SAMIS	(No information)		
	CMIP6	Medium		
	CORDEX-CORE	High		
Increase in number of dry days	CCKP-CMIP5	Medium	Medium	Yield reduction, increase demand for irrigation
	SAMIS	(No information)		
	CMIP6	(No information)		
	CORDEX-CORE	High		

Source: Authors. Model agreement has been calculated qualitatively based on the suggested results of CCKP, SAMIS, CMIP6 GCM, and CORDEX-CORE climate models.

[100] https://climateknowledgeportal.worldbank.org/
[101] FAO. Strengthening Agro-climatic Monitoring and Information System (SAMIS). https://www.fao.org/in-action/samis/overview/en/
[102] https://interactive-atlas.ipcc.ch/
[103] https://cordex.org/experiment-guidelines/cordex-core/

Box 2 SAMIS modelling approach

Results from the "Strengthening Agro-climatic Monitoring and Information Systems (SAMIS) to improve adaptation to climate change and food security in LAO PDR" project were used to inform the analysis presented on climate change impacts. SAMIS was developed to increase decision-making and planning capacity for the agricultural sector at national and decentralized levels in Laos. It provides downscaled climate projections for Laos and the results of pyAEZ (python version of the FAO Agro-ecological Zoning tool) which simulates maximum obtainable crop yield based on climate, plant, and soil characteristics. The crop results are available for Maize, Cassava, Robusta Coffee, Banana, and Rice under RCP 2.6 and RCP 8.5 scenarios.

The results of SAMIS are available online (https://lrims-dalam.net/). Yield levels are grouped into 5 classes (from very low to very high) that equally divide the range between maximum and minimum simulated potential yields for each crop. Projected changes (increase or decrease) in yield classes are calculated as difference in yield levels between present (2010-2019) and future periods up to 2099. The climate projections and subsequent crop simulations carry inherent uncertainties which are due to an incomplete understanding of Earth's system and its interactions with crops; natural variability in climate; the limitations of climate and biophysical models to numerically represent the reality; biases; and emissions of greenhouse gases in the next decades. Here, the results are presented for the ensemble of simulations.

Source: Authors

Vulnerability and adaptive capacity

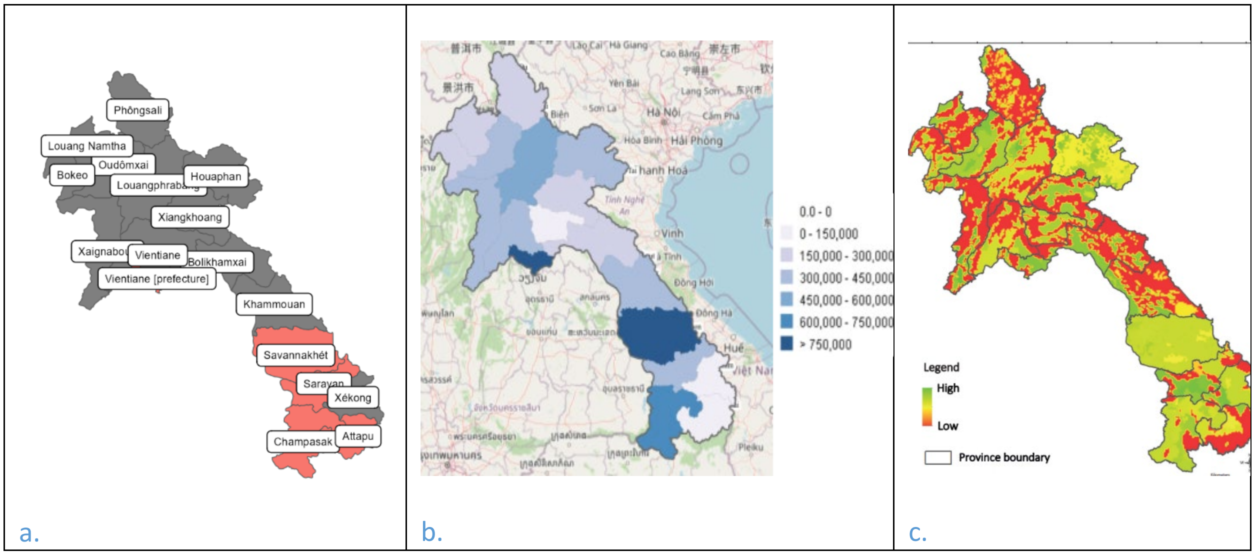
The southern provinces are the most exposed to future climate risks. Most cropland is rainfed and is in the southern provinces (Champassak, Saravane, and Savannakhet), with higher population density (Figure 9). Such areas show high climate exposure both for agriculture systems and human capital. Model projections under the SAMIS project[104] also show a possible decease in precipitation in these provinces, particularly in Savannakhet.

Most provinces have limited capacity to adapt to climate hazards. Out of the 17 provinces in Laos, Houaphan, and Savannakhet are the two provinces with medium to high adaptive capacity. Champassak, Xekong, Saravane, Vientiane Capital and Oudomxay follow with a low to medium capacity (Figure 9). The other ten provinces have low capacity to adapt to climate change, due to extreme poverty rates, poor connectivity, and limited access to agricultural services like irrigation, extension, and financial services. This indicates that most of the country has fragile adaptive capacities in the face of growing climate hazards.

With low adaptive capacity, climate hazard risks could significantly impact agriculture. The low level of adaptive capacity in the country, particularly in the northern and southern provinces makes the agriculture sector particularly vulnerable to climate-related risks. For instance, an increase in mean and maximum temperatures will intensify evapotranspiration, and if an increase in water supply does not meet this evaporative demand, substantial agricultural losses will occur. Other climate hazards will also impact agriculture (see *Table 6*).

[104] Strengthening Agro-climatic Monitoring and Information System (SAMIS). https://www.fao.org/in-action/samis/overview/en/

Figure 9. Lao provinces with (a) highest percentage of crop cover, (b) highest population, (c) lowest adaptive capacity index.



Source: SAMIS project (2022).

Climate change impact on crops

Projected warmer temperatures and delays in the onset of the rainy seasons are expected to decrease maize yields, especially for areas along the border with Thailand (*Figure 10*a). Extreme weather events will be the primary cause of negative impact on maize productivity[105] especially in the provinces bordering Thailand where maximum temperatures can surpass 30°C and will likely exceed the thresholds for optimal maize production. Simulated future crop yields show that agricultural inputs are a major constraint on achieving high productivity[106]. Medium-maturing varieties appear to perform better under climate change. The northeastern provinces will experience only limited negative impacts of climate change or will even benefit from modest improvement in maize production. Increasing temperatures will decrease the occurrence of below-optimal temperatures for maize production in those regions.

Cassava, a climate-resilient crop due to its stable performance under low soil fertility and water availability[107], will be moderately impacted by climate change. *Figure 10b* shows that the negative effect of climate change is less severe for cassava relative to other crops. A decrease in potential yield of cassava can be seen mostly in the central and northern provinces of the country, especially in the 2050s. The negative impacts of climate change will come from dry spells, heavy rainfall and flooding which will enhance weather-related pests and diseases, including the cassava witches' broom disease and the cassava mosaic Disease[108]. Projections also show that early maturing varieties of cassava will retain higher potential yields in the future than late maturing ones, particularly in southern provinces. If nutrient

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[105] GIZ (2013). Climate Proofing of the Rice and Maize Value Chain in Sayabouri, Laos, https://asean-crn.org/climate-proofing-of-the-%E2%80%A8rice-and-maize-value-chain%E2%80%A8-in-sayabouri-laos/.

[106] Footnote 93

[107] Assefa B. Amelework et al., (2021). Adoption and Promotion of Resilient Crops for Climate Risk Mitigation and Import Substitution: A Case Analysis of Cassava for South African Agriculture," *Frontiers in Sustainable Food Systems* https://www.frontiersin.org/articles/10.3389/fsufs.2021.617783.

[108] Souvannavong, P. (2021). Value Chain Analysis of Cassava in Lao PDR. Australasian Agribusiness Perspectives 2021, Volume 24, Paper 13 ISSN: 2209-6612 Postgraduate student, Centre for Global Food and Resources, University of Adelaide

applications are not improved, cassava production will impact soil erosion, soil fertility, and land degradation[109], with negative effects on cassava yields.

Extreme weather events will have detrimental effects on coffee production resulting in low and unstable yields and low-quality coffee beans. High rainfall and temperature increase will have a severe impact on coffee production. Projected increasing temperatures and changes in rainfall patterns are expected to impact the suitability of both Robusta and Arabica coffee production areas. Maximum potential yield of Robusta varieties is projected to particularly increase in central areas, while northern and southern provinces are projected to experience a decrease (*Figure 10c*). Robusta varieties have higher yield potential than Arabica ones [110]. Studies conducted in Vietnam's Central Highlands show that lower than average rainfall during the late growing season can increase the risk of below-average coffee bean size by 80%, whereas high rainfall and minimum temperatures above 22 °C during harvest period can increase by 75% the risk of above-average coffee bean defects. High rainfall and temperatures increase pests and disease spread (e.g. coffee berry borer, mealybugs, mold spread), causing mold and damaged beans at flowering, growing and harvest stages[111].

Banana production will be negatively affected by climate change through increased erosion and incidence of diseases. Banana yields will decline mostly in Savannakhet province, Vientiane capital, Vientiane province, Champassak and Khammuane provinces[112] (*Figure 10*d). Negative impacts are likely to emerge from heavy rainfall, floods, and droughts, which could increase erosion and incidences of diseases (e.g. banana bunchy top virus), which are already affecting the crop in Vientiane province[113]. Banana production can grow as an effect of climate change in provinces where current production is marginal. Suitability of banana production could change from marginal and moderate to high in Xieng Khuang province, and from marginal to moderate in Bolikhamxay and Oudomxay provinces, driven by the benefits of warming temperatures.

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[109]FAO and International Automatic Energy (2018). Cassava Production Guidelines for Food Security and Adaptation to Climate Change in Asia and Africa. https://www-pub.iaea.org/MTCD/Publications/PDF/TE1840_web.pdf

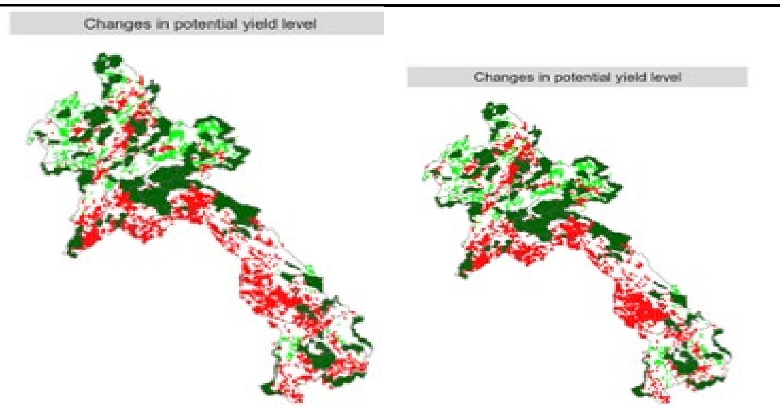
[110] "News | Strengthening Agro-Climatic Monitoring and Information System (SAMIS) | Organización de Las Naciones Unidas Para La Alimentación y La Agricultura."

[111] Jarrod Kath et al., (2021). Temperature and Rainfall Impacts on Robusta Coffee Bean Characteristics, *Climate Risk Management* 32 (January 1, 2021): 100281, https://doi.org/10.1016/j.crm.2021.100281.

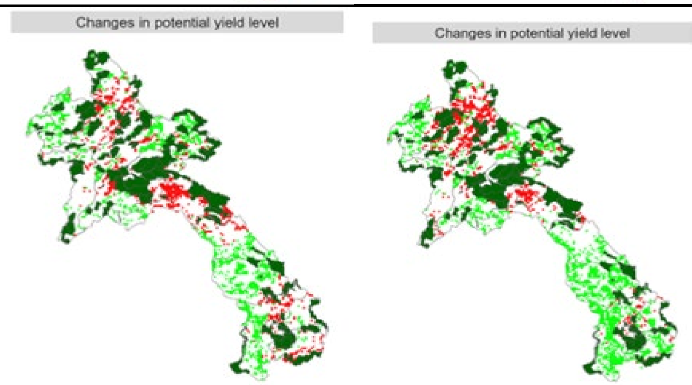
[112] FAO (2022). Exploring banana futures: Building banana sustainable and climate resilient pathways in Lao People's Democratic Republic. Available online at https://www.fao.org/3/cc2849en/cc2849en.pdf, accessed on 26 April 2023.

[113] Khonesavanh Chittarath et al., (2022). Presence and Distribution of Banana Bunchy Top Virus in Laos," *Australasian Plant Disease Notes* 17, no. 1 (November 9, 2022): 36, https://doi.org/10.1007/s13314-022-00482-y.

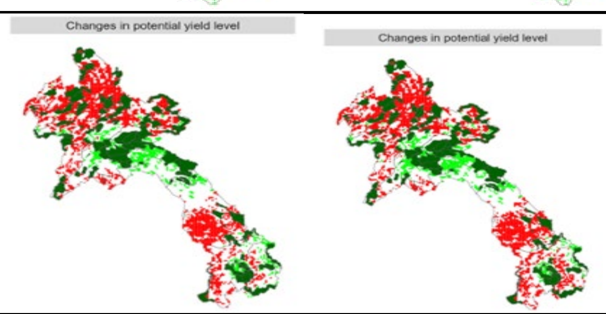
Figure 10. Projected changes I maximum potential yield for various crops (maize, cassava, Robusta coffee, banana, and rice under RCP2.6 scenarios and rainfed conditions simulated under the SAMIS project using pyAEZ. Red areas indicate a reduction in potential while light green indicate areas with a projected increase in potential yield relative to baseline. [Dark green is protected forest area]



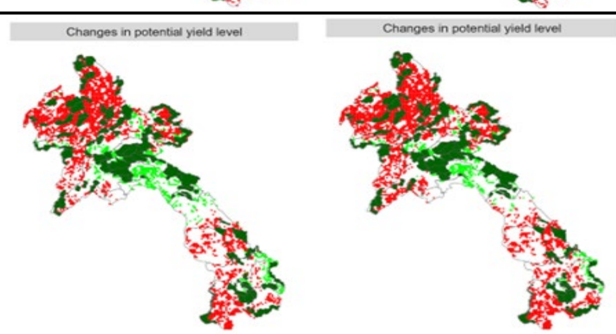
a. Projected changes in potential yield of medium-maturing varieties of Maize for 2031-2040 (left), and 2051-2060 (right)



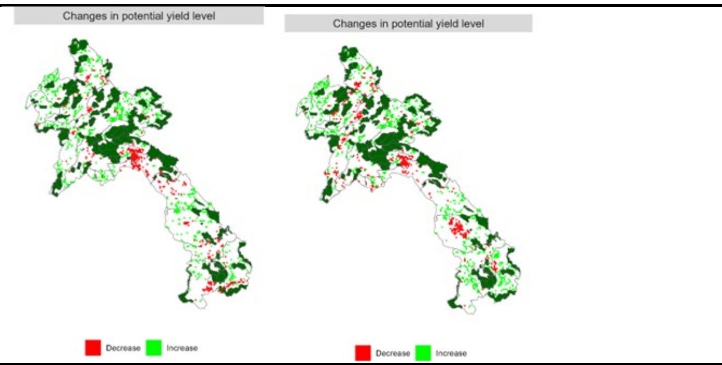
b. Projected changes in potential yield of early-maturing varieties of Cassava for 2031-2040 (left), and 2051-2060 (right), relative to 2010-2019



c. Projected changes in potential yield of Robusta coffee varieties for 2031-2040 (left), and 2051-2060 (right), relative to 2010-2019



d. Projected changes in potential yield of medium-maturing varieties of banana for 2031-2040 (left), and 2051-2060 (right), relative to 2010-2019



e. Projected changes in potential yield of late-maturing varieties of rice for 2031-2040 (left), and 2051-2060 (right), relative to 2010-2019

Source: SAMIS project (2022)

Heavy rains, heat stress, typhoons and flooding will affect rice production, but growing rice will still be possible in many parts of the country. Lowland rice production is more susceptible to flooding than upland rice. The most severe impacts of climate change on rice will be in the Bolikhamxay, Khammuane, Champassak, and Attapeu provinces. Heat stress from daily maximum temperatures above 35°C will adversely affect wet-season rice by limiting rice flower pollination, increasing evapotranspiration, decreasing water availability during the dry season, and reducing soil productivity during droughts[114]. The choice of rice varieties and optimal agricultural management strategies can have a substantial effect on moderating the negative impact of climate change on wet-season rice production[115]. Late-maturing varieties have the highest yield potential, particularly with high level of agricultural inputs use, and are projected to retain high yield potential in southern and northern provinces of the country (*Figure 10*e).

Climate change impact on livestock

Increasing temperatures will have detrimental effects on livestock through heat stress, diseases, and pastures loss. Most livestock species show a medium-high vulnerability to climate change. Table 7 summarizes the levels of risk from extreme temperatures for all livestock systems in the country, and their capacity to adapt. Heat stress could reduce productivity. Small commercial poultry production is particularly vulnerable to excessive temperatures in the Lower Mekong Valley as the optimal temperature ranges between 18-21°C and above 21°C animals experience a voluntary reduction in feed intake and growth rates. Rising temperature increases the likelihood of disease outbreaks through changing pathogen viability, vector population, and disease spread. It will kill animals and result in a substantial economic loss. Frequent and extended dry periods and droughts will affect fodder production and pastures, which will result in low-quality and insufficient feed for a sector which is already experiencing feed shortage. Heavy rains will cause rivers to overflow and flood many areas, destroying animal shelters and pasture, and killing livestock.

[114] "Derisking Delta-Oriented Value Chains in Cambodia, Vietnam and Myanmar."
[115] "News | Strengthening Agro-Climatic Monitoring and Information System (SAMIS) | Organización de Las Naciones Unidas Para La Alimentación y La Agricultura."

Table 7. Climate vulnerability of livestock systems in the lower Mekong[116]

Livestock system	Extreme high temperature impacts	Adaptive capacity	Vulnerability
Smallholder cattle/ buffalo	Low	Low	Medium
Dairy/ large commercial	Very high	High	High
Small commercial pig	High	Medium	High
Smallholder low-input pig	Low	Low	Medium
Small commercial chicken	Very high	Low	Very high
Scavenging chicken	Low	Low	Medium
Field-running layer duck	Very low	Low	Low

Source: USAID (2013).

Climate change impact on agricultural value chains

Agricultural value chains are exposed to climate hazards particularly through weak post-harvest storage and processing infrastructure. Weak access to milling facilities and use of traditional methods for paddy rice processing such as sun drying increases rice exposure to extreme weather events and can lead to grain quality degradation[117,118]. In Southeast Asia, temperatures between 25-30°C, combined with high water activity and relative humidity between 88-95% constitute an enabling environment of mycotoxin growth in rice bran[119]. Grain is frequently stored in inappropriate units, such as wood-based storage units, leading to losses due to the spread of fungi, mold contamination, and pest attacks, which contribute to 10% of grain losses during the dry season, and 7% losses during the wet season. Without appropriate storage and processing facilities, future climate change will entail that bananas quickly ripen under elevated temperatures, causing quality and shelf-life reduction. High temperatures and relative humidity are the primary cause of mold and mycotoxin spread during coffee storage. Heavy rainfall and flooding events cause the rewetting of dried coffee beans. The oxidative deterioration of cassava in the post-harvest phase cause changes in the root color, particularly where there are cuts and bruises. This is worsened by relative humidity conditions of 65-80%. The process of drying fresh cassava roots into chips causes a weight loss of 53-57%, which varies depending on the moisture and starch content of each variety. The roots are sliced and placed to be sun-dried for 3-5 days, leaving them to be exposed to weather-related hazards such as extreme rainfall events, high relative humidity, hot temperatures, and direct sunlight.

Extreme heavy rainfall and flooding are the principal cause of road infrastructure damage, with negative impact on market access. The occurrence of extreme weather events can hinder access to post-harvest facilities and markets, especially where roads are not climate proofed. Farmers often leave their produce in storage for prolonged periods, which increases the risk of fungal and pest attacks. The weak road

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[116] Jeremy Carew-Reid et al., (2023). *USAID Mekong ARCC Climate Change Impact and Adaptation Study: Summary*, https://doi.org/10.13140/RG.2.2.34024.37120.
[117] Fukai. S and Mitchell. J, (2019). Final Report Mechanization and Value Adding for Diversification of Lowland Cropping Systems in Lao PDR and Cambodia. Publication code: CSE2012-007. Australian Center for International Agricultural Research
[118] World Bank (2018). Commercialization of Rice and Vegetable Value Chains in Lao PDR: Status and Prospects. © World Bank
[119] Siri-anusornsak et al., (2022). The Occurrence and Co-Occurrence of Regulated, Emerging, and Masked Mycotoxins in Rice Bran and Maize from Southeast Asia. Toxins (Basel). 2022 Aug 19;14(8):567. doi: 10.3390/toxins14080567. PMID: 36006229; PMCID: PMC9412313. https://pubmed.ncbi.nlm.nih.gov/36006229/

network and the remoteness of farming areas reduces the presence of market off takers in the areas of production, which increases transportation costs and disrupts traders' mobility under heavy rains. Furthermore, at farm gate farmers sell their produce to small-scale collectors and market intermediaries without much flexibility to set adequate prices, with negative effects in terms of price profitability.

2.2 Technologies and practices for climate-resilient agriculture

Without urgent action, climate change will continue to place the Lao agriculture sector at risk. Adopting green and climate-resilient technologies and practices is an opportunity to improve farming efficiency and agriculture productivity, while adapting to climate change, and lowering the sector's GHG emissions and other environmental impacts. We discuss technologies which are feasible and scalable for Lao agriculture, based on evidence from trials, pilots, and projects implemented in the country and the region (these are summarized in Table 10).

Climate resilient, improved crop varieties

Laos should promote climate-resilient and improved crop varieties, which can address emerging climate change effects in different provinces. Improved varieties can address abiotic stresses such as drought and heat (drought resistant), flooding (water stress tolerant), and changing growing season timing (early maturing), and pests associated with changes in weather or climate patterns (disease and pest resistance). The country has a long-standing successful breeding program for rice dating back to the 90s. The breeding emphasized resistance to pests and diseases, and drought suitability in the central and southern provinces, creating seventeen varieties by the year 2006, and has recently focused on developing resilient varieties for specific environments[120]. They will be very important in the future as climate change will evolve differently across the country, demanding a shift in seed varieties. For instance, paddy rice production will require high yielding submergence tolerant varieties in the south of the country given projections of moderate-to-high risk of extreme rainfall events. Farmers involved in a participatory consultation on variety selections chose the TDK1-Sub1 (glutinous) and IR64-Sub1 (non-glutinous, early maturing) varieties as the most drought- and submergence-tolerant varieties in the lowland areas. For cassava, the government will need to surmount the current high use of local landraces (43%) and expand access to improved varieties, such as high yielding, flood tolerant, disease-resistant, and early maturing varieties, especially in the south. However, the country does not have a research and breeding agenda for cassava as established for other crops like rice.

System of rice intensification (SRI)

SRI is based on cultivating rice based on four fundamental principles that address plant, soil, and water management. These include the early establishment of healthy plants, low plant density, soil enrichment and the sparing application of water (Box 3). SRI provides benefits of vigorous root development and plant growth under low input practices like wetting and drying cycles during the first 50 days after transplanting. For successful implementation of SRI, the use of organic fertilizers should be integrated with training on pest and weed management since organic fertilization could enhance the proliferation of weeds and pests.

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[120] Mullen, J., Malcolm, B., and Farquarson, B., (2019). Impact Assessment of ACIAR-supported Research in Lowland Rice Systems in Lao PDR. ACIAR Impact Assessment Series No. 97. Canberra: Australian Centre for International Agricultural Research. 5 FROM SUBSISTENCE TO COMMERCIAL RICE PRODUCTION IN LAOS

Box 3. System of Rice Intensification (SRI)[121]

SRI was pioneered in the mid-1980s originating from unusual practices in farmers' fields in Madagascar.

The main practices of SRI are:

1. Early transplanting of young seedlings (less than 15 days old, preferably 8–12 days), contrary to the conventional practice of transplanting 20–60-day-old seedlings.
2. Transplanting one or two seedlings per hill, in contrast to a bundle (4–5) of seedlings per hill.
3. Wide spacing (more than 20 × 20 cm, in contrast to narrow (10–15 cm) or random spacing.
4. Alternate wetting and drying (AWD) to maintain moist, aerobic soil conditions, in contrast to continuous flooding from transplanting to maturity.

Proponents of SRI often advocate using compost or manure instead of chemical fertilizers to enrich soils with organic matter.

SRI is often considered a pro-poor rice management practice despite its complex, knowledge-intensive nature. It has been disseminated among low-and medium-income farmers in developing countries. The four core SRI principles described above are typically recognized as a package, as they are believed to have synergistic effects. However, actual practices can vary among farmers across places as SRI can be adapted to each specific locality and has been continuously evolving based on participatory on-farm trials.

System of Rice Intensification (SRI) has been promoted in the Lower Mekong River Basin between 2007-2018. Farmers reported higher yields and profits from paddy grown with SRI[122], A total of 2,134 Lao farmers in nine districts covering three provinces (Vientiane, Khammuane, and Savannakhet), who adopted SRI reported paddy yield increases between 27-35%, with respect to current yields of about 4.2 t/ha, obtaining 5-6 t/ha [123]. Economic studies in other countries have shown significant profit increases (44%) for farmers practicing SRI [124]. Such technology is suitable for poor Lao farmers because it can achieve yield gains without increasing external inputs demands. It favors organic manure over chemical fertilizers, which is consistent with the low chemical fertilizer application level in the country. Rice emissions primarily come from the anaerobic breakdown of organic matter in wetland rice. Methane (CH4) emissions from rice cultivation can be limited with adjusted water management. Alternate Wetting and Drying (AWD) practices can help to manage water use, while decreasing GHG emission contributions of rice production. The water management component of SRI can contribute to the national goal of improving water management practices in lowland rice cultivation (target area is 50,000 hectares), which aims to reduce emissions by 128 ktCO_2e annually between 2020-[125]. Research shows that SRI practices increase yield in Laos on average by 39% while reducing tCO_2e/ha GHG emissions by 33% in irrigated rice cropland and 44% in rainfed rice cropland.[126] Rice productivity can also be increased by shifting to a rice

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[121] Takahashi, K. (2022). A UFO? Assessment of System of Rice Intensification from the Agricultural Economics Perspective. In *Agricultural Development in Asia and Africa: Essays in Honor of Keijiro Otsuka* (pp. 87-97). Singapore: Springer Nature Singapore.

[122] Sustaining and Enhancing the Momentum for Innovation and Learning around the System of Rice Intensification (SRI) in the Lower Mekong River Basin (SRI-LMB), http://www.sri-lmb.ait.asia/

[123] http://sri.ciifad.cornell.edu/countries/laos/index.html

[124] Takahashi, K., (2022). A UFO? Assessment of System of Rice Intensification from the Agricultural Economics Perspective. In *Agricultural Development in Asia and Africa: Essays in Honor of Keijiro Otsuka* (pp. 87-97). Singapore: Springer Nature Singapore.

[125] Government of the Lao PDR (2021). Nationally Determined Contribution 2021

[126] Mishra. A, Ketelaar. JW, Uphoff. N, Whitten. M. (2021). Food security and climate-smart agriculture in the lower Mekong basin of Southeast Asia: evaluating impacts of system of rice intensification with special reference to rainfed agriculture. *International Journal of Agricultural Sustainability*.;19(2):152-174. doi:10.1080/14735903.2020.1866852

variety with higher drought tolerance. It was estimated to increase yield by 7% on average in Laos[127]. However, overall, adoption has been poor in Laos. SRI tends to initially be labor intensive, which is a disincentive for some farmers. Also, investments are required to upgrade systems to a standard that would allow for such practices. Further investigation can help to establish identify investments required to upgrade current irrigation systems to be more compatible with SRI.

Agroecological practices

Agroecology approaches to farm management can improve agricultural land productivity, and limit encroachment of cropland into forests. One of the major challenges of the agriculture sector in Laos is continued encroachment into natural areas like forestland, driven primarily by rapid expansion of cassava and coffee on rapidly deteriorating soils, conditions which are likely to be worsened by climate change. This is of particular concern in the uplands. Agroecology provides options for farmers to increase productivity and resilience through sustainable production systems more in harmony with nature. It enhances biological interactions and synergies among the components of agrobiodiversity, thereby promoting key ecological processes and services. The application of different agroecological practices at farm and landscape level can enhance the function of natural ecosystems akin to ecosystem-based adaptation approaches and nature-based solutions. An example is agroforestry systems, which are known to improve food productivity while enhancing biodiversity conservation, and ecological restoration under changing climate conditions[128]. Agro-ecological practices are also important for other crops where potential yields in Laos have not yet been achieved due to decreasing soil organic carbon (SOC) from poor soil management (like coffee, and maize). Poor soil management practices, such as crop residue removal and deep tillage, can lead to a 70% reduction in SOC[129]. In such a situation, organic manure application as an agroecological approach can be promoted to sustain the health of soils and ecosystems.

Sustainable intensification through creating conditions for soil protection, soil fertility restoration, and diversification (both of crops and practices) is the principal action to achieve agroecological outcomes in Lao agriculture. This is particularly important given that current monocropping practices for cassava, coffee, and maize are over-mining and degrading soils, reducing cropland biodiversity, and promoting continued expansion of agriculture on new lands. Since climate change will add more pressure through more dry days, intense rain events and soil erosion, three main approaches can address these challenges.

(i) *Agroforestry* – will replace land clearing and monocropping, while reducing heat stress, maintaining soil fertility, soil-water balance, and contributing to diversification of production.

(ii) *Cultivar selection* – will ensure that farmers use the most locally suited, climate adapted high yielding varieties to maximize their yields, under climate change pressures.

(iii) *Direct seeding mulch-based cropping (DMC)* - Intercropping, cover cropping, crop rotation, and organic mulching - will tackle soil erosion, soil degradation and nutrient leaching exacerbated by heavy rainfall and flooding events, and evapotranspiration from drought.

Applying this diversified agronomic package in Laos will reduce farmers' application of fertilizers, build resilience to climate change by reducing water use, erosion, and nutrient loss, boost net incomes and reduce GHG emissions. The diversified agronomic package DMC (rotating crops, intercropping, cover

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[127] Inthapanya, P. (2015) New High Yielding Promising Glutinous Rice Line TDK37-B-9-1-3-B. *The Lao Journal of Agriculture and Forestry*.

[128] Paudela, D., K.R. Tiwaria, R.M. Bajracharyab, N. Rautb, and B.K. Sitaulac, (2017): Agroforestry system: An opportunity for carbon sequestration and climate change adaptation in the Mid-Hills of Nepal. Octa J. Environ. Res., 5, 10 pp.

[129] L. K. Mann, "Changes in Soil Carbon Storage After Cultivation," *Soil Science* 142, No. 5 (November 1986): 279.

crops, organic manure application), cultivar mixtures, and agroforestry is suitable for sustainable production in the context of climate change. This has potential benefits for cassava production, known for severely depleting soil nutrients and necessitating the regular opening of virgin land. If cassava production is not accompanied by integrated soil management (including nutrient management), cassava production will exacerbate climate change impacts on soil erosion, soil fertility, and land degradation[130].

Over the past decades many agroecological options have been tested successfully in Laos to support sustainable intensification of upland agriculture. For example, diversified cropping systems based on agroecological principles have proved effective in restoring degraded soils and improving agricultural productivity while limiting the use of external chemical inputs[131]. Practices such as intercropping, and agroforestry using shade trees in coffee to reduce increasing temperatures and drought impacts on ripening of cherries, pest and disease attacks, and evapotranspiration have been successfully tested. Organic mulching using pruned branches and coffee leaves during drier than average conditions have been shown to increase yields by 7% and economic benefits by 10% through improved soil moisture, nutrient application, and reduced weeds, compared to coffee farmers not adopting such practice[132]. In central provinces, *Persea kurzii* trees have been grown on rice and banana fields generating raised financial income for farmers[133]. Intercropping with fast-growing crops such as pumpkin or Leguminosae such as *Leucaena* (which acts as a nitrogen-fixing plant) and followed by lemon grass, contributed to reducing soil erosion and nutrient leaching under heavy rainfall and flooding events[134].

Climate-proofed irrigation systems

Irrigation can effectively reduce exposure and vulnerability of crops to climate change by reducing dependence on rainfall for meeting crop water demand. As shown in Table 8, irrigation can help crops to cope with heat and water stress caused by climate change, reduce climate variability, and contribute to climate adaptation[135]. Maize, rice, and cassava yield losses from climate change under irrigated conditions are at least half of those under rainfed conditions (irrigation can moderate the negative impacts of climate change by a factor of 2.5 for rice, 2.2 for maize, and 1.9 for cassava).

Table 8. *Projected changes in crops yields for RCP 6.0 with different climate and crop models from the ISIMIP model ensemble*

	Average change	Minimum	Maximum
Irrigated Maize	-5%	-9%	-1%
Rainfed Maize	-11%	-49%,	+3%
Irrigated Rice	-6%	-13%	+14%
Rainfed Rice	-16%	-30%	+14%
Irrigated Cassava	-10%	-17%	+11%

130 "TE1840_web. Pdf," accessed April 14, 2023, https://www-pub.iaea.org/MTCD/Publications/PDF/TE1840_web.pdf.
131 ASEAN Technical Working Group on Agricultural Research and Development (ATWGARD) and Internationale Zusammenarbeit (GIZ) GmbH (2015). Promotion of climate resilience in rice and maize in Lao PDR. https://snrd-asia.org/download/forest_and_climate_change_for-cc/Lao-Report.pdf
132 Byrareddy et al., "Coping with Drought."
133 Alex van der Meer Simo, Peter Kanowski, and Keith Barney (2020). The Role of Agroforestry in Swidden Transitions: A Case Study in the Context of Customary Land Tenure in Central Lao PDR, *Agroforestry Systems* 94, no. 5 (October 1, 2020): 1929–44, https://doi.org/10.1007/s10457-020-00515-4.
134 "Cambodia National Study: Promotion of Climate Resilience in Rice and Cassava," *ASEAN-CRN* (blog), November 2, 2015, https://asean-crn.org/cambodia-national-study-promotion-of-climate-resilience-in-rice-and-cassava/.
135 Lorenzo Rosa (2022). Adapting Agriculture to Climate Change via Sustainable Irrigation: Biophysical Potentials and Feedbacks, *Environmental Research Letters* 17, no. 6 (June 2022): 063008, https://doi.org/10.1088/1748-9326/ac7408.

Rained Cassava	-19%	-31%	+4%

Source: Authors

The government has limited financial capacity to construct new irrigation infrastructure and should prioritize investment in climate-proofed irrigation systems, including rehabilitation of local irrigation systems and cementation of canals. Available irrigation schemes are not being utilized at capacity as they are in disrepair, especially in the central and southern provinces where floods repeatedly caused extensive infrastructural damages. In the uplands, only 50% of the cropland area available during the wet season is irrigated during the dry season, whereas, in the lowlands, the area irrigated during the dry season amounts at 68% of the cropland available during the wet season. As such, climate proofing irrigation systems is critical. Climate-proofing of irrigation systems has been applied successfully in the region (e.g. in Vietnam and Philippines[136]). It helps to ensure that climate risks are reduced to acceptable levels through long-lasting changes implemented during planning, design, construction, and operationalization of the irrigation system[137]. Overall, given the projected changes in rainfall patterns with highest impacts on smallholder farmers, to ensure uptake of integrated water resource management and climate-proofed small-scale irrigation systems, small-scale local approaches such as drainage systems, small-scale ponds, and rainwater harvesting tanks for water capture, diversion, levelling, and control should also be considered, using bottom-up approaches originating from farmers' initiatives at the local level funded by local institutions[138]. Lining of canals is recommended for higher-level public government interventions.

Climate proofed irrigation systems should be accompanied by functioning and cohesive water user groups (WUGs) and associations (WUAs). The government should expand irrigation access and climate-proof irrigation systems to improve water supply efficiency. The irrigation infrastructure must be effectively managed to avoid its under-utilization and improve water use efficiency, to increase resilience [139]. Strong and well-functioning WUGs and WUAs are indispensable for effective operation of irrigation systems, yet they do not function well in the country.

Climate resilient commercialization through intensification of livestock production

Livestock-focused strategies of commercialization through breeding and supplementary feeding can be an effective way of addressing climate risks to livestock. Commercialization of livestock, through focused intensification of production based on improved feeding, and breed management practices can be an effective way to increase meat production, and farmer incomes, while building resilience of livestock production systems and reducing emissions. Adoption of livestock intensification practices at smallholder farmer scales (improved breeds under more intensive systems where feed and veterinary services are provided) will provide higher and more consistent returns than communal free-range production, which is dominant in Laos (98% of livestock production), while generating fewer greenhouse gases. Such interventions need to be integrated with the climate-proofing of livestock houses to ensure animals' resilience to extreme heat and drought events, for example by improving the location, distance from

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[136] GIZ (2015). Promotion of Climate Resilience in Rice and Maize Lao PDR National Study. Jakarta

[137] ADB (2012). Guidelines for climate proofing investment in agriculture, rural development, and food security. ADB: Philippines. Available online at https://www.adb.org/sites/default/files/institutional-document/33720/files/guidelines-climate-proofing-investment.pdf, accessed on 26 April 2023.

[138] Lefroy, R., Collet, L., and Grovermann, G. (2010), Study on Potential Impacts of Climate Change on Land Use in the Lao PDR. (International Center for Tropical Agriculture (Centro Internacional de Agricultura Tropical - CIAT).

[139] Gonsalves, J., Carandang, A., Verallo III, J.R., Barbon W.J. (2022). Asian Mega-Deltas (AMD): Derisking delta-oriented value chains in Cambodia, Vietnam, and Myanmar. Scoping Study on Key Production Systems/Value Chains. Silang (Cavite), Philippines: International Institute of Rural Reconstruction (IIRR).

flood-prone areas, spaces, light, insulation, and ventilation, use of shade trees[140] using dry straw bedding during cold weather[141] and keeping the animals in dry and high places during flooding periods through raised platforms. Furthermore, the construction of wells to supply water for herders and drinking water of animals would be essential.

Mixing local cattle breeds with more productive breeds can increase the productivity and commercial value of local livestock. Smallholder cattle raising in Laos is dominated by native breeds i.e., yellow Asian cattle[142] which are attractive to smallholders because their protein requirements are less than those of the exotic breeds, and are adapted to local conditions, making them easier and cheaper to raise. However, they are less productive than exotic breeds[143] (*Table 9*). Cattle breeding should aim to raise productivity, enhance heat stress tolerance, and disease resistance, as these are the primary future changes that livestock producers will have to contend with. Finally, animals in healthy body conditions and with good immunity are more adaptable to environmental stresses such as heat stress conditions. This can be achieved through health-disease management practices for animal husbandry, feed, and sanitation, including regular vaccination of animals, and vector control.

Table 9. Comparison of productive performance of local and crossbred of cattle in Laos

Parameters	Local cattle	Hybrid *(Red Brahman X Local breed)*
Age at first calving (year)	2.5–3	3
Weight at first calving (kg)	180±17.26	306±15.81
Birth weight (kg)	12	21±3.2
Weight at 1 year of age (kg)	90±3.16	150±6.5
Weight at 4–9 years of age (kg)	250±39.37	450±13. 85
ADG (g)	N/A	431

Source: Khothsavang et al. 2022[144]

Farmers will need improved access to supplemental feed and nutrients. Large ruminant livestock in Laos are often malnourished, due to poor quantity and quality of pastures and crop residues used as feed. Future climate change will place even more pressure on already meagre pastures. Intensification of livestock through providing concentrated feed will alleviate the pressures of climate change by significantly increasing productivity and reducing grazing pressure. Farmers can process agricultural waste to provide high quality feed by adding chemicals like urea. They can also make use of feed blocks with urea and molasses, which have been reported to improve digestion, increase milk yield, and maintain good body condition, while reducing GHG emissions when used as supplement[145]. Studies have shown

[140] Cosmas Ogbu et al., (2013). Body Temperature and Haematological Indices of Boars Exposed to Direct Solar Radiation, Journal of Biology, Agriculture and Healthcare 3: 72–79.
[141] Khounsy, S., Nampanya, S., Inthavong, P. et al. (2012). Significant mortality of large ruminants due to hypothermia in northern and central Lao PDR. Trop Anim Health Prod 44, 835–842. https://doi.org/10.1007/s11250-011-9975-1
[142] Phomvisay, A., Souvannavong, P., and Ouanesamone, P. (no date). Assessment of cattle trade development in Lao PDR: study on potential impacts of trade liberalization under AFTA on cattle trade and its implication for the cattle development policy in Lao PDR.
[143] Xayalath, S., Mujitaba, MA., Ortega, ADSV., Rátky, J. (2021). A review on the trend of livestock breeds in Laos. *Acta agrar Debr*. (1):227-237. doi:10.34101/actaagrar/1/9047
[144] Khothsavang, B., Kounnavongsa, B. (2002). Experiment on improving the quality of local cattle by crossbreeding with Red Brahman bull. *Journal of national agriculture and forestry institute*.
[145] Windsor, P.A. and Hill, J. (2022). Provision of High-Quality Molasses Blocks to Improve Productivity and Address Greenhouse Gas Emissions from Smallholder Cattle and Buffalo: Studies from Lao PDR. Animals, 12(23), p.3319.

that providing high-quality feed additives like molasses blocks to smallholder cattle and buffalo in Laos can achieve productivity gains of +2.3% per block consumed. Including greenhouse gas reducing agents achieves a reduction of greenhouse gases of 470 kg CO_2e[146,147]. These technologies are already marginally practiced in Laos and have been tested for efficacy. In addition to rice straw, cassava pulp, present many opportunities given the expected growth in cassava production in the country. Wet brewers' grains are also a nutritious and affordable option for livestock farmers[148]. Effort will be required to increase access to supplementary nutrients, lower costs, train farmers to prepare feed and to address cultural practices like burning rice straw to clear fields for upcoming seasons. Finally, it is fundamental to ensure that fodder is appropriately stored during periods of shortage that may occur during the dry months[149] through common climate-proofed feed storage facilities to ensure optimal temperature and relative humidity conditions.

Digitally enabled weather advisory and early warning systems

The timely delivery of relevant and accurate climate and weather information is critical for ensuring effective risk management and address long-term adaptation in Laos. Managing climate and weather variability is fundamental to a long-term strategy for adapting agriculture to climate change. Hydro- and agro-met services are indispensable for achieving resilience in agriculture. Agro-weather advisories will enable farmers to better manage production risks, helping farmers make informed decisions on what, when, where, and how to produce.

Weather advisory and extension services have been used to inform land preparation, method of planting, water management and pest and weed management in Laos. Under a World Bank project, advisories are provided both for lowland and upland, rainfed and irrigated dry season rice based on forecasted wetter or drier than average conditions[150]. Three technologies were tested through a climate-smart agriculture project in Khammuane province in 2014, including a participatory weather monitoring system providing data at different rice growing stages and advisory on crop calendars adapted to changing weather conditions[151].

It is fundamental that weather-informed agricultural advisory services are effectively delivered to the last-mile through tailored information and communication tools as well as translated into clear and effective information for farmers' action. These include weather-informed cropping calendars (e.g. information on the onset and offset of the rainy season, information on water availability), early warning systems for extreme weather events (e.g. drought and flooding, storms, and typhoons), and crop insurance schemes (e.g. state seed replacement after drought and flooding impacts). Weather-informed agricultural advisory on land preparation, method of cultivation, nutrition, water, weed, and pest

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146 Windsor, PA., Nampanya, S., Olmo, L., Khounsy, S., Phengsavanh, P., Bush, RD. (2021). Provision of urea–molasses blocks to improve smallholder cattle weight gain during the late dry season in tropical developing countries: studies from Lao PDR. *Anim Prod Sci*. 61(5):503. doi:10.1071/AN20517

147 Windsor, PA., Hill, J. (2022). Provision of High-Quality Molasses Blocks to Improve Productivity and Address Greenhouse Gas Emissions from Smallholder Cattle and Buffalo: Studies from Lao PDR. *Animals*. 12(23):3319. doi:10.3390/ani12233319

148 Napasirth, P. and Napasrth, V. (2018). Current situation and future prospects for beef production in Lao PDR – A review. Asian-Australasian Journal of Animal Sciences (AJAS); 31(7): 961-967. https://doi.org/10.5713/ajas.18.0206

149 Nampanya, S. et al., (2013). Progressing Smallholder Large-Ruminant Productivity to Reduce Rural Poverty and Address Food Security in Upland Northern Lao PDR, *Animal Production Science* 54, no. 7 (October 22, 2013): 899–907, https://doi.org/10.1071/AN13180.

150 FAO (2021). Weather Dependent Climate Smart Recommendations. CB5888EN/1/09.21. https://www.fao.org/3/cb5888en/cb5888en.pdf

151 "Climate Smart Agriculture - Lao PDR | SNV," accessed April 13, 2023, https://snv.org/project/climate-smart-agriculture-lao-pdr.

management is provided by FAO based on wetter or drier than average conditions[152] Furthermore, longer-term climate services such as climate risk assessment and climate change adaptation strategies should be integrated into value chain actors' business plans to strengthen the climate resilience of the entire agrifood value chain.

Weather advisories can be improved by using digital technologies. About 85% of farmers follow the climate forecasts and have often changed their farming practices based on weather advisories, such as adopting more inventive fertilizers, insect control methods, switched crop types and irrigation approaches. User satisfaction for available weather advisories and early warning is low[153]. Digitally enabled weather advisory services like the Lao Climate Service for Agriculture (LaCSA), a climate service mobile application developed by the Ministry of Agriculture and Forestry in collaboration with the Ministry of Natural Resource and Environment, and FAO, have shown encouraging results. LaCSA provides agro-meteorological information to farmers in a compact and timely way, including weather forecasts, pest and disease bulletins, flood warnings, and drought information. The application has now reached over 110,000 farmers throughout the country. This demonstrates how digital technologies can be leveraged to effectively boost the coverage of extension information[154] and to scale e-extension services.

Climate resilient post-harvest processing and distribution

To achieve commercialization and raise farmer incomes, major commodity value chains need to be climate proofed. Agriculture development is increasingly oriented towards commercial value chains and export market. A robust approach to managing climate risks along agricultural commodities' value chains, including storage, processing and distribution is vital to advance the growth of agribusiness and commercial agriculture under climate change. The improvement of post-harvest storage and processing facilities could incentivize the diversification of cultivated and processed crops, as well as diversification of by-products and incomes to increase resilience to climate- and market-based shocks[155].

Evidence from Laos and the region shows that climate-proofed processing can enhance the resilience of the value chain by reducing food losses along the commodity value chain and reduce GHG emissions using renewable energy such as solar power and bioenergy. For rice, projects in Laos show that artificial drying for example through solar dryers can increase rice grain quality and marketing opportunities for farmers[156]. Rice drying using flatbed dryers instead of sun drying, can result in head rice yield of about 50% compared to less than 40% with sun-drying, which is common practice[157]. For example, through flatbed dryers and hermetic storage, farmers in Myanmar reduced post-harvest losses by 3-4% and increased net incomes by 30–50%, without increasing GHG emissions[158]. Solar bubble dryers may be more suited for subsistence farming, due to their low farmer capacities, whereas flatbed dryers can be used for commercially oriented small and medium producers for domestic markets, and recirculating batch

[152] FAO (2021). Weather Dependent Climate Smart Recommendations.

[153] World Bank (2023). LAO PDR Southeast Asia Disaster Risk Management Project. Available online at https://projects.worldbank.org/en/projects-operations/project-detail/P160930, accessed on 26 April 2023.

[154] https://www.fao.org/in-action/samis/resources/news/detail/zh/c/1480342/

[155] GIZ (2015). Promotion of Climate Resilience in Rice and Maize Lao PDR National Study. Jakarta

[156] Nguyen-Van-Hung et al., (2019). Best Practices for Paddy Drying: Case Studies in Vietnam, Cambodia, Philippines, and Myanmar, *Plant Production Science* 22, no. 1: 107–18, https://doi.org/10.1080/1343943X.2018.1543547.

[157] Fukai.S and Mitchell.J, (2019). Final Report Mechanization and Value Adding for Diversification of Lowland Cropping Systems in Lao PDR and Cambodia. Publication code: CSE2012-007. Australian Center for International Agricultural Research

[158] Gummert, M., Nguyen-Van-Hung, Cabardo, C. et al. (2020). Assessment of post-harvest losses and carbon footprint in intensive lowland rice production in Myanmar. Sci Rep 10, 19797. https://doi.org/10.1038/s41598-020-76639-5"

columnar dryers for exportation markets-oriented producers[159]. Large-scale solar greenhouse dryers developed and tested in Laos for banana and coffee drying are more effective than sun drying in terms of moisture content reduction, protection from insects, animals, and rainfall, and enhanced product quality. These can be promoted under sharing practices among farmer groups. For cassava, interventions should focus on reducing post-harvest losses from rapid product oxidative deterioration, through improved storage via fungicides, wrapping fresh cassava or freezing (which can be costly), or supporting farmers to rapidly process into by-products (animal feed, starch, and dried chips). Ultimately, climate-proofing the rural transportation networks will reduce post-harvest food losses and costs for farmers and value chain actors and open farmers up to larger and more profitable markets.

Climate-sensitive and inclusive marketing mechanisms should be promoted to strengthen farmers' linkages with international traders and domestic markets and enhance the resilience of the distribution stage of the value chain. Investments could support the climate-proofing of road construction and improvements[160]. This in turn can increase access to the farm fields, improve commercial opportunities, and reduce the cost of transporting grains and perishables from the farm gate, combined with increased access to small and climate-proofed trucks to improve access to unpaved roads. This will strengthen the enabling environment and incentives for profitable climate resilient coffee production and marketing in Laos through the implementation of weather-informed product quality and safety standards for exportation (e.g. through temperature and relative humidity controls), with a focus on young farmers and their involvement in post-harvest activities, including processing, roasting, storage, and marketing[161].

While climate smart technologies and practices are critical it is essential to recognize that successful adoption hinges on an enabling policy environment and capacities of various stakeholders including farmers, government, research institutions, and private sector. Key considerations to support technology adoption should include; (i) policy alignment across interacting sectors i.e. agriculture, environment, energy, water, and land-use, (ii) collaborative research efforts to develop and adapt innovative technologies and practices, (iii) capacity building for key institutions like the extension service, (iv) effective coordination among diverse governmental entities, NGOs, private sector and international organizations, and (v) access to sustainable sources of finance. Chapters 4 and 5 address some of the above key enablers to the adoption of technologies in Laos in detail.

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159 Nguyen-Van-Hung et al., (2019). Best Practices for Paddy Drying: Case Studies in Vietnam, Cambodia, Philippines, and Myanmar, *Plant Production Science* 22, no. 1: 107–18.
160 Guéneau et al., (2022). Understanding Commercial Relationships and Contract Farming in the Maize Sector in Houaphanh Province, Lao PDR.CIRAD. Lao PDR
161 FAO (2022). Exploring Coffee Futures: Building Coffee Climate Resilient Pathways in Lao People's Democratic Republic. CC2807EN/1/11.22. Lao PDR

Table 10. *Green and resilient improved technologies feasible and scalable in Laos* (*Source: Authors*)

Improved technology	**Climate-smart cropland production in rainfed areas**	**Sustainable intensification in irrigated areas**	**Climate-resilient livestock production**	**Climate-smart interventions at post-harvest stages**	**Weather-informed agricultural advisory services**
Crops	Cassava; coffee; maize; vegetables	Paddy	Cattle	Cassava; coffee; maize; vegetables; paddy	Cassava; coffee; maize vegetables; paddy
Description of the improved technology	Intercropping & crop rotation, cover-cropping, organic fertilization & mulching, use of climate resilient varieties, and agroforestry, Integrated land/soil management (e.g. minimum tillage and direct seeding), organic fertilization, crop residue management	Improved water management; SRI; cultivar change; alternate wetting and drying (AWD); Climate-proofed irrigation system and water reservoirs.	Breed improvement (crossbreeding); Improved feeding quality (e.g. MNB)	Artificial drying using flatbed dryers; large-scale solar greenhouse dryer; small-scale local storage, processing, solar dryers, and grading facilities; hermetic storage-metal silos, steel net and wire mesh storage bins; improved crop storage bags;	Flooding monitoring and control systems; Training agricultural extension services and farmers Weather-informed agricultural advisory services, early warning systems for extreme weather events, and crop insurance schemes.
Adaptation benefits	Resilience to pests and diseases; Reduced soil erosion; Reduced death of young seedlings from drought; Resilience to soil erosion, and nutrient leaching; Resilience to heavy rainfall events and increasing temperatures; Resilience to drought and floods;	Reduced drought impacts on hydrology, and yield losses; Lower heavy rainfall, flooding, storms, impacts on soil erosion; Reduced damage to agricultural land and water resources; Reduced damage to irrigation network and infrastructure.	Resilience of fodder production and grazing pastures to droughts, floods: Climate-proofed pastures against heavy rainfall and floods; Resilience to extreme temperatures; Resilience to weather-related diseases.	Resilience of storage and transportation to drought and floods; Reduced risk of mycotoxin growth, fungi, mold contamination, and pest attacks; Reduced risk of quick fruit ripening; Reduced quality and shelf-life, grain losses, from heavy rainfall events and increasing temperatures.	Resilience to weather-related pests and diseases: Reduced risk of fungi, mold contamination during storage and processing due to high temperatures and relative humidity; Reduced soil erosion and nutrient leaching; Reduced death of young seedlings from drought events.
Mitigation potential (emissions reduction *relative to conventional)*	Emission abatement due to the avoided cropland expansion -246 tCO_2e/ha of avoided deforestation[162] Agroecological practices also increase carbon sequestration and decrease emissions from synthetic fertilizer use.	Emission abatement through avoided CH4 emissions: -0.9 of tCH4/ha in irrigated areas, -1.2 tCH4/ha in rainfed areas[163] Emission abatement due to avoided rice land expansion -246 tCO_{2e}q/ha of avoided deforestation[164]	Emission abatement through reduced enteric fermentation: -470kgCO_2e per MNB per cattle[165] Crossbreeding may lead to higher emissions factors per cattle (higher manure quantity, higher feed requirements)	NA	N/A
Physical productivity *(Yield increase relative to conventional)*	Corn: + 20% kg/ha Coffee: + 3% kg/ha Cassava: +13% kg/ha Vegetables: + 34% kg/ha	Paddy rice: + 13% kg/ha	+ 80% tons of beef/TLU +18% liters of milk/head	Reduced post-harvest losses by 3-7% compared with traditional practices reduction of 120.000 tons of rice losses per year	N/A
Economic productivity (*income increase relative to conventional)*	*Gross margin:* Corn: + 21% $/ha Coffee: +121% $/ha Cassava: +14% $/ha Vegetable: +34% $/ha *Net margin:* Corn: +64% $/ha Coffee: +96% $/ha Cassava: +3% $/ha Vegetables: +54% $/ha	*Gross margin:* +14% $/ha *Net margin:* +9% $/ha	*Gross margin:* +105% $/ha *Net margin:* +126% $/ha	Increased the net income by 30–50% compared with traditional practices	N/A

[162] FABLE approach from FAO data.
[163] FABLE approach from FAO data
[164] FABLE approach from FAO data
[165] Windsor, PA., Hill, J. (2022). Provision of High-Quality Molasses Blocks to Improve Productivity and Address Greenhouse Gas Emissions from Smallholder Cattle and Buffalo: Studies from Lao PDR. *Animals*. 12(23):3319. doi:10.3390/ani12233319

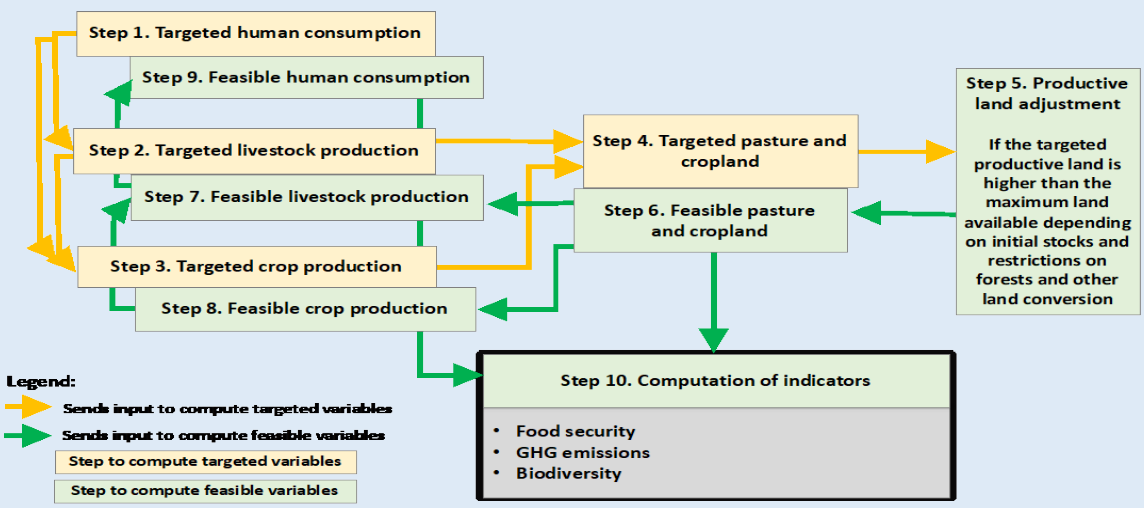
Chapter 3: Designing the Green Transition towards Low-Carbon Sustainable Agriculture

3.1 Future risks of carbon emissions

This section investigates possible trends for the Lao agriculture and land-use sector to transition towards more sustainability using the FABLE model[166](Box 4). We model pathways from 2020 to 2050 based on historical FAO data from 2000 to 2020 and look at their implications in terms of production levels, GHG emissions, and biodiversity losses. Detailed assumptions used to model business as usual (BAU) and green pathways can be found in Annex 2.

Box 4. FABLE modelling approach

The FABLE model is a free and publicly available Excel accounting tool used to study the potential evolution of food and land-use systems over the period 2000-2050. It focuses on agriculture as the main driver of land-use change and tests the impact of different policies and changes in the drivers of these systems through a combination of many scenarios. It includes 76 raw and processed agricultural products from the crop and livestock sectors and relies extensively on the FAOSTAT (2020) database for input data. For every 5-year time step over the period 2000-2050, the model computes the level of agricultural activity, land use change, food consumption, trade, greenhouse gas (GHG) emissions, water use, and biodiversity conservation according to selected scenarios. Users can replace data from global databases with national or subnational data. The structure of the model is shown below. More information can be found at https://fableconsortium.org/tools/fablecalculators/.



For this paper, the FABLE Calculator has been tailored to the national context by improving the data and aligning scenarios with the country context. FAO data was compared, when possible, with national data furnished by local consultants or National Agriculture and Forestry Research Institute (NAFRI). Assumptions and results about the BAU and Greener pathways were presented to stakeholders during an in-person consultation workshop in Vientiane, Laos, on March 24, 2023. A one-day workshop was organized by the World Bank, gathering around 35 representatives from different government agencies, academia, international agencies, and development partners. Assumptions were then revised following stakeholders' comments and are detailed in the table below. Detailed assumptions used in FABLE modelling can be found in Annex 2.

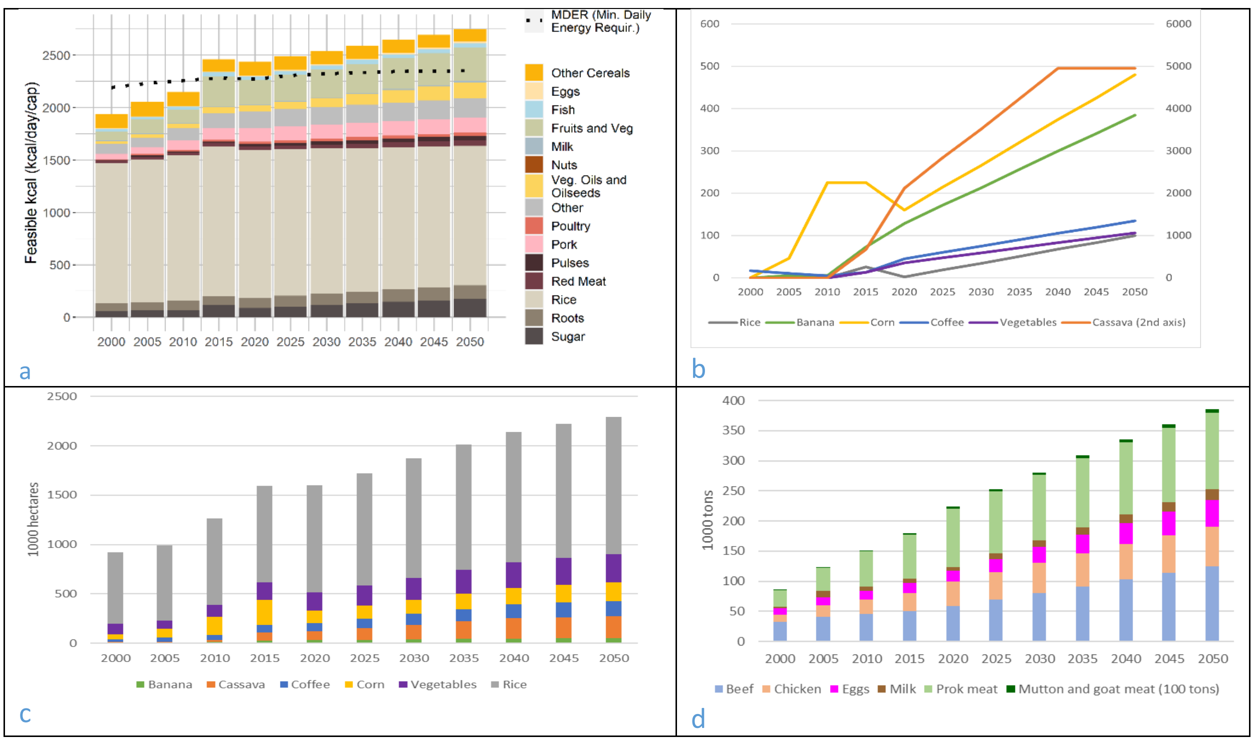
Source: Authors

[166] https://pure.iiasa.ac.at/id/eprint/16934/

The Business as usual (BAU) pathway

Under business as usual, internal, and external demand for crop and livestock products will drive a production increase of 65% by 2050 (Figure 11). On one side, the average daily total kcal intake per person will increase 7% above the Minimum Daily Energy Requirement (MDER) in 2020 to 17% above the MDER in 2050 (Figure 11a). This gain in total kcal consumption will happen through an increase in consumption of vegetable oils, eggs, milk, sugar, and pulses. On the other hand, over the same 2020-2050 period, export quantities may increase by about 3% for rice, up to 2.3 times for cassava, and 3 times for banana, coffee, vegetables, and maize (Figure 11b). Total exports are expected to grow from 22% to 33% of total production during the same period (Figure 11b). Such increases in both domestic and foreign demand will drive a surge by 65% of agricultural production, from 11.2 to 18.5 Mt in 2020-2050. Rice production is projected to increase by 24%, coffee, cassava, and beef production by 100%, and banana production by 90% (Figure 11c, d).

Figure 11. Projected business as usual scenarios for (a) food consumption per food group and Minimum Dietary Energy Requirement (MDER) (b) export quantities for major crops, (c) production levels for the main crops and (d) production levels for the main livestock products (BAU)

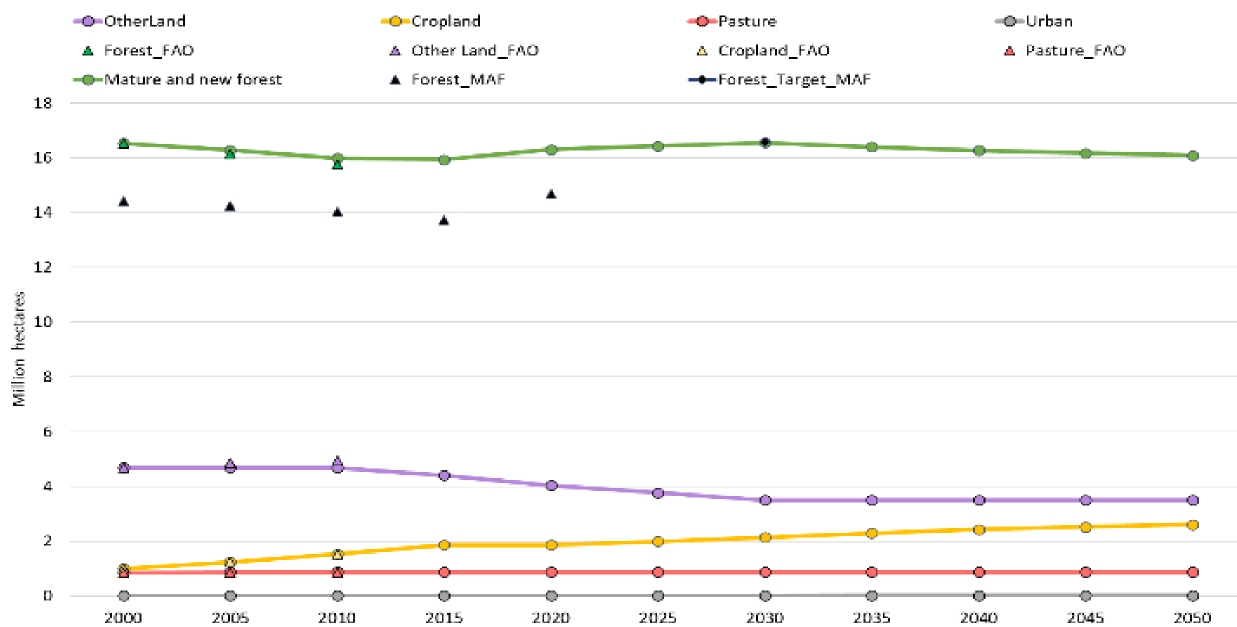


Source: Authors

An increase in agricultural production will lead to significant land use changes. Cropland area in Laos may increase by 26% over 2020-2050 (Figure 12), driven by expansion in the production of cassava, coffee, vegetables, and maize, at the expense of the forest area. Projections show that forest area planted before 2000 ("mature" forest) will decline by 1 Mha between 2020-2050 even if forest area will increase (+ 0.6 Mha) thanks to afforestation of non-productive non-forest land (+ 1.65 Mha between 2015-2035).

Depending on the type of afforestation made, this could also potentially increase the area where natural processes predominate[167].

Figure 12. Land use over time



Source: Authors

An important concern is that the pasture area in the country has limited room for expansion, although livestock herds are rapidly increasing. The FABLE calculator projects that the ruminants' herd in the country doubles between 2020-2050. Based on historical trends, pasture area will remain stable, and yields will have to raise from 2.2 to 6.4 t/ha in 2020-2050 (+187%) to provide enough feed for the growing ruminant stock.

Net GHG emissions from the AFOLU sector will continue decreasing through positive actions on forest protection and regeneration. According to NDC pathways, between 2000 and 2020, total GHG emissions decreased by 34% compared to the baseline scenario[168] through increased afforestation and reduced deforestation and forest degradation. Thanks to the policy goal to increase forest cover to 70% of national territory by 2020, postponed to 2030, emissions from deforestation will continue to decrease and carbon sequestration will increase from -2 $MtCO_2e$ per year in 2015 (starting date of afforestation) to -8.3 $MtCO_2e$ per year in 2030 and onwards (Figure 13a). It will largely contribute towards meeting the net zero emission target set for the year 2050.

Agriculture sector GHG emissions will continue growing until 2050, primarily driven by livestock expansion and expansion of cash crop production (Figure 13). Emissions from livestock (manure management and enteric fermentation) will almost double and will constitute 67% of agriculture

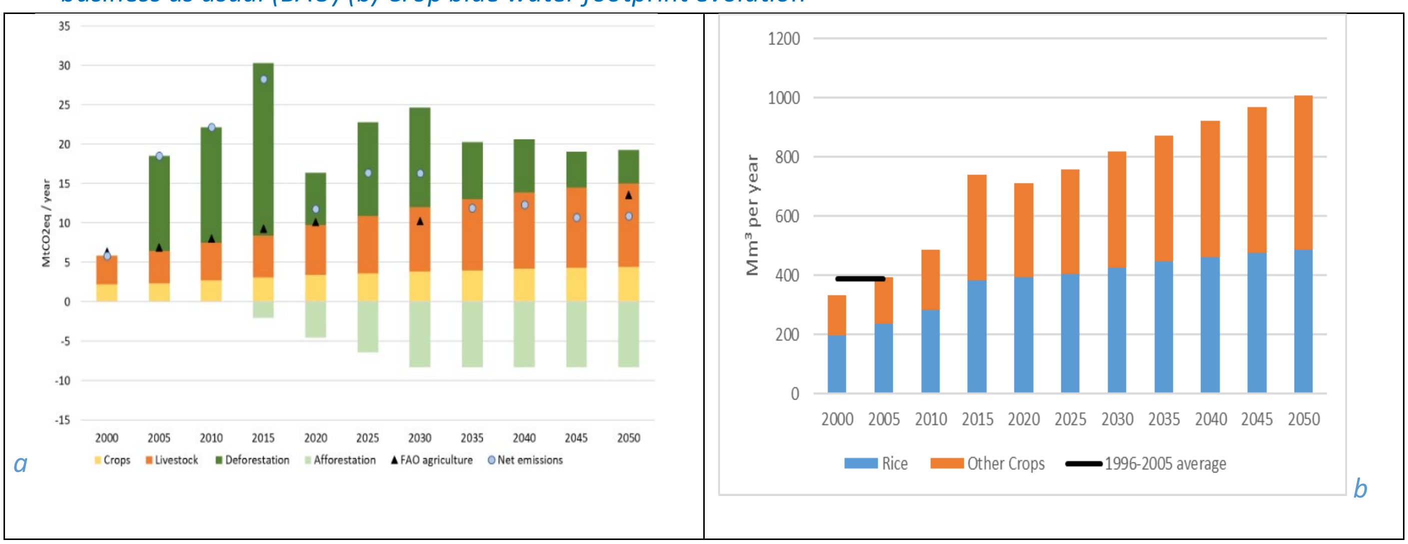
[167] LNPP refers to land where there is a low human disturbance and/or ecologically relatively intact vegetation, providing space and habitat for biodiversity to thrive.

[168] The Government of Lao PDR (2021). Nationally Determined Contributions (NDC). Available online at https://unfccc.int/sites/default/files/NDC/2022-06/NDC%202020%20of%20Lao%20PDR%20%28English%29%2C%2009%20April%202021%20%281%29.pdf, accessed on 27 April 2023.

emissions as the ruminant herd size increases between 2020-2050 (Figure 13a) to meet the higher demand for animal products. Enteric fermentation will become the largest source of emissions in agriculture (6.7 MtCO_2e per year in 2050). CH_4 emissions from rice cultivation will increase by 28% due to the higher demand for rice for food, feed, and export. Emissions from fertilizer use will increase by 66% to boost crop productivity between 2020-2050. Emissions from deforestation from cropland expansion will remain positive throughout the period. Farms are illegally expanding in the areas of national parks and protected forests, burning, and clearing large areas to make room for cassava and other cash crops[169]. GHG emissions from forest land conversion to cassava fields in Champassak and Khammuane, banana fields in Khammuane, and maize fields in Oudomxay is already evident. These practices reduce lands where natural processes predominate and thus threaten biodiversity. They can also jeopardize the national objective to achieve 70% of forest cover, even though accomplishing this target has become even more critical.

Annual crop blue water consumptive use will increase 1.4 times between 2020-2050 (Figure 13b**).** Agriculture sector's blue water footprint will increase from 711 mm^3/year in 2020 to 1,007 mm^3/year in 2050 driven by crop production expansion. While rice production will account for 48% of crop blue water consumptive use for agriculture by 2050 (down from 55% in 2020), there will be an increased demand for water from other expanding crops. Given that the agriculture sector draws over 90% of the country's water and the threats to water in a changing climate, current water use rates will not suffice in the future. The Lao agriculture sector must manage its blue water footprint while supplying growing demand.

Figure 13 (a) Evolution of Agriculture, Forestry, and Other Land Use (AFOLU) GHG emissions under business as usual (BAU) (b) Crop blue water footprint evolution



Source: Authors

[169] The Star News (2023). Cassava export boom leading to deforestation and poor air in Laos. Available online at https://www.thestar.com.my/aseanplus/aseanplus-news/2023/03/26/cassava-export-boom-leading-to-deforestation-and-poor-air-in-laos, accessed on 27 April, 2023.

3.2 Pathways to low-carbon agriculture

Mitigation and productivity impact of climate-smart technology options

Adoption of climate-smart technology interventions should reduce the growing emissions from the agriculture sector, while providing climate change adaptation benefits and sustaining productivity. In this section, we use the FABLE modeling approach to examine the impact on GHG emissions and productivity of a sub-set of the green and resilient improved technologies shown in Table 11, and selected based on what was already existing in Laos and mentioned in official policy documents. The list of assumptions made can be found in Annex 2. Expert knowledge is used to generate reasonable scenarios to test. These although these scenarios differ from those from the LT-LEDS recommendation (see Annex 2), they provide some insights into possible pathways for low carbon agriculture and the impacts they can have. While this section focuses mainly on GHG emissions, land use change and productivity, we underscore that all interventions for a low carbon agriculture should also aim to achieve synergy across productivity, adaptation/resilience, and ecosystem health wherever possible for a more holistic approach to agriculture.

Table 11. Overview of the mitigation options and adoption rates included in pathways

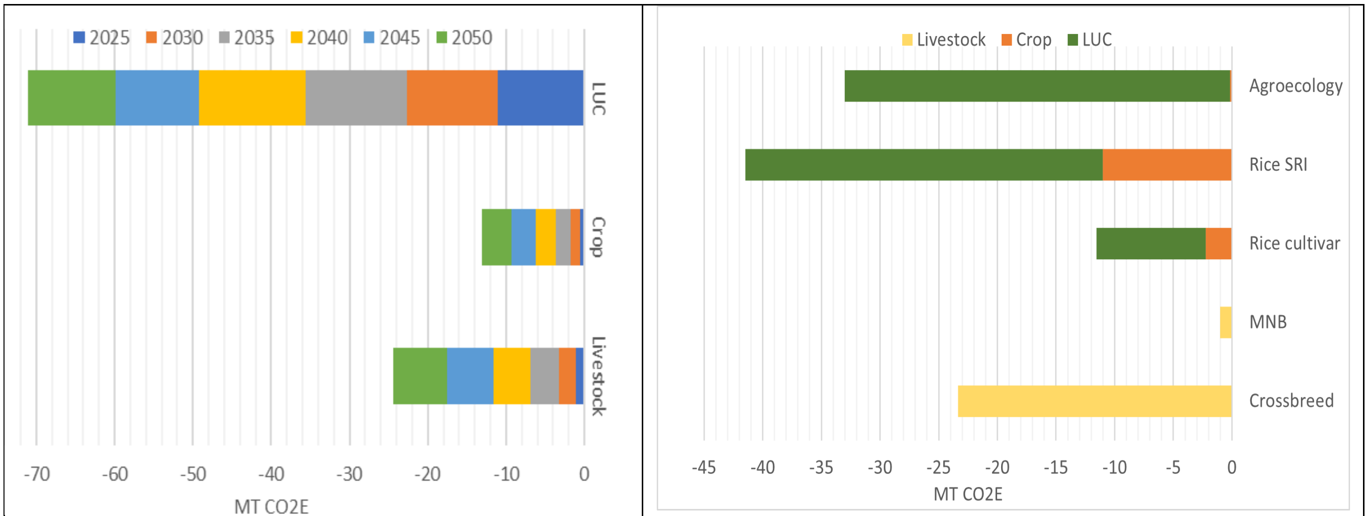
Cattle production	Cross-breeding – gradually reaching 30% of the cattle herd by 2050
	Improving feed quality with additives like molasses nutrients blocks (MNB) – gradually providing 40% of the cattle herd (including 15% of hybrid cattle) with MNB by 2050
Rice cultivation	Cultivar change – gradually applied to 40% of the rice harvested area by 2050
	System of rice intensification – gradually adopted in 20% of the rice harvested area by 2050
Cropland expansion	An agro-ecology package anchored in integrated soil management and diversification with DMC (crop rotation, cover-cropping, intercropping, organic mulching), cultivar-mixing, and agroforestry, applied to four major crops (cassava, coffee, corn, and vegetables) – gradual implementation in 50% of the harvested areas by 2050

Source: Authors. For more details, see Annex 2

Applying the combination of climate smart technologies will decrease GHG emissions from the AFOLU sector. It is estimated that 65% of the avoided emissions come from reduced deforestation, driven by the implementation of the five CSA technologies summarized in Table 11. The total cropland expansion is 289,000 hectares smaller than in the BAU scenario, thanks to productivity gains, thus saving the same amount of forest through avoided deforestation. It is also estimated that 22% of the avoided emissions come from the livestock sector due to the cattle herd decrease caused by enhanced productivity from sustainable livestock intensification practices (breeding, improved feeding). The remaining reduction in GHG emissions will come from improved rice cultivation (e.g. through SRI).

Implementing climate smart technologies will have different impacts on total GHG emissions from agriculture depending on the scale of application. By running realistic and sufficiently ambitious mitigation scenarios for rice, livestock, and other crops, all climate smart technologies and practices will have different impacts on GHG emissions. As shown in Figure 14, **i**mplementing SRI on only 20% of the lowland rice fields can account for 38% of the total GHG emissions reduction from agriculture through avoided CH_4 emissions and rice cropland expansion from intensification. Climate resilient cultivars can also sustain productivity. Implementing agroecology practices on 50% of the planted areas for cassava, corn, coffee, and vegetables can account for 30% of total GHG emission reductions due to avoided cropland expansion. Crossbreeding 30% of the local cattle herd can account for 21% of total GHG mitigation by reducing enteric fermentation. Switching rice cultivars in 40% of the planted area and giving one molasses block to 40% of the cattle herd can account for 10% and 1% of the GHG emissions reduction. Cross-breeding and improved feed for cattle could be effective for reducing livestock emissions as in Laos most GHG emissions come from cattle and buffalo (referred to from here on as 'cattle'). Monogastric animals (poultry and pork) and small ruminants (sheep and goats) have a small carbon footprint due to their low emissions intensity for the monogastric and small herd size for the small ruminants (see section 5 on the intensification of livestock production).

Figure 14. Cumulated avoided GHG emissions in the BAU with mitigation options compared to the BAU without mitigation options



a	*b*

Note: Panel (b) indicates the mitigation potential from each mitigation option combined with the BAU pathway as compared to the BAU scenario (i.e., without mitigation options).
Source: Authors

Applying climate smart technologies can provide productivity gains while reducing future GHG emissions (Figure *15*). Crossbreeding 30% of the herd and giving a molasses nutrient block to 40% of the herd leads to an 18% increase in global cattle productivity (Figure 15a). Under these mitigation conditions, total cattle stock can be reduced by 15% and still meet beef demand in 2050 compared to the BAU scenario. By 2050, thanks to the adoption of climate smart technologies in a portion of the harvested area and with respect to BAU: overall rice productivity can be 13% higher, maize productivity 20% higher, cassava productivity 13% higher, coffee productivity 3% higher, and vegetables 34% higher (Figure 15b,c,d,e,f). The application of climate smart technologies and practices will have triple win benefits (enhanced resilience, mitigation, and productivity). It allows to reconcile the double objective of the Lao government to improve efficiency and productivity of agriculture while maintaining a high level of biodiversity and conservation forest areas.

Figure 15. Crop and livestock commodities, average productivity with/without mitigation options

a Cattle; b. Rice; c. Cassava; d. Corn; e. Coffee; f. Vegetables

Source: Authors

Complementary levers for a low-carbon agriculture

Laos can also implement ambitious efforts to reduce GHG emissions beyond agriculture production. Such interventions can focus on the demand side of the agri-food system and land use regulations and be implemented in addition to the climate smart agriculture technologies. The FABLE approach is used here also to model two such improvements for efficacy relative to the BAU pathway (called the Greener pathway) : i) a transition to a diet closer to the EAT-Lancet[170] recommendations for a healthy and sustainable diet adapted to Laos consumption patterns; and 2) a progressive ban on deforestation leading to zero deforestation in 2050; as summarized in *Table 12*.

[170] https://eatforum.org/content/uploads/2019/07/EAT-Lancet_Commission_Summary_Report.pdf

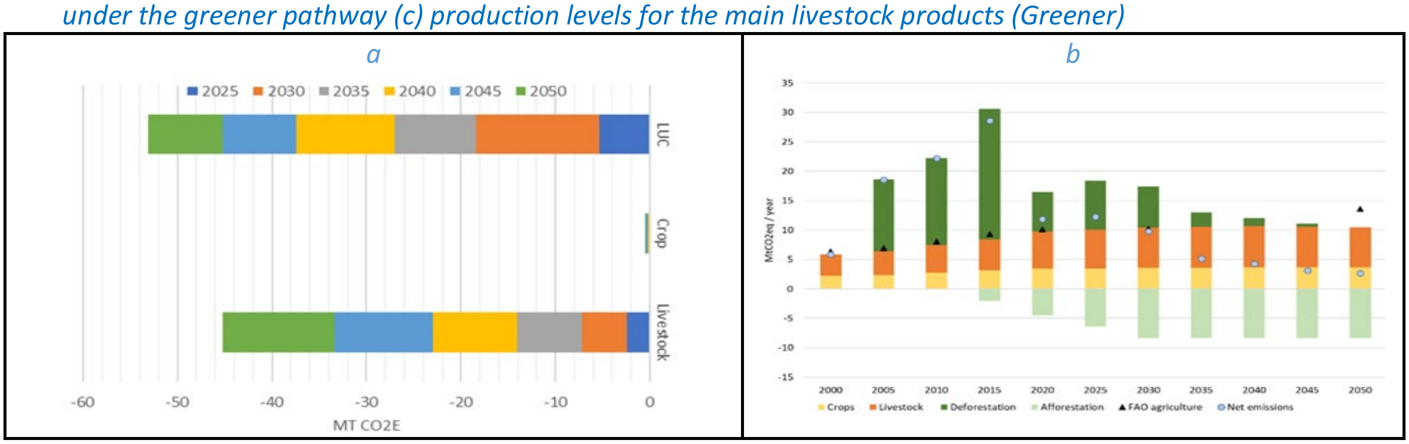
Table 12. Overview of the BAU and Greener pathways

	Business-As-Usual (BAU)	Greener
Drivers	Based on the continuation of **historical trends** and **current policies**	Based on the continuation of **historical trends** and **additional sustainable targets**
Diet	Kcal/person/day (++)	**Kcal/person/day (+)**
Productivity	Major crops (+) Livestock (+)	Major crops (+) Livestock (+)
Forest	Afforestation	Afforestation **Progressive ban on deforestation**
Trade	Exports (++) Imports (+)	Exports (++) Imports (+)
Climate	Yields (-)	Yields (-)
Climate smart agriculture		**(++)**

Source: Authors. For more details on the BAU and Greener pathways' assumptions, see Annex 2.

Implementing a greener diet and a progressive ban on deforestation, in addition to climate smart agriculture practices, will decrease GHG emissions from the AFOLU sector by –98.81 Mt CO_2e more over the period 2025-2050. This result is driven firstly by avoided deforestation (Figure 16a). Cropland expansion will progressively take place in other non-productive lands rather than in forest areas, saving 265,000 hectares of forest from deforestation. Converting a hectare of other lands into cropland emits 95% less than deforesting a hectare of forest areas since carbon content is much lower in other lands. Emissions from the livestock sector will also decrease sharply (Figure 16a). A greener diet would reduce domestic demand for ruminant products by 24% in 2050 as beef consumption per capita will be lower than in the BAU, determining a ruminants' herd decrease by 30%. The combination of a climate smart agriculture strategy, dietary changes and regulated deforestation will lead to 2.64 MtCO_2e net GHG emissions from the AFOLU sector in 2050 (Figure 16b), compared to 10.97 MtCO_2e under the BAU.

Figure 16 (a) Cumulated avoided GHG emissions in the greener pathway compared to the BAU with mitigation options (b) Evolution of Agriculture, Forestry, and Other Land Use (AFOLU) GHG emissions under the greener pathway (c) production levels for the main livestock products (Greener)



Source: Authors

Chapter 4: Enabling the Transition

4.1 The cost and benefits of transitioning to climate smart technologies

Climate smart technologies must demonstrate economic feasibility, resilience, mitigation, and productivity, to be attractive to farmers. This section shows the financial viability underlying the adoption of priority CSA technologies across key agricultural commodities. The approach applied is summarized in Annex 3. The financial analysis developed here is based on crop and livestock budget models which simulate the implementation of conventional/BAU and CSA practices. It estimates financial performance indicators (gross margins, net margins and returns per labor workday) that are instrumental in assessing the impact of climate-smart technologies on the economic results of targeted farms (Box 5).

Box 5. Economic modeling

Economic modeling is based on crop and livestock financial models. Crop models are built for one hectare of land. They simulate annual budgets considering quantities of all inputs and outputs, their unit costs and prices, and their profitability. Livestock financial models simulate the dynamics of an average herd, accounting for the costs associated with breeding activities (i.e., feed, vaccines, and pasture) and the benefits from the sale of animal products (i.e., live animals, meat, milk). Total revenues are computed by multiplying the quantity of agricultural products obtained (i.e., crop, meat, and milk output) by the corresponding farm-gate price. Operating costs comprise expenses for the purchase of seeds, chemical and organic fertilizer, pesticides, herbicides, plastic bags, plastic batch, sacks, fuel, irrigation services, and electricity for pumping water, feeding, animal husbandry and health care services. Labor is valued in the models using as a proxy the market rural wage (50,000 kip /person-day), no matter if the laborer is a family member or an external labor. In both crop and livestock financial models, the following financial performance indicators are assessed: gross margin, net margin, and returns to family labor. **Gross margin** is computed as difference between revenue and operating costs. It coincides with the cash flow. N**et margin** is computed by subtracting the family labor costs from the gross margin. **Returns to family labor** are computed as the ratio between the gross margin and the cost of family labor. The difference between annual net margin in the 'BAU' versus 'CSA' scenarios represents the net incremental financial benefits of switching from conventional to climate-smart agricultural systems.

Source: Authors

Evidence shows that adopting climate smart technologies is more profitable than the continued application of conventional methods (represented by the BAU scenario[171]**).** There is a wide literature showing that climate-smart technologies improve agricultural productivity and farm income on a sustainable basis[172]. For instance, livestock sector results show that the increase in milk productivity is 18% higher under "CSA" scenario, due to the gradual introduction of crossbred species (i.e., Red Braham) as well as the use of feed supplements (Table 13). As a result, the adoption of climate-smart practices in cattle breeding can lead to higher revenues (Table 13) lower costs and higher gross and net margins (Table 14 and Table 15). However, there are important costs that can become barriers to the adoption of technologies by farmers.

In most cases, the cost of agricultural inputs such as improved seeds, fertilizer, and other inputs are lower under conventional farming than with the adoption of climate smart technologies. The higher

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[171] The hypotheses made for the BAU scenario considered in this financial analysis are in line with those made in the FABLE modeling above. More details are provided in the methodological section (Annex 2.2).

[172] Adegbeye et al. (2019). Sustainable agriculture options for production, nutritional mitigation of greenhouse gasses and pollution, and nutrient recycling in emerging and transitional nations-An overview. J. Clean. Prod. 118, 319. https://doi.org/10.1016/j.jclepro.2019.118319;

costs of agricultural inputs are because of improved seeds, fertilizers, and chemicals. Many climate-smart technologies require adequate chemical levels to have beneficial effects on crop yields[173]. In addition, some technology options require establishment costs and yearly maintenance costs, such as establishing trees under agro-forestry systems. These may become critical barriers to adoption.

The labor cost is higher for farmers when they apply climate smart technologies, demonstrating a greater need for investments in labor (See *Table 14*). Climate smart technologies will come with higher labor costs for some specific agricultural activities like transplanting/seedling under the SRI method. Labor costs are an important determinant of whether households will adopt a technology since it represents a major component of total production costs. Although most smallholder farmers rely on family labor only, the overall labor requirements for the adoption of climate smart technologies are such that this may be a barrier to the adoption of some technologies. This may be particularly so for larger farming enterprises that rely on external labor.

Table 13. Results of physical and economic outputs (BAU, BAU with CC, and CSA scenarios)

Output summary	Yields						Revenues		
Crops	BAU		BAU with CC		CSA		BAU	BAU with CC	CSA
	kg/ha		*kg/ha*		*kg/ha*		*$*	*$*	*$*
Rice	2,681		2,602		2,940		1,003	974	1,100
Maize	8,847		8,808		10,569		1,085	1,081	1,127
Cassava	33,724		29,559		33,401		1,655	1,451	1,639
Vegetable	9,411		9,964		13,352		2,887	3,057	4,096
Coffee	2,252		2,442		2,564		2,764	2,996	3,146
Livestock	BAU		BAU with CC		CSA		BAU	BAU with CC	CSA
	liters/head	*meat/head*	*liters/head*	*meat/head*	*liters/head*	*meat/head*	*$*	*$*	*$*
Cattle	355	175	429	175	419	315	2,881	2,980	4,848

Source: Authors. Note: $1= 8,150 kip (in 2019 and in 2020).

Table 14. Production costs (BAU, BAU with CC, and CSA scenarios)

Cost summary		Input cost $			Labor cost $		
		BAU	BAU with CC	CSA	BAU	BAU with CC	CSA
Crops	Rice	91	91	92	498	498	591
	Maize	146	146	166	337	337	448
	Cassava	61	61	61	1,043	1,043	1,221
	Vegetable	150	150	211	1,294	1,294	1,399
	Coffee	515	515	650	1,294	1,294	1,601
Livestock	Cattle	1,746	1,746	1,896	172	172	172

Source: Authors. $1= 8,150 kip (in 2019 and in 2020).

Despite high production costs, the net margins gained by adopting climate-smart technologies are consistently higher across all commodities than for conventional farming (Table 15)**.** Favorable net

[173] Heeb, L., Jenner, E., Cock, M.J.W. (2019). Climate-smart pest management: building resilience of farms and landscapes to changing pest threats. *Journal of Pest Science* 92:951-969

margins suggest that farming households in Laos will have the capacity to cover the costs of adopting climate smart technologies. Overall, household incomes will increase because of the adoption of transition technologies. The increase is much higher under maize, vegetable, and coffee production, with net margins nearly double or more.

Table 15. Results of farm economic performance (BAU, BAU with CC, and CSA scenarios)

Economic performance		Gross Margin $			Net Margin $		
		BAU	**BAU with CC**	**CSA**	**BAU**	**BAU with CC**	**CSA**
Crops	Rice	908	878	1,004	409	379	413
	Maize	935	930	1,127	598	593	679
	Cassava	1,590	1,385	1,574	547	342	353
	Vegetable	2,733	2,903	3,881	1,439	1,609	2,482
	Coffee	2,246	2,479	2,494	952	1,185	893
Livestock	Cattle	964	1,233	2,952	792	1,062	2,780

Source: Authors. $1= LAK 8,150 kip (in 2019 and in 2020).

Additional costs to support CSA technology adoption will have to be incurred by the government. Off-farm (public) costs include investments in knowledge dissemination and capacity building (public good) (Table 16). Such investments represent a critical cross-cutting element focusing on introducing, strengthening, and maintaining knowledge of farmers, institutions, and local organizations in developing CSA systems. Using trainings, farmer field schools, field visits, and demonstrations, they provide various adaptation and mitigation practices to farmers to build their capacity to reduce the impact and cope with climate change. Off-farm transition costs are related to infrastructures, personnel (salary and equipment), transport and allowances, materials and generation of extension content, training of extension staff, administrative costs, and costs of monitoring and evaluation.

Societal benefits (off-farm) of climate-smart crop production may be higher than farmers' direct benefits (on-farm) (Table 16). Although farmers stand to benefit economically from the adoption of climate smart technologies, the adoption of the climate smart technologies will also generate carbon sequestration, biodiversity conservation, and other public goods that accrue to society. Results show that the public benefits can be far higher than on-farm benefits by a factor of 2-4 for most agricultural commodities. These ecosystem services could be an additional source of income to famers if they are valued and farmers are compensated for them. Annex 3 provides more on costs and benefits.

Table 16 Unit costs and benefits of the green transition in crop and livestock production

Crops	On-farm transition costs ($/ha)	Off-farm transition costs ($/ha)	On-farm benefits. ($/ha)	Off-farm benefits ($/ha)
Rice	93	171	127	842
Maize	130	171	216	750
Cassava	178	171	189	750
Vegetable	166	171	1,039	750
Coffee	442	171	150	750
Cattle	1,166	171	187	523

Source: Authors

CSA can generate additional environmental benefits, at the farm and landscape scale, in the form of enhanced soil fertility, water storage, agricultural ecosystem resilience, resource-use efficiency, residue valorization and recycling, and enhanced carbon storage in soils and biomass [174]. Crop rotation and intercropping boost soil fertility, increase soil moisture, and raise micro-fauna and soil carbon content [175]; minimal soil disturbance (minimum/zero tillage) reduces soil erosion, organic substance oxidation, and fertility loss; residues management and mulching lift water infiltration and protect soil from sealing and crusting caused by rainfall [176]; improved soil and water management practices (i.e. tied ridging and planting pits) retain surface runoff, diminish water and soil erosion, and harvest and store rainwater [177]. Further indirect economic and social Co-Benefits comprise increased commercial opportunities associated with higher crop yields of cash crops for export and an augmented number of jobs driven by the expansion of labor-demanding CSA practices[178].

4.2 Entry points for financing the transition to climate smart agriculture

Laos will need to maximize all forms of financing possible to drive more action in resilient and low carbon agriculture. This should include domestic government spending supporting climate goals, bi-laterals/multilateral agencies (such as multilateral development bank balance sheet investments with climate benefits), multilateral climate funds (like the Global Environment Facility), commercial banks, and micro-finance institutions (MFIs), agro-business, household and community funds, and carbon markets (revenues from selling carbon emission offsets).

In a context of growing climate risks, and agriculture being a risky area for investments, there are some existing options for de-risking the agriculture sector. At macro-level, the government has contingent

[174] Lipper L., McCarthy N., Zilberman D., Asfaw S., Branca G. (Eds.), Climate Smart Agriculture: Building Resilience to Climate Change, Springer, New York (2018), 10.1007/978-3-319-61194-5_22

[175] Thierfelder C., Cheesman S., Rusinamhodzi L. (2013). Benefits and challenges of crop rotations in maize-based conservation agriculture (CA) cropping systems of southern Africa. International Journal of Agricultural Sustainability, 11(2), 108-124.

[176] Branca G., Perelli C. (2020). 'Clearing the air': common drivers of climate-smart smallholder food production in Eastern and Southern Africa. Journal of Cleaner Production, 270, 121900

[177] Wiyo K.A., Kasomekera Z.M., Feyen J. (2000). Effect of tied-ridging on soil water status of a maize crop under Malawi conditions. Agricultural Water Management, 45(2), 101-125

[178] Dinesh D., Frid-Nielsen S., Norman J., Mutamba M., Loboguerrero Rodriguez A.M., Campbell B.M. (2015). Is Climate-Smart Agriculture effective? A review of selected cases. CCAFS Working Paper

liabilities (whether implicit or explicit) for losses to the agriculture sector from disasters and climate shocks. It can transfer its liabilities to the private sector through insurance or other types of risk transfer instruments. For example, this was done through the Southeast Asia Disaster Risk Insurance Facility (SEADRIF), which is a regional platform aimed at building financial resilience against climate shocks and disaster in ASEAN. Payouts through SEADRIF can already be disbursed to poor and vulnerable farmers that suffer losses.

Smallholder farmers are willing to pay for agriculture insurance, especially if they have experienced climate disaster related losses before. Studies show that that rice farmers are willing to pay premiums equivalent to 17% of the indemnity, which is consistent with neighboring countries' insurance policies[179]; and that most farmers did not face challenges with rice market prices, but the lack of a mechanism to reduce or prevent losses from disasters was a major concern for farmers[180]. Farmers who have been impacted by disasters are more willing to pay for insurance than those who have not been affected. Given the regular climate disasters, and projected future climate extremes, there is an opportunity to introduce agriculture insurance in Laos. The country, through the National Disaster Risk Financing strategy (DRF), has put agriculture insurance as one priority and the National Disaster Management Committee (NDMC) is already exploring the possibility of establishing a national insurance scheme.

The country can take advantage of a growing international climate finance architecture to improve access to finance for smallholder farmers and SMEs in the agriculture sector. Opportunities exist to take advantage of upfront and result based climate finance as summarized in

Table 17. For example, in Vietnam, results-based financing (Transformative Carbon Asset Facility - TCAF) is being used following the successful Vietnam Sustainable Agricultural Transformation (VNSAT) project, which applied alternative wetting and drying (AWD) to rice production with positive outcomes including for GHG emission reductions (Box 6). Laos could aim to pilot projects like VNSAT to demonstrate the potential for carbon asset creation in agriculture and attract climate finance.

Table 17. Examples of climate finance funds and facilities

	Upfront climate finance		**Results based finance**
1	Adaptation Fund	1	Transformative Carbon Asset Facility (TCAF)
2	Global Environmental Facility	2	Forest Carbon Partnership Facility (FCPF)
3	Green Climate Find	3	Biocarbon Fund (Bio-CF)
4	Special Climate Change Fund	4	Bio-CF Initiative for Sustainable Forest Landscape
5	Least Developed Countries Fund	5	Scaling Climate Action by Lowering Emissions (SCALE)
6	Pilot Program for Climate Resilience		
7	Climate Investment Funds		

[179] Wongpit, P. and Sisapangthong, V., (2022). Willingness to pay of rice farmers in Lao PDR on agriculture insurance. Thammasat Review of Economic and Social Policy, 8(1), pp.49-66.
[180] Wongpit, P., & Sisapangthong, V. (2022). Willingness to pay of rice farmers in Lao PDR on agriculture insurance. Thammasat Review of Economic and Social Policy, 8(1), 49-66.

Box 6 . Carbon Payments Support for AWD in Vietnam – TCAF

The Vietnam Sustainable Agricultural Transformation Project (VNSAT), an IDA-funded project supported over 240,000 rice farmers in implementing AWD and One Must Do, Five Reductions (1M5R) over 163,418 hectares. Rice farmers reduced input levels (i.e., pesticide and fertilizer applications, water uses, and post-harvest losses) by 20-30%, increased rice productivity by 3-4%, raised the sale price by 5-10%, and boosted net profits by 28%, mainly due to reduced production costs. The project reduced GHG emissions by nearly 1.5 milliontCO2e.

Following the successful VNSAT project, the World Bank through the Transformative Carbon Asset Facility (TCAF) has proposed a program to incentivize Vietnam in transforming to 1 million ha into high quality and low carbon rice development by adding result-based climate and carbon finance support. The program is under preparation. The program will:

1. Promote domestic enabling environment for low-carbon rice sector transformation
2. strengthening institutions and building capacities needed
3. facilitate private sector and other stakeholders' participation in low-carbon rice transformation.
4. support the generating of high quality/high market value carbon emission credits (ERCs) from low carbon rice transformation.

Source: Authors

There is a nascent local green and sustainability finance market. The results of a survey from Asian Development Bank (ADB) on the green bond market in the Laos indicated that: (i) 60% of institutional investors were actively exploring potential investment opportunities in such markets; (ii) 40% of respondents highlighted renewable energy and sustainable agriculture as the most promising sectors for Laos to develop its domestic sustainable bond market. However, narrow awareness and resources regarding green bonds, lack of policy guidance from regulators, and insufficient resources to develop and launch new green bond products will however need to be addressed. A Green, Social, and Sustainability Bond Development Ministerial Committee was established in 2023 to foster the growth of climate-friendly investments by facilitating the issuance of green bonds and expanding financing opportunities[181]. In addition, the Bank of the Lao PDR plans to: (i) design criteria for green loans (with priority on agriculture sector); (ii) identify green finance needs and develop green, social, and sustainability bonds; (iv) prepare guidelines for green bond issuance and establish laws and regulations to support the market; (v) design incentive policies and encourage listed companies to issue green bonds; (vi) raise awareness in the capital market, and educate banks about the benefits of green finance, encouraging their participation in sustainable investments; (vii) create a comprehensive framework for identifying and categorizing sustainable activities and investment through the ASEAN green taxonomy. The Bank of the Lao PDR and the International Finance Corporation signed an agreement on technical assistance to develop a market

[181] In March 2023, the Lao Securities Commission Office (LSCO) organized a meeting involving key ministries to discuss and brainstorm ideas regarding green finance. The meeting assessed the progress of green development initiatives within each ministry and explored possibilities for collaboration and further advancements. Furthermore, LSCO is actively studying ASEAN standards and principles related to green, social, and sustainability bond issuance. The objective is to incorporate these standards into LSCO's regulatory framework, aligning it with regional best practices. This step will facilitate the issuance of green bonds and enable the creation of incentive policies for the private sector, encouraging their participation in the green bond market and supporting sustainable investment projects.

for green finance.[182]. These efforts point to a nascent sustainability market that could play an important role in financing resilient and low carbon agriculture.

The National Green Growth Strategy of the Lao PDR (2030) provides for green investment and finance. The NGGS proposes several actions to promote green investment and green finance for sustainable development. These include the development of green financial products and services, strengthening the capacity of financial institutions and regulators, and mobilizing domestic and foreign resources for green growth. This policy framework for sustainable agriculture finance is being strengthened through several initiatives to develop green finance and sustainable investments, focusing on taxonomy development, awareness-raising, and a supportive regulatory environment for capital market growth.

Digital technology has potential to unleash private-sector investment and enhance access to financial services. Empirical evidence shows tangible and positive impact of ICTs on agriculture. Commercial banks in Laos allocate significant resources toward the development of mobile banking, QR code payment systems, ATMs, and other financial technologies to bolster their service offerings. Although the reach of digital technology remains restricted primarily to urban areas, while individuals in rural areas face limited access to banking and financial services, there is vast potential for the leverage of digital technology to expand financial access. As of 2021, 65 percent of the population are mobile phone users[183] and 43 percent of the population has access to the internet compared to 70 percent in the east Asia region[184]. Cost of internet is higher than countries in the region, with monthly costs double that of neighboring Thailand[185]. Rural communities in isolated mountainous terrain experience little to no access to broadband. Improving access to affordable internet services will unlock vast opportunities for digital financial services for Lao farmers.

4.3 Addressing barriers to the transition

Helping farmers defray initial and maintenance costs of implementing climate-smart technologies will be key to address high costs of adoption of climate smart technologies. Despite the productivity and climate benefits, the adoption of climate-smart technology and practices can be costly. Farmers adopting climate-smart technologies incur higher costs of labor and inputs (see section 4.1). Some options require establishment costs (e.g. to plant trees under agro-forestry systems) and higher yearly maintenance costs. Helping farmers defray these initial and maintenance costs of implementing climate-smart technologies for instance through incentive payments for the public benefits they provide (e.g. GHG reduction, and ecosystems services) could help to improve adoption and persistent application of technologies.

Improving access to agricultural inputs such as fertilizers and improved seeds will help overcome a major barrier to adoption. Access to enough and affordable organic and inorganic fertilizer is a barrier to the adoption of the climate resilient technologies, such as GAP, and soil fertility management measures. Fertilizer is not supplied in the quantity needed to satisfy its demand and has a high price which farmers often cannot afford. Similarly, limited availability and high cost of improved seed varieties (e.g. drought and submergence tolerant, early maturing) reduces opportunity for technology adoption. Stimulating greater private investment in the multiplication and delivery of climate resilient seed and developing marketing arrangements to reach poor segments of the rural population, are critical for addressing such a barrier.

[182] Bank of Lao PDR. (2023). A new Partnership between the Bank of Lao PDR.

[183] World Bank Data

[184] CSIS, 2022. Digitalizing Laos Improving Government Transparency, the Business Environment, and Human Capital.

[185] CSIS, 2022. Digitalizing Laos Improving Government Transparency, the Business Environment, and Human Capital.

The suboptimal performance and failure of irrigation schemes in Laos needs to be addressed as it restricts implementation of some climate-smart technologies. Many climate-smart technologies such as SRI and AWD and practices require well-functioning irrigation systems. Implementation of the SRI principles of production in the dry season in the irrigated environment under Lao conditions is restricted by the poor water reticulation systems (both delivery and drainage) that prevail in most irrigation schemes. Even with good reticulation systems, there is further difficulty in implementing the system in a scheme because of the necessity of synchronized cropping activities of all farmers to achieve the desired patterns of water delivery and drainage[186]. Therefore, proper functioning and well capacitated local water user groups and associations (WUGs and WUAs) who can satisfactorily management the operations and maintenance costs of the water infrastructure and the associated fees, will be needed to take advantage of climate-smart practices in irrigated systems even after investing in climate proofing of irrigation systems.

Knowledge and capacity of farmers to implement climate smart technologies needs to be strengthened. For instance, farmers will need knowledge on commercial livestock rearing to ensure climate-resilient and low carbon livestock production. Most of the climate-proofed and low-carbon livestock rearing techniques have not been adopted in the traditional smallholder sector (e.g. improved location and sheltering of livestock, preparation of supplementary feed, fodder production, breeding, etc.) due to lack of knowledge and investment resources. This applies to most other climate-smart technologies. The country will need an ambitious awareness and capacity building program to ensure farmers are prepared to implement new technologies like commercial livestock production in a smallholder farmer dominated livestock sector. This will entail extension and advisory services that cater to the specific needs and demands for climate smart technologies and practices.

Research and development, demonstration of new technologies, and agriculture extension services are vital for the implementation of climate smart technologies. The absence of appropriate technology packages developed for the specific agro-ecological zones reduces the opportunities to implement climate-smart technologies. For example, research is needed to develop high yielding, flood tolerant, disease-resistant, and early maturing crop varieties. Certain techniques associated with climate-smart technologies can be incompatible with traditional practices (e.g. burning crop residues) that farmers are accustomed with. Farmers are conservative adopters of technology, and need capacity building, extension, and advisory services to make climate-smart technology adoption more effective and to minimize risks. Therefore, there is need to enhance extension services' capacities for knowledge transfer. However, there is limited fiscal space in the Laos government to support R&D and extension.

Improving access to markets will drive changes in production patterns and incentivize adoption of new technology and practices. Inadequate production and market infrastructure constraints development of and access to domestic and regional agricultural markets, which reduces income opportunities and incentives to invest in new practices or diversify production. For instance, minimizing distances to paved roads reduces transportation costs for both inputs and outputs, connecting farmers to markets and providing incentives to adopt improved practices or diversify production. In addition to hard market infrastructure, improved business skills, timely information about market prices, or the possibility to coordinate and aggregate produce, for instance through farmer associations or producer groups, will enhance farmers' market access, and improve chances of adoption of new technologies.

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186 Schiller, J.M., (2004). System of Rice Intensification – SRI - suitability for lowland rice production in the Lao PDR. Consultant's report, Food and Agricultural Organization (FAO), Lao PDR, March.

Commercial banks and MFIs can take more into account the specificities of the farming sector to bridge the financing challenges for smallholder farmers and develop more suitable financial products. Financial products should consider the conditions and calendar of production of different farming activities (e.g. by applying different interest rates for different products) and better deal with farming risks (e.g. by introducing some flexibility in the payback period for credit/loans if disease outbreaks or extreme climatic event disrupted production). They can take advantage of community financial institutions to reduce the transaction costs of time-intensive follow-up of loans, which can be handled by local institutions. This approach may be further supported by on-farm technical support services delivered through farmer organizations and NGOs to help reduce risks.

Improving security of land tenure and other formalized land use rights will encourage invest in land improvement and in sustainable production systems. Secure land tenure is critical to the sustainability of land use and climate-smart technology implementation. If land tenure cannot be protected effectively, farmers and commercial investors will be unwilling to invest, or even give up entirely long-term investments on farmland. Currently, 70% of the country is designated as forestland, inside which there is no clear legal pathway to recognize land tenure. There is no national provision for transfer of land use rights inside forestlands. Local people do not formally have land use certificates or any title to back their land claims. Consequently, communities are increasingly vulnerable to the economic push for cash crop, which requires more land and to the action of relatively less responsible companies which have a comparative advantage in investing in an unclear business environment. Improving tenure rights, transparency, and security would substantially improve prospects for sustainable and responsible land management, and adoption of climate-smart technologies, limit land disputes and improve grievance resolution.

Strengthening smallholder farmers' financial management skills and business orientation, will improve their reliability as borrowers and improve the flow of finance. Farmers' lack of financial management skills such as absence of trading and production records, credit history, lack of collateral, small turnover means that financial institutions believe them to be too risky and too costly to serve as customers. These lending procedures for farmers need to be simplified, farmers need to be helped to prepare the required financial documents, and to pull together as cohesive groups to increase their attractiveness to lenders.

Chapter 5: Recommendations for a Green Transition in Agriculture

The transition to resilient and low carbon (green) agriculture is a desired objective for Laos as expressed in several national policies ranging the Agriculture Development Strategy (ADS) to 2025 and Vision to 2030, the 9th Five Year National Socio-Economic Development Plan 2021-2025 (NSEDP), the National Green Growth Strategy (NGGS), and the Green and Sustainable Agriculture Framework (GSAF) to 2030. The country will need to ensure that climate smart technologies are taken up by farmers with the goal to boost productivity, drive commercialization, and higher incomes of farmers, while building resilience to climate hazards and promoting low carbon agriculture. This will require government and partners to put in place suitable policies, make targeted investments in high impact areas, provide the right incentives, and build institutional capacities to implement. A set of recommendations on key actions over the next 10 years to support the transition to resilient and low carbon agriculture in Laos based on analysis presented in this report are presented here and summarized in Table 18.

Investments in climate-smart technologies

Re-orient irrigation investments from a focus on infrastructure repairs to enhancing return on investment and sustainability. The country needs to expand irrigation coverage to ensure that more farmers have access to water all-year round. However, the current investment model for irrigation schemes is unsustainable, as public resources are regularly spent on infrastructure repairs, and farmers are unable to realize profits due to high operating costs, and limited avenues for commercialization. A new investment approach anchored on ensuring returns on investments will ensure sustainability of irrigation schemes. This can include:

- Encouraging production of high value marketable crops along with traditional crops to diversify incomes.
- Strategically locating new irrigation investments along the economic corridor to ensure better access to markets, and higher returns for farmers.
- Mainstreaming resilience elements in irrigation systems design to reduce damage from extreme weather and improve water management during the dry season e.g. through improved water harvesting and storage capacity on farms.
- Improving water use efficiency and encouraging water and input saving techniques like System of Rice Intensification (SRI) and Alternate Wetting and Drying (AWD) to reduce operating costs.

Ultimately government will need to track the economic performance of irrigation schemes and make future investments based on lessons about what works to support economic viability of irrigation schemes.

Prepare a breeding and improved seed multiplication agenda for key strategic crops. Climate resilient seeds are the bedrock of resilient future agriculture systems. The government should seek to build a strong crop cultivar improvement and seed multiplication program for strategic crops like rice to ensure timely supply of seeds, which are adapted to farmers' local conditions. However, given budget constraints, government should leverage international research partnerships and domestic/regional private sector players to increase the supply of affordable improved climate resilient seeds for other key crops.

Expand the roll out of good agriculture practice (GAP) building on lessons from on-going and past projects. Lao GAP standards are a great foundation for resilient, low carbon, environmentally friendly commercial production, with potential to expand further into more stringent sustainable production systems. But the uptake of GAP has been very low. The World Bank-supported Lao agriculture commercialization project (LACP) shows that GAP adoption can be improved through support to farmers for keeping farm records, access to inputs like certified seed, and organic fertilizer, and by streamlining GAP certification by the Department of Agriculture (DOA). Through removing these barriers and other barriers and creating an enabling environment through overall improvement of knowledge and understanding, access to critical inputs and incentives, and improving the certification process (e.g. through the broader application of voluntary certification methods like participatory guaranteed systems), government can boost the uptake of GAP, and achieve the ambition for GAP to be implemented throughout the country.

Establish a program on sustainable livestock commercialization primarily focused on animal health and nutrition. Current livestock production systems in Laos are predominantly subsistence, with livestock grazed on meagre pastures and low nutrition crops residue. Livestock therefore are small and fetch meagre incomes for farmers. Reforming the sector to improve performance will entail sustainable intensification and commercialization. A sustainable livestock commercialization program can begin with; (a) improved location and sheltering of livestock, (b) preparation and provision of high-quality supplementary feed, and fodder production, and (c) provision of reliable animal health services. These interventions will raise productivity, build resilience to pests and diseases, and reduce GHG emissions, while earning farmers more income. The program will need to be accompanied by awareness raising and capacity building to prepare farmers to implement new technologies and practices.

Institutional strengthening

Repurpose public spending to support outcome-oriented climate smart research and development. The country needs to increase its budget allocation for agriculture R&D for the development, testing and dissemination of resilient and low-carbon technologies (such as climate-resilient seed varieties, water-saving technologies, integrated soil fertility management, agro-meteorological services, and improved post-harvest technologies). However, given budget constraints, R&D budget allocation will need to be more targeted to specific outcomes that help the country achieve its sustainable and green agriculture goals. As such, R&D funding can be conditioned on specific outcomes, to concentrate the country's R&D capacities and available resources on key topics and desired technology progress. On the other hand, government should leverage domestic, and regional private sector players by incentivizing them to carry our R&D and to facilitate the supply of key climate-smart technologies. Where partnerships are possible with the private sector, the government should seek to explore public private partnerships (PPPs) in R&D and technology transfer.

Reform the extension service to support more pluralistic services that include private sector and NGOs. Although Laos has a well-established network of central, provincial and district agricultural extension units, public extension services will need to deliver more and new information and technologies, speedily and in an interdisciplinary and participatory manner. They will need to deliver more than just technical production services, but include climate services, agribusiness, and market access information. Existing extension services will be hard-pressed to manage to deliver on all these new demands, especially under budgetary constraints. The government will need to leverage other providers of extension services to farmers such as NGOs and the private sector through partnerships and policies that drive pluralistic extension service in the country. Under a pluralistic extension service, private sector (agro-dealers) can be involved in service delivery to improve farmers' business skills and facilitate market linkages, and NGOs can enhance community-based learning and technology dissemination.

Implement a program for strengthening O&M of irrigation schemes. To address the disfunction of many irrigation schemes in the country, government should support water user groups (WUGs) and water user association (WUAs) to effectively manage irrigation schemes and implement operation and management (O&M). Interventions should; (a) strengthen cost-recovery in irrigation schemes, (b) provide financial management and business management training to enhance farmers' incomes, and boost their abilities to pay operation fees, and (c) strengthen conflict resolution and grievance management, to ensure more cohesive groups. Well capacitated and cohesive WUAs and WUGs will also be key to implement climate-smart technologies and practices that require coordinated water management and use such as SRI and AWD.

Build the capacity MAF on climate finance access through local, regional, and international learning exchanges to raise awareness and build experience. Access to climate finance will be an important opportunity for years to come. However, given that this is a new area, it's critical that MAF develops internal capacities to engage meaningfully on the subject and prepare to take advantage of the growing climate finance landscape. The government should seek out countries in the region who are fore runners in accessing climate finance in the region and beyond and facilitate learning exchanges. Vietnam for instance has recently generated experiences in designing projects for low-carbon rice funded through the TCAF fund and supported by the World Bank. Furthermore, some lessons can be found in-country from the $42 million FCPF/Carbon fund emissions reduction program under REDD+.

Develop an MRV system for tracking impacts of climate smart technologies on GHG emissions and other key agricultural indicators. Monitoring reporting and verification protocols for tracking the impact of climate smart technology interventions in achieving climate smart outcomes, like reduced GHG emissions, are critical for ensuring that desired outcomes are achieved. Therefore, putting in place MRV mechanisms and strengthening information and accountability systems in agriculture is critical for creating and trading in carbon assets. This will also be vital for ensuring that the agriculture sector contributes to the country's international commitments under the NDC, since agriculture is such an important contributor to national GHG emissions, and a potential sink. An initial step will be to develop an MRV framework for agriculture, including the institutionalization mechanisms, and capacity building needs.

Policy and regulation

Develop marketing procedures and product standards for climate-friendly/green and safe products for select value chains to meet demand from local and export markets like China and EU. Consumers in middle income and high-income countries are increasingly showing preferences for products that meet climate, environmental and health standards. While Laos aims to tap into this growing market (for instance specialty and sustainable coffee), there is a still a lack of ability to sufficiently implementing standards, tracking, and verifying products and market produce. The country needs to improve on the development of the necessary standards and certifications, which respond to key target markets like China and the EU and improve enforcement of environmental and safety standards from the farm to market. China for instance requires a comprehensive traceability and inspection system from production to export, including close inspection of farm registration, and farm management. A key lever will be to implement a digital traceability and certification system for climate-friendly/green products and food safety.

Apply a dual approach of empowering local administrators to enforce forest protection and land use regulations and incentives to farmers for sustainable land management to reduce forest encroachment. The government needs to improve the enforcement of regulation for land-use and forest preservation at the local level through empowering and capacitating local administrators to reduce the rampant encroachment on forests by agriculture land expansion. However, regulation alone will not be enough as traditional practices dictate unregulated land use and forest land exploitation. However, providing incentives linked to responsible farming and adoption and maintenance of sustainable intensification approaches, which can boost farmer productivity and incomes and reduce the prevalence of monocultures, and soil nutrient mining practices, which are strong factors in forest-land encroachment by agriculture may be useful. This way the government may be able to limit agriculture land encroachment as a complement to enforcement of laws and regulations. It will be key to investigate which incentives are most appropriate and effective.

Improve land use monitoring to track forest encroachment by completing the Forest and Land Use Zoning (FLUZ) exercise. The development of a strong land-use zoning monitoring system will benefit enforcement of environmental regulation and provide clarity on land use modalities at the local level, which can limit farmland encroachments into forestlands. The government should therefore complete the Forest and Land Use Zoning (FLUZ) exercise under implementation by MAF/DOF, and clearly demarcate good-forest boundaries based on satellite and ground-validated maps. Completing this zoning will provide an information base that can be used to inform broader policy dialogue on effective forest management, planned agriculture expansion, and regularize land tenure inside state forestlands.

Finance and incentives

De-risk commercial lending to farmers through organizing farmers and investing in farmer financial literacy. The government can de-risk commercial lending to farmers through the formation and strengthening of functional registered farmers groups capacitated to collectively orient to the market and perform joint selling and coordinated marketing of produce to create economies of scale that could be more attractive to commercial lenders. Furthermore, recognizing the relatively low financial literacy scores in rural areas[187], it is crucial to develop targeted support for the financial needs of rural populations. Efforts to enhance financial literacy should be coupled with capacity building in business development, marketing, financial management, record keeping, and promotion of other forms of collateral beside land (e.g. collectively owned equipment). Practically farmer groups can be provided with imbedded resource persons to support the strengthening of farmer groups in these diverse areas over defined periods of time. These interventions can stimulate entrepreneurship among farmers, and generate increased demand for financial services, thereby driving the growth and expansion of bank lending.

Pilot a cooperative program with commercial lenders for financial services for smallholder farmers, including technical assistance on developing and implementing tailored financial products which suit farmer's needs. Currently, commercial lenders and micro-finance institutions in Laos \have limited outreach to smallholder farmers and small agro-businesses. A significant hurdle to provision of financial services is the lack of experience in dealing with smallholder farmers and agro-businesses, and the perceived high risk of their operations. Government should establish a cooperation program with

[187] Morgan, P. & Trinh, L. Q. (2019). Fintech and Financial Literacy in the Lao PDR, ADBI Working Paper Series, No. 933. Asian Development Bank Institute

commercial banks to pilot green financial products suitable for farmers' conditions e.g. different interest rates for different products, introducing some flexibility in the payback period for credit/loans if disease outbreaks or extreme climatic events disrupt production, and (iii) time-intensive loan issuance that align with the timing of farming seasons. The program can focus on a select few high value agricultural commodities in high potential areas, to provide a safe demonstration case. The cooperation should include dedicated technical assistance through partnerships with experienced organization to provide training to commercial banks on farmer tailored financial product development, farmer appraisal, effective means of reducing transaction costs for loan follow-ups for instance.

Support the introduction of agricultural insurance schemes under public private partnership (PPP) arrangements. The national Disaster Management Committee (NDMC) is exploring the possibility of establishing a national insurance scheme the Ministry of Agriculture and Forestry (MAF). However, while there is great interest from government in insurance products, and evidence that farmers are willing to pay for insurance, it appears that private sector players are hesitant to enter the agro-insurance space in Laos. Establishing a framework for implementing a PPP-based insurance product could be useful to better organize and test insurance products. The framework can be based on lessons from successful insurance products in the region and beyond and seek to identify lesson that are applicable to Laos, which can inform a pilot later.

Provide incentives for private sector technology transfer and for agro-business to enter sustainable business partnerships with farmers. Since public budgets are very tight in Laos, public investment can be used to leverage private investment to advance climate-smart technology implementation. Incentives can focus on supporting private engagement in regional and domestic companies to increase the diffusion of technologies to fill the R&D gap in the country. The absence of a viable business model for private sector to engage millions of smallholders in mutually beneficial business enterprise is a huge lost opportunity. Government should facilitate sustainable business partnerships between agro-businesses and farmers, through blended finance instruments and guarantees.

Concluding remarks and next steps

Lao agriculture will have to undergo a transformation to realize the vision for green and sustainable agriculture set out in various national strategies and plans for the near term (2030s) to the longer term (2050s). Key to achievement of these goals will be a strong focus on actions that boost productivity, drive commercialization, and higher incomes of farmers, while building resilience to climate hazards and lowering the carbon and environmental footprint of the sector. Technological change, targeted investments, incentives, and mature institutional capacities will be needed. This report detailed these needs and recommended priority actions over the coming decade to address climate risks, while achieving other priority goals in the agriculture sector. While not a part of the recommendations provided here, there are several structural issues that need to be addressed to increase the success of the green agriculture transition. These include land tenure security, access to affordable internet services, and reliable energy.

Finally, developing implementation/action plans for green and sustainable agriculture may help to better elaborate above recommendations into specific guidance for government actions. The action or implementation plan/s should detail how the priority activities of government over the next decade can be implemented, including investment envelops, sources of financial resources, delivery mechanisms and implementation modalities.

Table 18. Summary of Recommendations (Urgency: M-Medium; S-Short-term; L-Long-term)

	Recommendation	Urgency	Responsible
	Investments in climate-smart technologies		
1	Expand irrigation services and ensure sustainability through a return-on-investment focused approach and tracking economic performance.	M	DOI
2	Establish a program for variety improvement and multiplication for select strategic crops like rice, through leveraging partnerships	M	DOA
3	Expand the roll out of GAP building on lessons from on-going and past projects	S	DAEC/DOA/NAFRI
4	Establish a program on sustainable livestock commercialization focused on animal health and nutrition.	L	DLF
	Institutional strengthening		
5	Repurpose public funding towards R&D through outcome-oriented allocations of research grants.	M	DOPC/NAFRI/ MOF
6	Reform the extension services to support more pluralistic services including private sector and NGOs.	M	DAEC/NAFRI/DOA
7	Introduce a program for improving the operation and sustainability of irrigation schemes through strengthening cohesion and capacities of WUAs, and WUGs.	S	DOI
8	Build the capacity of MAF on climate finance access through local, regional, and international learning exchanges to raise awareness and build experience.	S	DOPC
9	Develop an MRV system for tracking impacts of climate smart technologies on GHG emissions and other key agricultural indicators.	M	MAF/MONRE
	Policy and regulation		
10	Develop marketing procedures and product standards for climate-friendly/green and safe products for select value chains to meet demand from local and export markets like China and EU.	M	MAF/MOIC
11	Apply a dual approach of empowering local administrators to enforce forest protection, and land use regulations and incentives to farmers for sustainable land management.	M	DaLAM/DOF/MAF; DLM/MONRE
12	Improve land use monitoring to track forest encroachment by completing the Forest and Land Use Zoning (FLUZ) exercise.	M	DaLAM/DOF; DLM/MONRE
	Finance and incentives		
13	De-risk commercial lending to farmers through providing partial guarantees, organizing farmers, and investing in farmer financial literacy.	S	MAF/MOF
14	Pilot a cooperative program with commercial lenders for financial services for smallholder farmers, including technical assistance on developing and implementing tailored financial products which suit farmer's needs.	S	MAF
15	Establish a framework for implementing agriculture insurance products for farmers through based on international and regional good practice.	M	MAF/NDRC/MOF
16	Provide incentives to private sector to support technology transfer and to agro-business to enter sustainable business partnerships with farmers.	L	MAF/MOIC

Source: Authors

Annexes

Annex 1: Key national policies, plans and projects for a green transition

a) National policies and plans

Policies and plans	Objectives	CSA relevance
Agriculture Development Strategy to 2025 and Vision to the year 2030	Ensuring food security, producing comparative and competitive agricultural commodities, developing clean, safe, and sustainable agriculture and shift gradually to the modernization of a resilient and productive agriculture economy linking with rural development contributing to the national economic basis.	Continue to improve production forces and production relations by establishing strong farmer organization that to be able to access to credit, technology and modern production equipment.
Laos 9th Five Year NSEDP 2021-2025	The Plan aims to implement the Resolution of the 11th Party Congress, as well as continue the implementation of the National Strategy on Socio-Economic Development 2016-2025 and Vision 2030 of the Lao PDR.	On Climate Change Mitigation, the Plan highlights (1) Continue the implementation of the NDC and greenhouse gas emission mechanisms such as the REDD+ project; and (2) Mainstream climate change adaptation and community-based adaptation (CBA) into sectoral development plans to protect people from natural disasters.
National Green Growth Strategy (NGGS) of Laos till 2030	To enhance capacity for integrating green growth into the formulation and implementation of sector and local strategies and plans in each period to ensure achievement of long-term goals of NSEDP.	Allocation and participatory formulation of the national land management and use plan as soon as possible to ensure efficient, effective, and sustainable use of land with is the valuable property of the nation.
Green and Sustainable Agricultural Framework (GSAF) to 2030	Green and sustainable agriculture (GSA) development is a priority of the Government of Laos as articulated in the NGGS and other policy statements. The framework elaborates on the policy and guides the development of green and sustainable agriculture programmes such as the Clean Agriculture Programme, Agroforestry Programme.	The GSAF focuses on the sub-sectors of crops, livestock, fisheries, agroforestry, and non-timber forest products. The Framework applies to all participants and stakeholders involved along the entirety of the agricultural value chain, ranging from farmers to retailers, as well as policy actors, researchers, interest groups, and consumers within those five sub-sectors.
Decree on Climate Change No. 321/GoL	The Decree identifies principles, regulations, and standards on management, monitoring the climate change to mitigate, protect and reduce the impact from climate change aiming at safe livelihood, health, asset, environment and biodiversity, infrastructure linking to regional and international practices and contributing to the NSED based on the sustainable and green direction	Identify mitigation measure to reduce GHG from targeting changes of agriculture and forestry land use, eradicate deforestation, reforest, and re-fertilize agricultural land. Relevant sectors must identify mitigation for climate change periodically to improve resilience and reduce GHG such as land use, agriculture and forestry, water resources
National Agenda No. 1356/MAF	The agriculture and forestry sector must implement two plans, including strengthening agricultural production, import substitution, reducing foreign exchange outflows, and improving agricultural product processing and increasing exports.	Strengthen agricultural production and processing. Create conditions and environment conducive to production. Strengthen SPS and TBT to reduce import for those could be produced domestically. Promote clean, safe, and green agriculture production with strengthening standards such as OA and GAP. Strengthen livestock production with GAHP, GAQP.

b) Summary of main constraints for CSA in relevant departments

Agency/Organization	Main constraints for CSA
Department of Agriculture (DOA), MAF	• Limited capacity of technical staff in plant quarantine, pesticide use, SPS, GAP, OA inspection and certification. Technical expertise and information for CSA is rather limited due mainly to limited government budget support. • Since 2016, DOA has been planning to strengthen the capacity for OA and GAP inspection for at least 5 staff in each province. However, these plans have not been implemented due to financial constraints. • Weak coordination among lines technical departments under MAF.
Department of Agricultural Land Management (DALaM), MAF	• Limited detailed information on crops parameters, soil fertility, water saving, and crop quality • Limited available information on agricultural land use planning linking to CSA technologies. • The government's promotion on green and sustainable agriculture production with commercialization does not align with the sustainable land use planning and allocation. • DALaM recognizes the impact of climate change on agricultural land use; however, there is no specific program to mitigate climate change impacts in the sector.
National Agriculture, Forestry and Rural Research Institute (NAFRI), MAF	• Limited information on CSA in terms of detailed technical and market demand and information for specific products. • Limited government's budget to support the technical research on CSA technologies. • Limited demonstration and research on CSA including the greenhouse with sprinklers and other modernized facilities with clear cost benefit analysis for each technology. • Limited coordination between research and extension services on CSA.
Department of Livestock and Fishery (DLF), MAF	• Lack of technical capacity to efficiently collect samples and test for animal diseases and impact of climate change in the livestock sector. • Limited information on GHG emissions in livestock sector.
Department of Irrigation (DOI)	• Irrigation facilities and water source has not been well supplied to the right users for commercial production. • There is a need for policy makers to better understand and improve their awareness on better irrigation use with right regulations, and proper irrigation design • Limited coordination among lines technical departments such as DOI, DOA, NAFRI, DALaM and DAEC
Department of Planning and Cooperation (DOPC), MAF	• Limited government's budget support to consolidate information on CSA from line technical departments. • No specific information system and database on CSA and impact of climate change on agriculture sector. • Limited coordination mechanism and clear strategy and action plan for CSA.

c) Selected projects from international development partners

Project and organization	Brief description
Agriculture Competitiveness Project (LACP), World Bank ($29.3 million)	LACP implements the productive alliance approach to demonstrate that smallholder farmers can successfully increase agricultural productivity and efficiency in response to market opportunities and demand for food safety and sustainable agriculture development along the rice, vegetable, and maize value chains.
Lao Landscapes and Livelihoods Project (LLL), World Bank, GEF, Canada Clean Energy and Forest Carbon Facility ($57.4 million)	LLL aims to promote sustainable forest management, improve protected area management, and enhance livelihoods opportunities in 5 large landscapes, comprising 8 provinces. The LLL is financing the development and piloting of a FLUZ approach that aims to differentiate between existing good forest (non-disturbed for 7 years or more) and agroforestry zones (degraded forestland that has been used by villagers). Once the delineation is completed, this information base can be used to inform broader policy dialogue on effective forest management, programmed agriculture and livelihoods expansion, and land tenure inside state forestlands. The project directly funds forest-smart livelihoods centered on CSA in 544 villages.
Governance Forests Landscapes and Livelihoods (GFLL), World Bank, Forest Carbon Partnership Facility/Carbon Fund (up to US$42 million in results-based payments)	GFLL is an Emission Reduction Program signed between Laos and the FCPF/Carbon fund within the framework of Reducing Emissions from Deforestation and forest Degradation (REDD+). The carbon fund committed to purchase up to $42 million in emissions reductions (ERs) from the six northern provinces. These emissions reductions are verified by an independent auditor and purchased at $5 per ton. Revenues generated by the ERs will be re-invested in the forest villages in the jurisdiction under a benefit sharing plan supervised by the Bank. Forest-smart livelihoods supported by the program center on CSA.
Enhancing Systematic Land Registration Project (ESLRP), World Bank, ($31.6 million)	The ESRLP aims to enhance land tenure security and land administration service delivery. These objectives are achieved by i) issuing one million land titles in all 18 provinces of Laos mainly in rural areas; ii) modernizing and digitalizing the land administration system; and iii) supporting land policy and legislation development. The registered land titles can be used then as collateral when applying for credit for CSA investments. At policy level, the Project is supporting the recognition of land rights of 25% of population living within state designated forestlands.
Funded by GEF, the Strengthening Agro-climatic Monitoring and Information Systems to Improve Adaptation to Climate Change and Food Security project (SAMIS), FAO ($5.4 million)	SAMIS technically aims at: 1) strengthening agroclimatic monitoring, analysis, communication and use of data and information for decision-making in agriculture and achieving food security. 2) strengthening institutional and technical capacity for monitoring and analysis of agricultural production systems and development of the Land Resources Information Management System (LRIMS) and agro-ecological zoning (AEZ).
Climate Adaptation in Wetland Areas in Lao PDR (CAWA), FAO ($4.7 million)	Planning with science & local knowledge: Vulnerability assessments -interviews and meetings. Understanding of Climate Change impacts and risks, to enhance capacities of communities, Local and central administrations design priorities and implement Climate Change Adaptation, Promote Disaster Management Measures in the two target wetlands.
Funded by SDC, the Lao Upland Rural Advisory Service (LURAS III), Helvetas	LURAS III through Climate Resilient Extension Development (CRED) is expanding the green extension approach to include a participatory process for improving the resilience of rural communities engaged in commercial farming and marketing, who are among the hardest hit by the effects of climate change.

($5 million)	
Implementation of Governance Forest Landscapes and Livelihoods (I-GFLL), GIZ ($42 million)	I-GFLL aims to reduce greenhouse gas emissions by promoting sustainable forest management and forested landscapes at scale in six provinces of the Lao PDR through implementation of the Lao Emission Reduction Program (ERP)
Climate-Friendly Agribusiness Value Chains Sector Project, ADB ($40.5 million)	The project supports the implementation of the government's Agriculture Development Strategy to 2025 (ADS) by boosting the competitiveness of rice value chains in Khammuane, Saravane, and Savannakhet provinces, and vegetable value chains in Vientiane Capital, Champassak, and Sekong provinces.
Sustainable rural infrastructure and watershed Management Project (SRIWMP), IFAD ($47 million)	The project is intended to address issues of PRI and watershed management in mountainous provinces of northern Laos by using an integrated land use planning approach that integrates efficient, sustainable and climate resilient rural infrastructure, and feasible watershed protection measures. For an ecosystem based sustainable rural development, infrastructure and the watershed must be considered simultaneously.
Savannakhet Landscape Program, WCS ($1.2 million)	A scalable model of sustainable community-led wetland management delivers long-term benefits through strengthened livelihoods linked to biodiversity protection, endangered species recovery, improved ecosystem services and reduced habitat degradation

Annex 2: The FABLE model assumptions

Assumptions and sources of data

Domain	Assumption	Source and justification
Population	The total population increases by 33% between 2015 and 2050. In 2050, the share of people that are younger than 25 years old drops to 36% compared to 63% in 2000. The older part of the population, that is +50 years old, will grow to 28% in 2050 compared to 10% only in 2000.	***Source***: SSP2 for total population for years 2015-2050 (UN-ESA 2017) and UN medium estimate for population distribution by age and sex group for years 2020-2050 (United Nations, Department of Economic and Social Affairs, Population Division (2017). World Population Prospects: The 2017 Revision, DVD Edition.). ***Justification***: SSP2 population projections are close to 2020 observations and national projections by 2050.
Diets	For 2000-2020, we follow FAO trends. In 2050 we assume the following changes in average per capita consumption compared to 2020 FAO levels: - rice and cereals: -6% - fruits and vegetables: +35% - roots: +37% - sugar: +100% - vegetable oils: 170% - eggs: +113% - poultry meat: +34% - vegetable oil and oilseeds: +170% - milk: +100% - red meat: +74% - pork: +7% - fat from animals: +25% - pulses: +91% - fish: +4% - and beverages and spices: +42%.	***Source***: FAO Food Balance Sheet for the period 2000-2020 ***Justification***: Calibrated based on observed trends 2000-2020 from FAO Food Balance Sheet.
	GREENER PATHWAY In 2050, we assume the following changes in average per capita consumption compared to the 2050 BAU diet: - cereals: -17% - roots: +23% - sugar: -75% - fish: +25% - poultry meat: +88% - eggs: +100% - red meat: -34% - pork meat: -21% - roots: +23% - pulses: +60% - fat from animals: -27% milk, vegetal oils, beverages and spices, fruits, and vegetables equal to BAU pathway	Inspired by EAT Lancet diet, adapted to Laos. Reduction in pork and red meat to reduce enteric fermentation. Reduction in cereals to reduce CH4 emissions from rice, and to reduce the diet's dependency on staples with low dietary diversity. Reduction in sugar to avoid health issues. Lower total kilocalories per person and per day to be closer to MDER.
Crop productivity	For 2000-2020, we follow FAO trends. Then, we assume that productivity increases at a constant growth rate equal to 25% of 2000-2020 observed rate for most crops, relying on increasing fertilizer use. We also account for climate change effect (see below). Yields in 2020 and 2050 respectively: - banana: 23.4 t/ha and 25.3 t/ha - cassava: 33.7 t/ha and 29.6 t/ha - coffee: 2.25 t/ha and 2.44 t/ha - corn: 8.85 t/ha and 8.81 t/ha - rice: 2.68 t/ha and 2.60 t/ha - vegetables: 9.41 t /ha and 9.96 t/ha	***Source***: FAOSTAT annual crop yield over the period 2000-2020 ***Justification***: Based on yield potential from geographically close countries with similar climates (Thailand, Indonesia, China). Over the past two decades, there have been important increases in crop productivity. Laos was catching-up neighboring countries' productivity levels. This phenomenon is ending but there is still room for improvement.

Livestock productivity	For 2000-2020, we follow FAO trends. Then, we assume that productivity increases at a constant growth rate equal to 200% of 2000-2020 observed rate. Yields in 2020 and 2050 respectively: - red meat from cattle: 0.026 t/TLU and 0.032 t/TLU - milk from cattle: 0.355 t/TLU and 0.429 t/TLU - red meat from sheep and goats: 0.045 t/TLU and 0.050 t/TLU - eggs from poultry: 0.833 t/TLU and 0.855 t/TLU - chicken meat from poultry: 0.202 t/TLU and 0.207 t/TLU - pork meat from pigs: 0.094 t/TLU and 0.120 t/TLU ***Note:*** *An increase in livestock productivity implies a proportional increase in feed requirement.*	***Source***: FAOSTAT annual livestock productivity over the period 2000-2020 ***Justification***: Based on historical yield growth from 2000-2020 trends and current shift towards more productive systems. The Lao government and foreign companies are increasingly investing in the livestock sector to shift towards more productive systems.
Ruminant density	Ruminant density is computed as the total number of ruminants divided by pasture area reported by FAO. In the case of Lao, the ruminant density automatically adjusts when the herd increases to prevent pasture expansion beyond the FAO pasture area in 2010.	***Justification***: According to FAOSTAT, the pasture area remained stable over 2000-2010. Ruminants are held by smallholders and graze in fallow cropland, communal areas or along roads, rivers, fields, and forests (ADB, 2002; MAF, 2017). Consequently, we assume that the ruminant herd growth is decoupled from the evolution of pasture area. Moreover, access to land is under great pressure in Laos and pasture is not competitive with cash crops and forest plantations so pasture has no possibility to increase further (farmers have no interest in enlarging their pasture areas).
Land use change	Free expansion of agricultural land outside protected areas (protected areas remain constant to 2010 level, 3.847 million hectares). We assume afforestation started in 2015 and will increase linearly towards 1.65 million hectares in 2030 so that the total forest area represents 70% of the territory in 2030. Data for land use is based on FAOSTAT from 2000 to 2020 as well as carbon sequestration from land.	***Source***: Land cover data from FAO, protected areas from WDPA, afforestation data from Laotian National Statistical Yearbooks, MAF Statistical Year Books. ***Justification***: We are not aware of plans to further increase protected areas and/or limit agricultural land expansion in the future. The Lao government sets the objective to cover 70% of its territory by forest by 2030, so we consider there will be more afforested areas until 2030 to fulfill the objective and then no more afforestation. Note: Official Laotian statistics report a lower forest area than FAO for the period 2000-2020, thus reaching 70% of total area might imply a larger afforestation target than the one we model. It seems that there exist discrepancies between the official definition of forest cover in Laos and the FAO definition. Carbon sequestration data associated to forests is also higher in FAOSTAT data than in official Laotian sources[188].
	GREENER PATHWAY In the BAU pathway, there is no restriction on deforestation. Here, we assume that Laos progressively stops deforestation to achieve zero deforestation in 2050.	Deforestation is a key issue in Laos.
Trade	Net exports: - FAO trends for 2000-2020, then no change in quantity except for sesame, rice, banana, corn, coffee, vegetables, and cassava - For sesame, banana, corn, vegetables, and coffee, quantities triple between 2020 and 2050 - For rice, quantities are multiplied by 50 (from 2,000 tons in 2020 to 100,000 tons in 2050)	***Source***: FAOSTAT from 2000 until 2020 ***Justification***: Calibrated on observed 2000-2020 FAO trends for exports and imports. Laos is engaging more into agricultural trade with China, Vietnam, and Thailand. The government wanted to double export values between 2015 and 2025 (MAF, 2015).
Climate change impacts	Climate change impacts are introduced through crop models simulations on crop yields using climate projections as input. In the model, we have used estimates for climate change impacts on crop yield with RCP 6.0, the climate model *HadGEM2-es,* and the crop model *LPJmL* and without CO_2 fertilization effects. It only covers 12	***Source***: ISIMIP (Inter Sectoral Impact Model Intercomparison Project), https://www.isimip.org/impactmodels/details/48/ ***Justification***: In the absence of stronger efforts to reduce GHG emissions, a global mean warming increase

188 Ministry of Agriculture and Forestry (2018). Lao PDR's Forest Reference Emission Level and Forest Reference Level for REDD+ Results Payment under the UNFCCC. Lao PDR

	crops, cassava, field pea, groundnut, maize, millet, rapeseed, rice, soy, sugar beet, sugarcane, sunflower, and wheat.	between 2°C and 3°C above pre-industrial temperatures by 2100 would be likely.
Losses and waste	No change in the share of consumption wasted (3%) and production lost through post-harvest losses (on average 2%) in 2010.	***Source***: FAO Food balance sheet for post-harvest losses and (FAO. 2011. Global food losses and food waste – Extent, causes and prevention) for waste percentages for the South and Southeast Asia region ***Justification***: We are not aware of plans that aim to limit losses and waste.

Climate smart technologies

For this study, the FABLE Calculator included scenarios of climate smart technologies adoption – a new development. They were selected based on the literature review from Chapter 2 in alignment with Lao policies. Bilateral in-person meeting in Vientiane with stakeholders also helped prioritize the choice of technology. Data, sources, and justifications are detailed in the table below. Data on available mitigation and adaptation options specific to Laos is still limited. We relied on local sources every time possible but also had to use more global databases, thus creating some noise in the results.

Assumptions and sources of data for the climate smart technologies		
Domain	**Assumption**	**Source and justification**
Mixing cattle breed	Local cattle can be crossbred with more performant breeds such as Red Braham. Hybrid cattle body weight is 80% higher on average compared to local breed. Thus, productivity (tons of beef per TLU) is also 80% higher on average. We assume that 30% of the cattle herd will be hybrid by 2050. **Note:** *we assume same feed quantities and same GHG emission factors as the local breed since we lack complementarian data.*	Breed mixing is already a solution that the Ministry of Agriculture is promoting to improve cattle productivity (MAF, 2020)189. Interest for this practice was confirmed during the stakeholder engagement process of this study. Some Red Braham bulls have already been introduced in Laos (Xayalath et al. (2021). Source: Xayalath et al. (2021)[190]
Molasses Nutrient Blocks for cattle	We assume that programs are developed such that cattle have access to one molasses nutrient block that is eaten in one month before being slaughtered. The consumption of one block leads to: - Productivity gains +2.3% - Emission abatement of 470kgCO_2e We assume that 40% of the cattle while have access to one molasses blocks by 2050, including 15% of hybrid cattle. **Note:** *Molasses nutrient blocks increase feed digestibility and thus reduce emissions from enteric fermentation. They can also have other benefits such as delivering health interventions or boosting lactation that we do not account for.*	Molasses nutrient blocks are already introduced in Laos through trials or development programs. They seem affordable for farmers (with benefits larger than costs of the blocks (Windsor et al. 2021)[191]. Interest for this practice was confirmed during the stakeholder engagement process of this study. Source: Windsor and Hill (2022)[192]

[189] Ministry of Agriculture and Forestry (2021). *Agricultural Development Strategy to 2025 and Vision to 2030 (Revised) DRAFT* 2021.
[190] Xayalath, S., Mujitaba, MA., Ortega, ADSV., Rátky, J. (2021). A review on the trend of livestock breeds in Laos. *Acta agrar Debr*. ;(1):227-237. doi:10.34101/actaagrar/1/9047
[191] Windsor, PA., Nampanya, S., Olmo, L., Khounsy, S., Phengsavanh, P., Bush, RD. (2021). Provision of urea–molasses blocks to improve smallholder cattle weight gain during the late dry season in tropical developing countries: studies from Lao PDR. *Anim Prod Sci*.;61(5):503. doi:10.1071/AN20517
[192] Windsor PA, Hill J. Provision of High-Quality Molasses Blocks to Improve Productivity and Address Greenhouse Gas Emissions from Smallholder Cattle and Buffalo: Studies from Lao PDR. *Animals*. 2022;12(23):3319. doi:10.3390/ani12233319

System of Rice Intensification	The system of rice intensification is a cultivation method that can be used on both irrigated and rainfed rice cultivation. Locally defined SRI practices have been developed to be low-cost solutions for smallholder farmers. We assume that 20% of total harvested area shift to this Lao specific SRI method. This leads to:
	- Productivity gains +39%
	- Emission abatement:
	    o Irrigated area: -33%
	    o Rainfed area: -44%
	We assume that by 2050 20% of the rice planted area will implement this practice.
		This practice is mentioned in the NDC list of conditional mitigation targets for 2030. Improving rice irrigation is also considered as a key mitigation practice in the Long-Term Low-Emission Development Strategy (LT-LEDS) recommendations report identifying Action Scenario GHG Impact Assessment.
		
		Source: Government of Lao (2021)193

Cultivar change for rice	We assume that there is a shift to rice varieties with a higher tolerance for drought for lowland rainfed ecosystems. This ecosystem corresponds to about 78% of the total rice harvested area in 2020194, and we model that 40% of the harvested area will shift to this new cultivar. The new high yielding glutinous rice variety increases yield by 7% on average. **Note:** We assume that cultivar change, and SRI are not applied to the same areas.	Cultivar change is mentioned as an adaptation action by Lao government (National Strategy on Climate Change by 2030 and 2050, 2021 draft)[195] Source: Inthapanya, 2015196
Set of agroecological practices for cash crops	Agroecology is a combination of diversified practices in-field such as intercropping, cultivar mixtures, agroforestry, cover crops, low-tillage, or crop rotations. It generally leads to higher yields than monocultures. In particular: - Corn: +40% [sd: -38%, +216%] - Coffee: +5% [sd: -67%, +231%] - Cassava: +26% [sd: -32%, +132%] - Vegetables: +68% [sd: -13%, +151%] We assume that by 2050 50% of the planted areas for the concerned crops will implement this set of practices. **Note:** *These estimates are global, i.e. not particular to Lao PDR. Agroecology has also benefitted on biodiversity and resilience to extreme climatic events that we do not account for.*	MAF identifies green agriculture, defined as a more sustainable and inclusive agri-food systems, as an opportunity to transition towards a more sustainable and resilient agriculture system (Green and Sustainable Agriculture Framework for Lao PDR to 2030, 2021)[197] The Long-Term Low-Emission Development Strategy (LT-LEDS) recommendations report also mentioned low tillage, crop cover and agroforestry as key mitigation options. Source: Jones et al. (2021)[198]

FABLE and LT-LEDS mitigation scenarios

The Long-Term Low-Emission Development Strategy (LT-LEDS) report for Laos also built scenarios of adoption of key agricultural mitigation practices. The table below compares FABLE scenario under the BAU and LT-LEDS scenario. Most identified mitigation options are common to both studies.

Mitigation option	Target in 2050	LT-LEDS	FABLE (BAU)	FABLE (Greener)
Manure management (composting, anaerobic digestion)	Head of cattle and buffalo	300,000	Not covered	Not covered
Improved feed quality or use of additives for cattle	Head of cattle and buffalo	300,000 (+3% fat in feed)	1,325,000 (one MNB)	875,000 (one MNB)

[193] Government of Lao PDR. *First Nationally Determined Contribution (Updated Submission).*; 2021.
[194] Ministry of Agriculture and Forestry (2020). *Agricultural Statistics Yearbook 2020.* Lao PDR
[195] Ministry of Natural Resources and Environment, Department of Climate Change (2022). *Third National Communication on Climate Change (Draft).* Lao PDR
[196] Inthapanya, P. (2015). New High Yielding Promising Glutinous Rice Line TDK37-B-9-1-3-B. *The Lao Journal of Agriculture and Forestry*.
[197] Ministry of Agriculture and Forestry (2021). *Green and Sustainable Agriculture Framework for Lao PDR to 2030.*
[198] Team, Scientific Data Curation. Metadata record for: A global database of diversified farming effects on biodiversity and yield. Published online 2021:5969 Bytes. doi: 10.6084/M9.FIGSHARE.14723913

Cross breeding cattle	Head of cattle and buffalo	Not covered	990,000	655,000
Cover-crops	Hectares	200,000	Cassava: 100,000 Coffee: 75,000 Corn 80,000 Vegetables 105,000 (Set of agroecological practices)	Cassava: 100,000 Coffee: 75,000 Corn 80,000 Vegetables 105,000 (Set of agroecological practices)
No or low-tillage agriculture practices	Hectares	200,000		
Annual to perennial crop conversion	Hectares	50,000		
Nitrogen Management through nitrification inhibitors	Hectares	200,000	Not covered	Not covered
Adjusted water managements practices in lowland rice cultivation	Hectares	100,000	250,000 (SRI)	240,000 (SRI)
Shift rice cultivars	Hectares	Not covered	490,000	485,000

Annex 3: Economic analysis

Crop and livestock financial models

The financial analysis illustrates cost-effectiveness and financial viability of selected CSA technologies as compared to the continued business as usual (BAU) case (conventional farming). The main objective of the financial analysis is to estimate the cost-effectiveness and financial viability of CSA practices by measuring on-farm incremental net benefits underlying the transition from conventional farming to CSA. The analysis is based on crop and livestock models which simulate the implementation of conventional/BAU and CSA practices for a variety of rain-fed and irrigated crops.

In the financial models, three pathways are considered: (i) "business as usual (BAU)", which is the baseline of the analysis; (ii) "BAU with climate change (CC)"; and (iii) climate-smart agriculture (CSA). The BAU scenario refers to 'conventional' farming activities where farmers are not engaged in any improved climate-resilient agronomic practice, yields are below the potential, and the returns of labor are lower. Such scenario is representative of the current situation. "BAU with CC" pathway represents a future scenario where current policies are implemented, and current trends are continued. It illustrates the projected impacts of climate change (RCP 6.0) on the baseline scenario if no adaptation strategy is implemented. Finally, under the CSA scenario, farmers are hypothesized to adopt climate-resilient and low-carbon technologies to improve both environmental and financial performance. Considering one hectare of land, crop financial models simulate crop annual budgets reporting all the quantities of inputs and outputs, their unit costs and prices. Livestock financial models simulate the dynamic of a typical herd (average) estimating annual budgets that account for costs associated with breeding activities (i.e., feed, vaccines, and pasture) as well as benefits from the sale of animal products (i.e., live animals, meat, milk).

Production costs include cash inputs and labor costs. Cash costs considered include costs for purchase of seeds, chemical fertilizers (NPK), organic fertilizer (manure), pesticides, herbicides, plastic bags, plastic batch, sacks, fuel, irrigation (when present) and electricity (water pumping). Livestock management costs include labor, feeding, animal husbandry and health care. Labor is valued in the models using as a proxy the market rural wage (50,000 kip /person-day) derived from the data available. Since the goal of the analysis is to consider all the input costs, labor is valued in the same way, no matter if the laborer is a family member or an external labor. In other words, the analysis looks at labor costs within overall production costs. Most smallholders, however, do not rely totally on hired labor and use family labor, without accounting for their labor costs. In both crop and livestock financial models, financial performance indicators such as gross margin, net margin and return of family labor are estimated. Gross margins (cash flow) are computed as a difference between total revenue and total operating (variable) costs. Therefore, in each crop model, both the gross and net margins are computed (where the net margin is obtained by subtracting the labor costs from the gross margin), to also consider family labor costs. Labor, overall productivity and incomes are expected to increase as an effect of the implementation of such climate-resilient practices. The difference between annual net incomes in the 'BAU' versus 'CSA' scenarios represents the net incremental financial benefits of switching from conventional to climate-smart agricultural systems.

Enabling investments

An estimation of the financial investment costs associated with the transition to a climate-smart agricultural systems relate to the definition of extension and capacity building systems at country level. Such costs will possibly factor the effects of key policy actions and enabling investments**. The structure and the economic estimate of such off-farm investments** is illustrated in the following table. It considers a target of 1,660,000 households and a period of 5 years.

Investment components	***Description***	***Million US$***
CC knowledge management	Climate hazards and vulnerability information for Laos compiled and integrated into an agriculture and climate risk system. Agricultural land-use planning in flood and drought-prone areas. Comprehensive national long-term information system for climate related hazards	319
Capacity building and training	Agricultural officers, extension workers and farmer cooperatives in target districts trained in climate change impacts on agricultural production and socio-economic conditions, and potential community-based climate-smart adaptation options.	398
Extension advisory services	Community-based climate-smart agricultural practices and off-farm opportunities demonstrated and promoted at district level within suitable agro-ecological systems.	576
Adaptation monitoring and evaluation	Definition of a systematic and periodical monitoring and evaluation system	124
Total		1,418
Total cost/ha (US$)		*854*
Total cost/ha/year (US$)		*171*

Source: Authors' elaboration based on the project "Improving the resilience of the agriculture sector in the Lao PDR to climate change impacts"

The costs and benefits of the transition

For each crop and livestock species considered in the present report, the costs and benefits underlying the transition through climate-smart agricultural systems have been estimated. The results are reported here. The value of both on-farm and off-farm benefits increases gradually over time, due to a hypothetical gradual adoption rate of climate-smart agricultural practices by targeted farms (which determine a steady increase in both agricultural productivity and emissions abetment). The off-farm transition costs appear only in the first 5 years of the considered time (20 years) due to the hypothesized duration of the investment project in infrastructures and capacity building. For all crops and livestock species considered in this report, the transition to climate smart agricultural systems generates positive net incremental benefits. This means that, despite the increase in on-farm costs incurred by farmers, and the cost of investments in infrastructures and capacity building sustained by the government authorities, the adoption of resilient and climate-smart agricultural systems leads to greater financial benefits. The transition to climate-smart systems is therefore economically profitable.

Since the abatements of GHGs emissions here hypothesized are linked to both the adoption of climate-smart agriculture practices and the reduction of deforestation, the price of a carbon offset credit (equal to 3.05 $per tCO_2e reduction) is estimated as an average of credit prices underlying agricultural and forestry project categories (respectively equal to 1.36 and 4.73 $per tCO_2e)[199]. Table 16 provides an estimate per hectare of costs and benefits (on-farm and off-farm) underlying the CSA transition of crop and livestock systems.

Net incremental benefits of climate-smart transition in rice cultivation

Costs and benefits - RICE	***Unit***	***Y1***	***Y2***	***Y3***	***Y4***	***Y5***	***Y6-Y20***
On - farm net benefit	'000 $	-	27,517	55,035	82,552	110,069	137,587
Off - farm transition costs	'000 $	185,678	185,678	185,678	185,678	185,678	185,678
Off - farm benefits	'000 $	-	183,009	366,018	549,027	732,036	915,045
Net Incremental Benefits	'000 $		24,848	235,375	445,901	656,427	1,052,63 2

Note: Estimates based on a total number of hectares under rice cultivation equal to 1,087,010

Source: Authors

Net incremental benefits of climate-smart transition in the maize cultivation

Costs and benefits - MAIZE	***Unit***	***Y1***	***Y2***	***Y3***	***Y4***	***Y5***	***Y6-Y20***
On - farm net benefit	'000 $	-	5,524	11,048	16,573	22,097	27,621
Off - farm transition costs	'000 $	21,828	21,828	21,828	21,828	21,828	-
Off - farm benefits	'000 $	-	19,176	38,352	57,529	76,705	95,881
Net Incremental Benefits	'000 US$	(21,828)	2,872	27,572	52,273	76,973	123,502

Note: Estimates based on a total number of hectares under maize cultivation equal to 127,790

Source: Authors

[199] State of the Voluntary Carbon Markets 2021 https://www.forest-trends.org/publications/state-of-the-voluntary-carbon-markets-2021/

Net incremental benefits of climate-smart transition in the cassava cultivation

Costs and benefits - CASSAVA	*Unit*	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6-Y20*
On - farm net benefit	‘000 $	-	3,480	6,960	10,440	13,920	17,400
Off - farm transition costs	‘000 $	15,759	15,759	15,759	15,759	15,759	-
Off - farm benefits	‘000 $	-	13,845	27,689	41,534	55,378	69,223
Net Incremental Benefits	‘000 $	(15.759)	1,565	18,890	36,214	53,538	86,622

Note: Estimates based on a total number of hectares under cassava cultivation equal to 92,260

Source: Authors

Net incremental benefits of climate-smart transition in the cassava cultivation

Costs and benefits – VEGETABLES	*Unit*	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6-Y20*
On - farm net benefit	‘000 $	-	38,036	76,072	114,108	152,144	190,179
Off - farm transition costs	‘000 $	31,259	31,259	31,259	31,259	31,259	-
Off - farm benefits	‘000 $	-	27,461	54,922	82,383	109,844	137,305
Net Incremental Benefits	‘000 $	(31,259)	34,238	99,735	165,231	230,728	327,484

Note: Estimates based on a total number of hectares under vegetables cultivation equal to 183,000

Source: Authors

Net incremental benefits of climate-smart transition in the coffee cultivation

Costs and benefits - COFFEE	*Unit*	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6-Y20*
On - farm net benefit	‘000 $	-	2,455	4,910	7,366	9,821	12,276
Off - farm transition costs	‘000 $	13,997	13,997	13,997	13,997	13,997	-
Off - farm benefits	‘000 $	-	12,296	24,592	36,888	49,184	61,480
Net Incremental Benefits	‘000 $	13,997	754	15,506	30,257	45,008	73,756

Note: Estimates based on a total number of hectares under coffee cultivation equal to 81,940

Source: Authors

Net incremental benefits of climate-smart transition in cattle rearing

Costs and benefits – CATTLE	*Unit*	*Y1*	*Y2*	*Y3*	*Y4*	*Y5*	*Y6-Y20*
On - farm net benefit	‘000 US$	-	99,421	198,843	298,264	397,686	497,107
Off - farm transition costs	‘000 US$	454,369	454,369	454,369	454,369	454,369	-
Off - farm benefits	‘000 $	-	17,371	34,742	52,113	69,485	86,856
Net Incremental Benefits	‘000 US$	(454,369)	(337,576)	(220,784)	(103,991)	12,802	583,963

Note: Estimates based on a total number of cattle heads equal to 2,660,000

Source: Authors