ENHANCING CLIMATE RESILIENCE THROUGH INTEGRATED ENERGY, AGRICULTURE, AND WATER MODELLING

SUMMARY

This technical brief argues the need for integrated land use and energy and water supply planning for achieving Laos' Green Growth Strategy afforestation targets while ensuring food security under changing climate. By using the CLEWs modelling framework, we show that the least-cost pathway for achieving the afforestation target includes the mechanization of agriculture, with high-input small-scale farming covering 52% of the production of the nine main crops by 2055 and commercial-scale farming covering 44%. This increases the pressure on surface water resources by 51% per year (compared to a baseline scenario) and the need for electricity for irrigation by 0.64 TWh in 2055, highlighting the need for integrated infrastructure planning and for diversification of energy primary supply. Emerging and available climate-resilient and rainfed rice varieties can lower overall costs of rice production by 17% and water used for rice production in the north by 21% while increasing the yields of low-input rainfed rice crops by 114%.

1. INTRODUCTION

Agriculture remains a cornerstone of Lao PDR's economy and rural livelihoods, contributing over 15% to national GDP and employing the majority of the population (Lao Statistics Bureau, 2023). However, the sector faces rising challenges due to land degradation, limited irrigation coverage, climate variability, and fragmented planning. The expansion of cash crops such as cassava and maize has intensified the pressure on land resources while increasing demands on water and energy systems (World Bank, 2023; WFP, 2020). Agricultural expansion is often occurring in areas where seasonal water availability is highly variable, and where irrigation systems often rely on electricity or diesel pumping without considering long-term resource limits (ACIAR 2020).

As irrigation expands and cropping patterns shift, land-use change is also accelerating in many parts of the country. New irrigation schemes, solar-powered pumping systems, agro-industrial zones, and emerging bioenergy initiatives are reshaping landscapes and competing with forests, conservation areas, and hydropower catchments. In many regions, yields remain low and productivity could be improved through sustainable intensification rather than further land clearing. Without a shift toward climate-smart practices, soil degradation and declining water availability may undermine long-term food security (World Bank, 2023). Policies that focus on improving soil health, promoting diversified cropping systems, and expanding access to improved inputs are essential to reduce the environmental footprint of agriculture while supporting farmer livelihoods. These land-use dynamics underscore the need for planning approaches that link agriculture, energy, land, and water management decisions to national development strategies, particularly those outlined in the **National Green Growth Strategy**.

Energy access is also linked to agricultural development. Distributed renewable energy systems such as mini-grids and solar home systems can support rural irrigation, agro-processing, and household needs in remote upland villages where grid extension remains limited. This approach aligns with the goals of the **9th National Socio-Economic Development Plan (2021–2025)**, which prioritises rural development, climate resilience, and sustainable resource management. It also creates opportunities to design programmes that directly support agricultural productivity, income generation, and climate resilience.

Electricity use for agriculture is expected to grow in the coming decades as demand for irrigation, processing, and mechanization increases. Meeting this demand will require connections to national power planning, including diversification beyond hydropower through increased investment in solar, wind, small hydro, and biomass, as emphasised in the **National Power developed Plan** and the **Lao PDR Nationally Determined Contribution (2021 Update)**. These trends align with national commitments to climate-resilient development, low-emission growth, and sustainable land and water management.

Despite the strong links between agriculture, water, and energy, planning efforts in Lao PDR are often pursued in isolation. Land-use decisions rarely account for seasonal water availability, and irrigation development does not consistently consider the electricity or fuel required for pumping,

storage, and distribution. Reviews of irrigation and water management practices led by the Ministry of Agriculture and Forestry and development partners highlight the need to improve water-use efficiency and to better integrate irrigation planning with energy and resource availability considerations (Banks et al., 2020; World Bank, 2023). Similarly, rural electrification programs do not always integrate agricultural production needs or the spatial distribution of irrigated areas, despite the priorities outlined in the **National Electrification Program** and the **Renewable Energy Development Strategy**. This fragmented approach makes it challenging to manage interconnected risks, such as seasonal water scarcity, rising irrigation demand, energy access gaps, and potential yield losses (IWMI, 2022; IRENA, 2021).

The weak coordination between the agriculture, water resources, energy, and land management ministries continues to create fragmented planning processes. Data on land zoning, water allocation, and electricity use are held separately, making it challenging to design coherent policies or identify trade-offs across sectors. Strengthening interministerial coordination and establishing shared data systems would enable more consistent decision-making and improve national planning outcomes.

2. ADDRESSING THE CHALLENGES

Taken together, these developments show why the Lao PDR would benefit from an integrated analysis of Climate, Land, Energy, and Water systems (CLEWs). A CLEWs approach can help link land-use planning with water allocation, energy supply, and agricultural production in ways consistent with national policies such as the **Agriculture Development Strategy 2025**, the Land Use Master Plan, and the National Green Growth Strategy. It enables policymakers to explore how irrigation expansion affects electricity demand, how crop changes affect land and water use, and how distributed renewable energy can support rural development. By evaluating trade-offs and synergies across sectors, a CLEWs framework can support more coherent planning and help the Lao PDR achieve its goals for food security, climate resilience, and sustainable resource use.

Many countries have adopted the CLEWs modelling framework as a decision-support tool. For example, a CLEWs exercise supported by UNECA and the African Climate Policy Centre was used in Ethiopia to explore cross-sector linkages relevant to climate and NDC implementation. In Mauritius, a dedicated CLEWs case study combined water, energy, and land-use analysis to examine water security, irrigation needs, and energy options under climate change. More recently, Kenya has applied CLEWs modelling to assess long-term interactions between land, energy, and water systems, with a focus on the implications of agricultural land use and energy access choices for wider resource pressures. Similar CLEWs applications have also been developed for Uganda, highlighting how integrated climate, land, energy, and water analysis can support balanced strategies under resource and climate constraints.

This technical brief aims to identify key gaps in land, energy, and smart agriculture planning in Lao PDR, and to demonstrate the value of adopting CLEWs as an integrated modelling tool. The CLEWs framework enables policymakers to explore alternative policy scenarios, test trade-offs, and design resource-efficient development strategies that align with national goals for food security, climate resilience, and sustainable land management.

3. APPROACH AND SCENARIO DEVELOPMENT

The analysis draws on national agricultural statistics and scenario-based modelling using the CLEWs framework to explore integrated planning options for Lao PDR. The modelling focuses on the interactions between land use, afforestation targets, innovative agriculture practices, and resource demands across the land, energy, and water systems.

3.1. Scenario development

The United Nations Department of Economic and Social Affairs (UNDESA), KTH Royal Institute of Technology and the National University of Laos ran a UNDESA-funded 1-year program where a large group of analysts from various governmental institutions, research organizations, and utilities were trained in the use of CLEWs. The group jointly created a CLEWs model for Lao PDR and designed scenarios to deliver insights on key questions for the country's long-term integrated resource planning.

The inter-ministerial working group identified several policy questions with a high priority in the government's agenda, of which two could be promptly analyzed with CLEWs:

1. **How can the development and mechanization of agriculture support the achievement of the afforestation target of Lao PDR's Green Growth Strategy?:** We model an *Afforestation Target* scenario, where we impose a target of 70% forest cover by 2030, based on Lao PDR's Green Growth Strategy. We introduce the possibility of improving the yields of key food crops in the country (rice, cassava, sugarcane, beans, maize, coffee, and rubber) by improving crop management via mechanization and irrigation, thereby intensifying agriculture and freeing up land for forests.
2. **What are the benefits and resource use implications of available options for climate-resilient agriculture?:** Starting from the baseline (i.e. without an afforestation target), we model a *Smart Agriculture* scenario, where we introduce a currently available but little-known climate-resilient rainfed rice variety with reduced cost and proven higher yield than other varieties used in small-scale agriculture. This scenario is motivated by IPCC as-

sessments for Southeast Asia, which project increased rainfall variability and more frequent dry periods under climate change, increasing risks for irrigation-dependent systems and strengthening the importance of resilient rainfed crop varieties (IPCC, 2022). We observe the impact of its deployment on land and water uses, under an assumption of pure cost-competition with existing rice varieties.

3.2. Analytical framework

Integrated Systems Analysis. The CLEWs model in this study links electricity generation, agricultural output, land-use change, and water uses in agriculture, to quantify cross-sectoral impacts of agricultural development and land-use policies. Climate is represented through its impact on the water cycle (precipitation and evapotranspiration) and the accounting of GHG emissions, but this study only uses a baseline climate scenario.

Policy Alignment. Scenarios are benchmarked against Lao PDR's Agriculture Development Strategy 2025 and Vision 2030, Land Use Master Plan, National Green Growth Strategy, National Irrigation Strategy, the Lao PDR Nationally Determined Contributions (2021 Update), and the National Adaptation Plan (NAP) to ensure that afforestation, climate-smart agriculture, and land-water-energy interactions remain consistent with national targets for forest restoration, sustainable agriculture, and climate resilience

Data Inputs. The CLEWs scenario development for Lao PDR is informed by several core datasets covering land, energy, agriculture, and water system interactions. These include capital, fixed, and variable costs for power supply and agricultural practices (under different crop management systems, i.e. rainfed vs irrigated and small-scale, low-input vs commercial, high-input); input/output efficiencies such as irrigation water use per unit of harvested crop land; and yields of major crops (rice, cassava, sugarcane, beans, and maize, and also export-oriented crops such as coffee and rubber) under different management systems.

Following suggestions of the working group, and the classification made in most of the input datasets used for the climate, energy, land and water systems, the CLEWs model has been configured with three different regions (North, Centre and South) to reflect differences in land-use patterns, crop productivity, irrigation potential, and water availability.

The scenario assumptions include the expansion of climate-resilient crop varieties (including improved rice varieties), the expansion of forest land in line with the afforestation targets, and projected growth in crop demand under both baseline and other scenarios. These scenario drivers are combined with data on land productivity, crop suitability, and water demand derived from GAEZ v4.0 and national statistics.

A detailed power system model developed by the Climate Compatible Growth program (CCG) is integrated alongside the land and water system representations to capture the time-variant electricity demand and supply and the evolving generation mix. The power system inputs are harmonized with the regional CLEWs structure to ensure consistency between agricultural electricity use, irrigation pumping requirements, and long-term energy planning. Together, these datasets define the resource constraints, policy targets, and demand projections that shape the Lao PDR CLEWs model.

The technical description of the model, its boundaries and structure, its datasets, and all data sources are provided in detailed technical annexes.

4. POLICY RECOMMENDATIONS

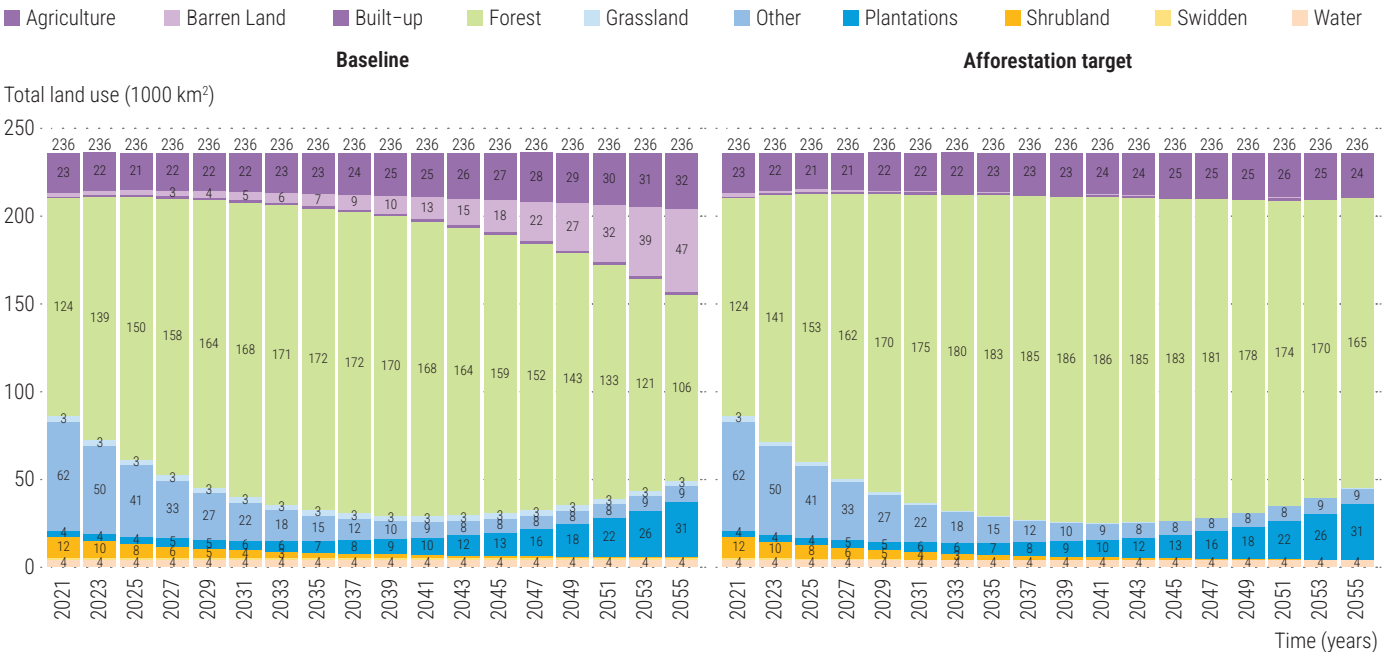
1. **How can the development and mechanization of agriculture support the achievement of the afforestation target of Lao PDR's Green Growth Strategy?**

The Afforestation Target scenario demonstrates that achieving 70% forest cover by 2030, as outlined in the National Green Growth Strategy and the Land Use Master Plan, is technically feasible. However, meeting this target requires a rapid conversion of existing land covers, as shown in Figure 1. In the scenario, around 61% (by 2030) and 89% (by 2050) of barren land, grassland, shrubs, swidden, and regenerating forests are reallocated to forest cover (Figure 1). This large-scale reclassification sharply restricts the land available for agriculture, compared to the baseline (Figure 1). The domestic crop demand can still be met under these conditions, but the system needs to rapidly move toward intensive, high-input production methods.

As land becomes scarcer, the crop production not only shifts toward higher inputs but demands also more intensive irrigation. As a result, mechanized irrigated cropland more than triples between 2021 and 2055, becoming the dominant production mode. This intensification drives a steep rise in water demand: the water used for irrigating the crops considered in this study increases from around 1.2 billion m^3 in 2021 to more than 1.8 billion m^3 by 2055. Overall, surface water resources are on average abundant and the increased use of water is not projected to exceed the limits, being thus a sustainable option initially. However, the sharp increase merits further investigation into its spatial distribution, to ensure that it does not create hotspots of high water abstraction that may lead to localized unsustainability. The electricity demand for irrigation increases in parallel, rising from about 0.83 TWh in 2021 to nearly 2 TWh by 2055, more than doubling the baseline trajectory. This underscores a significant water-energy-land trade-off, where forest expansion reduces land availability for agriculture while increasing long-term dependence on irrigation. This occurs at a time when climate projections for Lao PDR indicate potential changes in rainfall patterns,

Figure 1

Land-use conversion and forest expansion under the afforestation scenario



including seasonal reductions in dry-season rainfall and greater variability in precipitation, which could reduce the long-term reliability of water supplies for agriculture (Government of Lao PDR, Third National Communication to the UNFCCC, 2024; IPCC sixth Assessment report, 2022).

Despite the aggressive mechanization of agricultural production and consequent 7.8% average increase of the yields, the domestic production cannot fully compensate for the reduced cultivation area under the afforestation constraints and cannot fully meet the food demand of a growing population. Therefore, the country becomes reliant on imports in the very last years of the analysis, with close to 3 million tonnes of cumulative imports between vegetables, fruits, and rice by 2055 (see Figure 2).

The afforestation pathway, therefore, introduces vulnerabilities, particularly under climate change. The rising water use for irrigation may increase the pressure on the water resources locally. It also increases the exposure to dry-season water scarcity, and the higher energy requirements create dependency on a reliable electricity supply. At the same time, the rise of crop imports after 2050 highlights that physical limits of productivity increase and land use for agriculture are reached, and no more increase of domestic production is realistically achievable under the resource constraints considered. These limits may become more stringent under climate and market shocks. These cross-sector pressures reinforce the importance of coordinating forest policies with irrigation planning, agricultural productivity strategies, and energy system expansion, as emphasised in the Agriculture Development Strategy 2025, the National Irrigation Strategy, and the Lao NDC (2021 update).

Recommendations

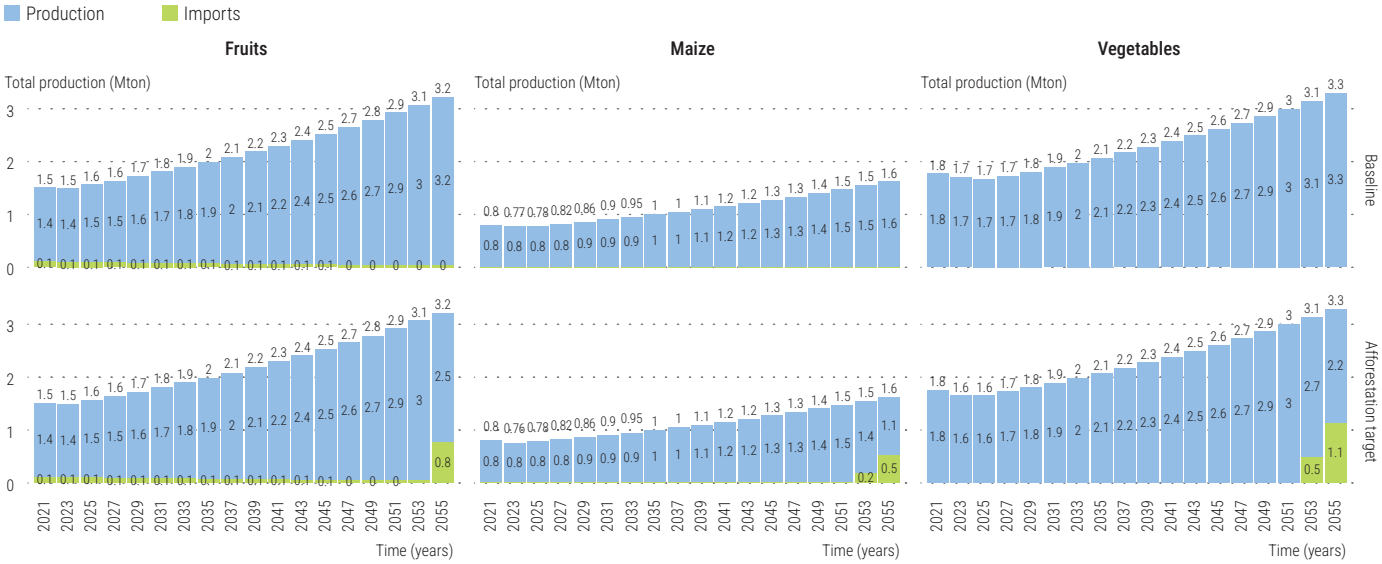
- Support with policy and economic incentives the sustainable intensification of agricultural practices (like irrigation) instead of expanding agricultural land. This includes increasing irrigation coverage from 22.5% of the harvested land to 45.5% by 2055 under the afforestation scenario, and increasing mechanization from 88% to 96% by the same year. This is expected to lead to a yearly increase in yields of 7.8% and provide an average yearly increase of 420,000 tonnes of crops. In this way, up to 8,000 km^2 can be saved to contribute to the afforestation target. Further support may also be directed to climate-smart practices, improved soil health, and high-productivity crop varieties.
- Plan water and energy infrastructure in parallel with afforestation targets, given the expected 51% rise in water needs for irrigation and 34% rise in power needs for irrigation by 2055. From a least-cost perspective, the additional 4.48 TWh of cumulative energy demand over the model period is met by 2.98 TWh of solar power (+1.2% relative to the baseline), 1.86 TWh of wind generation (+2.5%), accompanied by a decrease in hydropower generation (−0.36 TWh or −0.05%). Deploying efficient pumping systems is critical to manage rising irrigation needs amid constrained land availability.

2. What are the benefits and resource use implications of available options for climate-resilient agriculture?

In the Smart Agriculture scenario, the introduction of the new crop shifts rice production, as illustrated in Figure 3. The total land area under rice cultivation increases by around 4 times to 12,000 km^2 in 2055 in the northern

Figure 2

Crop import trends under the afforestation scenario versus the baseline



region compared to the baseline, while it decreases in both the central and southern areas. This is driven by the uptake of the new crop in the northern region, covering 5,900 km^2 in 2055 (pink area in the top right graph). The higher uptake in the north compared to the other regions is attributed to the combined effect of higher yields and lower variable costs of the new rice variety in the north compared to the old crop mix. As a result, part of the total land for rice cultivation at a national scale shifts from mostly irrigated (13,300 km^2 or around 98% of the total harvested land in 2055 in the baseline scenario) to rainfed (around 5,900 km^2 or 40% of the total harvested land in 2055 in the Smart Agriculture scenario). This shift leads to a decrease in water use for agriculture (from 1.2 billion m^3 to 0.7 billion m^3 in the smart-agriculture scenario in 2055) and in the electricity used for irrigation (from 1.25 TWh to 0.75 TWh in 2055). With a 114% increase in the yields of low-input, rainfed rice crops, the overall rice crop cost decreases by 25% in 2055 compared to the baseline. The decreased water and electricity use makes the Smart Agriculture scenario an excellent opportunity (in terms of cost and resource use) to improve agricultural productivity. With this approach, the use of water for irrigation becomes more sustainable than in the baseline: it reduces both the risk of exhausting the available water resources and the investments necessary in energy supply infrastructure (−40 MW).

Recommendations

- Support the shift to more climate-resilient rainfed rice varieties such as TDK11 (source of the data used in this brief), especially in the north where they appear to have the lowest cost (−25%) compared to the old mix while providing a 114% higher yield than the old low-input rainfed crop mix.

5. FINAL CONSIDERATIONS AND FUTURE STEPS

The above policy recommendations, deriving from the modelling insights, lead to some more general considerations and recommendations.

The interministerial coordination between institutions in charge of agriculture, water resources, energy, environment, and land planning could be enhanced by a dedicated interministerial CLEWs working group, or by incorporating CLEWs analysis as a recurring agenda item into an already existing working group, in support of coherent resource planning that prevents siloed decision-making.

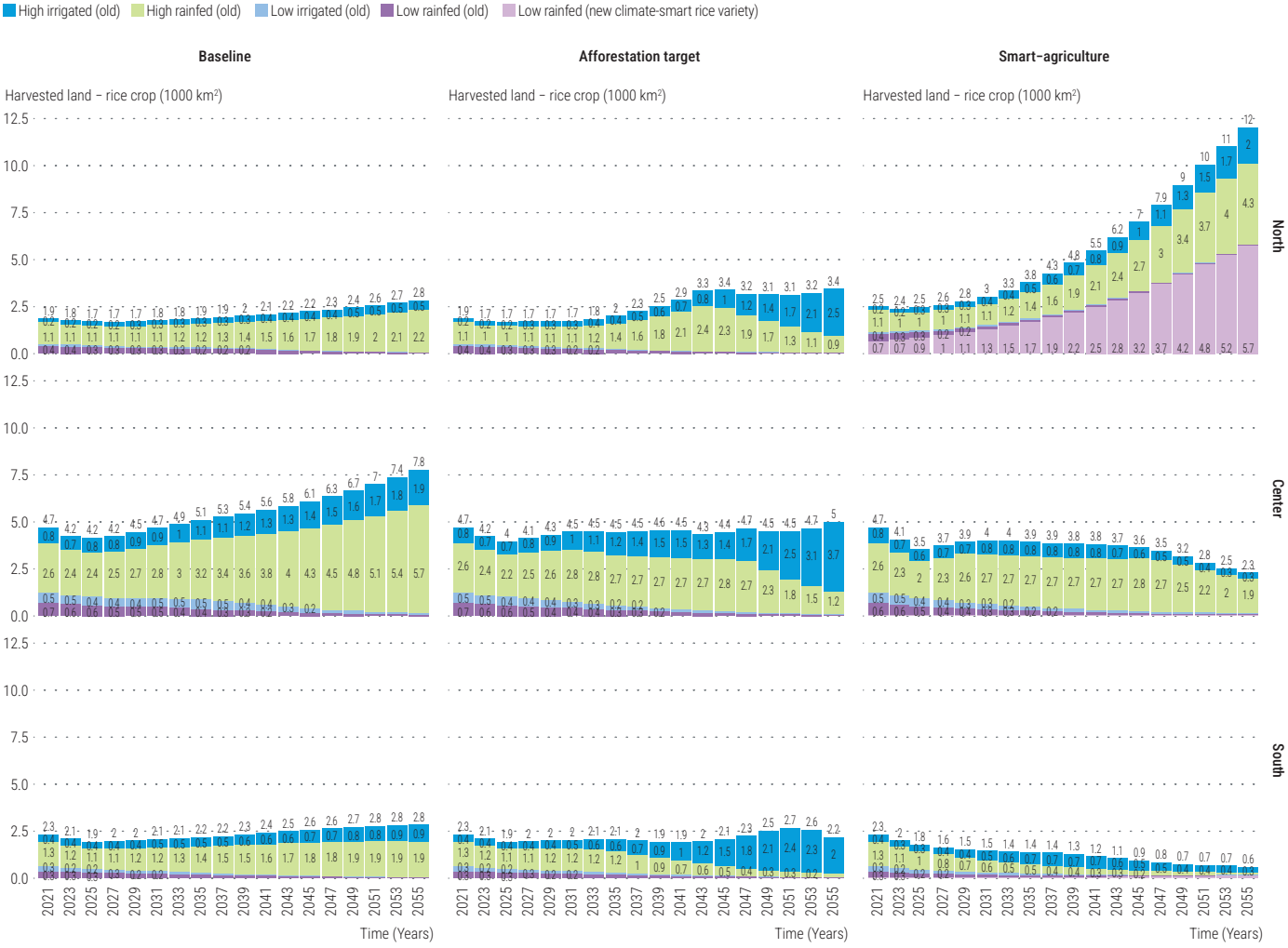
The institutionalization of CLEWs modelling in national planning frameworks may support updates to the Agriculture Development Strategy, the National Green Growth Strategy, the National Adaptation Plan, and future revisions of the Land Use Master Plan and the Nationally Determined Contributions to the United Nations Framework Convention on Climate Change.

For the institutionalization of CLEWs, there is a need to invest in local capacity for data collection and organisation, modelling, and scenario development. Strengthening national capacity to collect and analyse land, water, energy, and climate data ensures that CLEWs analyses become a routine input to policy processes rather than an external isolated exercise.

Moving forward, the model should be expanded to encompass the entire agricultural value chain, including livestock and agro-processing, to capture resource needs and sector emissions better. Strengthening national data systems for land use, irrigation, crop production, and water flows will improve the quality of future scenarios, support the coordination between government institutions in charge of

Figure 3

Rice crop harvested land area projections by region (in the rows) and scenario (in the columns)



climate mitigation and adaptation, energy, land use, agriculture, and water supply planning, enabling integrated planning.

As climate variability increases, the next phase of modelling should incorporate seasonal patterns of water availability and shifts in precipitation plus improved georeferenced representation, enabling more robust evaluation of irrigation reliability, localized water stress, and long-term resource risks. This will provide a stronger foundation for future policy briefs, capacity development, and ongoing institutional integration of systems modelling tools across the government. It will be also worth combining the assumptions of the two scenarios represented in this brief, to assess if and how much the penetration of the new rice variety may be affected by reduced land availability.

6. ACKNOWLEDGEMENTS

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