ACIAR Sustainable Development Investment Portfolio

ACIAR SDIP Phase 2

Draft Final Report

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June 2021

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Acronyms List

ACIAR	Australian Centre for International Agricultural Research
ASEAN	Association of Southeast Asian Nation
BIN	Bangladesh, India and Nepal
CA	Conservation agriculture
CASI	Conservation Agriculture based Sustainable Intensification
CECA	Centre of Excellence for Conservation Agriculture
CHC	Custom Hiring Centres
CIMMYT	International Maize and Wheat Improvement Center
CRAP	Climate Resilient Agriculture Programme
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DASCOH foundation	Development Association for Self-reliance, Communication and Health, Bangladesh
DFAT	Department of Foreign Affairs and Trade
DoA	Department of Agriculture
EGP	Eastern Gangetic Plains
FEW	Food-energy-water
GDP	Gross domestic product
GoWB	Government of West Bengal
HS	Happy Seeder
ICEWaRM	The International Centre for Water Resources Management
ICIMOD	The International Centre for Integrated Mountain Development
IFC	International Finance Corporation
IFPRI	International Food Policy Research Institute
IWMI	International Water Management Institute
LFP	labour force participation
LSP	local service providers
NABARD	National Bank for Agriculture and Rural Development
RDRS	Rangpur Dinajpur Rural Development Society, Bangladesh NGO
SC	Scheduled Caste

SAARC	South Asian Association for Regional Cooperation
SAWI-World Bank	South Asia and Water Initiative World Bank
SDIP	Sustainable Development Investment Portfolio
SRFSI	Sustainable and Resilient Farming Systems Intensification
TAF	The Asia Foundation
UBKV	Uttar Banga Krishi Vidyalaya, North Bengal Agricultural University, Coochbehar
VMP	Versatile Multi-crop Planter
ZT	Zero Tillage

Executive Summary

The ACIAR SDIP program goal is to **maximise agriculture's contribution to sustainable food systems in the Eastern Gangetic Plains (EGP)**, for improved food, energy and water security. Over eight years the program has transitioned from understanding and promoting sustainable farming technologies based on conservation agriculture, to include the wider context of the food system and a deeper understanding of the various external factors which influence sustainable food production. ACIAR SDIP has focused on sustainable food systems as a way of integrating different sectors at a range of scales, and ensuring gender-inclusive planning processes and outcomes. The aim was to promote resilient and inclusive food systems supported by robust institutional arrangements, policies and strategic regional planning, to address the challenge of scaling sustainable and inclusive farming systems in the context of a changing food system.

In Phase 1, the SRFSI project tested and promoted sustainable farming systems based on CASI. This allowed work in Phase 2 to focus on what is needed in the wider enabling environment to allow these systems to be used at scale; to understand the big drivers of food systems in the EGP, and how they impact on farming systems. In Phase 2, the ACIAR SDIP program worked with a wide range of stakeholders from policy makers and implementers, including food policy and gender researchers to understand constraints to and impacts of scaling sustainable farming systems. This included deepening understanding of how institutional and social factors, markets and technologies interact to constrain or enable the adoption of sustainable intensification technologies. Additional work explored biophysical constraints such as soil and weed dynamics, and a better understanding of the context for water and energy resources management. The growing challenges of climate change, and the need to promote gender equality by empowering women and girls are themes that were integrated in activities across the program.

Highlights from the ACIAR SDIP program include:

Scaling of Conservation Agriculture based Sustainable Intensification (CASI) approaches, with an increasingly nuanced understanding of the science behind the scaling. CASI farming practices increase productivity and farm incomes, reduce labour requirements and farm level water use, and have emission reduction benefits. In total, around 120,000 farmers (25% female) are now using more productive, profitable and gender inclusive farming systems. The cumulative impacts of this adoption over the life of SDIP includes an estimated additional AUD $100 million in farm household income, 60,000 tonnes of CO_2-e mitigated and 63,000 megalitres of water saved, and positive benefits for women in households using CASI. Importantly, CASI is now integrated into state government programs and policies in West Bengal, and will continue to scale without project support.

Helping our partners to bring together the 'big picture' related to sustainable food systems, through application of Foresight processes in the EGP. This work has included engaging key stakeholders in informed dialogue on the drivers and trends for regional food, water and energy security through enhanced foresight and scenario processes; synthesising the current status of key influencing factors and their potential future trajectories; and using future-focused processes at the local level as a dialogue tool, to probe deeper into existing situations, and to determine future pathways for food systems transformation.

Exploring effective institutional arrangements to support sustainable food systems. A better understanding has been generated about the current alignment of policies and delivery mechanisms related to knowledge transfer, risk management, water rights, and inclusion and empowerment. Knowledge transfer to farmers, especially on new technologies, offers promise on multiple fronts, but its benefits are not universally accessible because of the delivery apparatus, with women particularly disadvantaged but (ironically) having much to gain from better transfer mechanisms (like mobile phones). Water access in the region is intimately tied to energy and the incentives for using energy differently. Leveraging diverse preferences around pumping technologies offers promise for further developing groundwater markets and widening water access. Policies that are seemingly focussed on risk reduction (e.g. input subsidies, energy policies) are producing perverse impacts and require a re-think in terms of how they are rolled out. Additional international support around broadening better governance and financing systems can have important benefits in agriculture. In Nepal, the Roadmaps process has proved to be an effective institutional process connecting farmers' groups, policy makers, machinery owners and scientists to improve agricultural productivity in Province 1 and 2, which have the potential to be the food bowl of Nepal. This project addressed a key demand for mechanisms to promote coordination and develop a plan for agricultural machinery use that supports CASI technologies.

Creating new approaches to research and new knowledge which promotes a more nuanced macro and micro understanding of women's roles in agriculture in the EGP, and the impacts of systems change. This research challenges policy makers, academics and donors to ensure they target their interventions based on an appreciation of both the macro and micro drivers which affect the success of women farmers. Several projects have contributed to a better understanding of the role of women in agriculture, highlighting the heterogeneous situation across the EGP. A chief concern is the low female workforce participation in Bihar and West Bengal, which has declined to as little as 10% in some districts. Other work has looked at how inclusive CASI approaches are, finding that it reduces women's workloads, and offers opportunities to diversify into alternative income generating activities.

Contributing new knowledge to support sustainable groundwater development in the EGP, using a food-energy-water (FEW) nexus lens. Individual projects have looked at patterns of availability and access to groundwater, local level water management solutions (i.e. CASI, managed aquifer recharge), and the impacts of commonly used policies that aim to influence groundwater development and sustainability. Results indicate the links are not always as expected. For example, increased access to electricity has not resulted in a strong change in groundwater use or productivity in West Bengal; and water savings at the farm scale do not always result in reduced groundwater use overall. In the EGP, impacts of climate change will result in delayed monsoons and increased incidence of flooding, which makes summer crops more vulnerable to water stress (both too much and too little). Groundwater resources, which in many places are annually recharged (as at least four ACIAR SDIP studies have confirmed), are more resilient to climate change and offer assured irrigation in the dry winter months.

Identifying options that contribute to mitigation of emissions and adaptation to climate change. CASI based systems reduce the emissions footprint of food production systems in the EGP by 6 - 18%. Emissions reductions vary by cropping system, and so any changes to the cropping system can have wider impacts on the carbon intensity of the agricultural sector. There is potential for significant impact if these systems are adopted widely; for example, increasing the use of CASI to 20% of the area of rice, wheat and maize systems in the EGP would reduce carbon emissions by over 740,000 tonnes of CO_2-e. CASI systems also have a positive impact on both the amount and types of carbon present in the upper soil layers. Identifying and managing soil acidity through better management of nitrogen fertiliser also offers potential to reduce emissions. Importantly, these reductions do not need to come at the expense of productivity or profitability, creating win-win situations for farmers, rural agribusinesses and governments alike, who are all struggling to find ways to adapt to climate change and reduce future levels of emissions.

Developed new knowledge on the challenges and opportunities for Nepal's food systems in the context of federalisation. The changed federal structure gives more power to local governments at the municipal level, adds a provincial level of government for facilitation and support, and changes the role of the federal government to policy, governance, knowledge and oversight issues. This restructuring brings enormous opportunities for agriculture sector services to be prioritised and managed at the local level, but a coordinated and co-operative mechanism is essential for success. Work has been undertaken to define the context, and understand priorities at different levels of government, to reach a consensus on preferred pathways towards sustainable food systems. In particular, there has been a focus on planning for sustainable agricultural mechanisation by offering a linking mechanism for one part of the agricultural system at the provincial level; and on enhancing linkages within the extension system.

The ultimate goal of the ACIAR SDIP program is to engage in applied research that promotes agricultural development a sustainable and equitable way, so that future food systems can provide what is needed while still working within sustainable extraction limits.

1 Introduction

Current food production systems are under pressure from many sources: the population explosion, environmental demands, increased competition for water from other sectors, physical water scarcity due to climate variability and a greater demand for biofuels and renewable energy among them. In the broader context, these pressures occur within complex bio-physical and socio-economic settings and have impacts on social, economic, ecological and political outcomes. Often decisions made with regard to the management of food, water or energy are not considered in relation to the other interlinked elements, and so perverse outcomes are experienced. For any given circumstance there may be synergies and/or conflicts between the sectors. This is true at a range of levels, from the field or farm through to community, policy and regional levels. We need ways to understand and manage the food-energy-water nexus at different scales, and to communicate these understandings to generate action for widespread transformation of sustainable food systems.

The Eastern Gangetic Plains (EGP) of Bangladesh, India and Nepal is home to 450 million people, with the world's highest concentration of rural poverty and a strong dependence on agriculture for food security and livelihoods. The EGP has the potential to become a major contributor to South Asian regional food security, but rice and wheat productivity remain low and diversification is limited because of poorly developed markets, sparse agricultural knowledge and service networks, and inadequate development of available water resources and sustainable production practices. Labour shortages are becoming more acute. These factors lead to smallholder vulnerability to climate and market risks that limit farmer and private sector investments in productivity-enhancing technologies. Options are needed to sustainably improve food systems in the region.

Managing the interactions between food, water and energy at different scales is of critical importance to sustainable development. To address these challenges, the Sustainable Development Investment Portfolio (SDIP) was an Australian Government initiative, coordinated by the Department of Foreign Affairs and Trade (DFAT). SDIP aimed to improve the integrated management of food, energy and water in South Asia, to facilitate economic growth and improve the livelihoods of the poor and vulnerable, particularly women and girls, and addressing climate risks. The SDIP focused on the Indus, Ganges and Brahmaputra river basins. These basins are shared by several countries in the region and are highly vulnerable to conflicts over the management of increasingly scarce resources. SDIP ran in two phases – Phase 1 from 2013 – 2016 ($45 million); and Phase 2 from 2016 – 2020 ($47.9 million), although it was initially designed as a twelve year investment.

In the SDIP, DFAT worked in a partnership arrangement with seven Australian and regional partners (ACIAR, CSIRO, ICIMOD, ICEWaRM, IFC, TAF, SAWI-World Bank[1]). Partners were engaged to advance the goal and objectives of the SDIP according to their mandate and expertise, meaning that the portfolio worked on a range of areas including integrated water resource management, management of floods and other water-related disasters, new knowledge of water-energy-food systems and the impact of climate change, renewable energy, sustainable food systems and improved resource efficiency. With all partners, SDIP worked towards the following outcomes:

1. **Strengthened mechanisms for regional cooperation:** operating at a regional, national and/or sub-national level in the sub region.
2. **Critical new knowledge generated and used:** within the priorities acknowledged by regional forums, governments and national bodies and addressing said knowledge gaps through science and/or well evidenced and reflective practice.
3. **Improved enabling environment:** within the policies, regulations, market systems and investment conditions for cross border management of shared water, food and energy resources.

[1] Integrated Mountain Development, International Centre of Water Resources Management, International Finance Corporation, The Asia Foundation, South Asia Water Initiative – World Bank

As a partner, ACIAR focused on food and agriculture elements of the food-energy-water nexus. The ACIAR SDIP program goal was to maximise agriculture's contribution to sustainable food systems in the Eastern Gangetic Plains, for improved food, energy and water security. The program transitioned from understanding and promoting sustainable farming technologies based on conservation agriculture in SDIP Phase 1 (see Section 2.1) to the wider context of the food system and a deeper understanding of the various factors which influence and enable sustainable food systems in Phase 2. The ACIAR SDIP investment strategy focused on sustainable food systems as a way of integrating different sectors at a range of scales, and ensuring gender-inclusive planning processes and outcomes. The aim was to promote resilient and inclusive food systems supported by robust institutional arrangements, policies and strategic regional planning. The specific ACIAR SDIP Phase 2 objectives are outlined in Table 1, which also indicates how these objectives relate to end of program targets and the overall SDIP outcomes.

Table 1 ACIAR SDIP Phase 2 objectives, end of program target and alignment with SDIP outcomes

ACIAR SDIP Objective	End of program target	SDIP Outcome
1. Improve collaboration between key partners (regional, national, state) to strengthen understanding of longer-term food systems changes and the implications for food, water and energy security; particularly in the context of gender and climate change.	Key stakeholders (both women and men) in the EGP (including decision-makers) are engaging in regular dialogue with respect to the drivers and trends for regional food security.	Strengthened practices for regional cooperation; Improved regional enabling environment.
2. Increase capacity within district, state and national agencies in the EGP to promote effective institutions for sustainable food systems.	Key agencies (local, state, national) have improved capacity to identify and support institutions that promote inclusive and sustainable food practices (including CASI).	Strengthened practices for regional cooperation; Improved regional enabling environment.
3. Optimise the learning from scaling field level activities and local engagement to promote two-way flow of information for improved field – policy links.	Better links between field level learning and policy levels established	Critical new knowledge generated and used for regional cooperation.
4. Critical knowledge gaps identified, filled and used to support sustainable food systems, and to allow better decision making at a range of scales.	The technical and socio-economic knowledge base with respect to sustainable food systems and practices, including the role of women and men and the impact of climate change, has been strengthened.	Critical new knowledge generated and used for regional cooperation.

The focus of this report is the context for work in the EGP, the approach taken within the ACIAR SDIP program during SDIP Phase 2, and the outputs and impacts associated with the work. The work undertaken in SDIP Phase 1 provided a strong base of farming systems research, partnerships and emerging impacts from which to build the current program of work.

2 Approach

The ACIAR SDIP program focused on maximising agriculture's contributions to food systems, while working towards food, energy and water security in the EGP (Figure 1). In Phase 1, the focus was on understanding local systems, and testing and promoting sustainable and resilient farming systems. In Phase 2, the scope expanded to situate those farming systems in the wider food system, and explore how changes impact on and are constrained by institutional settings and natural resources, both now and under future pathways. This section describes the evolution of ACIAR SDIP (Figure 2) and its current structure (Figure 3). A list of the projects that correspond to the components, and their main focus, is presented in Table 2.

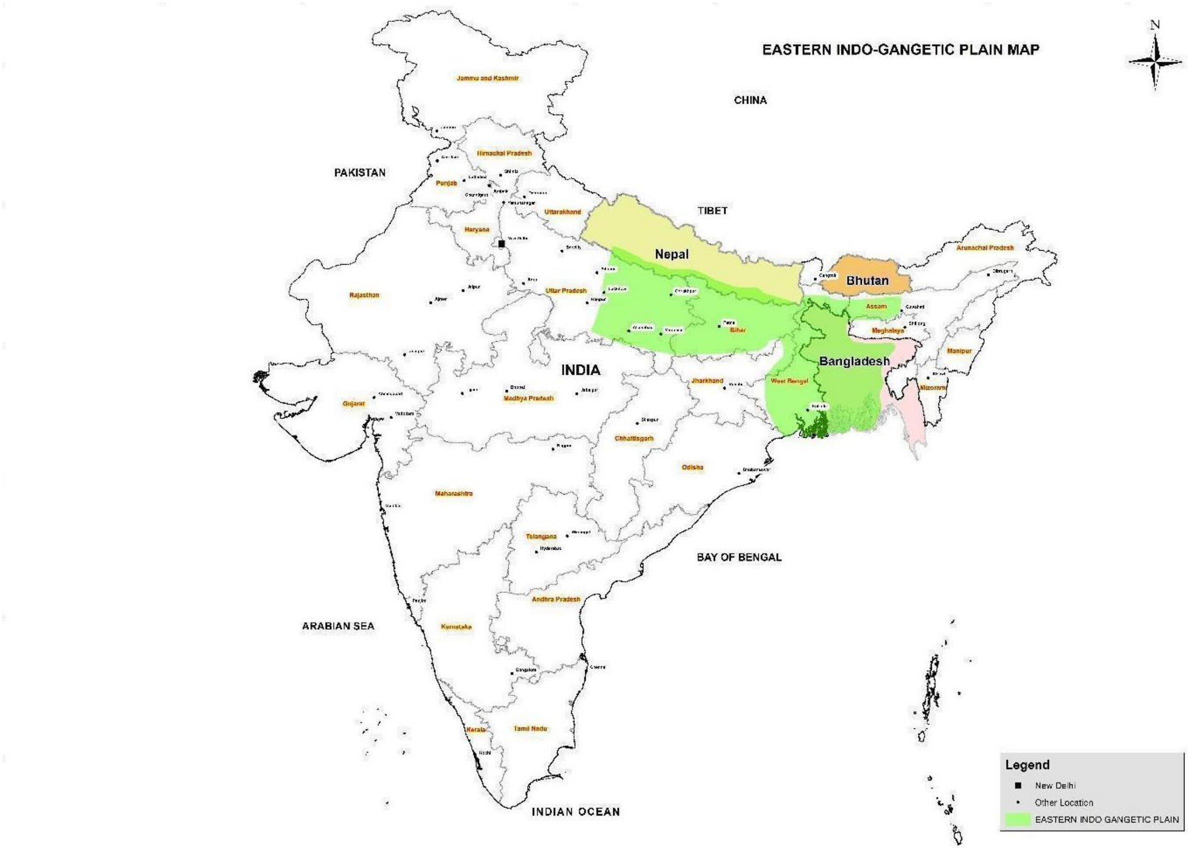

Figure 1 The ACIAR SDIP program focus of the Eastern Gangetic Plains

2.1 A phased approach

The SDIP portfolio was designed in stages, and ACIAR's contributions changed throughout the course of the program, as shown in Figure 2.

Figure 2 The evolution of ACIAR SDIP, 2012 - 2024

ACIAR SDIP Phase 1 (see summary here), consisted of one large project, the Sustainable and Resilient Farming Systems Intensification (SRFSI) project, managed by CIMMYT and involving more than twenty partners from Bangladesh, Bihar and West Bengal (India) and Nepal. This project focused on understanding local systems, demonstrating the contribution of Conservation Agriculture based Sustainable Intensification approaches (together referred to as CASI) to smallholder farming systems, and at the same time exploring the enabling environment that was required to support and scale out these technologies. It worked mainly at the farm and community levels.

The CASI approach is a broader form of Conservation Agriculture (CA) that incorporates agronomic, socio economic and institutional aspects of food production, including more sustainable agroecosystem management, increased input use efficiency and increased biological and economic productivity. These are based on the CA principles of minimising soil disturbance, ensuring soil cover and diversification through rotations – and including use of improved varieties, better irrigation practices and improved crop management techniques. The four pillars of the SRFSI project were farmer participatory technology generation; strong local innovation systems to help overcome value chain bottleneck; enhanced capacity of market and service agents to support farmer innovation, and farmer-to-farmer knowledge exchange. Extensive work was also undertaken in terms of understanding the local context from agro-ecological, socio-economic, institutional and policy angles.

The research and development activities under the project were conducted in eight districts in the EGP: Rajshahi and Rangpur in Bangladesh; Malda and Coochbehar in West Bengal, and Purnea and Madhubani in Bihar, India; and Sunsari and Dhanusha in Nepal. These locations were chosen specifically to test techniques in a range of agro-ecological settings, as well as to enable cross-border comparison of results, and to explore the effects of institutional and policy settings. The project developed activities in 40 locations across eight districts, and then used these activities as training grounds for up-scaling of project methodologies and out-scaling of technologies.

Proof of concept of CASI has been widely published (Dutta et al., 2020; Gathala et al., 2021; Gathala et al., 2020; Islam et al., 2019; Jat et al., 2020), and a summary of the work undertaken in Phase 1 can be found in this Synthesis Report (Jackson et al., 2018). In Phase 2, an extension of SRFSI to September 2021 (despite initially plans to end in 2017) allowed the focus to shift to scaling of project technologies, as well as understanding the science of scaling and the impacts and extent of CASI adoption. Work undertaken within the timeframe of SDIP Phase 2 (i.e. 2018 – 2021) is described in this report, as it formed a key foundation from which to build the other elements of the program, as well as offering locations where other research could be ground-truthed.

In Phase 2, the ACIAR SDIP investment began working with a wider range of stakeholders from policy makers and implementers, including food policy and gender researchers to understand constraints to and impacts of scaling sustainable farming systems. This included deepening understanding of how institutional and social factors, markets and technologies interact to constrain or enable the adoption of sustainable intensification technologies. Additional work explored biophysical constraints such as soil and weed dynamics, and a better understanding of the context for water and energy resources management. The growing challenges of climate change, and the need to promote gender equality by empowering women and girls are themes that were integrated in activities across the program.

2.2 Program structure

In Phase 2, ACIAR SDIP moved to a program approach managed by ACIAR, with 18 projects of various sizes, and working with a range of commissioned organisations from independent consultants to local research and development agencies, and international research organisations. Extending SRFSI allowed us to learn from Phase 1 activities, and maintain a connection to field locations. The ACIAR SDIP program was implemented through five interlinked components (Figure 3). A list of projects that correspond to the components, and their main focus, is found in Table 2.

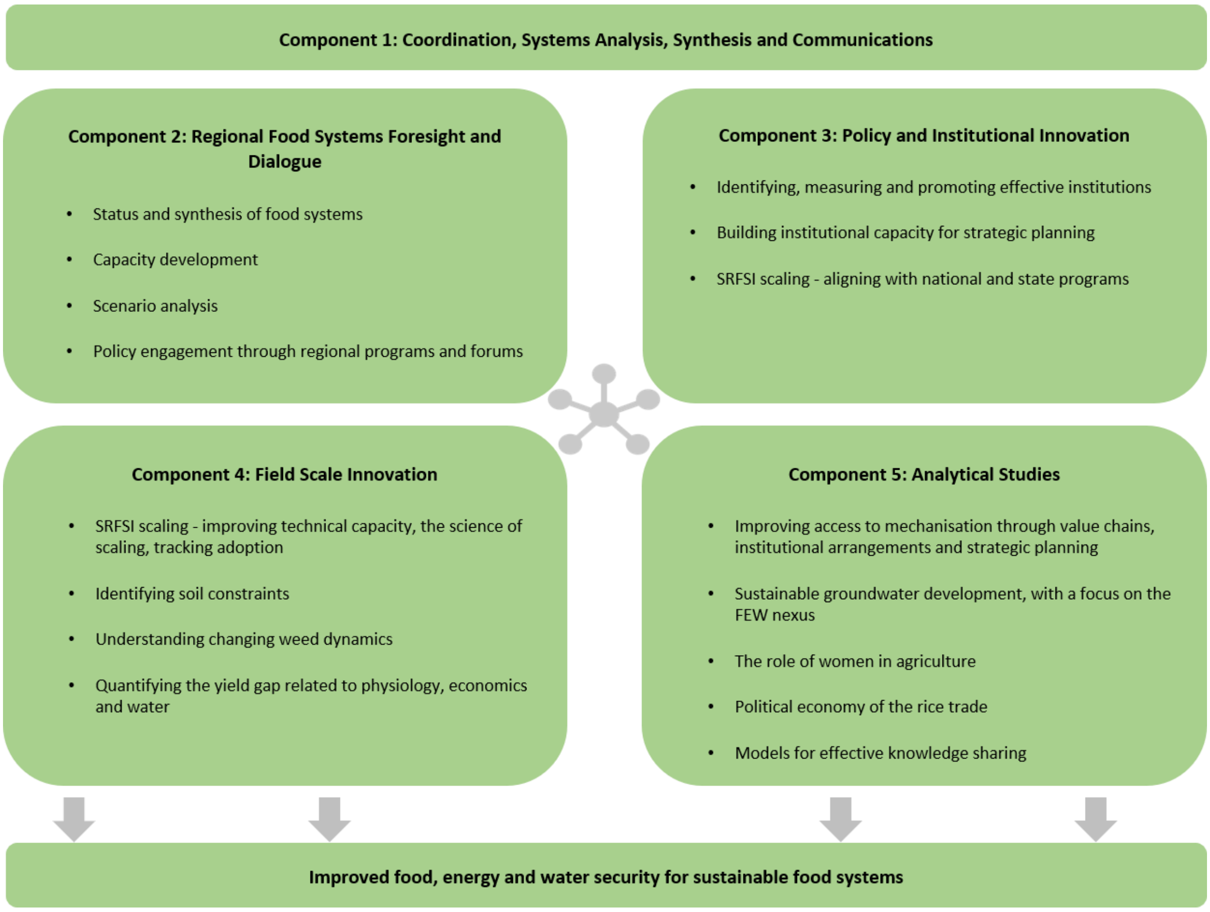

Figure 3 ACIAR SDIP Program Components

The flexible structure of the program allowed the ACIAR team to build a program that addressed issues where ACIAR projects could make a significant contribution to critical knowledge gaps and key policy priorities of partner countries, and respond to emerging issues. This set of complementary activities was designed to integrate local, meso and regional level visions and engagement, to create the enabling conditions for the development and scaling of sustainable and resilient food systems. More information on the planning for Phase 2 can be found in the Implementation Framework and Investment Strategy, which contain more detail about the objectives for the different components.

The five components contributed to the program in the following ways:

1. **Integration and synthesis:** Ensure project activities and outputs are coordinated and communicated for maximum benefit to the end user from farmer to policy level.
2. **Foresight:** Improve collaboration between key regional partners to strengthen understanding of longer-term food systems changes and the implications for food, water and energy security; and identify transformational opportunities, particularly in the context of gender and climate change.
3. **Institutional innovation:** Create a more conducive enabling environment for sustainable food systems by building capacity within district, state and national agencies in the EGP to identify and promote institutions that foster successful intensification, integrated decision making and inclusiveness in agriculture.
4. **Field scale innovation:** Optimise the learning from scaling field scale activities and local engagement to promote two-way flow of information.
5. **Analytical studies:** Fill critical knowledge gaps to support the development of an enabling environment, and to allow better decision making.

Table 2 List of projects in ACIAR SDIP Phase 2

Component	**Project**	**Commissioned Organisation**
Foresight	Foresight for sustainable food systems in the EGP (WAC/2018/168; WAC/2019/136; WAC/2020/158)	IFPRI
Policy & Institutional innovation	Institutions to support intensification, integrated decision making and inclusiveness in agriculture in the East Gangetic Plain (LWR/2018/104)	University of South Australia
	Sustainable Agricultural Mechanisation in the EGP: Facilitating change through institutional innovation (WAC/2018/220) "Roadmaps"	CIMMYT
Field scale innovation	Sustainable and Resilient Farming Systems Intensification – Variation 4 & 5 Learning from scaling (CSE/2011/077)	CIMMYT
	Quantifying crop yield gaps across the IGP from new perspectives – production, farmer profit and sustainability of water use (WAC/2018/169)	CSIRO
	Understanding the gendered implications of changing weed dynamics in farming systems intensification in the Eastern Gangetic Plains (WAC/208/221)	CIMMYT
	Identifying Eastern Gangetic Plains Soil Constraints (CROP/2018/210)	University of Queensland
Analytical Studies – Context for Development	Understanding women's role in agriculture in the EGP: The macro and micro connections	SACIWATERs
	Political economy analysis of cross border agricultural trade in Bangladesh, India and Nepal	The Asia Foundation

Analytical Studies – Scaling Mechanisation	Value chain and policy interventions to accelerate adoption of zero tillage in rice-wheat farming systems across the Indo-Gangetic Plains (CSE/2017/101)	University of Adelaide
	Pilot project on commercialisation of the Virtual Multi-Crop Planter in Bangladesh (LWR/2018/111)	Murdoch University
Analytical Studies – Sustainable Groundwater Development	Regional scale water impacts (WAC/2019/104)	CSIRO
	Unravelling the WEF nexus in WB, India. Does increased access to groundwater irrigation through electricity reforms affect equity and sustainability outcomes? (WAC/2019/151)	IWMI
	Role of groundwater in agrarian change in West Bengal and Bangladesh: A comparative analysis	IWMI
	Aquifer characterisation, artificial recharge and reuse of suddenly available water in south Bihar (WAC/2018/211)	Nalanda University
Analytical Studies – Knowledge Sharing Mechanisms	Farmers' Hubs as a vehicle to deliver solutions and services to farming communities (CROP/2020/202)	CSIRO
	Pilot study on knowledge transfer mechanism for effective agriculture extension services in Nepal	Centre for Green Economic Development Nepal

2.3 Cross-cutting research approaches

In collating the wide range of outputs from specific projects, the major themes and methods were mapped into a framework (Figure 4) that shows the links between farming systems and food systems; and the range of cross-cutting themes and research approaches that are covered by the program:

1. Links between sustainable farming systems and food systems, where basic levels of intervention at the field and community level are centred around conservation agriculture, mechanisation and groundwater. Foresight approaches provide an overarching method for synthesis and dialogue;
2. Underpinned by cross cutting research approaches including working at multiple scales and locations; multi-stakeholder engagement; capacity building; and with the ultimate aim of scaling;
3. Cross cutting themes of gender, the Food – Energy – Water nexus, institutions, climate change, knowledge sharing mechanisms.

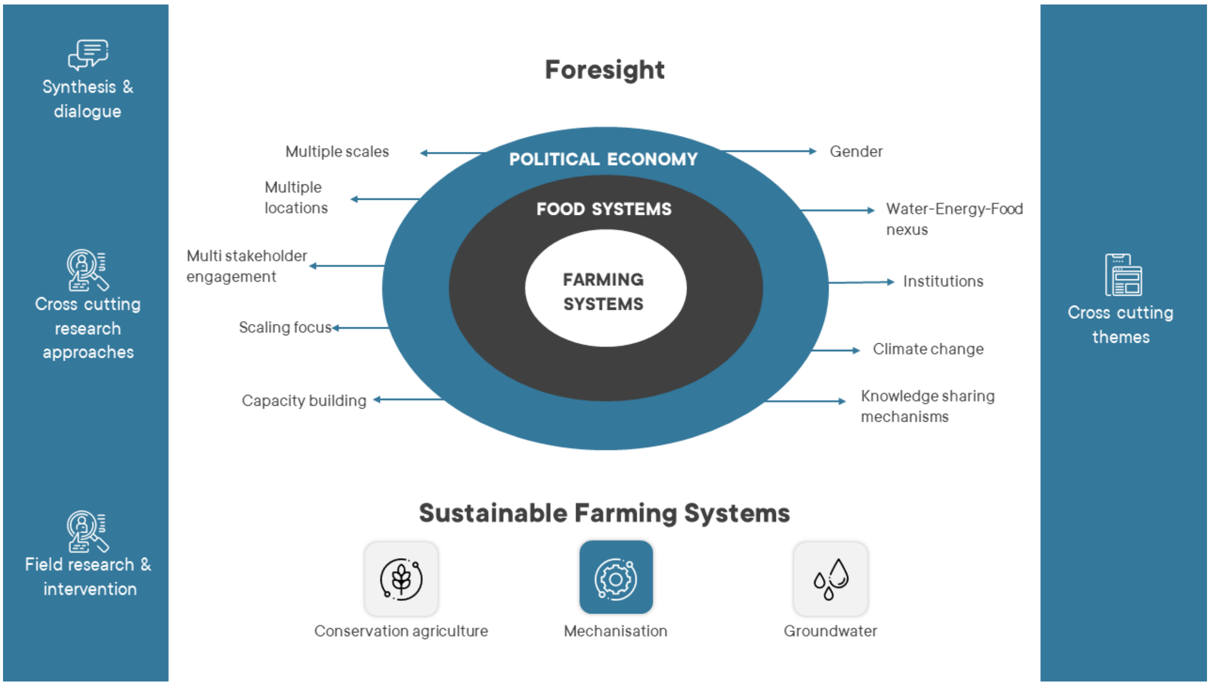

Figure 4 ACIAR SDIP Framework showing cross-cutting research approaches and cross-cutting themes

3 Food systems in the EGP

Part of the work of ACIAR SDIP has been to explore the context for and links between farming and food systems in the EGP, to understand the various factors that influence agricultural development, from farm to country levels. This section is drawn from the work of multiple projects within ACIAR SDIP, and provides a comprehensive snapshot of food systems in the region.

3.1 Agricultural systems

Agricultural systems in the EGP are dominated by a single rain-fed rice crop in the kharif (monsoon) season, although it is possible for two kharif crops to be produced (i.e. kharif 1 and 2). The rain-fed kharif crop(s) are followed by a crop in the rabi (dry, winter) season when farmers have access to irrigation or residual soil moisture. The main cropping systems differ by location, but are traditionally rice-rice and rice-wheat, with rice-maize a relatively new system in most areas. The kharif crop is central to household food security in a region where most farming households operate at subsistence level.

Rabi (winter) crops in the study areas include wheat, maize, mustard, pulses (lentil, mung bean), jute and leafy vegetables depending on the location and water availability. In Bangladesh, tobacco, potato and mustard are other important crops in the rabi season, while rice, maize, jute, vegetables and pulses are grown in kharif. In Bihar, vegetables and potato are planted in the rabi season, with rice, vegetables, maize, mung bean and jute in kharif. In West Bengal mustard, potato, summer rice, maize, pulses, tobacco are planted in the rabi season, with rice, jute, maize and vegetable in kharif. In Nepal, wheat, maize, lentils, vegetables and potato are planted in the rabi season, with rice, maize, mung bean and vegetables in kharif.

Cropping intensity is highly variable across the EGP, ranging from 180 – 247% at the district level. This is coupled with low productivity and limited diversification due to a range of interacting factors including limited market access; sparse agricultural knowledge and service networks; and inadequate development of water resources (whether due to physical infrastructure or economic barriers to pumping). Mechanisation is similarly limited to mostly diesel irrigation pumps, and 2- and 4-wheel tractors for farm operations. There is thus, significant scope to improve the sustainable productivity of these systems using appropriate technology and institutional settings, such as the CASI systems tested in the SRFSI project.

CASI can improve productivity and profitability in the kharif season through the use of improved seed of appropriate varieties, mechanised crop establishment techniques for rice (mechanical transplanting and drill seeding), elimination of the traditional puddling operation, and better irrigation and fertilizer management. The rabi season is where CASI approaches can potentially have the biggest impact in terms of water savings and increased profitability, and where opportunities for diversification are ecologically more feasible and more likely to be accepted by local communities.

Considering the entire cropping system as opposed to each singular crop is vital from a food-energy-water perspective, as there are residual effects (both positive and negative) from changes made in one season on subsequent crops. For example, minimizing or eliminating tillage and maintaining crop residue as per CASI principals builds soil carbon and improves soil structure which improves water holding capacity of soil; fertilizer applied on a rabi maize crop often has a positive effect on the yield of the subsequent rice crop; planting pulses and legumes provides nitrogen for a following crop. From a FEW perspective, the biggest benefits from wide-scale implementation of CASI are likely to be through improved water use efficiency for rabi rice; the replacement of rabi rice with a lower water use and higher productivity crop like maize; expansion of rabi crop production through improved access and management of irrigation; and/or the ability to intensify with a third crop in between kharif and rabi seasons. All of these options improve water and energy efficiency at the farm level, while at the same time improving system productivity and profitability.

3.2 Socio-economic settings

The socioeconomic make-up of the EGP is complex, with a range of agro-ecological systems, livelihood strategies, farm sizes and tenure types, and access to technologies and institutions. The historical co-evolution of farming systems and agrarian socioeconomic structures has differentiated states and nations out of what was originally one Bengali region. Famine and food insecurity which have featured for centuries in the EGP region, have shaped the contours of the EGP's modern jurisdictions and are deeply ingrained on the psyche of farmers and policymakers. Food security is entangled with caste and tribal identities and their relative socioeconomic status within (rapidly eroding) strict social hierarchies. Regional differences are exacerbated by competition for energy, water resources, investment and market access. The EGP jurisdictions are in varying degrees of transition from feudal, agrarian socioeconomic structures, and of integration into the global economy.

The region, in which some 450 million people live, features the world's highest concentration of rural poverty which is interwoven with the social structures of class, caste and gender. The EGP remains strongly dependent on agriculture, and landholding size is small even by South Asian standards. Average land size is just 0.6 ha, and this is often both highly fragmented and tightly held. Property rights are poorly defined in most parts of the region, including laws related to share cropping. Most farmers are classified as marginal or subsistence level farmers. The major share of household income comes from cereal production (rice and wheat), and income tends to be spent on food and farming. Access to markets is variable, with physical proximity to market sites ranging from 5 – 60km from the household. Some locations are linked to national markets via private sector initiatives, and in these locations farmers benefit greatly from these links. While the biophysical landscape is similar in terms of the extensive lowland alluvial plains, there are notable differences for example in soil quality which impact productivity. Importantly from an intensification angle, access to irrigation is highly variable.

Credit availability is a long-standing issue within the EGP. Although there are financial institutions in all areas under the study, the ability of a farmer to access credit is highly variable. Due to limited public services in the EGP, most farmers depend almost entirely on the private sector to secure agricultural inputs and access markets for their farm produce. The EGP is a difficult environment for more formal medium and large-scale businesses; profitability is generally low, with farmers having small input requirements, low purchasing power and small marketable surplus. Generalised infrastructure is poor, the region has low rates of urbanization, and it is distant from major urban markets and ports. Poor connectivity (roads, power, credit, markets) increases inefficiency and decreases profitability. The cost of doing business in the EGP is thus high for the private sector which is dominated by small, informal and unorganized local businesses with limited reach among consumers, limited capital, and little value-adding capacity.

Widespread male circular and overseas labour migration is a common strategy to diversify household income. Such change inevitably alters gender relations, as the everyday decision-making that farming women who are left behind are forced to take over, incrementally loosens patriarchal social structures. Although the 'feminisation' of agriculture is not universal in the EGP, it is a notable trend in some parts, with the average incidence of female headed households ranging from 13 – 19%. Feminisation in Nepal and Bangladesh is consistent with expected trends, but defeminisation appears to be occurring in Bihar and West Bengal. This could be related to several factors, including higher levels of unemployment, lack of jobs and increased remittances. Within the household, women reported spending 50-60% of their time on household activities, with the remainder engaged in farming, livestock and leisure activities. Throughout the region population growth is high, and there is a large youth population.

The information in this section is taken from Brown et al. (2020) and Jackson et al. (2018), where work undertaken in Phase 1 of the SRFSI project was synthesised.

3.3 Geo-political economy

The EGP countries of Bangladesh, India, and Nepal all have overarching agricultural development strategies which aim to improve the incomes of smallholder farmers, improve profitability, and achieve sustainable resource use. Agriculture employs 38% of the total population in Bangladesh, 41% in India, and 65% in Nepal while its contribution to the GDP of the three countries is only 13%, 16% and 24% respectively. The income gap between those engaged in the farming and the non-farming sector has increased rapidly in South Asia. Most farmers in the EGP cannot earn a living income from their small and shrinking landholdings if they rely on growing food grains only. Nor can grain agriculture gainfully employ the rapidly growing numbers of working-age people. Various strategies have been developed to address these problems.

3.3.1 Bangladesh

Bangladesh emerged as a nation in the early 1970s as a result of a war of independence from west Pakistan and was immediately plunged into famine. Market liberalisation policies under structural adjustment settings throughout the 1980s helped the new nation to kickstart a Green Revolution in the 1990s that achieved national food grain self-sufficiency by 1995. Agriculture is a central subject in Bangladesh, with policy formulation and funding to provinces disbursed by the central government. It remains one of the most important sectors of the Bangladeshi economy, contributing 13% to the national gross domestic product in 2019, although remittances from international labour migrants are just as significant. Trade liberalization and a focus on infrastructure, for example the Jamuna bridge connecting the north to the south, helped agriculture to thrive and grow with cheaper water pumps and machinery. There is significant donor funding to this sector which has influenced the Government of Bangladesh's 's policies towards agriculture. A focus on achieving national food security, and significant and regular climate shocks brought about a degree of protecting farmers and agriculture over the last two decades through state interventions like subsidies (Islam, 2014). Currently, about 45.1% of the labour force is engaged in agriculture, but significant seasonal labourer scarcity and increasing labour wages have led to increasing production costs.

The Bangladesh Agriculture Development Strategy, developed as a part of the 8th Five Year Plan (2020-2025), describes the major strategies for agriculture as being diversification of agricultural production with high value crops, strengthening supply channels, and ensuring credit for smallholder farmers. It is critical that smallholders aggregate to form links with domestic and international markets. There is a need for institutional innovations and research which is inclusive and responds to research that enable smallholders to increase their incomes while maintaining resource sustainability, particularly in terms of water resources.

3.3.2 India: Bihar and West Bengal

The key strategy for India which guides agricultural development and research is the policy of *Doubling Farmers Income by 2020* (NITI Aayog; equivalent of the Planning Commission). The need for transformational change in food systems is to meet the challenges of sustaining food and nutrition security, adaptation and mitigation of climate change, and sustainable use of critical resources such as water, energy, and land. A new vision for agriculture is required, with a focus on production efficiency and employment generation, climate change adaptation and sustainability. Suitable policy interventions, regulations and reforms are needed to support the new vision. It is likely that they would include a shift in emphasis from food security to nutrition and health security; and from input intensive to knowledge intensive systems (Ramesh Chand, NITI Aayog, personal communication 2020).

Agriculture is a state subject in India. The Central Government makes policies and provides 40 - 60 % of funds, which are matched by the states in what can be called cooperative federalism. Several large policies like RKVY, National Food Security Mission and Bringing Green Revolution to East India (BGREI) can be modified by the states into programs which suit their constituent farmers' requirements.

Subsidies on fertilizer, electricity, Minimum Price Support (MSP) and insurance use a major chunk of the central budget leaving very little for investments in irrigation, processing and storage (Bathla & Hussain, 2021). A major change in the way the government relates to farmers is underway in India. Nearly 50% of the

Government of India's Agriculture budget is spent on an income support program where landowners receive a direct cash transfer of Rs. 6,000/year irrespective of their holding size. State and central governments are also switching to cash transfer of other subsidies, but not fertilizers or energy yet. The income support program has not replaced the existing subsidies, it has instead become yet another subsidy. Economists favour cash transfers but only if they replace the existing distortionary subsidies. The increase in total agricultural subsidy is crowding out public investments in R&D, infrastructure, and other forms of capital formation in agriculture. On the positive side, the system to ensure a smooth transfer of cash to millions of landholders has created a platform to promote digital agriculture in India and may even be used to promote e-commerce in rural regions.

The terms of trade for farmers in India have worsened in recent years (Himanshu, 2019). This is true for all of India but even more so for Bihar and West Bengal, because most of the farmers in these two states do not benefit from high electricity subsidies and assured output prices - the Minimum Support Price (MSP) scheme - unlike their neighbours in the states of Odisha, Chhattisgarh, and much of the north west.

3.3.3 Nepal

There have been years of political instability in Nepal at the federal level, with frequent changes in ruling coalitions and Prime Ministers. This instability has hampered cohesive long-term planning and implementation of supporting policies, which is important for developing sustainable food systems. The second major issue is the change in the structure of governance in recent years, from a centralized system to a federal one with a three-tier governance structure. There is a lot of confusion on how different units will coordinate vertically (local-provincial-federal) and horizontally (between provinces). Coordination is essential for the management of shared resources such as water, and agricultural market systems. There is also a lack of clarity on how to reconfigure the agricultural knowledge and extension system. Added to this is the challenge of low state capacity (Dahal et al., 2020).

A further major challenge for Nepal is that its government(s) have fewer degrees of freedom when devising agricultural policies because of the long, open border with India that provides unfair competition for input and output markets. Inputs are expensive in Nepal compared to India and productivity is low, but Nepali farmers have to compete with their heavily subsidized and more productive Indian neighbours in the output markets. Input markets are similarly influenced; for example, Nepal cannot subsidize all the Urea its farmers need or use because of limited budgetary resources. But nor can it do away with subsidies; when the Government of Nepal abolished fertilizer subsidies for more than a decade under an ADB program, it did not work. Nepal's fertilizer companies cannot compete with the cheaper Urea smuggled in from India in large quantities. This unfair competition limits Nepali farmers' incentives for intensification of farming, especially, of staples like rice and wheat that India grows in large quantities. As a result, Nepal's imports of rice and wheat are rising rapidly.

3.3.4 Trade in South Asia

The formal food trade in Bangladesh, India and Nepal (BIN) is much smaller than the neighbouring ASEAN countries (Ajmani et al., 2019). Both food exports and imports of the three countries are small relative to their agricultural GDP. The food trade is not only small in value, but also highly vulnerable to domestic and international price shocks, weather events and swings in international relations. Both tariff and non-tariff barriers in BIN have led to their low trade openness. The policy quest for self-sufficiency in the production of rice and wheat (and other food items like pulses and sugar), even at the cost of resource depletion, is partly responsible for low values of food imports. Poorly developed value-chains, weak infrastructure, and low food safety standards limit export potential. Ad hoc export bans to protect consumers from episodes of spikes in food prices are also responsible for underdeveloped food exports in BIN. Greater trade openness in South Asia can benefit both farmers and consumers and help agriculture in the region become environmentally more sustainable by permitting production to take place in regions most suited to it. Farmers benefit from trade through specialization, increase in efficiency and technology transfer and knowledge spillover while the consumers get access to a larger variety of better-quality food items available at more affordable prices (Ajmani et al., 2019).

An example of the above is the trade of rice, as explored by The Asia Foundation in a small research project (Pillai & Prasai, 2018). The trade of rice across the political boundaries of South Asia is centuries old, and while the formal institutions that support and mediate this trade have transformed with the emergence of the modern state, the essential practices that undergird them retain a familiar shape. Relationships between the farmer and aggregator of rice, the cycles of informal capital that dictate production and the political importance of the grain in stability of the state are as central to the politics of rice in the region today as they were in the 17th century. The key institutional practices of rice trade between India, Bangladesh and Nepal were identified, and the salient political economy motives that drive it explored.

Much of this report deals with Indian institutions because India is the largest producer, consumer and exporter in the region. The social complexities of India's rice markets are equally important because of its position as the largest rice exporter in the world, reaching around 140 countries each year. Trade volume drivers are sudden and significant fluctuations in volumes from year-to-year are common. These are caused by climate related events such as floods or droughts, short-term fluctuations in currency values or political disturbances that lead to changes in import tariffs in Bangladesh or Nepal, the two net importers in the region. Rice trade policy in South Asia should be seen as a safety valve for domestic markets, serving as an instrument to stabilize domestic prices. However, fears of scarcity lead to the erection of export barriers, just as spikes in wholesale prices facilitate imports. Trade plays a crucial function in cushioning the price volatility induced by increasingly unpredictable weather, particularly precipitation, in the region. Untimely bursts of rain or multi- year dry spells that disrupt paddy output in the region and beyond are balanced by large surpluses in India. This adaptive aspect places a renewed emphasis on developing smoother systems for trade, particularly at the borders where several forms of distortions tend to undercut the desired predictability and efficiency in trade practice.

Just as trade has the potential to fill supply gaps and stabilize consumer prices across in import markets, it can also in theory have a positive impact on farm incomes by reducing glut and expanding markets. It was found, however, that sub-regional trade between India, Bangladesh and Nepal does not produce such an impact. There are two main reasons for this counter-intuitive reality. First, all intermediary marketing functions between on-site collection of produce at the farms and delivery of consignments across the border are, in effect, run by businesses functioning in competitive landscapes, where capital accumulated can yield exponentially higher growth. These intermediaries, such as the aggregators of paddy, have entrenched financial and social relationships with farmers that allow them to extract favourable terms of purchase and employ capital in profitable informal banking ventures to farmers. This mechanism prevents a fair share of the marketing revenue from reaching the farmer. Second, the millers of Indian rice, who themselves often operate as aggregators, both usurp windfall profits and absorb hits on the margin without either of these effects reaching the farms in full measure. For exports to play a significant role in increasing farmer incomes, a new type of regulatory thinking that recognizes the incentives and vulnerabilities of each layer of intermediation before acting upon them is required.

In considering the food-energy-water nexus, food exports also contain embedded water and energy. Rather than focus on exports, policies to regulate the amount of embedded water in rice exports must begin with decentralized technology, systems and incentives that reduce the water intensity of rice production in general. The theoretical appeal of virtual water export curtailment through "sustainable" input pricing also crumbles when one begins to imagine the political backlash in a country where the core of politics is still the farm. Any change in input prices, subsidies, and access to free water either thins margins further or impacts the output.

Improved trade facilitation matters. The domestic production, processing and pricing of rice in the sub-region have tentacles in difficult domains of public policy where change is often difficult to drive. In this landscape, resolving some of the most nagging problems of cross-border trade actually appears more achievable. Problems such as lack of port-level infrastructure or inadequate digitization of procedures and approvals or a lack of mutual recognition agreements can be resolved with additional allocations of budget, a couple of rounds of staff training and a few administrative changes. Although more difficult to implement, bilaterally negotiated, stable import tariffs (particularly in the case of India-Bangladesh trade) would go a long way in making demand signals for exporters and millers more reliable. Slight improvements in internal governance and accountability standards of border agencies can begin to undercut a thriving world of syndicates and cartels that operate cross-border trade and transit services. The net effect of these trade facilitation measures has the theoretical potential to impact consumer prices directly and significantly.

3.4 Major drivers of food systems

The status reports on major trends of the food system of the EGP, encourage a better understanding of the current status, future challenges, research and knowledge gaps. These reports form part of the Foresight for Food Systems work in the EGP (more details in Section 5), which is a project laying the groundwork for an open, scientifically informed and participatory foresight for food exercise. The reports have been summarised to highlight the important trends in the EGP which in turn are impacting its food systems. These trends are acting collectively to shape and effect the food systems in the region. The Foresight status brief reports can be accessed here.

3.4.1 Water

The major features that influence agricultural water use in the EGP are:

1. Alluvial deep plains with rich reserves of groundwater fed by ephemeral to seasonal, and sometimes perennial streams and rivers of the river Ganga.
2. Near to absent systems of reliable surface water irrigation.
3. High dependence on irrigation through groundwater for basic livelihoods.
4. Problems with accessibility for many households due to socio-economic factors.

Energy Irrigation Nexus

States of India in the EGP have rich and stable groundwater endowments. Though physically abundant, groundwater is economically scarce (for more details please see Sections 4.3.3 and 7.1). The high cost of irrigation makes farmers under-irrigate their crops resulting in low yields, low cropping intensities, high vulnerability to droughts and terminal heat, and lower profit margins. Groundwater irrigation is expensive in the region because it has been dependent almost entirely on diesel pumps. Diesel is more expensive than grid electricity, and diesel pump-sets are significantly less energy efficient. The majority of farmers rely on pump rental markets for irrigating their crops. Irrigation with rented pumps is significantly more expensive because rental markets are not competitive. The high cost of access to irrigation disproportionately affects marginal and Scheduled Caste (SC) farmers. Although there have been policy changes to reducing barriers of electricity connections for irrigation, these systems are also being manipulated for capital gain at the expense of the small holder farmer. Full report can be found here.

Groundwater Quality

Groundwater contamination is rife and the widespread presence of arsenic, and other emerging contaminants, such as fluoride, iron, manganese, chromium and uranium are threatening the status quo of irrigation and livelihoods. Diarrhoea and viral contamination are also widespread, due to poor sanitation and hygiene combined with a high dependence on drinking from shallow groundwater sources contaminated by toilet pits.

The majority of usage of groundwater in rural areas of the EGP region is for irrigation and is a primary cause of the geogenic water contaminants crises related both to arsenic and salinity. This combination is estimated to affect 60% of the area in the Indo Gangetic Plains (MacDonald et al., 2016). The mechanisms by which geogenic contaminants are released into aquifers are quite closely related to the manner in which groundwater is used through tubewells. Groundwater pumping can increase arsenic levels due to over pumping over clay layers releasing arsenic from deeper aquifers. Water table fluctuations from summer to monsoon is also responsible for arsenic release. Fluoride contamination is also seen with increased groundwater exploitation through tubewells but is dependent upon the type of geology in the region. High iron concentrations in the groundwater are also locale dependent. Pesticides, herbicides, the use of agricultural chemicals and industrial chromium are also contributing to groundwater contamination.

Alarm over contaminants such as arsenic in rice or contaminants in the food chain could significantly affect the region's agricultural economy. Investigations are required to determine whether better control over irrigation could reduce the problem of contaminants. Testing this needs a strong convergence across sectors, and policy support. The highly sensitive linkage between groundwater-based livelihoods and contamination also means that policies need a balance between minimising impacts to livelihoods while reducing public health risks.

3.4.2 Climate Change

There is a clear consensus across the literature that the impact of projected climate change on agricultural productivity in the EGP will be overwhelmingly negative and crop yields (especially grains) are likely to fall. This could have potentially serious repercussions for the maintenance of food security and millions of rural livelihoods. The most critical threat in the short to medium term will be the increase in year-on-year climate variability including changes to the frequency and intensity of extreme weather events (particularly heat extremes, droughts and intense rainfall events). In the longer term the expected changes to mean temperatures and seasonal water availability are likely to make existing cropping regimes unviable and may necessitate a move out of agriculture for millions of people, especially if warming exceeds 2.5-3°C. Full report can be found here.

3.4.3 Food Trade

There is significant informal, undocumented trade across the 1,751 km long open border between India and Nepal and the 4097 km porous Bangladesh-India border. However, reliable estimates of the volume and the value of the informal food trade are not available. Food exports of Bangladesh, India and Nepal (BIN) grew rapidly in the early 2000s and have stagnated or declined in recent years. Food imports of all three countries are however growing rapidly at a compound annual growth rate of more than 10%. India runs a trade surplus in food trade while Bangladesh and Nepal have rapidly growing trade deficits which have increased 5-6 times in real terms over the last 15 years. India is a large exporter of rice, animals and animal products while fish and fish products are the main exports of Bangladesh. Nepal's main food exports are now coffee, tea and spices. Palm oil is the largest import of Bangladesh and India while in recent years, cereals (rice and wheat) have become the largest imports of Nepal.

. Both tariff and non-tariff barriers in BIN have led to low trade openness. The policy quest for self-sufficiency in the production of rice and wheat (and other food items like pulses and sugar), even at the cost of resource depletion, is partly responsible for the low values of food imports. Poorly developed value-chains, weak infrastructure, and low food safety standards limit the export potential. Ad hoc export bans to protect consumers from episodes of spikes in food prices are also responsible for underdeveloped food exports in BIN. Greater trade openness in South Asia could benefit both farmers and consumers and help agriculture in the region become environmentally more sustainable by permitting production to take place in regions most suited to it. Farmers benefit from trade through access to larger markets, specialisation in production, increases in efficiencies and economies of scale and technology transfer and knowledge spillover while the consumers get access to a larger variety of better-quality food items available at more affordable prices. Full report can be found here.

ASEAN, SAARC and China in the Food System

ASEAN (Association of Southeast Asian Nations) and SAARC (South Asian Association for Regional Cooperation) are two of the largest trading blocks in Asia, with a combined population of 2.4 billion (2016). Openness in food trade is desirable as it allows access to larger markets, creates opportunities for specialisation in production, and creates gains from economies of scale, technology transfers, and knowledge spill over. An assessment of trade between and within SAARC and ASEAN countries and China, reported that most country-pairs under-export. Overall, wherever there is under-exporting in food products, SAARC countries tend to be under-exporting to a greater degree than ASEAN countries.

A country may over-trade with its potential partners due to its weak economic fundamentals which determine trade. Relatively weak economic characteristics such as domestic infrastructure and an unfavourable investment climate may predict a lower trade level, resulting in countries over-exporting. Over-exporting may highlight the importance of focusing on policies that enhance the trade potential of the country. Where countries under-trading, countries exports could be increased by focusing on their competitive commodities with high export potential in foreign markets. Tariff levels on food products are much higher in South Asian countries relative to ASEAN countries, making access to South Asian markets more difficult.

The high level of informal trade within this region provides indirect evidence of the significant trade potential between the countries. It is estimated that informal trade among South Asian countries is 50 percent of their formal trade. Factors which prompt informal trade include higher tariffs, stringent Non Tariff Measures, distorted domestic policies, and non-economic and institutional factors. Another unobservable factor is trust. Lack of trust between the countries can severely affect their bilateral trade flows. Trust between South Asian economies is described as fragile because of their complicated history, conflicts, and size asymmetry, which prevent them from reaping the full economic benefits of geographical proximity and complementary resource endowments. Full report can be found here.

3.4.4 Credit

Credit plays a vital role in agricultural development. It enables farmers to undertake new investments and adopt improved technologies. In the EGP, farm households borrow money for agriculture as well as to meet basic household needs. Access to credit enhances the risk-bearing ability of farmers and acts as a catalyst to break the cycle of poverty in rural areas. Realising the importance of credit in promoting agricultural growth and development, agricultural credit policies within the EGP have sought to expand the outreach of institutional credit by replacing traditional money lenders with formal institutions such as cooperatives, commercial banks, and rural development banks.

The experience of farmers in the region, the majority of whom are smallholders, suggests that the extent of financial inclusion varies greatly and only a small proportion of agricultural households are able to access institutional credit, with poor families lacking collateral or guarantors often excluded. Deliberate delays in the disbursement of loans, long paperwork, demand for bribes and opaque procedures are common problems farmers face when borrowing money from banks. The relationship between land size and access to formal credit is positive. Agricultural households with better resources find their access to formal credit systems relatively easier compared to households with fewer resources. Non-institutional sources of credit tend to charge exorbitantly high interest rates and are frequently considered exploitative. Full report can be found here.

3.4.5 Migration

Throughout the EGP, labour out-migration (generally male) to better remunerated urban labour-markets, is an important livelihood strategy for the rural poor. It provides supplemental income which is pivotal to agricultural household security. This circular and seasonal migration pattern tends to entrench subsistence agriculture, as the additional income is generally spent on consumer goods, health care and schooling, rather than investment. Remittances from international migrants contribute significantly to national economies. Male out-migration results in farm labour shortages, increasing the cost of employing labourers, and the demand for labour-saving farm machinery. Significant seasonal agricultural labourer scarcity and increasing wages have led to rising production costs and food prices. Male migration has also undermined the functioning of many irrigation management institutions, and persisting limitations on women’s engagement has failed to counterbalance these changes (Brown et al., 2020). The impacts of the Covid-19 crisis on migration are being explored and will be reported separately.

3.4.6 Gender relations

Widespread male migration inevitably alters gender relations, as the decision making by women-left -behind, incrementally loosens patriarchal social structures. The increasing participation of women challenges social norms, which could initiate lasting changes in the gender relations observed historically. However, in the last decade, due to an increase of unemployment among men in both rural and urban areas, male migrants have been returning seasonally as cultivators, leading to a decline in the share of women cultivators. In Nepal, where out migration tends to be by young couples rather than by men alone, the burden of increased farm labour falls on older women. As women have historically been required to work agriculturally in Nepal, out-migration is less likely to change social norms despite the farm workload increasing for women.

Women's Labour Force Participation

Women's labour force participation (LFP) in rural India has been consistently low over the past three decades. Women's work is determined by both supply and demand-side factors in rural India. On the supply side, it is affected by socio-cultural norms that reward housework and child-rearing. Working outside the house is considered a social-stigma or a low-status activity. As a result, only the poorest women engage in wage work out of necessity and once family incomes increase, they withdraw from the workforce. On the demand side, factors like gender discrimination in hiring, gender wage gaps, un-safe environment, un-suitable transport/commute, and lack of jobs can result in low female LFP. For more information refer to section 7.2 Women in Agriculture. Full report can be found here.

Rural Women: At Work or Out of Work

Spatial and temporal pluralities exist with respect to gender and work in agriculture across the EGP. The context is derived from the generally accepted view that feminisation of agriculture is typical of most developing countries which primarily stem from male-selective outmigration. The agricultural labour forces of Nepal and Bangladesh reveal positive feminisation trends, but a consistent de-feminisation that cannot be fully explained, has been observed in India (Bihar and West Bengal). A defeminisation process linked with higher levels of unemployment is indicative of distress and is suggestive of displacement from jobs or lack of jobs that women can take up along with the care work. Women's burden of extra-domestic work like collection of water, fuel and fodder has increased over time, with the degradation and privatisation of common property resources. Full report can be found here.

3.4.7 Diet and nutrition

Poor diets are a big reason for persistently high levels of hidden hunger in the EGP. Overall, while there are broad similarities in diets across the region it is important to note that there are significant differences in consumption patterns across different incomes groups. There can also be large intra-household differences in diets of men and women, boys and girls in South Asia, with girls and women having poorer quality diets.

Among whole grains, consumption of coarse cereals is low. EGP is relatively poor even by the South Asian standards and cereal consumption is high in poor households worldwide. High subsidies on rice and wheat through the public distribution system in India and active management of rice prices in Bangladesh and Nepal at low levels, have also contributed to high share of rice and wheat calories in the diets in the region. Consumption of all protein is also significantly low in the EGP. The region under-produces pulses, the most common vegetarian source protein in diets here. Calories from fruits are significantly more expensive than the cereal calories as are calories from processed foods, resulting in their low consumption.

The region has a low consumption of added fats. In addition, most of the fat comes from palm oil which is high in unhealthy saturated fats and low in healthy polyunsaturated fats. Palm oil is the largest food import of both India and Bangladesh and the second largest of Nepal. It is cheaper than other vegetable oils, and cheap imported palm oil from east Asia crowds out the production and consumption of oils in the EGP. Full report can be found here.

4 Foresight for food systems

The Foresight component contributed to Objective 1: *Improve collaboration between key partners to strengthen understanding of longer-term food systems changes and the implications for food, water and energy*. Changes in the agricultural production system, such as those demonstrated by the SRFSI project, need to be understood within a wider context of long-term changes in food systems, in particular economic transformation, a changing climate, altered consumption patterns, trade and issues of nutrition.

Sustainable food systems are those which promote production and consumption of safe and healthy food without compromising the environment. They consider sustainability, health and economic issues from the integration of consumption, distribution and production.

Food systems foresight aims to help to provide a long-range perspective on key drivers and trends in regional and local food systems and the implications for water and energy use. Foresight is a process for bringing greater social and political awareness of these issues and for driving change through engaging key stakeholders and exploring alternative future scenarios and transformation pathways.

In terms of foresight for agriculture, the work has explored how the sector is unfolding, what the key pressures are, and what it may look like in the future under business as usual and other scenarios. This can help to identify preferred transformation pathways for the future of small-scale farming.

4.1 Approach

Working with international, regional, national and local partners to test foresight approaches to understanding the food system at different scales in the EGP, the framework in Figure 5 has been applied within ACIAR SDIP. This follows the steps of:

1. Engaging with relevant actors, and identifying the purpose and motivation for foresight;
2. Understanding the system of analysis;
3. Identifying drivers, trends and uncertainties;
4. Exploring visions and scenarios;
5. Influencing change.

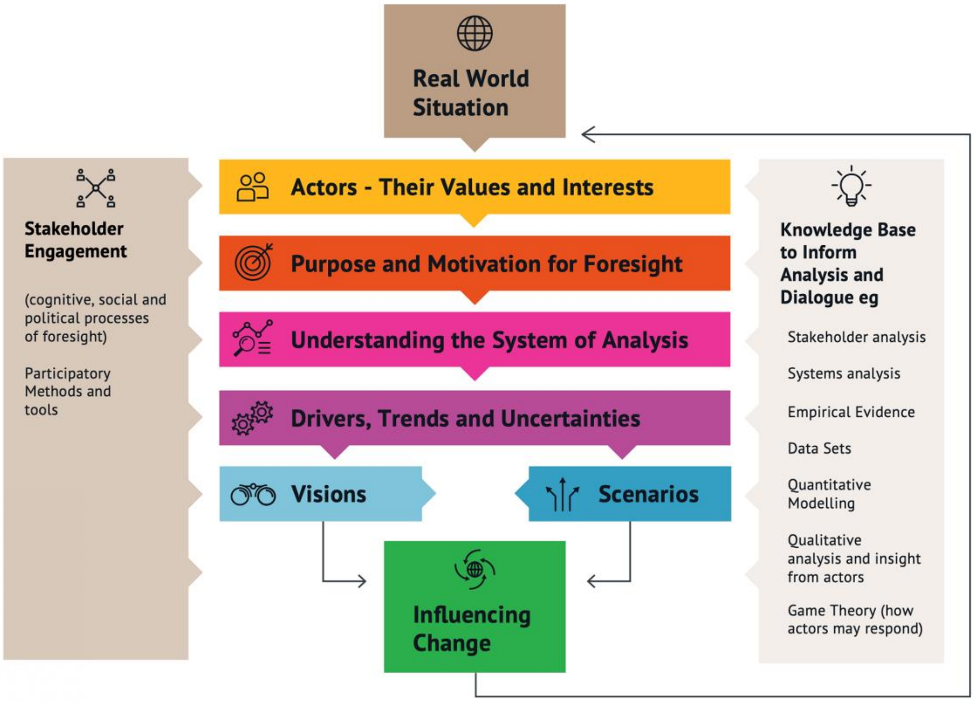

Figure 5 Foresight Framework (Woodhill & Hasnain, 2019).

4.1.1 Engaging with relevant actors and identifying motivation

The first stage of the Foresight work was to engage with relevant actors. A group of researchers, farmer leaders, and policymakers were convened, who were interested in foresight and scenario building exercises for a more sustainable food system. From the outset, participants noted that foresight work should be linked to the wider food system and include bigger donors, the private sector and the people who are making the decisions.

Over a series of workshops in 2018 – 19, more than 200 researchers, planners, policymakers, entrepreneurs, civil society members came together for planning, learning, and information sharing. These workshops helped us build and strengthen a core group that is interested in undertaking foresight for food exercises in the region. The workshops also helped us generate new ideas, gain new perspectives, and disseminate our research findings.

We organized training and capacity building of regional actors to develop a shared understanding of what foresight for food means and how to carry out foresight and scenario building exercises. A participatory learning workshop was held in February 2019, with 47 participants. It was designed as a series of training presentations and participatory exercises in methods for foresight and scenario analysis, using real world examples based on the four focus geographic regions of ACIAR SDIP: Bihar, West Bengal, Nepal (Terai) and Bangladesh. Tools practiced included developing rich pictures, systems diagrams, causal loop diagrams, participatory scenario development and considering the relevance and application of models for foresight analysis. Throughout the workshop, participants worked in regional groups to define a set of foresight activities that could be undertaken at the local level to inform and improve the future of food systems in different parts of the EGP.

Economic transformation in Bangladesh, India, and Nepal offers new opportunities and challenges for smallholder farmers in the region. Some of these opportunities and challenges are predictable and already apparent while many others are not. Whether leveraging the opportunities offered by rapid economic transformation or addressing the new challenges created by it, both require foresight and a systems-oriented approach to research and policymaking.

4.1.2 Understanding the system of analysis: building the evidence base

To commence the Foresight process, country level presentations were given by local partners to show the current situation for food systems, and to identify key drivers of change. This was followed by a session where mind maps were developed at country or province levels (Nepal), considering the key elements of the food system and the links between them. Interestingly, these drivers of change played out differently when they were prioritized in the different locations. Following this meeting, key deliverables were assigned to Foresight partners, including preparation of food systems mapping for India, Nepal and Bangladesh; a series of status briefs; and the need for a centralised repository for regional data and reports related to understanding food systems in the region.

Through a series of workshops, participants explored country level food systems to show the current situation, and to identify key drivers of change. Food systems status reports were produced for each country (e.g. (Subedi et al., 2020)). The key drivers of change in the food system, and the links between them, were identified for each country (province in Nepal) through mind mapping and group discussion. Most of the existing food system mapping exercises focus on nutritional and health outcomes. Our analysis used a food-energy-water nexus lens to understand the food system in the EGP and focused more on sustainable environmental and resource management aspect. The role of women in the region’s food systems and the implications for them if the food system follows different trajectories of change was a core concern for all our analytical work and the workshops we organized in this SRA.

Once a priority list had been agreed as outputs from the first workshops, a set of short Status Reports was developed as background material to support a better understanding of food systems in the EGP. These highlight the key facts, trends and patterns, and gaps in our understanding of the dynamics of these parts of the food system, and are summarised in Section 3.4. As well as the Status Reports, research papers were prepared on a) food trade in EGP countries; b) comparing Indian diets with the EAT-Lancet reference diets; c) demand elasticities of different food items in rural and urban India; and d) farmers' responses to food policies and weather shocks. It is recognised that there is a wealth of information related to food systems in the EGP, but it is scattered and exists at various scales. A key output of this project has been to synthesise and collate relevant information, hosted on the website here.

4.1.3 Visions and scenarios

The Foresight work has intentionally explored visions at different levels and from different stakeholders. It has aligned the work with the priorities of the state/provincial and national governments in the EGP, and their ongoing activities for preparing a vision for the agriculture and food sector for the future and in realizing these visions. It has also undertaken foresight activities at the local level, recognising that there are many opportunities and challenges that are unique to each location, and there are few levers of change at the global or regional level. The agency for change in the food system is at subnational levels, as highlighted by participants in early Foresight meetings.

In a comprehensive training workshop in February 2019, partners worked through the stages of a Foresight process, applying tools and processes to the food system in their respective countries and local settings. At the end of the training workshop, they had identified specific research questions that would be undertaken to explore foresight at the local level, with the intention of understanding and influencing change in local food systems. These exercises aimed to strengthen local capacities for scenario-based foresight exercises through training, mentoring and supporting a learning-by-doing approach. They also helped connect the big picture context with work at the local and regional level where change can happen.

In Nepal, foresight approaches were used as a policy dialogue tool to understand the implementation of agricultural development at a range of local levels: community, municipal, and provincial. Participants have collated and validated secondary data on different aspects of the food system in Province 2, and organized 12 participatory foresight activities with farmers including women and near landless farmers and other stakeholders in different parts of the province. These activities used a food systems framework and scenario building approach. The team also plans to organize a stakeholder dialogue to share their findings with provincial and local level officials and other key actors in the food system of the province, but this is delayed by COVID-19 restrictions.

In West Bengal, foresight will contribute to expanding our understanding of the impacts of CASI for sustainable and equitable rural livelihoods. The UBKV team have worked closely with Dr Sucharita Sen to plan a mixed-methods study in the state. They have prepared interview schedules for primary survey of women and men farmers and protocols for participatory foresight activities with women and youth farmers. The survey instruments and FGD protocols have been validated in the field. They will start the field activities once COVID-19 restrictions are relaxed.

In Bangladesh, the potential for high value crops for a diversified food system will be explored. The BAU team in Bangladesh proposed to explore the potential for high-value crops for a diversified food system using both primary and secondary data, and as the basis for conducting participatory foresight exercises with farmers, researchers and key actors in the food value chain. The collation and analysis of secondary data is being undertaken, and the team has also prepared protocols for participatory foresight activities and key informant interviews. The field activities will start as soon as COVID-19 restrictions are relaxed.

At a national level, IFPRI are using the IMPACT model to assess potential pathways to make healthy diets more affordable in India. Three policy scenarios are being explored: 1) change in tariff and non-tariff restrictions on food trade; 2) change in food policy from distortionary subsidies to non-distortionary cash transfers to farmers and consumers; and 3) change in power tariffs for groundwater irrigation. Besides food prices, IFPRI will also assess the impact of each of these policy changes on farmers' incomes, water use in agriculture, and greenhouse gas (GHG) emissions. They are also using the MAgPIE model to understand the potential impact of changes in power pricing policies for farmers on land and water use, cropping patterns, GHG emissions, and a whole range of economic outcomes. The results will be available in the coming months.

4.1.4 Influencing change

A multifaceted approach to influencing change has been undertaken in the Foresight work. First, participants in the various meetings and workshops have been intentionally targeted from a range of disciplines, sectors, organisations and stages of career development. This has provided rich discussion and understanding of the key issues influencing food systems; and connects to a wide network of actors.

Local level work has been included, recognising that there are many opportunities and challenges that are unique to each location, and there are fewer levers of change at the global or regional level. This is a way of connecting ground level realities and priorities with the wider context of change in the EGP.

For example, at a workshop in July 2019 in Kathmandu, elected leaders, senior officials from provincial and federal governments and participants from the Nepal Agricultural Research Council (NARC), leading think tanks and international organizations joined to discuss ways to capitalise on opportunities created by the federalization of Nepal to build sustainable, inclusive and safe food systems for the country. Participants from across sectors focused on the role of credible knowledge and its extension to women and men farmers to build a sustainable food system. Participants called upon researchers to help build a shared understanding of the challenge before Nepal, and facilitate greater coordination across the three levels of government—local, provincial and federal—for sustainable intensification of agriculture. These priorities have subsequently been incorporated into a small research activity that is looking at ways to coordinate knowledge exchange in two locations of Province 2.

The final stage of work under this program will produce a regional report on foresight for food systems in the EGP region that synthesizes the big picture analysis and the inputs from local level participatory foresight exercises, to share the findings with the policymakers, entrepreneurs and other stakeholders from the region, and connect the work done on foresight for food under SDIP with similar work by other national and international organizations. Planning and envisioning how food systems cope with big expected and unexpected shocks (black swan events) is an important part of foresight for food exercises. The project will also use the COVID-19 experience to explore the impact of a major disruption in the food system.

The Foresight component is linked to a wider global initiative, Foresight4Food, being developed by a group of international organisations, research institutions, business networks and funders. It seeks to improve foresight and scenario analysis for the global food system, including strengthening the links between science and forums for dialogue.

4.1.5 Summary lessons

Foresight processes can create an opportunity for learning by bringing together different views and a breadth of intellectual enquiry that can contribute to the bigger picture of challenges in the region. Integration and synthesis of existing information, coupled with scenario planning can enhance the knowledge-policy interface.

The Foresight work has contributed to the ACIAR SDIP Phase 2 goals of developing a better understanding of the drivers and constraints that affect development of a sustainable food system in South Asia, to ultimately create a more effective enabling environment.

The participatory research process in this project and its outputs will help ACIAR in engaging with policymakers and the private sector in the EGP region in broader discussions about future directions, especially in the context of the food-energy-water nexus. The high-level policy forum on sustainable food systems for the EGP region will offer an excellent opportunity for public diplomacy in the region and create greater visibility for the Australian Government’s efforts to support agricultural research and policymaking in the region.

5 Institutions to support sustainable food systems

The work on institutions has both conceptual and practical elements, where the ultimate aim is to use the conceptual outputs to strengthen and inform on-ground work.

5.1 Identifying effective institutional arrangements for intensification

The *Institutions to support intensification, integrated decision making and inclusiveness in agriculture in the East Gangetic Plains* project, managed by the University of South Australia has identified institutional arrangements that foster (and constrain) intensification, integration and inclusiveness. It focuses on three areas: the institutions for transferring knowledge to farm households; the institutions and activities related to risk mitigation by rural households; and those institutions and practices related to water property rights.

A review of CASI and related development work by Joshi et al. (2017) suggested that there were major opportunities to enhance adoption of alternative farming practices in the EGP through improved institutional settings. But questions remained about what were the 'best' policy/delivery combinations, and whether experts could be engaged to critically review the extant approaches and look for better solutions. In addition, could the 'best' solutions from experts align with those most acceptable to farmers and thus generate win-win outcomes? The purpose of this project was to tackle these questions head-on, but to do so in a way that encouraged the policy communities to be directly engaged. This approach hinged on the interaction with policy communities to generate primary data that could then be transposed to compare with the views of farm households.

To make the overall task manageable, the ambition was to build a set of insights from three related domains covering: (1) knowledge transfer to farmers (2); water rights (defined as access to the benefits of water) for farming households, and (3) risk management for farm households. These three strands of research were also overlapped with an interest in the impacts of institutional design on inclusion, especially for women and tenant farmers. The overall aim of this project was to develop capacity within district, state and national agencies in the EGP to identify and consistently promote institutions that foster the '3 I's' (Intensification; Integrated decision making, and Inclusion).

The project had planned to assemble sets of primary data that would both inform policy-making communities and engage them in a discourse about the current settings. This data would reveal policy/delivery institutional combinations that were most effective and also provide farmer insights into the perceived merits of different combinations. The primary data collection of experts in the policy communities was completed, and analysis consistently highlighted the important role of increased access to inputs as the preferred means of raising and stabilizing farm incomes across the region. In addition, there was strong support for the use of private sector institutions to deliver on this goal, rather than government.

A Delphi study was completed to extract from experts their knowledge of existing institutions that impact rural households' well-being and their key characteristics. Delphi is a structured means of engaging with experts to gather information and ultimately reach consensus. Delphi is usually conducted over several rounds with information provided by experts interrogated by investigators and then put back to experts for validation. These have shaped a Best-Worst Scaling (BWS) survey, which allow a measure of institutional effectiveness to be generated. To match the outputs from experts, the project planned to conduct a similar BWS survey with farmers, to understand how well expert and farmer preferences match.

The onset of COVID19 and the related uncertainty resulted in the main farmer survey instrument being deemed unfeasible in the current environment, regardless of the significant investment in its development. The project team thus sought to develop an alternative methodology, which resulted in analysis of several secondary data sources to meet the other objectives of the project, along with a reduced primary survey focussed on specific topics.

Overall, the findings from the numerous studies support the view that:

- Knowledge transfer to farmers, especially on new technologies, offers promise on multiple fronts. However, its benefits are not universally accessible because of the delivery apparatus, with women particularly disadvantaged but (ironically) having much to gain from better transfer mechanisms (like mobile phones);

- Water access in the region is intimately tied to energy and the incentives for using energy differently. Leveraging diverse preferences around pumping technologies offers promise for further developing groundwater markets and widening water access;
- Policies that are seemingly focussed on risk reduction are producing perverse impacts and require a re-think in terms of how they are rolled out. Additional international support around broadening better governance and financing systems can have important benefits in agriculture.

The project has made significant progress by shaping new thinking amongst the local policy communities about policy and delivery institutions. Leveraging this beyond virtual dialogue would deepen and widen this influence. In addition, the innovative primary data collection from farm households is poised for deployment and, if ultimately sanctioned, will deliver important low-cost, high quality data to sharpen future dialogue.

Across the expert communities that span the EGP, policies focussed on increasing access to inputs are seen as having the greatest prospect of increasing and stabilising farmer incomes. These policies are best supported by actions that involve greater use of the private sector. There is some support for policies that increase access to modern technologies but the delivery mechanisms for these policies are not clear-cut.

Continued strengthening of governance at the State level in West Bengal should be a priority if private investment is to be stimulated. The delivery of irrigation as an input is of itself not a panacea, and a range of accompanying factors need strengthening. Careful attention needs to be paid to the linkages between energy reforms and their impacts on groundwater markets as these can have perverse impacts for the poor. The differences in preferences of some farming groups are material, and policies that favour the preferences of some better-off groups can reinforce inequalities or even make them worse. Overall, the work reinforces the important role of access to inputs and the capacity of the private sector to deliver better outcomes, provided governments take care to avoid establishing perverse incentives.

Subsidies for inputs, like fertilizer, have limited impacts on production and incomes. They are also distortionary and unless well targeted will likely benefit larger, richer farmers disproportionately. Shifting to income transfers as a policy approach has some prima facie merits but the detail of delivery again matters. Unless comprehensive transfer systems are in place that cover all the community there is risk that more transfers will simply accrue to landholders. International funders of agricultural development research might consider broadening their focus to go beyond the farm to achieve better poverty-reducing outcomes. The adoption of new techniques might on average lead to higher farm incomes. Greater attention to the stability of those incomes and the risks of new production techniques is required.

Technology can increase incomes and make them more stable. Focussing on how technologies can specifically address the needs of less advantaged groups can lead to even greater welfare gains than simply looking to increase universal access. Policy communities have made substantial progress in recognising the benefits of greater empowerment of women, but this needs to be matched by efforts to measure and monitor change in the status of women over time. Care also needs to be taken when reviewing data on empowerment – there may be some instances where aggregate improvements in empowerment disguise the welfare impacts on some women.

5.2 Implementing processes for improving institutional effectiveness

Other projects are demonstrating practical approaches to improving institutional effectiveness and building capacity, focusing on multi-stakeholder coordination. The Roadmaps project is working to facilitate the development and implementation of ‘participatory roadmaps’ to create an enabling environment for sustainable agricultural mechanization in Province 1 and 2 of Nepal. Roadmaps has had to build completely new relationships beyond SRFSI which took considerable time and effort. However, these have now been overcome and common visions and declarations have been finalised in both provinces. The project has undertaken establishment meetings, drafted roadmaps, partners have implemented field level interventions, cross border capacity development and contributed to a national symposium on sustainable agricultural mechanisation.

Before Roadmaps, there were no formal linkages or forums for larger cooperatives and various departments within each provincial Ministry of Land Management and Cooperatives (MoLMAC), or between provincial and municipal government stakeholders. Roadmaps has provided a forum to come together and discuss key and emerging issues and a platform for needs of different stakeholders to be communicated. The project has conducted 42 semi structured interviews with Nepali agricultural service providers to understand their business decisions and the viability and perspectives on providing CASI services and an additional 26 service provider interviews were conducted in India and Bangladesh to enable comparison.

In total, more than 30 organisations have participated in activities. Formal roadmaps were drafted to guide future activities and interventions, some of which have begun to be actioned. Technical support was provided to agricultural cooperatives for machinery testing and demonstration, and for analysing subsidy programs for agricultural machinery, which are an important part of agricultural support in South Asia. An exposure visits to Satish Satmile Club, West Bengal was facilitated by CIMMYT to explore their experiences and learn of different business modalities and new learnings related to agricultural mechanization which can be successfully adopted in Province 1. Extension activities included demonstrations in both Rabi and Kharif cropping seasons, although financial support was very limited to ensure buy in from participating partners, with CIMMYT providing primarily technical support. As well, the project developed a Nepali language booklet on how to use a Zero-Till Multicrop Planter . The booklet was displayed and distributed among the participants from the Roadmaps working group of both the provinces. Despite all activities being affected by COVID-19 restrictions, virtual meetings have continued at the request of group members, and this resulted in some activities being implemented in the Kharif season such as the establishment of demonstration sites, and training sessions. work has resulted in new working relationships, wider sensitization to potential mechanization options relevant to Province 1 and 2, and a set of extension activities co-funded by key change making organizations and individuals.

6 Sustainable farming systems

In the context of the challenges facing the food system in the EGP, solutions are needed that can address them at a range of levels, including at the farming system level. ACIAR SDIP has worked from the basis of conservation agriculture (CA) as an appropriate technology to address challenges in the farming system, as evidenced by the work from SDIP Phase 1. Phase 2 has explored the context for scaling CASI in the wider food system. Key lessons demonstrated from the work in this component include the need to promote and work with multi-stakeholder arrangements for outscaling; that effective field-policy links can result in convergence with government programs; and that groups continue to provide opportunities that are not possible for most individual smallholders to capitalise on.

6.1 Demonstrating the suitability of CASI for the EGP

The farming systems improvements tested in ACIAR SDIP are based on CASI, which is a broader form of Conservation Agriculture (CA) that incorporates agronomic, socio economic and institutional aspects of food production, including more sustainable agroecosystem management, increased input use efficiency and increased biological and economic productivity. These are based on the CA principles of minimizing soil disturbance, ensuring soil cover and diversification through rotations – and include improved varieties, better irrigation practices and improved crop management techniques. Proof of concept of CASI for the EGP was the focus of ACIAR's work in Phase 1. Results from more than 400 participatory multi-year field trials demonstrated that CASI practices improved productivity (3 – 6%) and profitability (17 – 41%) while reducing input related emissions (6 – 12%), water (11%), energy inputs (6 – 11%) and labour requirements (40%) in rice-wheat, rice-maize and rice-lentil systems in the EGP (Gathala et al., 2021; Gathala et al., 2020; Gathala et al., 2020; Islam et al., 2019).

Gross margins were found to increase by an average of 25% (Gathala et al., 2021). Based on socio-economic survey data (n=1,313) (Rola-Rubzen et al., 2019), the aggregate value of production of CASI adopters for Kharif, Rabi and summer seasons was significantly higher than non-CASI adopters. The value of production of CASI farmers was higher by AUD$222 per ha, with males experiencing a higher value of production by AUD$190 per ha and females an even higher value of production by AUD$538 per ha compared to their non-CASI counterparts. Also, the net income for CASI farmers overall was also significantly higher by AUD$115 per ha. Female CASI farmers had a higher net income by AUD$509 per ha compared to their non-CASI counterparts.

The work in SDIP 2 has helped up to 113,000 farm households in total adopt more productive, sustainable and inclusive farming techniques that improve profitability, address labour constraints, and reduce the emissions footprint of food production systems in the EGP with the potential for significant impact if widely adopted.

6.2 Scaling mechanisation in the EGP

6.2.1 The science of scaling CASI systems

This section currently describes work done in 2019-20. It will be updated to incorporate the project's achievements once the final report is received in mid 2021.

The SRFSI project has progressed through several phases, from proof of concept of CASI systems, to actively scaling using a capacity building approach. The most recent phase has focusing attention on the science of scaling, identifying key lessons from the SRFSI experience that are being preserved as legacy documents to enable longer term communication and dissemination with relevant stakeholders. For SRFSI, strong progress has been made in finalising lingering activities and creating legacy products, while working towards institutionalisation for sustained impact. Notwithstanding the critical impact and implications of COVID-19 and subsequent lockdowns which have severely limited field level activities, stronger efforts have been put into academic analysis and publication, an important deliverable for the successful closure of the project. An ongoing focus on successful integration and convergence in line with maintaining and sustaining impacts has also continued.

Research has been undertaken to create a comprehensive and unique qualitative dataset of 336 interviews, which are being analysed to create new understanding on how to scale Conservation Agriculture in South Asia. A separate evaluation of Innovation Platforms has been undertaken. Four successful 'hands-on' workshops and two seminars on evaluating adoption drivers were held with end-users and project teams in Nepal and India in January 2020. These involved evaluating the potential adoption of new innovations, and examining the characteristics of earlier innovations and subsequent adoption rates using the Smallholder ADOPT tool. In response to a government directive banning the use of Glyphosate in West Bengal, trials have contributed to a new set of protocols based on results that show Glufosinate @ 500 g a.i/ha +Flucetosulfuron @ 30 g a.i./ha may be an alternative for Glyphosphate. Several publications have been completed (see Annexe 1).

Extension and legacy materials have been created to synthesise and communicate project results. This includes the completion of chapters 1 and 2 of the 'CASI visual Syllabus', development of an outline for the 'SRFSI online knowledge repository', contribution to the world first 'CASI Massive Open Online Course' with BAU, in which more than 8,000 participants from 22 countries participated. In Bangladesh, iDE are developing survey tools for self-assessment and contextual analysis of social enterprises using CASI machinery. In West Bengal, the Satmile Satish Club has expanded to a usually forgotten area of the state, Sitai Block, through a cost sharing 50:50 arrangement with SRFSI. This has seen Satmile working with a women's Farmer Producer Club to establish a seedling factory and demonstration sites.

CASI Networks are being formalised, through for example, a CASI Service Provider Digital Network in Bangladesh, which has established a Facebook group who are communicating their ideas and experience to share their proven knowledge. A CASI Service Providers Union in West Bengal is in the final stage of development.

Successful convergence has been achieved in several locations, which is the ultimate demonstration of strong field – policy links. In West Bengal, the government has made Conservation Agriculture (CA) machineries a compulsory part in new Custom Hiring Centres (CHC) that receive government subsidies, which means that every new CHC has CA machineries to out-scale CASI technologies. To support this mandate, a Centre of Excellence for Conservation Agriculture (CECA) has been approved by the GoWB to be located at UBKV. Given the rate of adoption within the State, and aligned with government subsidies for machinery purchase, it is necessary to ensure that at the same time there are enough people trained in CASI principles and practical elements, to ensure good quality operations for farmers. The CECA will increase the number of people professionally trained in CASI across the state and improve the quality of information available to farmers and service providers. This centre will establish the infrastructure to further promote CASI beyond the scope of SRFSI and beyond the life of the project, a great development for CASI training infrastructure for long term capacity impact. The GoWB is also providing the operating funds for this centre to ensure sustainability outside of SRFSI. In 2019-20, UBKV sponsored three state level and six district level policy dialogues to finalize the CASI related policies described here.

Block level initiatives by the Department of Agriculture (DoA) officers for CASI technology are now visible in most of the blocks in the northern districts of West Bengal. Previous advanced CASI training for DoA personnel undertaken through SRFSI is now paying dividends, as these staff have confidence to take up challenges to demonstrate the technology on different crops in their respective areas, and are using other programs (for example Agricultural Technology Management Agency, National Food Security Mission) to promote and scale CASI without project support.

In Bihar, the technologies validated by the SRFSI project were integrated into government plans and schemes as part of convergence like Mera Gaon Mera Gaurav, Zero Budget Farming and NABARD, in the form of demonstrations and machinery subsidies. The AUD$12 million state project Climate Resilient Agriculture Programme is being implemented in nine districts of Bihar, and each district has targets of covering about 250 acres using various CASI technologies. During the 2020-21 year, all districts of Bihar will be integrated under that Programme.

Substantial demonstrations (>50 across the region) have continued for CASI, but mostly from non SRFSI funds highlighting convergence with other programs. In Rangpur, Bangladesh, RDRS implemented various programs to enhance capacity of staff, farmer's hub committee members, service providers, machine operators and farmers. Training and community to community exchange visits were organized to enhance the capacity of relevant stakeholders. CASI is now being intreated into normal RDRS federation work. In Rajshahi, despite no financial or technical support from the project, activities undertaken by Bangladesh Agricultural Research Institute are linking with development agencies (e.g. DASCOH foundation, the NGO CCDB) to out-scale laser land levelling technology in the Barind area, where reducing irrigation water use is a target. Machinery subsidies of up to 50% are available, and an Agricultural Machinery Fair was held as a promotional activity.

6.2.2 Alternative mechanisation options: the Versatile Multi-Crop Planter

Crop production in Bangladesh is becoming increasingly unattractive as a business proposition due to high production costs and its dependence on many labour-intensive manual operations. Widespread use of 2-wheel tractors (2WT) for land preparation and the recent development of small farm machineries, provide a platform for implementing farm mechanisation, cost savings and the practice of conservation agriculture (CA).The use of the Versatile Multi-crop Planter (VMP), developed in a previous ACIAR project (LWR-2010-080) improves the efficiency of resource use (irrigation water, labour, fuel, seed, fertilisers), that in turn increases the profitability of crop cultivation for farmers and service providers.

The Pilot Project on Commercialisation of Small Holders' Conservation Agriculture-based Planters in Bangladesh aims to promote small scale mechanisation of planting operations using CA practices. The ACIAR project links medium scale manufacturers, Banks, farmers organisations, and small entrepreneurs (local service providers) as partners whose aim is to enable the business of mechanised planting, and create demand for the VMP to reach a scale where no further specific public funding is needed. New and prospective local service providers (LSP) of VMP are being actively sought. The partnerships work together to help new LSP secure loans for purchasing machinery (VMP and/or Two Wheel Tractor, 2WT). The project will also conduct a desktop scoping study of the medium-term opportunities for a four-wheel tractor CA planting machine, and develop a prototype of this VMP.

Two business models are being tested to create sales of the Versatile Multi-crop Planter (VMP) at a commercially viable scale. The first is a Planting Incentive Model which ensures business can be maintained for the first season while the technology is still unfamiliar to both farmers and the LSP (the new VMP owners get a one-off payment). The second scheme involves a Tri-party Investment Model (a cost sharing arrangement between the LSP/farmer, bank loan and project support, with agreed acreage to be planted within two seasons to create demand). In total since the start of the project, 95 VMPs and 26 2WT have been sold.

During the project, a partnership with an international NGO (Solidaridad Network Asia (SNA)) has been developed, which has helped expand the VMP use into the south-east regions of Bangladesh. They are currently working with 26,000 soybean farmers. Twenty units of VMP and 19 units of 2WT have been purchased by farmers in this area during 2019-20, most taking advantage of a soft loan organised by SNA. The total benefit for soybean farmers was AUD$547/ha relative to conventionally planted soybean, and they have obtained higher soybean grain yield by about 600 kg/ha in VMP planted plots.

This project is identifying policy level bottlenecks and barriers to the adoption of CA and mechanised planting (including gender impacts); and pilot testing two commercialisation models for scale out of the CA-based planter (i.e. VMP) which are needed at this critical juncture to advance the CA-based mechanisation program for smallholders' in Bangladesh.

6.2.3 Value chain and policy interventions to accelerate adoption of ZT

A study on value chain and policy interventions to accelerate adoption of zero tillage (ZT) in rice-wheat farming systems across the Indo-Gangetic Plains looked at what factors were currently impeding uptake of the ZT technology as well as making recommendations for the steps necessary to encourage its adoption.

The current, traditional practices of rice-wheat farmers in north-west India include both heavy soil tillage and concentrated seasonal burning of rice stubble prior to cultivating and sowing. The burn-off is recognised as causing significant air pollution and a measurable deterioration in air quality for cities such as New Delhi and the heavily populated regions of Punjab and Haryana. Soil health and quality are also negatively impacted by the repeated tillage practices. These environmental impacts coupled with climate change, a reducing labour force and rising costs all contribute to the threat to the long-term sustainability of farmers in this region.

The Happy Seeder (HS) is a ZT drill developed specifically for the intensive rice-wheat cropping system of the Indo-Gangetic Plains. It has proven capacity to directly sow wheat crops into standing rice stubble and has been commercially available for over a decade. The study identified a range of opportunities for accelerating the adoption of ZT/HS. Whilst a number of these opportunities have been identified in the past, there remains both a lack of awareness and availability of information relating to ZT/HS technologies. Traditional farmer beliefs that crops can only be sown into well-tilled residue-free seed beds continue. In addition, the availability of HS seeding equipment remains a challenge, with poor sales and distribution networks, and very limited capacities in terms of machinery servicing, maintenance and operation. This combined lack of education and ongoing supply/support issues constitute major constraints to accelerating the adoption of the ZT/HS seed drills in Eastern India.

Based on the study's findings, a range of recommendations were developed and targeted to State Governments to create enabling environments that support the accelerated adoption of ZT and HS technologies:

1. Implement an awareness raising strategy incorporating digital media approaches that support the adoption of ZT/HS technologies.
2. Expand the Innovation Platform approach to other targeted regions to support the introduction and implementation of ZT/HS related technologies, facilitated through KVKs and Farmer Producer Organisations (FPOs).
3. Provide financial incentives to assist in improving the network of retail agents, service centres and farmer training schools (focusing on the maintenance and operation of equipment).
4. Establish a collaborative platform between multiple levels of Government, responsible ministries and the manufacturing sector to help ensure that long-term relationships and the needs of the industry sector are clearly identified and supported to improve the development of effective ZT/HS seed drill supply chains.
5. Re-orient mechanisms that currently provide direct subsidies for machinery purchase and devise alternative models of support directed towards a range of options.
6. Assemble a specific project team and support service comprising State Governments, universities and international experts to provide a range of support services for the establishment of Custom Hiring Centres (CHCs).
7. Maintain a Regional Collaborative Platform (RCP) comprising representatives from the highest level of Government for the IGP region. Such a central platform would develop supportive government policy and the out-scaling of ZT/HS technologies through sharing and dissemination of information, knowledge and training resources, on-farm validation of best management practices, and training and capacity building.

Priorities remain the increase in awareness of the HS/ZT seed drills and changing farmer perceptions and acceptance of conservation agriculture techniques; notably removing misconceptions relating to the requirement to have a residue free, well tilled soil for successful crop establishment. A coordinated effort between governments, the university sector, manufacturing, finance and end-users is required to address the complexities of transitioning to CA systems, through information, extension, training, and technology exposure.

6.3 Constraints to sustainable intensification in the EGP

Alongside distilling the lessons from scaling, work has been undertaken to understand different constraints to the implementation of CA systems. Technical constraints to CASI implementation at scale often include those associated with soil health; ‘new’ weeds, pests and diseases; water management; and agronomic management (Reeves et al., 2018). Several projects have been implemented to explore these constraints.

6.3.1 Soil constraints

An external review of SRFSI (Reeves et al., 2018) identified soil health as an area of particular concern in the EGB with soil pH and associated toxicities, trace element deficiencies (Zinc, Copper, Boron), low organic carbon levels, and soil structural problems identified as key issues. The University of Queensland is working with local partners to determine the extent of these problems.

Acidification

The soils of the Eastern Gangetic plains are poorly pH buffered, and hence at risk of acidification through product removal (crop harvest) and N fertiliser use. Acid soils threaten agricultural productivity, by causing problems with nutrient availability and nodulation of legume crops, and as there are no specific symptoms, the issue can go unnoticed until the problem becomes critical. Agricultural yields within the EGP have considerably increased in recent years, and intensification of the system (better agronomy, better cultivars, additional crops/year, increased fertiliser application) further accelerates the rate of acidification.

There is very little published data on soil acidification in the Eastern Gangetic region, but in India, 16Mha of soil degradation is attributed to acidification, while researchers have reported soil acidification in West Bengal, Bangladesh, and the Terai of Nepal. The SRFSI project found that 15 to 20% of sites in the Coochbehar, Rangpur and Sunsari areas are acidic and require treatment, while another 30 to 45% of sites should be monitored for pH. In the Madhubani district, at least four nodes (87%) required lime application as a matter of urgency. The Gangetic Plains is an area of existing high productivity, current relatively heavy N fertiliser use, and an expectation of increasing usage. However, N fertiliser use is relatively inefficient and any nitrate leaching increases the extent of acidification. The overall generation of acidity varies depending on the fertiliser source. In India, ammonia-based N fertilisers (Urea, DAP) predominate in use, which results in net acid generation. Historically, calcium ammonium nitrate was widely used which is less likely to lead to acidification but is considerably more expensive per unit N than Urea.

The predicted time for soil pH to drop to 4.5 (a critical level) is estimated at less than 10 years for the majority of sites. These projections are predicated on highly conservative estimates (relatively low yield 2.5 t/ha, and moderate N input, 100 kg/ha). Even a moderate increase in productivity (3.5 t/ha yield, 160 kg/ha N fertiliser) substantially increases the rate of acid input (13 kmol/ha/y) and markedly reduces the time until soil acidity problems are likely to emerge. Irrigation with alkaline groundwater has the potential to neutralise as much as half of the acidity generated in the conservative system modelled. Thus the time taken to reach a point at which soil acidity limits productivity may be pessimistic. Use of groundwater irrigation was not factored into the time estimates because it varies widely, while the acidification processes (product removal and N fertiliser use) are generally applicable.

While the estimates of acid input and rate of acidification are crude, they are undoubtedly sufficient to confirm that soil degradation through acidification is a considerable risk to agricultural productivity. There is an urgent need to understand the risk of acidification more accurately. An obvious aspect to addressing the acidification problem will be to ensure that as N fertiliser use increases, N use efficiency does not drop. New fertiliser technologies currently being evaluated may present opportunities to better manage N in the Gangetic Plains cropping systems.

It is also important to note that more efficient use of N fertiliser will have a positive greenhouse gas impact, and that in the long-term this may be more important for climate than the carbon dynamics in the system. Any studies undertaken should consider the greenhouse gas impacts of the remediation approach. For example, simply liming to overcome acidification developed through poor N fertiliser management, would result in a very poor greenhouse gas outcome.

Zinc Deficiencies

Zinc deficiency in soils is known to be widespread in the EGP, but Zn fertiliser is not commonly used. While Zn is generally present, in many soils it is found at levels that are inadequate for plant growth, with modest symptoms of Zn deficiency in rice being comparatively widespread, being most pronounced in Rangpur (Bangladesh) and India. In this study, the addition of Zinc and Boron fertilisers generally increased yields by around 0.5 – 1.0 t/ha, although this was not observed at all sites. Thus, there is a need for agricultural extension projects to ensure that adequate Zn fertilisers are effectively applied to crops in order to maximise productivity.

In Nepal, the work was extended to citrus at the request of the National Agricultural Research Council (NARC). Analysis of 93 leaf tissue samples from across Nepal confirmed that growth (yield) is likely greatly reduced due to nutritional constraints. Preliminary data shows that substantial increases in yield can be obtained from the addition of inorganic fertilisers. Of particular importance were Zn and N, with 98% of the samples having Zn concentrations lower than that considered to be marginal (81% below the value considered to be deficient), whilst 67% had N concentrations lower than that considered to be marginal (57% below the value considered to be deficient). There is a clear need to more accurately determine the nutritional requirements of crops across Nepal, especially for Zn and N. Of importance is the impact that improved nutrition has on yield and profitability. Preliminary data from project trials indicate that improving nutrition can result in marked increases in yield.

Evaluating the soil structural benefits of conservation agriculture

Conservation agriculture practices such as zero tillage are generally reported to increase soil organic matter contents, especially in surface soil layers. An increase in Water Stable Aggregates (WSA) suggests an improvement in aggregation and therefore soil structural stability in soils under ZT. As implemented in the Eastern Gangetic Plains however, the effect of retaining stubble and reducing tillage in the rabi season (e.g. wheat) crop, are dissipated to some extent in the kharif season (rice) crop as the benefits of improved aggregation were largely offset by traffic from equipment during the rice season which negatively affected infiltration rates.

Limited overall changes in soil structure are being reported as a result of the conservation tillage practices implemented in the SRFSI project. Nevertheless, even modest increases in soil organic C can result in improved soil physical characteristics, and this is an anticipated benefit of the adoption of conservation agriculture. While there are multiple reasons why increasing soil organic matter may be considered beneficial, the effects of organic matter which most directly impact on crop production are its effects on soil structure.

6.3.2 Groundwater availability and access

Water availability

In accessing water for irrigation, there is an important distinction between availability (i.e. physical access) and accessibility (i.e. infrastructure and affordability). The International Water Management Institute (IWMI) conducted a temporal and spatial assessment of water available for irrigation in the eight districts of the SRFSI project (2015). They examined groundwater potential and surface water availability (including tanks and river). Groundwater potential for irrigation was based on the groundwater recharge and storage volumes within the limits of surface pumping systems, which have a limit of 9m below ground level (bgl).

Groundwater resources are under-utilized in most of the project's study sites, and are not a constraint for irrigation. Most study districts show groundwater tables within 9m bgl, which means that small surface pumps can be used to access groundwater. The exceptions are parts of Dinajpur, Rangpur and Malda. Groundwater levels fluctuate on average by 0.49m in India, 0.36m in Bangladesh and 0.28m in Nepal on a seasonal basis, indicating heavier withdrawals in India followed by Bangladesh and Nepal. Temporal assessment of groundwater tables indicates significant hotspots of withdrawals that are likely associated with domestic and industrial activities. Apart from Dinajpur and Rangpur, these withdrawals are in isolated pockets.

There is an extensive network of temporary and permanent ponds in the region, but they are not commonly used for irrigation. River pumping is also not common, and surface water irrigation schemes are limited. Thus, surface water is a minor source of irrigation and does not offer an efficient strategy to support the expansion of irrigation in the short term, although may be developed in the longer term.

Apart from the project areas in Nepal, almost 90% of the study area is under cultivation for at least one season. Currently, continuous irrigation for three seasons ranges from 2% (Dinajpur) to 72% (Purnea), so there is scope to increase irrigation intensity given availability of water resources. To determine the potential for development of irrigation intensity, groundwater availability was linked to the optimal crop water requirements for the dominant cropping patterns in each district. AquaCrop was used to model three crop intensive irrigation patterns in all areas. The results show that there is a potential to use groundwater resources to irrigate between 57 – 188% of the total land areas within the study sites, based on using flood irrigation with application efficiency of 70%. Improvements to irrigation management, including the use of conservation agriculture could further increase the area irrigated.

Water accessibility

Although groundwater is readily available, access is variable in terms of affordability. In the EGP, over 90% of farmers rely on groundwater for irrigation, although there is some conjunctive use of groundwater and surface water from government canals in the Nepal sites. Most farmers have access to irrigation through private, informal rental markets. These markets play a major role in ensuring irrigation access for almost all farmers. In a survey conducted by IFPRI in 2015, 25% of farmers owned pump sets, and a further 75% rented pumps to access irrigation. Given the nature of landholdings in the region that are small and fragmented, access to irrigation through rental markets will continue to be important. However while access is almost universal, costs are high due to high diesel costs and low efficiency of diesel pumps in general. Water buyers, who are often smaller and poorer farmers, feel the high prices acutely. Most farmers practice deficit irrigation due to high pumping costs; this is evident because pump owners apply more water than renters. This has effects on yield and productivity for the whole system, since farmers are more likely to delay sowing of kharif rice as they wait for monsoon rains rather than irrigate. This in turn delays sowing of the subsequent rabi wheat crop, which then is more likely to suffer terminal heat stress later in the season, impacting on yields. Many farmers do not grow rabi crops due to the high costs of irrigation, despite a relative abundance of water and labour in compared to land.

While the number of pump sets has increased rapidly in the past 5-10 years and been coupled with increased efficiencies, irrigation costs continue to rise. Water markets have not responded to this increase in supply, and prices continue to rise disproportionately. Pump sets are most expensive in Nepal and cheapest in Bangladesh, a consequence of policies that restrict imports of agricultural equipment in Nepal and India. In Bangladesh where there are no restrictions on the import of low-cost pump sets from China, the capital cost of pump sets is reduced, which has allowed more widespread ownership and more competitive water markets.

Dependence on electric pumps is higher in WB and Bangladesh as electricity supply in those locations is more reliable. A policy change in West Bengal in 2011 which liberalised the tube-well permit system and reduced capital costs and barriers to electricity connections for irrigation, resulted in approximately two-thirds of all irrigation pumps in the State now being run on electricity. Recently, the Government of Bihar also started a program to electrify irrigation pump-sets. The number of electric pumps is targeted to increase from less than 20,000 in 2017-18 to more than 0.4 million in 2022. Even if Bihari farmers pay the full cost of electricity, the hourly cost of irrigation will be one-fourth of what it is now with diesel pumps. As the flat tariff system incentivises farmers to use scarce energy and groundwater wastefully, connections should be metered, ensuring accountability and transparency.

In other locations where electricity supply is more variable, there is more of a mix between electric and diesel pumps. Indeed, diesel prices are one of the main reasons given for high pumping charges across the region; because the variable costs associated with diesel pumps account for up to 90% of the operating cost, owners of diesel pumps choose to keep prices high and reduce the hours rented rather than lower prices and extend the hours of operation. This behaviour appears to extend to pump renters who use electric pumps as well, despite lower pumping costs in general.

In considering policies to promote irrigation, subsidising diesel pump sets does not benefit small and marginal farmers or tenant farmers, since pump owners on average do not maximise the time rented. These subsidies would be better targeted at smaller or tenant farmers who would seek to maximise the time rented. It is unlikely that prices for irrigation pumping will decrease until alternative – and cheaper- sources of energy are found for the EGP. Machine reforms could help to reduce inequality in income from agriculture, in a way that has not been possible with land reforms. Targeting machinery subsidies for landless or marginal farmers, and supporting rural youth to become service providers can increase incomes among small and marginal farmers.

High rates of groundwater utilization in northwest Bangladesh are due to concerted and integrated efforts and coordination on the part of the public and private sector, but in the Indian EGP and Nepal Terai groundwater is under-utilized due to a combination of poor electricity supply, high diesel prices and uncompetitive groundwater markets. There is significant scope to develop sustainably intensified irrigation systems based on groundwater in these regions with the right institutional arrangements. Refer to Section 7.1 for more details related to sustainable groundwater development.

6.3.3 Weed management

Conservation Agriculture (CA) is currently practiced in over five million hectares in the Indo-Gangetic Plains. The greatest challenge to CASI adoption is weed control, which covers changing weed dynamics and crop-weed competition. While the agronomic implications of changes in weed management have received some attention, socioeconomic issues, farmer decision making practices and the impact on gender relations, have been less explored. Project WAC-2018-221 addressed this gap in the evidence base, focusing also on the gendered dimensions of weed management, in the context of CASI systems in the EGP.

CASI practices enhance biodiversity and biological processes inside and outside the soil, contributing to the maintenance of soil quality, water use efficiency, and sustaining crop production. It is a proven technology for climate variability resilience, due to the higher soil infiltration that minimises the impacts of flooding and erosion. CASI practices change weed management protocols, due to a lesser number of tillages required than are traditionally used to create a clean seedbed. Herbicide usage is an integral component of CASI and is used to control weed emergence. In developing countries, especially those that are facing labour shortages in rural areas, use of herbicides has been found to facilitate agriculture intensification by making it economically viable for smallholder farmers.

This research used semi-structured interviews to discover farmer views and experiences of CASI practice in the EGB. Due to the importance of herbicides for successful CA uptake, opinions of its usage were sought. Often, where farmers expressed negative perceptions on herbicides or admitted very little experience of them, dis-adoption or a lack of further progression to ZT systems occurred. Of farmers who were herbicide users, there were nearly unanimous positive responses to its implementation, especially in regards to saved time and cost, and reduced farm drudgery. Positive comparison made between hiring multiple labour against purchasing herbicides was also common.

Whilst herbicide use in the region is not a new phenomenon, there remains a low level of awareness on both safe handling and storage techniques, and their associated human health aspects. Environmental literacy, comprising safe use of herbicides, health hazards, concerns over air and water pollution, and long-term ecological problems and trade-offs, can be packaged through ZT technology promotion. This would assist in risk minimisation as well as reducing negative impacts on the environment.

It was also found that spraying of herbicides is becoming the male member's responsibility due to spray tank design and weight. Thus, zero tillage technology usage has had some gender implications. This is more apparent in areas where there is higher tendency of male labour out-migration and that may consequently increase the wage rate of male labour with such 'male-friendly' technologies.

ZT was found overall to provide time saving benefits for both male and female farmers, especially for women due to the reduced weeding requirements, with no shifting of the burden of weeding from men to women..

With some diversities across the EGP owing to different sets of drivers and benefits, generalised time savings during crop production have been found, pointing positively to plans for subsequent scaling out in the region. However knowledge of weeds that grow in ZT fields is limited, with women farmers able to name fewer weeds than men. Based on further in-depth research on gendered farmer knowledge on herbicide usage, an agronomic literacy programme on the effective, efficient, and economic management of weeds would help promote ZT technology. Such agronomic literacy programs can be tailored through existing extension service mechanisms prevalent in the region.

Understanding the weed management problems and evaluating practices used by men and women farmers to manage weeds in these systems successfully will be important components of efforts to develop efficient weed management packages and thereby facilitate the further sustainable intensification of smallholder farms in the EGP. The promotion of CASI must incorporate the understanding that the shift from conventional to conservation agriculture systems involves a change in farmers cultural practices and a paradigm shift around management of crops and resources such as soil, water, nutrients, weeds, and farm machinery. Thus, there is a need to establish a systems perspective; a holistic perspective including knowledge transfer, especially around weed identification, better management practices, and safe handling of herbicide use. Scaling up of CA technologies may be more about farmer perceptions and mind-set, than about the technology itself.

CASI promotes equality of opportunities and outcomes and may help farmers take up additional economic activities and expanding livelihood portfolios due to the time savings generated by herbicide use. This is of particular significance for women, who are finding more time available for tasks of their choosing, instead of the drudgery associated with traditional weeding practices.

7 Exploring key elements of sustainable food systems development

This section identifies key themes that have been explored within ACIAR SDIP, including groundwater development, the role of women in agriculture, and climate change mitigation and adaptation. This work recognises that access to groundwater and the wider scale implications of its use are critical, including interactions with energy and food security. These interactions are becoming more important as climate change impacts on rainfall timing, quantity and intensity (Dawson, 2019). The role of women is very variable, and often not well understood. These elements are critical parts of developing sustainable food systems.

7.1 Contributing to sustainable groundwater development in the Eastern Gangetic Plains

The EGP differs from other areas of South Asia in that groundwater resources are generally under-developed, with only around 40% of net annual groundwater availability utilised. Over 90% of groundwater currently used is for irrigation, although access is limited by high energy prices, since most farmers have had to rely on diesel pumps, although this is changing rapidly.

For smallholders in the EGP, intensification is key to maximizing profitability and productivity. Future development based on diversification and intensification requires better access and more efficient use of more water (up to sustainable limits), especially in the dry winter season, when groundwater is the main source of available water.

The ultimate goal of the ACIAR SDIP program is to engage in applied research that promotes the development of groundwater resources for agriculture in a sustainable and equitable way, so that the current cost of irrigation is reduced while still working within sustainable extraction limits. The key research themes have focused on options for more efficient use of water more efficiently at local levels; what the impacts of these savings are; and how energy and groundwater policies interact to influence agricultural production.

7.1.1 Access and availability

Initial work within ACIAR SDIP looked at the context for groundwater use in agriculture in the EGP, both in terms of availability and access (for a summary of findings see here). Groundwater potential and surface water availability (including tanks and river) were assessed. Groundwater is used by more than 90% of farmers, and hence surface water is a minor source of irrigation. Physical groundwater resources were found to be underutilized in most of the project’s study sites. However, there are pockets where groundwater use is over-committed. 75% of farmers have access to irrigation through private, informal rental markets. These markets play a major role in ensuring irrigation access, but costs are high due to widespread use of diesel pumps, and the associated high diesel costs and low efficiency of diesel pumps in general. However, in many areas, access to electricity is occurring quickly, and this potentially has implications for pumping costs. Water buyers, who are often smaller and poorer farmers, feel the high prices acutely. Most farmers practice deficit irrigation and do not grow rabi crops due to the high costs of irrigation, despite a relative abundance of water and labour in relation to land availability.

7.1.2 Local water management options

Proving and scaling farm-level water saving technologies,

From the SRFSI project, farm-level water savings have been confirmed when CASI techniques are used, with total water use reduced by 5 – 13%; and irrigation water use by 11% (Gathala et al., 2020). At the same time, yields can be maintained and profit increased. Higher water savings were recorded in wheat, maize and lentil. Diversification of rice-rice systems to an alternate winter crop could have major impacts on water use. Details of local hydrology, irrigation water use and water productivity of individual crops and cropping systems are found in Islam et al. (2019).

Improving local water availability using Managed Aquifer Recharge

South Bihar is one of the most water-challenged regions in the country, having semi-arid climatic conditions. The region faces occasional floods and droughts. Seasonal water availability determines the cropping pattern, as agriculture in the region is mainly rain-fed. Ensuring reliable irrigation sources is crucial for meeting the demands of sustainable agriculture. Nalanda University explored the potential of aquifer storage and recovery (ASR) techniques for supporting sustainable agriculture intensification in South Bihar. This technology helps to store rainfall during the wet season due to rainfall events or floods, and makes it available during the dry winter season. The main objective of this project was to demonstrate the technical viability of this technique and to deliver information for minimizing the uncertainties in planning and design for its future use, including socio-economic aspects of its management. Initial results have been published by Bandyopadhyay et al. (2021).

To develop an understanding of the physical, chemical, and social aspects that affect the potential adoption of ASR in the South Bihar aquifer, primary fieldwork was undertaken in two villages in Nalanda district. Based on geo-morphological parameters (i.e., rainfall, elevation, soil and aquifer characteristics, surface and groundwater quality) and socio-economic indicators (tacit knowledge, land ownership, willingness to participate), seven suitable sites were identified in two villages, Nekpur and Meyar in Nalanda, Bihar. The construction of seven ASR systems were completed in September 2020. The geophysical and geochemical characterization of the aquifer at the installation sites showed a highly heterogeneous nature of the aquifer. In both villages, the local community had supported the team in various ways. Focus group discussion, personal interviews and socio-economic surveys in the study area revealed the willingness of farmers to adopt and operate the new ASR systems. Conversion of “failed bore-wells” into ASR installations emerged as a priority for farmers from the participatory discussions being promoted during the study period, since it may require construction of the filtration unit only (i.e. recharge pit) but not the actual bore-well. Overall, the project has demonstrated the feasibility of ASR in both hard rock and deep alluvial aquifers in the marginal alluvial plains of South Bihar.

This study has also demonstrated an “entrepreneurial farmers-led model”. The critical elements of this model include (i) a multi-disciplinary approach to site selection in which scientific assessments can be integrated with socio-economic insights, (ii) system will be initially adopted by entrepreneurial farmers who agree to invest and share benefits, and (iii) co-designing the recharge pit using locally available material and ease of maintenance. While a strong knowledge input from scientific literature ensures credibility and confidence necessary for the technical feasibility of ASR, the flexibility of a participatory approach allows the farmers to creatively engage with the design and governance aspects of recharge pits. This exploratory work has generated interest for conducting long-term research on groundwater quality and quantity changes that may occur as a result of ASR. There were delays in construction of the ASR structures before the monsoon season of 2020 due to COVID restrictions and flooding, so planned monitoring of water yield and quality implications will be ongoing after the project completion.

The scaling up of ASR would require significant policy support. There is an opportunity to engage with the *Jal-Jivan-Hariyali* mission of the State Government of Bihar, which is attempting an integrated approach to water resources management and environmental well-being. Under this mission, the State Government is constructing both surface-based and groundwater-based water recharge structures. However, the mission’s top-down model leaves little space for meaningful participation of local stakeholders, jeopardising both the effectiveness and efficiency of the program. The State agencies can initially adopt our design at institutional level for augmenting aquifers in selected parts of Bihar. The entrepreneurial farmer-led model builds local accountability, creates avenues for private investments, and opens up the space for continued innovation in technology and management while also committing to resource distribution justice and environmental sustainability. However, the model emerging from our pilot study needs further analysis; even though the initial findings are promising, the long-term viability of such projects needs to be monitored.

7.1.3 Understanding wider impacts of groundwater development through a Food-Energy-Water lens

Governments in the region use a range of policy instruments with the intention of both increasing accessibility of irrigation, and ensuring sustainability of groundwater resources. Alternative – and cheaper – sources of energy are one option to reduce the cost of irrigation and boost access. Based on experiences in the western IGP, many policy makers are concerned about declining water-tables and the implied unsustainable use of groundwater. There is significant scope to develop sustainably intensified farming systems based on groundwater in the EGP with the right institutional arrangements and within sustainable resource limits. Several studies have looked at the impacts on groundwater of changing one part of the system, particularly keeping a framing of the FEW nexus. This work demonstrates that common policies for managing groundwater development do not always achieve the intended outcomes.

Understanding regional hydrological implications of on farm water savings

Work from CSIRO demonstrates that policies that promote farm level water savings such as those associated with CASI technologies do not always reduce overall water use or improve groundwater levels at a regional scale. This work contributes to our understanding on how field scale water savings impact on the local and regional water balance and groundwater recharge. When irrigation water is applied, it is common for some of it to pass below the root zone as drainage and/or run off the field. In groundwater dependent areas with good quality, shallow water tables, this drainage is not lost but rather replenishes the aquifer and is available for other users. It is suggested that the key comparisons between cropping systems options (e.g. CT vs CA) should be based on total evapotranspiration (ET = soil evaporation + crop transpiration), not on the amount of irrigation water applied and its subsequent drainage component.

In the northwest of Bangladesh where groundwater tables are declining, the Government policy responses to prevent further decline focuses on more efficient irrigation. It has been demonstrated that without reducing the actual crop evapotranspiration, adoption of any water-saving technologies (e.g. AWD, deficit irrigation, conservation agriculture) to reduce seepage and percolation loss of water will have little impact on improving the declining groundwater levels in the region (Mainuddin et al., 2020). Work undertaken in ACIAR SDIP has extended the findings to the rest of the EGP. Simulations using the APSIM model indicate that in rice-wheat, rice-maize and rice-rice systems, although CA results in a reduced amount of irrigation pumping requirement, there is very little difference in overall ET between CT and CA practices. If anything, CA is likely to result in higher ET due to enhanced rooting and higher levels of Rabi crop production. In this sense, claims that CA will result in reduced water use and groundwater drawdown in the EGP on a wider scale are likely to be baseless, although they will still contribute to reduced costs and emissions associated with groundwater pumping. Many water saving measures reduce the amount of water applied (which is a saving from the perspective of the farmer), but not the evapotranspiration from the field. Only measures which result in reduced evapotranspiration on the farm will save water for the region. However, the farm water saving measures may include altering the source of irrigation water or the destination of water drained (by surface or subsurface drainage) from the farm, and this may have an impact at regional scale.

In a desk study of the regional water balance in several districts, it is demonstrated that there is a large excess of rain over potential evapotranspiration in the northeastern parts of the region, and the actual evapotranspiration is likely to be close to the potential (Mojid & Mainuddin, 2021). Conversely, there is a large deficit of rain to satisfy the evapotranspiration demand in the southwestern parts. This suggests that incentive to save water at the farm scale is likely to be limited in the northeast, but significant in the southwestern parts. The impact of any water saving on the regional hydrology is likely to be more limited in the northeast and greater in the southwest. There is evidence to suggest that more groundwater use could be developed in parts of India and Nepal, whereas in parts of northwest Bangladesh the use may already have reached its potential.

Links between energy and water policy

A study implemented by IWMI shows that the impacts of groundwater and energy policy reforms have had a much lower than intended impact on water use and agricultural productivity and profitability in West Bengal, India. Over the past two decades, the state has undertaken three important policy reforms related to groundwater and electricity. These were: (i) universal metering of electric-run agricultural tube wells starting in 2007; (ii) change in the groundwater law in 2011, which removed the requirement of farmers having to procure a prior permit from the groundwater department to get an electricity connection; and (iii) provision of a capital cost subsidy for the electrification of groundwater pumps in 2012. These three policy measures helped remove barriers to the electrification of agricultural wells and tube wells. This resulted in a more than threefold increase in the number of electric pumps – from 86,776 in 2007 to 303,018 by 2018. In this study, the impact of the increase in the number of electric pumps on agriculture- and groundwater-related outcomes was analysed using government (block level) data and community inputs.

It was expected that electrification of wells and tube wells would affect agricultural and groundwater outcomes through lowering the costs of irrigation, as had happened in other states in India. Per unit costs of pumping groundwater with electric pumps is much lower than pumping with diesel pumps. Therefore, it was expected that farmers with access to electric pumps would operate their pumps for longer hours and grow more water-intensive crops. However, despite the positive effect of the groundwater policy reform on the immediate outcome in terms of the number of pumps electrified, the effect on agricultural outcomes such as cropping pattern, cropping intensity, cropped area, production and yield was not evident. There was a positive effect of the policy on the summer (boro) paddy area and production, and a negative effect on the area under pulses. Yet, these effects were not robust and were found only in a limited number of blocks. It was found that groundwater policy changes led to slight improvements in groundwater levels in the period after 2011, as compared to the period before. The expectation was that groundwater levels would decline further, but given that cropping patterns and crop water use had not changed significantly in the post-2011 period, there was no overall acceleration in the pace of groundwater extraction either.

This work demonstrates that common policies for managing groundwater development do not always achieve the intended outcomes. Farmers reported that the reasons they had not increased or diversified production was mainly because during the same period, profit margins had declined; electricity and other crop input costs had increased, while prices received for their crops had stayed the same. These results from West Bengal show that energy and water policies need to be made in collaboration with agriculture and food policy if they will be successful in sustainably increasing food production.

Quantifying sustainable water yields and their interaction with food production

At different locations across the IGP, an assessment of the trade-offs between physiologic, economic and sustainable water yields has been undertaken for rice, maize and wheat. Water resources are generally under-developed throughout the region, and an assessment undertaken now allows adequate time to plan for the sustainable development of groundwater resources.

Quantifying sustainable water yields and their interaction with food production shows that physiological crop yield gaps are greater in the IGP, and confirms there is opportunity to increase use of groundwater in some locations with the right mix of crops and farming techniques. There is a clear trend for over-exploitation of groundwater in the western IGP, and under-exploitation in the east. Modelling allows us to look at different crop and farming system combinations to find the most appropriate mix for both productivity, groundwater sustainability and economic returns.

For the vast majority of the IGP, the real measure of sustainable irrigation is a balance between evapotranspiration and groundwater recharge. A simplistic assumption in the context of a GW overexploitation of (for example) 30%, is that decreasing irrigation pumping by 30% will bring it into sustainability. Simulations show however that a reduction by 30% in Haryana will decrease ET by less than 10%, and that to achieve an actual reduction in ET of 30% would require reduced pumping of over 50%, a rice yield reduction of around 50%, and even greater decreases in economic returns to farmers. Alternative options include different cropping patterns in combination with water conservation measures and would be more appropriate in addressing multiple constraints such as productivity, profitability and water management.

Farmers in the North-Western Gangetic Plains operate closer to the physiological potential yield for major crops, whereas farmers of the Eastern Gangetic Plains (EGP) have greater physiological yield gaps and greater potential to increase their current crop yields. Cropping districts in the WGP currently overexploit GW resources and are farming unsustainably with their current cropping practices, whereas the examined EGP sites in India and Nepal, are underexploited. This, together with current yield gaps, strongly suggests the possibility of shifting key crop production in India (particularly rice) eastwards into the north eastern states in the future. Analyses have shown that even with increased fertiliser and irrigation application (bridging physiological gaps), cropping systems in many sites in the EGP would still not be overexploiting their GW resources; Bangladesh is an exception to this.

It also calls into question the current focus on crop diversification in the EGP, and asks whether the EGP is not better suited to carry a large load of India's rice production – with more crop diversification (less water-intensive non-rice cropping) to be encouraged in the currently over-exploited WGP. Analyses for Karnal (Haryana) in the WGP indicate that modifying the current rice-wheat system to (40% rice:60% maize in kharif) followed by 100%wheat in Rabi is both sustainable and profitable for the region. India needs that missing 60% rice to be grown somewhere, however.

Electricity subsidies have a significant effect on farmer profitability in the WGP, but the effect of these subsidies decreases with less rice in the system, due to decreased GW pumping for example, when substituting maize for rice to achieve sustainability. Analyses were conducted at all sites on how sensitive the 'Maximum Economic Yield' for major crops was to (i) cost of nitrogen; (ii) cost of irrigation; and (iii) price of grain. We found that variation in the selling price of grain was the greatest influencer of a farmer's profit, and hence a key determinant of the Economic Yield Gap. Variation in the cost of irrigation and the cost of fertiliser N were similar, and both considerably less than grain price impacts – across all sites West to East in the IGP.

Learning from past development patterns in West Bengal and Bangladesh

The study of agrarian change in Bangladesh and West Bengal has a long history spanning several centuries. The region has experienced periods of high agricultural growth, and others of poverty and famine. The trajectory of agrarian growth in two countries – with the same agro-ecology, history and culture, but with two different policy settings, became a topic of intense interest among scholars of agrarian change. A book comparing agrarian change in Bangladesh and West Bengal from 1970s to mid-1990s concluded that West Bengal had better growth rates than Bangladesh due to agrarian reforms. However, since the mid-1990s, it is clear that Bangladesh has experienced higher growth rates, while growth in West Bengal has slowed down and even stagnated. Recent work has explored the trends in agricultural growth since the 1990s, and analyzed the reasons for these trends.

Six common themes were identified that can explain the different trajectories of agricultural growth. These include the expansion in area, production and yield (APY) of *boro* paddy; groundwater irrigation that has made the expansion in APY of boro paddy possible; informal markets for groundwater irrigation services, and role of electric and diesel pumps in promoting these markets; the rising cost of cultivation and lowering of profits from *boro* paddy, and move towards crop diversification; public policies and policy discourses on water-energy and food; and groundwater depletion potentially linked to climate change.

These themes have been used to construct two different story lines. The first story line is for the period of early 1980s to mid-1990s in West Bengal, and early 1980s to end 2010s in Bangladesh. During this period, both West Bengal and Bangladesh saw rapid rise in APY of *boro* paddy, supported by policies in water, energy and food domains that also encouraged intensive groundwater use. The second story line is for West Bengal (from mid 1990s onwards) and Bangladesh (from early 2010s onwards). Both started experiencing stagnation in APY of *boro* paddy, which can be attributed to unfavourable cost of production and output price ratios. In recent years, declining groundwater tables, possibly due to climate change, is another cause for worry. Farmers are trying to diversify away from paddy, and yet, paddy remains important from food security perspective, and diversification brings in its own sets of challenges.

7.1.4 Summary

This work recognises that access to groundwater and the wider scale implications of its use are critical, including interactions with energy and food security. These interactions are becoming more important as climate change impacts on rainfall timing, quantity and intensity (Dawson, 2019). Agriculture-related groundwater management must be incorporated as a component of a wider water focused program.

7.2 Understanding the role of women in agriculture

Gender is a crosscutting theme for the Sustainable Development Investment Portfolio (SDIP), which required the seven SDIP Partners to integrate the gender context within all interventions and to embed it within their institutional approaches. ACIAR SDIP explored the variations in spatial and temporal pluralities with respect to gender in agriculture within the EGP and found it shaped by the cultural roots and economic status of the respective countries, regions and sub-regions. Recognising the gendered dimensions of the water, energy and food sectors and nexus, and the disparities in the agency and engagement of women and men, ACIAR SDIP framed projects to allow gendered data collection and aimed for gender equity or women-positive implementation. A review of the macro and micro factors impacting on gender outcomes within the EGP contextualises the various pieces of work, and assists in assessing outcomes and forming recommendations.

Key themes around gender that emerged from the ACIAR SDIP program work include:

- Understanding the context for women's engagement in agriculture, including the trends of feminisation and defeminisation;
- Ensuring participation in research activities;
- Identifying the impacts of farming system change for women;
- Using experiences to inform a scaling paradigm and priorities for future work.

All references in this section are reports and publications produced within ACIAR SDIP.

7.2.1 The big picture for women in agriculture

Mapping the spatial variations in gender vulnerabilities at sub-regional levels in the EGP provides a backdrop to understanding changing gender roles in agriculture (Sen et al., 2019). The report on *Understanding Women's Role in Agriculture in the Eastern Gangetic Basin* showed that work participation rates of women in the rural EGP demonstrate both considerable regional variations and diverging trends over time, defying its relatively small size and the shared agricultural and economic characteristics of the basin. Within the region there is also a high incidence of male-selective outmigration, which is known to impact women's work, and spatially embedded physical and cultural pluralities. The report concludes that there is an a priori rationale for expecting intra-regional variations in women's role in agriculture within the region, that is likely to be shaped by complex intersecting factors, necessitating a comprehensive understanding of the region from both macro and micro perspectives.

Patterns of feminisation and defeminisation

The term feminisation of agriculture refers to the gendered nature of agrarian transitions under conditions of rapid and globally interconnected socio-economic change (Darbas et al., 2020). The increase of female involvement in agriculture has been attributed to male-labour outmigration in the face of persistent rural poverty, growing numbers of female-headed households, and an increase in labour intensive cash cropping on both family and corporate farms. Much of the primary fieldwork-based literature assumes feminisation as a temporal trajectory in South Asia in general and the EGB in particular, especially as a consequence of increased male out-migration. The macro level data published by government sources in Nepal and Bangladesh reveals workforce feminisation processes do seem to be occurring in both regions. At the sub-regional level, almost the entirety of Bangladesh EGP is feminising, which conforms to the macro trends. The Terai part of Nepal is feminizing, which is where the majority of work-force in the country is concentrated. However in India, West Bengal reveals a mixed picture, while Bihar almost entirely is defeminising. There is a consistent pattern of defeminisation, both in absolute and relative terms, in spite of significant male-selective outmigration, which raises questions about defeminisation processes emanating out of economic progress. The status briefs published by the Foresight component (Joshi et al., 2019; Sen et al., 2019) found a lack of comprehensive discourse on the processes behind feminisation in the EGB belonging to Bangladesh and Nepal, or the drivers of defeminisation on the Indian side (West Bengal and Bihar). Sen et al (2019) provide the following explanations based on analysis of macro level and micro level data.

Women's Labour Force Participation

Sen et al. (2019) found that in terms of levels of work participation of women, Nepal has a high base, while Bangladesh and India started with a much lower base. Over time, both Nepal and Bangladesh have had a feminising rural and agricultural workforce, the latter more sharply so. However Joshi et al. (2019) suggest that the quality of work and wages have not sufficiently improved for the women in these two countries, and at a few sub-regional contexts have actually deteriorated. The Foresight Briefs analysed the data on the Indian EGB, which has defeminised steadily over the last 30 years, with some reversal in the last three years to 2015. The report by (Joshi et al., 2019), shows that in rural India, the engagement of women in agriculture has decreased from 36% in 2004–05 to 21% in 2015–16 and the women's labour force participation rate has also declined from 50% in 2004–05 to 25% in 2017–18. Simultaneously, the share of women who are out of the labour force has increased from 51% in 2004-05 to 67% in 2015-16. It uses the nationally representative dataset National Family Health Survey to predict the labour force participation (LFP) of sample women in rural India based on sixteen demographic and socio-economic variables. Sen et al. (2019) noted that the rate of unemployment among women has risen at a rate far exceeding that of men, suggesting that of the women going out of work, many still seek it. Both reports find the pattern of defeminisation to be somewhat counter-intuitive as all the potential characteristics typically linked with feminisation - like low agricultural income and male outmigration, exist in the region.

Joshi et al. (2019) provide some insights into factors affecting LFP. In India, poorer women have dropped out of work faster than women from better-off households, which, coupled with high unemployment rates, is indicative of a distress driven process. Education and LFP have a "U" shaped relationship: women with median levels of education (7 to 10 years) are the least likely to work, which means that wealthy educated women and poor uneducated women have the highest LFP. The combination of wealth and education matters in determining women's LFP.. However, workforce participation rates (WPR) have reduced faster for the poor than the rich and the relative unemployment rate (females/males) in EGB India has gone up over the years. Women are still in the labour force looking for work, which would not have been the case had it been primarily a case of either prosperity- or education- induced withdrawal.

Joshi et al. (2019) also noted that working women face higher chances of domestic violence, likely due to unobserved socio-cultural norms. Women who are out of the labour force have a greater number of young children (<5 years of age), and also have lower levels of autonomy and mobility outside the house. Women whose husbands have out-migrated are less likely to be working than those who are living with their husbands, which challenges the normal assumption that outmigration leads to increased LFP for women. A defeminisation process linked with higher levels of unemployment is indicative of distress and is suggestive of displacement from jobs or lack of jobs that women can take up along with care work. In the last decade, due to an increase of unemployment among men in both rural and urban areas, male migrants have been coming back to increasingly impoverished agriculture as cultivators, leading to a decline in the share of women cultivators (Joshi et al., 2019). In the last three years, there appears to have been a reversal of the trend of defeminisation in Indian EGB, though it is impossible at this stage to conclude that this reversal is of a long-term nature.

Sen et al. (2019) conclude that the recent increase in participation of women in agriculture in Bangladesh as a response to long-term male migration, challenges the social norms in the country, and this could thus initiate a lasting change in the gender relations observed historically there. The stark improvement of gender gaps noted in multifaceted aspects during the last decade in Bangladesh, is very likely a harbinger of this path. The feminisation process in Nepal, in contrast, is a continuation of its societal historicity, unlikely to bring about deeper changes in the gender relations in the region from the way it is now. The inability to run the rural economy without women, in a region that experienced years of traditional male outmigration, arguably shaped this historicity of social norms that found women working in the agricultural fields or their presence in public spaces acceptable. The relatively high gender gap in literacy rates in Nepal is a case in point, which indicates that the high participation of women in agriculture in Nepal is probably more functional, than part of an all-encompassing pathway towards gender equity.

Contextualising the Gender Vulnerability Index

Sen et al. (2019) used selected gender gap criteria that includes the child sex ratio, relative literacy rate and relative work participation rate, showing gender vulnerability as a whole to define the EGB region. The spatial variations of these variables indicate that the gender space of the EGB, is very often shaped by both cultural roots and the economic status of the respective country. The performative aspect of gender in particular often tends to be shaped by the latter over time, though the rules of patriarchy in the different spaces provide its initial context.

There is a clear regional difference in the levels of the three variables, both spatially and temporally. In the terminal period, Bangladesh and Nepal are seemingly at par with respect to the relatively high child sex ratio, Bangladesh far exceeding the status of the other two countries vis-à-vis relative literacy rates, while Nepal performs the best in terms of relative work participation rates. India falls behind in all three indicators,

In terms of improvement in the Gender Vulnerability Index (GVI) over the decade that the study considers, Bangladesh is far ahead of India and to some extent, Nepal (Raju *et al.,* 2016). Though the study comes up with broad regional patterns, there are significant sub-regional differences in both Nepal and Bihar. India's case, particularly with respect to Bihar, is worrying as the high gender gaps in most indicators have further widened, leading to an exceedingly low status of GVI in the latter period. The de-feminising trend of agriculture in particular and rural work in general needs to be contextualised in the perspective of a declining status of women in India. The study also noted that the regional plurality of patriarchies leads to qualitatively different outcomes in terms of the type of roles women undertake in agriculture, in addition to the magnitude of their participation.

As previously noted, the main driver of the defeminisation process is usually agrarian distress. The influence of changing cropping patterns, the transformation of land-uses, increasing mechanisation, along with effects of remittances following male outmigration are all negatively impacting the feminisation process. There has been an increase in the incidence of unpaid work, along with feminisation in Nepal and particularly in Bangladesh, and a shifting burden of feminisation in Nepal to the elderly women (due to increased outmigration by young couples). Bihar is defeminising, in spite of being a state with high male out-migration. The returned remittances, though meagre, often offer a choice to women not to join agricultural work that pays little and requires long hours. This cannot be termed as the 'prosperity-induced withdrawal' as commonly suggested in the literature, but a slight widening of choices responding to an unfavourable labour market.

Macro and micro constraints to agricultural development

There are major socioeconomic constraints confronting all EGP smallholder and tenant farmers, including those headed by females, including:

- Small and fragmented land size: small input requirements, little purchasing power, small marketable surpluses and difficulties in identifying appropriate technologies and ensuring that small farms can access them.
- High rates of poverty: connected to the social structures of class, caste and gender. These axes of inequality mediate access to irrigation, a core prerequisite to agricultural growth and intensification in the region, which are compounded by high prices and land fragmentation.
- Food security: entangled with caste and tribal identities and their relative socioeconomic status within (rapidly eroding) strict social hierarchies.
- Landlessness: Tenants struggle to deal with absentee landlords or negotiate reasonable terms for renting or sharecropping land.
- Poor infrastructure. Poor connectivity makes the cost of doing business in the region even higher.

- Low productivity and high costs.
- Geographic disadvantages.

An extensive scoping study of female-household heads early in the program was completed in a number of districts throughout the EGP (Brown et al., 2020). Male out-migration affected more than 50% of those surveyed, and very few respondents had title to their land apart from those in Nepal (20%) and East Champaran (30%). About 25% of respondents had no easy access to a bank or held a bank account. There were few animal or domestic assets, and farming assets were limited to spades, shovels and sickles. About 16% of households owned an irrigation pump and the occasional chaff cutter. However, 33% of survey respondents belonged to a self-help group, which has potential benefits in terms of increasing bargaining power.

Land tenure and irrigation

Groundwater management, including access, availability and use, is a critical element in the nexus between the water–energy–food sectors within agricultural production and land management strategies throughout the EGP (Brown et al., 2020). This is especially true for women farmers and women-headed households, where more limited social networks and gender ideologies can be constraining in traditional settings. Male outmigration has undermined the functioning of many irrigation management institutions, and persisting limitations on women's engagement has failed to counterbalance these changes. Improving access to, and the affordability of, groundwater-based irrigation is necessary to boost agricultural production in the EGP. Potential solutions to improve the access of small and marginal farmers, and especially women cultivators, include short-term options such as innovative models of collective land and water management. This may include collective leasing or a user group approach to tube well management. In the long term, radical redistributive land reform—or, at least, clarification and improvement of sharecropping rights—is one of the few options in regions such as Bihar and Nepal.

Institutional arrangements

The *Institutions to support intensification, integrated decision making and inclusiveness in agriculture in the EGP* project is looking specifically at women's preferences for institutional arrangements related to water markets, knowledge transfer and risk management, and a comprehensive survey has been developed to capture these from 2,000 farming households. The survey includes a specific component that teases out the empowerment of women. Coupling this information empirically with the other data gathered in the primary survey (e.g. insight into preferences for knowledge transfer), including households' ratings of policies and delivery institutions, has the opportunity to explain the link between different institutional settings and women's wellbeing.

These results will be updated based on their final reporting.

7.2.2 Approaches to engaging and assessing benefits for women

Between 2014 - 2018, the SRFSI project trialled CASI technologies with smallholder farmers, in eight districts of the EGP. In line with the project's aim to be gender-inclusive, there was a concerted effort to mainstream gender in all project activities. The project utilised three main strategies to engage females as cultivators. First, prompting gender mainstreaming of (project funded) extension services with a 30% quota for female participants in all project activities. Second, development of female entrepreneurs as part of improving value chains. Third, partnering with NGOs proficient in socio-economic mobilisation of resource-poor rural females (Darbas *et al.,* 2020). All project data was gender disaggregated. The approach to ensuring women's participation included:

- Awareness of gender was increased through formal training, as was the importance of incorporating gender aspects in all components of the project. 'Gender Focal Point' positions were assigned in each location;

- Mainstream project extension services for farming women with a 30% quota for women participants in all project activities;
- All project activities included men and women, with participation monitored;
- All districts used protocols for gender activity reporting and templates;
- The impacts of farming systems change was monitored for both men and women in farming households.

While the SRFSI project was conscious of achieving a parity level of men and women's participation rate, some activities such as training and workshops and focus group discussion need more deliberate gender mainstreaming efforts. Overall, women's participation rate culminated with above parity level, however, female participants were mostly engaged in scaling-out activities but not in other activities. In future projects, there will be a need to focus gender mainstreaming efforts across all activities and project sites.

In other components such as Foresight and Institutions, research considered the context for women and the impacts of change. For example, the Foresight component contributed an understanding of the context for women's participation in agriculture, including identifying the drivers behind the trends. Training was provided to mainstream gender in food systems research, the use of mixed methods for research, and different tools and techniques that can be used to conduct participatory foresight for food exercises with communities. In West Bengal, local level studies focused on changes due to mechanisation, and the impacts at the community level with a particular focus on women and youth.

7.2.3 The impacts of farming systems change on women: gender positive outcomes

Household level

The SRFSI project has introduced, tested and promoted CASI-based technologies which can reduce inputs (labour, water, seed) while improving profitability and maintaining yield (for more details, see Section 6.1). The SFRSI project worked with multi-stakeholder innovation platforms (IPs) to improve coordination between farmers and agricultural agencies, and to develop conservation agriculture business models. Increases to gross margins using CASI compared to conventional practices were experienced by both male and female headed households. Importantly, the increase in returns for female headed households was usually greater than for male headed households, demonstrating higher impact and improved benefits for women.

Changes in farming systems impact men's and women's assets such as land, time, labour, and extension services differently, so gendered data collection is an essential component of research. A project on weed management in the EGP focused on gender outcomes from the uptake of zero-tillage technologies (Brown et al., 2021; Gartaula & Suri, 2021). Weed control is considered the biggest challenge to CASI adoption, with perceptions about the impracticability and workload implications of adoption being significant barriers. It is hoped that the time saved by adopting CASI, will have significant impacts on women's time allocation, with freed time available to engage in other income generating opportunities if desired. However other research has indicated that where herbicides are too costly to purchase, the extra labour required for weeding with CASI technology can lead to an increased labour burden for women (Brown et al., 2021; Gartaula & Suri, 2021).

Semi-structured and in-depth interviews were conducted in households adopting the technology in the EGP. The findings from these suggested that ZT aligns positively with reduced time burdens with no reallocation of roles or burden when herbicides are used; and that substantial time is saved, on balance more so for women. However, spray tank weight and design make the spraying of herbicides less feasible for female use, which could have further implications on gendered labour allocations, especially for rural migrant households where women are in-charge. These findings suggest that on balance, ZT is women friendly and inclusive and should be supported by governments, not just because it has agronomic and economic benefits, but because it can also enable equitable development. It produces time savings, no reallocation or increased burden of roles and responsibilities on women, and balanced spousal knowledge of weed management practices. Herbicide use as part of a CASI system enables diversification, (both agricultural and livelihood) which emerges from saved time and money. These may have substantial impacts for ZT using households that enable livelihood transformation towards many of the sustainable development goals.

Scaling

SRFSI responsible-scaling targets were such that 7,000 resource-poor farmers were to adopt one or more of the project's CA technologies by 2017–18, rising to 130,000 farmers (including 50,000 female farmers) by 2025 (Darbas *et al*., 2020). The concept of responsible CA scaling is particularly relevant to females in the EGP as it conditions the opportunities they receive and risks they are exposed to within a rapidly changing socio-economic landscape. At issue is whether bargaining power within female's household and community is increased, so they are economically empowered, and their drudgery decreased (Darbas *et al.,* 2020).

An enabling environment is critical, that allows female household heads to take control of livelihood assets, and be included in existing and new institutions such as agricultural extension centres, farmers clubs, and water-user committees (Brown et al., 2020). Women in the EGP women have less control over land and non-land productive assets than men, and land preparation is traditionally done by men. Farm mechanisation is a process of forming rural capital goods, which are likely to alleviate poverty through rural development. Women's access to CASI knowledge and machinery was thus central to the SRFSI project. Darbas *et al.* (2020) concluded that resource-poor female farmers need to be empowered to grasp the opportunity that agricultural mechanisation, CA, and intensification offer, in order for them to become active stakeholders in the EGP's rural development. This requires continuous assistance for women, collectivisation to gain bargaining power, access to institutional credit, machinery subsidies, and training.

As Darbas (2020) explained, prevailing gender roles and relations in the EGP make it particularly difficult for women to invest in rural capital goods and threaten to marginalise resource-poor women from new value chains arising from farm mechanisation and cropping intensification. Rural women are rarely named on land titles, lack the assets (e.g. named on a land title) necessary to obtain institutional credit, and are subject to mobility restrictions that limit their ability to obtain inputs or negotiate sales on advantageous terms. The extent to which this risk of small-holder farming females being excluded from economic opportunities arising from CA interventions is acknowledged and engaged with, by development interventions such as SRFSI, is contingent upon how the scaling challenge is framed.

Public agricultural research, development, and extension organisations continue to be heavily influenced by the linear scaling paradigm (Darbas *et al.,* 2020). The systemic notion of scaling is typically experimented with by adding an objective that an enabling environment be created. This does not acknowledge or deal with the structural barriers facing resource-poor households, let alone those facing the left-behind women acting as household heads—often doing so surreptitiously. Regular interaction in some regions between NGO staff, and agronomic and extension project members, was effective in interrupting conscious and unconscious bias towards women as cultivators within the first four years of SRFSI.

7.3 Promoting climate smart food production systems in the EGP

Climate has been an overarching priority for SDIP as a whole. ACIAR SDIP's contribution to improved resource use efficiency and climate smart production systems in the EGP includes a multi-scale understanding of the situation, from farm scale to regional levels. The likely future trends in climate and implications for agricultural production have been synthesised. Extensive on-farm trials tested sustainable farming systems and considered their performance in terms of climate change mitigation and adaptation. The performance and mitigation potential of conservation agriculture-based approaches were modelled under different climate regimes to consider performance over the long term. The practice changes tested also have positive impacts on soil health in terms of the amount and types of carbon present, and improved soil structure. At the same time, these climate smart farming systems can be profitable for farmers and local businesses, creating new employment opportunities for women and rural youth. The work of the program has contributed to a better understanding of climate change impacts through synthesis of the likely trends and their implications for agricultural production at the regional level. Several reports and publications contain details of the work around climate impacts (Dawson, 2019; Gathala et al., 2020; Gaydon et al., 2020; Jackson et al., 2019).

7.3.1 Climate change trends and impacts on agriculture

Over the past 50 years, changes to the climate of the EGP have already been documented. Annual mean temperatures have increased by around 1°C, and the number of extreme heat days has increased while extreme cold days have decreased. There has been a slight decrease in annual precipitation and rainfall intensity has risen. These have influenced optimal planting times and the cropping season length, which have shifted through time (Aryal et al., 2019)(IPCC, 2007). Over the next century, climate change will adversely impact the agriculture sector in South Asia, jeopardising food security and rural livelihoods. The information summarised in this section is reported in full in Dawson (2019), in a report commissioned to synthesise likely climate projections and their influence on agriculture in the EGP.

By 2050, average annual temperatures are projected to be between 1°C-1.5°C higher than the 1980 – 2010 average; by 2100, temperatures will be 2.5°C-4°C+ higher, with warming more pronounced in winter and for night time minimum temperatures. The number of extreme heat days will rise two or three-fold, and the number of extreme cold days will fall by a similar amount. Although trends in annual average precipitation are less certain, the average of all models indicates that total rainfall will increase slightly (up to 10% by 2050), with most of the increase to occur during the summer monsoon months. This increase in the summer monsoon will occur at the expense of winter rainfall, with an increased risk of drier winters. Rainfall intensity will increase, in particular during the summer monsoon. In line with temperature increases, evaporation and evapotranspiration will rise by 5 – 7% by 2050, which will likely offset the projected precipitation increases. Floods and droughts will increase both in frequency and intensity, contributing to more extreme climate variability on a year-on-year basis. River flows will be lower in winter and late spring/early summer, and higher in early spring/late summer.

The changes that will occur to the region's climate will impact on the agriculture sector in a variety of ways, both positively and negatively, although the cumulative effect will most likely be negative. The most immediate threat to agricultural production is due to the increased incidence of extreme weather events, including extreme heat, droughts and floods. Underlying changes to average mean temperatures are the most significant threat in the long term and will push many regions beyond optimal growing conditions and reduce growing season length, particularly during the Rabi (winter) season. As a result, grain yields are expected to fall 10-15% by 2050. By late century, many areas of the EGP will be unsuitable for grain production at all. Although elevated atmospheric CO_2 concentrations will boost crop growth rates and yields, primarily for C3 plants (e.g. maize), but may result in negative effects such as a lower nutritional content of crops. These interacting impacts will have a devastating effect in a region where many people are already malnourished. Pest and pollinator regimes will also change, affecting crop growth cycles, but the net impact on crop yields remains uncertain.

Targeted research on the impact of climate change on EGP agriculture remains limited and needs to be significantly increased, especially in relation to crop heat resilience, changes to insect pest/pollinator regimes, and crop responses to elevated CO_2 concentrations. Farmers and policy makers alike need climate smart, profitable production systems that can help them deal with climate variability and maintain food and nutrition security.

7.3.2 Promoting conservation agriculture for mitigation and adaptation

As well as being impacted by the changing climate, the agriculture sector is a significant contributor of emissions, and hence management practices that can minimise emissions and prevent the loss of soil carbon are important considerations in minimising wider scale impacts. Options are needed that can help farmers build resilience to climate change and mitigate emissions while at the same time maintaining or improving food security.

Reducing indirect on-farm emissions

CASI approaches contribute to climate mitigation by reducing fuel inputs (i.e. for mechanised soil tillage and pumping for irrigation), minimising tillage and improving soil carbon levels, while maintaining or increasing productivity. CASI based systems build resilience to climate change and are demonstrated to reduce the emissions footprint of food production systems in the EGP by 6 - 18% (Gathala et al., 2020). Indirect emissions reductions associated with production inputs vary by cropping system (i.e. for individual crops, CASI techniques reduce emissions on average by 14% for wheat, 10% for maize, 18% for lentil and 8% for rice), and so any changes to the cropping system can have wider impacts on the carbon intensity of the agricultural sector.

Figure 6 shows the relationship between yield, income and energy intensity, clearly demonstrating that with lower levels of energy inputs, higher yields and profit can also be achieved (Gathala et al., 2020; pp 11). Similar work on intercropping of maize with leafy vegetables such as potato, peas, spinach and red amaranth showed that these systems were always more profitable than sole maize, although requiring higher energy inputs, which were offset by higher yields (Tiwari & Gathala, 2017).

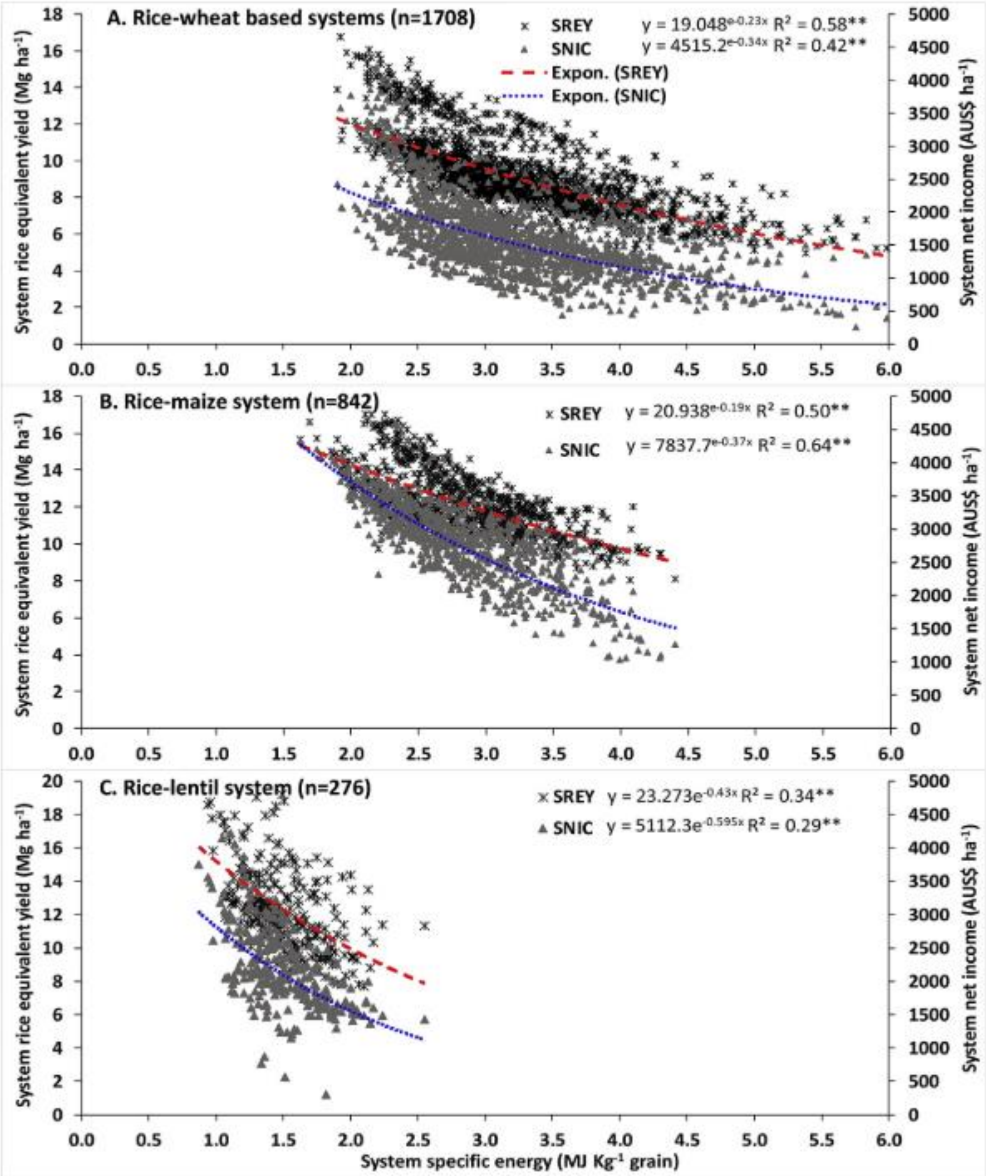

*Figure 6 System rice equivalent yield (SREY) and system net income (SNIC) plotted against system specific energy (SSE) across districts and tillage options under different cropping systems. (A) rice-wheat (RW) systems; (B) rice-maize (RM) systems; (C) rice-lentil (RL) system in the EGP, South Asia. Values in parentheses show the total number (n) of data points; **significant at p = 0.01 level.*

There is potential for significant impact if CASI systems are adopted widely; for example, increasing the use of CASI to 20% of the area of rice, wheat and maize systems in the EGP would increase productivity by almost 2 million tonnes, generate more than $2 billion (AUD) in additional farm profits, reduce irrigation water use by over 2,000 GL, reduce energy use by over 12 PJ and reduce carbon emissions by over 740,000 tonnes of CO_2-e.

Modelling the effect of future climate change scenarios

Using the APSIM model that was validated at ten locations in the EGP during the SRFSI project, further modelling explored the effect of future climate change scenarios on crop production and greenhouse gas emissions under a range of Conventional (CT) and Conservation Agriculture (CA) management interventions (Gaydon et al., 2020). The findings suggest that in the future, the general trends are for increased Rabi crop yields (maize and wheat) and slightly reduced kharif rice yields under CA practice compared with CT. Yields for Rabi season crops (wheat and maize) tend to decrease with harsher climate scenarios and with increasing timeframes. However, wet-season rice yields exhibit the opposite trend and are predicted to increase in future years, primarily as a function of increased CO_2 fertilisation, which overshadows any losses due to increased temperatures and shorter seasons. This is under the assumption that irrigation water can meet any rainfall shortages. Purely rain-fed crops would likely also be challenged by rainfall variability, which will increase in the future (Dawson, 2019).

Simulated emissions were reduced by around 24% by employing CA technologies in the rice-maize and rice-wheat cropping systems, averaged across the SRFSI sites using historical climate data. This represents emissions due to plant-soil-fertiliser-residue processes in the field only. A changing future climate slightly reduces the benefits from CA, with historical, 2050, 2070, and 2090 climates revealing a 20 - 24% benefit. There was no particular protective effect on future grain yields of CA under climate change, compared to CT. The yield gains from implementing CA technologies in wheat under historical, 2050, 2070, and 2090 climates (averaged over all SRFSI sites simulated) ranged from 6 - 2%, and illustrate a declining value of CA on yield as the climate became harsher. Maize follows an opposite trend, ranging from 1 – 4%.

Improved resilience to climate variability

Climate change will affect temperature and rainfall patterns in the EGP. This includes delayed onset of the monsoon, which can prolong harvest dates and hence the planting of dry season crops. The effect of planting date on wheat and lentil yield was examined using data from long-term trials. Yield reductions were recorded for wheat and lentil, including 22 kg/day for planting wheat after the start of December, and for lentil 62 kg/day after the 15th November. This pattern of yield reductions with later sowing was supported by APSIM modelling outputs, with variability between sites and crops captured (Gaydon et al., 2020). An excel based Decision Support Tool was developed based on this modelling, to allow extension agents to compare Rabi crop options as a function of location, management (conventional or CA) and date of sowing opportunity (Gaydon et al., 2020). This kind of information is important under proposed climate change scenarios to maintain optimal planting dates, and to help farmers make decisions about which crop to plant in the dry season to maximise yield and profit.

Improved soil health

CASI systems have a positive impact on both the amount and types of carbon present in the upper soil layers. Soil organic matter is crucial for soil fertility, water retention and maintenance of crop productivity (Awale et al., 2017), and is heavily influenced by management practices such as tillage, residue retention and fertiliser regimes. Impacts on soil carbon have been monitored within the life of the program, with CASI systems appearing to have a positive impact on both the amount and types of carbon present in the upper soil layers. However, changes in soil organic carbon (SOC) are often variable in the early stages of using CA techniques, and stronger trends are often only seen in the longer term. This is supported by modelling results which show potential for 150% increase in SOC over a 35 year time frame.

7.3.3 Avoiding emissions through better resource management

Work from the University of Queensland has contributed to a more nuanced understanding of the impacts of sustainable intensification on emissions, in line with the SDIP’s overarching goal of working to address the impacts of climate change.

Ongoing work is focusing on the following themes:

- **More comprehensive accounting of emissions for CA versus CT systems** to quantify the impacts of different crop management techniques on systems related emissions. This would include combining input related emissions (measured at the farm scale), direct emissions (modelled) and emissions related to residue management pathways (to be calculated), to give a more complete set of emissions for cropping systems in the Eastern Gangetic Plains.

- **A better understanding of nitrogen (N) use efficiency for CA and CT**, including the impacts on emissions, productivity and soil acidification rates.

A major strategy to halting acidification is better management of N fertiliser use efficiency, to ensure minimum losses from the system. As noted in Section 2.3.2 efficient use of N fertilizer will have a positive greenhouse gas impact, and that in the long-term this may be more important than the carbon dynamics in the system. Future studies should consider the greenhouse gas impacts of improving N use efficiency, both in terms of reducing the amount of N applied, hence reducing emissions associated with N fertiliser manufacturing, and the amount of N lost from the soil. Additionally, studies should also consider the greenhouse gas impacts of the remediation approach. For example, remediation measures (applying lime to soils) to overcome acidification developed through poor N fertilizer management, would result in a very poor greenhouse gas outcome.

Focused work on groundwater, as reported earlier, offers an option to improve climate change adaptation and resilience, given likely impacts on rainfall timing, quantity and intensity. At present, groundwater in the EGP is an underutilised resource, and so a better understanding of availability and the implications of its management alongside energy and food policies is critical to maintain sustainability.

Interacting policy drivers for resource management

Avoiding future emissions from different parts of the agricultural system may have more potential impact in the long-run than building soil organic carbon, as this by its nature reaches a new equilibrium after which no additional gains can be made. Reducing emissions associated with residue burning and better management of nitrogen use efficiency are pathways that can have positive benefits in the future.

Rice based cropping systems result in a high level of crop residue after harvest that must be managed before a subsequent crop can be grown. Across India, around 90 million tonnes of crop residues are burnt annually, with rice (43%) and wheat (21%) straw both major residue sources (Bhuvaneshwari et al., 2019). Much of this occurs in the NW Indian states of Punjab and Haryana, within the narrow timeframe available for planting the subsequent crop. Burning of crop residues emitted 141.15 Mt of CO_2 in 2008–09. This contributes detrimentally on atmospheric pollution and greenhouse gas emissions. Stubble burning is currently practiced at low levels in the EGP, but is likely to increase as mechanical harvesting and systems intensification increase. Zero-till crop establishment methods, including the Happy Seeder, are an option to allow a subsequent crop to be sown into standing rice stubble. The adoption of zero till crop establishment methods could reduce future CO_2 emissions significantly by eliminating the need for stubble burning in the EGP.

Sapkota et al. (2019) have estimated the potential emissions reductions associated with a range of agricultural practices for different parts of India. Their analysis shows that it is possible to reduce emissions without compromising food and nutrition security, and indeed up to 80% of the mitigation potential could be achieved using only cost-saving measures. Three mitigation options that fit with CASI approaches tested in the SRFSI project could provide over 50% of the technical abatement potential: efficient use of fertilizer, zero-tillage and rice water management (Sapkota et al., 2019).

The tensions between managing groundwater, emissions and food production should rely on new technologies like the Happy Seeder, as well as policy incentives associated with energy that result in full pricing of electricity. There are lessons for the EGP, where water resources are not constrained, and crop residues are more highly valued for livestock production (Balwinder-Singh et al., 2019).

7.3.4 Climate smart business opportunities

In addition to resource conservation and improved profitability at the household level, CASI systems have resulted in business opportunities in rural communities, including for individual service providers and Farmers Groups, including those with solely female members, because a range of services are required for these farming systems, such as machinery provision and associated inputs like rice seedling mats.

Service Providers are a critical part of the wider CA system in a region where farms are small and fragmented, access to finance is low, and the opportunity for individual farmers to own machines and tractors is limited.

Service Providers fill the gap by taking on the mechanisation services as a business, and selling their services for crop establishment, harvest and post-harvest processes to farmers. CA mechanisation adds an additional income stream in a portfolio of services. Timely and quality service provision is a key enabler in successful CA systems.

In West Bengal India, Farmers Club/Producer Organisations are acting as a linking mechanism between farmers and markets, government programs, financial institutions, research, NGOs and input suppliers research, providing training and associated CA services. The benefit of the FC and FPO model is that they are embedded and supported by government policy initiatives. The introduction of CA techniques has initiated additional income revenue streams for existing groups. Some also act as machinery distributers and centres for repairs and maintenance. Where the mechanical rice transplanter is becoming popular due to lower labour requirements for crop establishment, this technique requires rice seedlings to be grown in specific mats, that are then fed into the machine; production of these mats has added another income stream for farmers groups, particularly women.

7.3.5 Conclusion

Based on work within the SRFSI project across the EGP, there is scope to improve climate resilience and mitigation options for smallholder farmers. Sustainable CA practices that reduce resource use and input related emissions associated with crop production have been tested and are being used by some farmers. Importantly, these reductions do not need to come at the expense of productivity or profitability, creating win-win situations for farmers, rural agribusinesses and governments alike, who are all struggling to find ways to adapt to climate change and reduce future levels of emissions.

These farm level production systems operate within a wider policy context, and the interactions between policy decisions for management of different resources are demonstrated to have unintended consequences, such as the attempt to control groundwater depletion in north west India causing an increase in fires and associated air pollution. Although the situation is different in the EGP, such interactions must be considered and pre-empted, for example in interactions between electricity availability and groundwater use and the impact on emissions. Similarly, if mechanical harvesting becomes more widespread (as is likely with an increasingly mechanized system), residue burning may also become problematic, since mechanized harvesting changes the physical characteristics of the residue, making it harder to manage physically.

7.4 Supporting agriculture in the process of federalisation in Nepal

Nepal is in a transition phase as the full implementation of the new federal system is still underway. This period of change means translating the newly enshrined constitutional rights to food and nutrition security and food sovereignty into effectively working systems at the local government levels. The changed federal structure gives more power to local governments at the municipal (rural and urban) level, adds a provincial level of government for facilitation and support, and changes the role of the federal government to policy, governance, knowledge and oversight issues. This restructuring brings enormous opportunities for agriculture sector services to be prioritised and managed at the local level, bringing the government closer to the people.

But there are challenges associated too, in changing roles, responsibilities and funding mechanisms. For agriculture, the new system means that agricultural services are primarily the responsibility of the provincial and local governments, while research remains at the federal level. Stakeholders at all levels recognise the need for coordination mechanisms to ensure that the new system operates effectively. In this context, ACIAR SDIP is working at several levels to support the transition to federalisation to ensure effective agricultural services.

In the Foresight component, the Centre for Green Economic Development (CGED) have led work on understanding the wider food system in the Nepal Terai (Subedi et al., 2020), and exploring the current situation for agriculture in the new system. They found a multitude of policies and plans that related to agricultural development at all levels, but also challenges in both their coordination and implementation. Discussions with local municipal and provincial staff and community members revealed a lack of staff to fill assigned positions in various government offices, a lack of subject matter specialists, and low budgetary spending despite allocations. These initial constraints could be seen as areas of potential risk that must be managed to allow the implementation to unfold effectively.

A high-level policy dialogue was conducted in Kathmandu that attracted over 40 participants including policy makers from federal and provincial government levels, and other relevant organisations. The objective was to present the evidence and ideas from the initial work, and to get feedback on priority areas for research and support within the new system. Key themes that emerged included the lack of mechanisms that exist for coordination and collaboration, both vertical and horizontal. Policy dialogue was recommended to include local governments to demonstrate promising techniques and ensure informed decision making. Another important area was the need to link the new Agricultural Knowledge Centres (AKC) with research and other knowledge sources. The importance of building human resource capacity across all parts of the system was highlighted.

In the next phase of Foresight work in Nepal, the team from CGED together with the DoA and IWMI will use foresight approaches as a dialogue tool to identify preferred pathways towards a resilient food system, through identifying synergies between the different levels of government who are responsible for delivery of agricultural services. This project will incorporate recommendations from the peer learning workshop and science policy dialogue, to align with identified priorities.

The activities within the ACIAR SDIP program have highlighted the potential for conservation agriculture based sustainable intensification (CASI) practices to improve the livelihoods of those in rural areas of the Nepal Terai. This has led to the development of substantial recommendations to create enabling environments that facilitate the uptake of CASI in farming communities. Yet there remains a gap in how to ‘put into action’ such recommendations. CIMMYT are leading a project that focuses on ‘Building Provincial Capacity for Sustainable Agricultural Mechanisation in Nepal’ to address this gap through the production of participatory roadmaps. Roadmapping is a flexible planning technique to support strategic planning and programming. This process is being developed and applied in Province 1 and 2 in Nepal, where the SRFSI project has been working since 2012. It is exploring the pathways for increased CASI mechanisation through a series of activities that aim to improve linkages and capacity to create and maintain enabling environments. This project responds directly to the need within the new federal structure for cooperative mechanisms at the provincial level.

In several projects and activities we have explored the challenges and opportunities for Nepal’s food systems in the context of federalisation. The existing work goes some way to defining the context, and understanding priorities at different levels of government, to reach a consensus on preferred pathways towards sustainable food systems. The work on mechanisation offers a linking mechanism for one part of the agricultural system at the provincial level. As recommended by policy makers, what is missing is testing and supporting mechanisms for coordination and collaboration for local government to define and implement sustainable food systems and inclusive methods of water management, in the context of their increased power and budgetary availability.

8 Lessons for regional program approaches

The ACIAR SDIP program has focused on understanding the context for and enabling conditions for the development and scaling of sustainable and resilient food systems in the EGP. Experience from the program approach highlights lessons for important elements to include in research for development activities that can help to address complex challenges.

8.1 Capitalising on working across locations

The SDIP had a regional focus at the portfolio level, and ACIAR chose to focus on the EGP at the request of partner governments, as a place with high levels of poverty and serious constraints to agricultural production, and yet with major potential to become a major contributor to regional food security. The EGP, although a contiguous area, has very different political, policy and institutional settings, and covers a range of agro-ecological zones. Most projects worked across locations, with the benefits being cross-site learning, exchange of ideas among different team members, ability to contrast and compare different results to learn lessons for the future development of the EGP.

In Phase 1 (the SRFSI project), the research and development activities under the project were conducted in 40 nodes in eight districts across the EGP in Bangladesh, India and Nepal. These locations were chosen specifically to test techniques in a range of agro-ecological settings, as well as to enable cross-border comparison of results (e.g. Nepal and Bihar; Bangladesh and West Bengal), and to explore the effects of institutional and policy settings. These locations became the basis for subsequent work, although additional sites were also included depending on the project, and particularly in Nepal.

8.2 Working across scales

For a range of issues, projects have worked at multiple scales, from individual to household, community and regional levels. Macro level data let us understand the broad context for diverse elements such as gender, foresight and groundwater development. Connecting this macro level data with micro level data provided a more nuanced understanding of the factors influencing food systems, and let us look for levers of change where they might be most effective. There are multiple examples of linking macro and micro scales, both in individual projects and within key themes.

When researching the role of women in agriculture in the EGP, the analysis of national level secondary data showed feminisation of agriculture in Nepal and Bangladesh, and four reasons for defeminization in India. A primary survey was carried out based on exploratory qualitative field work in selected locations, to provide location-specific explanations for women’s changing role in agriculture. The field insights reveal information not available in labour survey data bases, including the influence of changing cropping patterns, transformation of land-uses, and increasing mechanization. The primary survey complemented explanations provided by the macro analysis in several ways. While the macro analysis suggested an increase in the share of male cultivators which can be interpreted as return of men to agriculture, the primary survey revealed that men are in fact moving back to agriculture in the form of seasonal work during the times of peak labour demand due to lower availability of jobs in urban areas; this in turn is rendering the women jobless or leaving them with less than full employment. These complex processes need to be followed up by detailed research based on systematic primary surveys representative of sub-regions, to inform policy makers so that enabling interventions can promote gender equity based on women’s meaningful engagement in agriculture in the region, rather than a one size fits all approach.

The Foresight work first focused on understanding higher level drivers of food systems in the EGP. Subsequently, a package of work was developed that focused on local level activities (Bangladesh, West Bengal, and Nepal) and national (India) to inform and improve the future of food systems in the EGP region and to strengthen local capacities for scenario-based foresight exercises through training, mentoring and supporting a learning-by-doing approach. Ideas for the local and regional level foresight activities emerged from the discussions and evidence generated in a training workshop held in February 2019. The aim of this work is to connect the big picture context with work at the local/regional level where change can happen.

Several projects contributed a better understanding of options for sustainable groundwater development. Multiple studies within ACIAR SDIP confirm that groundwater in the EGP is an underutilised resource in many locations, and so a better understanding of availability and the implications of its management alongside energy and food policies is critical to maintain sustainability. Work has been undertaken to explore the wider impacts of changes to farm level management of water in response to conservation agriculture and changed energy policies. Understanding these changes demonstrates the importance of understanding the integrated nature of water, energy and food decisions; and points to areas that policy makers can prioritise which can achieve sustainable outcomes.

8.3 Multi-stakeholder engagement

The SDIP portfolio aim was on building capacity for regional integration, so at all levels there was a focus on engaging with multiple stakeholders. Capacity building has been a key area of focus in both phases of ACIAR SDIP, and working on building capacity in several different areas and using a range of methods to improve the enabling environment for scaling sustainable food systems in the EGP. In focusing on multi-stakeholder engagement as a critical element of the program, it meant that capacity building was important to ensure people were on the same page and able to contribute to their best potential. There are a range of examples that show how different projects have engaged with multiple stakeholders throughout the program, to bring together different actors in the food system.

In the SRFSI project, institutional arrangements to support the adoption of CASI were predicated on the idea of working with multi-stakeholder groups or Innovation Platforms (IP). IP are groups of stakeholders that interact within an agricultural system to solve problems at the local level. These groups have actively included the local private sector, who benefit from increased business opportunities, for example through providing custom hiring services of small scale machinery (such as bed planters, zero/strip till drills, Happy Seeders, laser levellers and mechanical rice transplanters, reapers); agro-processing; and seed multiplication and certification services. Together, these groups have built capacity and networks that can self-organise and problem solve to provide information, improve commercial viability, ensure machinery access and identify and exploit market opportunities. IPs are also a way to leverage public extension systems through coordinating local stakeholders and providing an interface between extension officers and smallholders. Local IPs can be linked to higher levels of decision making and resourcing. Importantly, this approach has been flexible and able to be applied differently in the different locations – and a key strength is its ability to be adapted to different contexts and with different stakeholders as the driving force. Importantly, the experiences in working with IP across three countries have given the team valuable experience in applying these approaches in the South Asian context, and will make a valuable contribution to the literature, which is often Africa-centric.

The VMP project is a pilot project testing feasible commercialization models for scale out of the CA-based planter developed in a previous ACIAR project. It specifically collaborates with Hoque Corporation (HC, a manufacturer), the Conservation Agriculture Service Providers Association (CASPA), and the National Bank Ltd (NBL). In this project, HC leads the VMP manufacturing, and piloting of VMP commercialization models. They work with CASPA to identify new and prospective local service providers (LSP) of the VMP. NBL works together with all partners to help new LSP to secure a loan for purchasing of the VMP alone or with a 2WT. In bringing together the partners necessary for production, access to credit and use of this machine, the intention is to smooth the process and make it easier for more farmers to access the machine.

In the Foresight component, multi- disciplinary teams were brought together to understand the drivers and trends outside the farm which influences the food system. These participants represented a range of sectors, expertise and career stage related to the wider food system. The advantage of bringing in people from various disciplines is that it helps to understand the broader context within which farm production takes place.

8.4 Convergence with existing programs

Convergence (i.e. aligning project activities with existing government and development programs) offers scope for scaling that is not always possible in a research project. Key elements of the approach to achieving convergence are highlighted in Figure 7 . These include:

- Policy makers in South Asia care about things that are close to their constituents, and farmers are an important part of it. Addressing farm distress can win elections. Working with partners at multiple levels from farmers to policy makers builds ownership, and they are interconnected and influence each other;
- Local trials provide evidence that a particular innovation in technology and institutions are grounded in reality.
- It is important that we create space for members of the agricultural innovation system to interact and engage with each other, building on successful models in different locations.
- Partnerships with established international partners and national partners adds value as it has a bigger influence and credibility to research results.

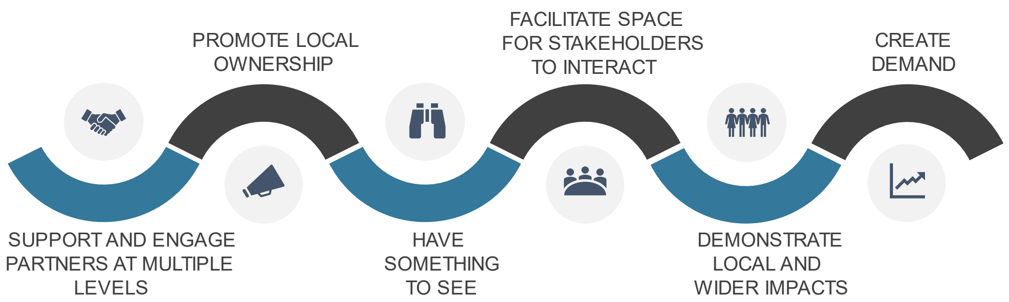

Figure 7 Important considerations on the pathway to impact

8.5 The value of a program approach

The benefits of a program approach experienced during the ACIAR SDIP program include:

- An efficient research process utilising established research infrastructure, networks, research sites, etc.
- An ability to look at an issue from several different angles and at different scales.
- Exploring cross learnings and links across diverse pieces of work.
- Synthesising across different – and emerging – themes.
- The ability to be flexible, for example in undertaking discrete pieces of work as knowledge gaps. emerge. Importantly, these are often able to be done with local partners who have excellent local and regional knowledge and connections.
- Maintaining partnership networks as a solid platform for project work (i.e. as has been developed through the ACIAR SDIP program).
- Adds a wider narrative, and helps to move ACIAR's work along the research to development continuum.
- Creates a platform for debate, sharing and convergence.
- Brings together research and community levels, which gives relevance on the ground.

These benefits rely on dedicated staff who have time and resources to play a supporting, convening and integrating role to ensure that program level benefits are realised.

9 Impacts

The program has demonstrated impact across science, capacity and community sectors during the nine years of operation; and these impacts will continue to be felt in the coming years.

9.1 Scientific impacts – now and in 5 years

The use of CA practices has been rigorously tested across eight districts of the EGP, and more than 3,000 trials have contributed to identifying the impact of changing practices for a range of indicators including biophysical, socio-economic and environmental. Results have been published in 20 journal papers and presented at a range of conferences, making a significant contribution to the knowledge base for CA in South Asia, specifically focused on the often-neglected EGP.

In addition to the farm level testing of CA, work has also been undertaken to scale these approaches, and new knowledge based on these scaling approaches has been identified. In Bangladesh, models of cost-sharing between public-private partners have been identified that lead to sustainable scaling.

New approaches to research and new knowledge which promotes a more nuanced macro and micro understanding of women's roles in agriculture in the EGP, and the impacts of systems change have been identified. For example, a new methodology was developed to allow comparison of secondary datasets between Nepal, India and Bangladesh, specifically related to women's engagement in the workforce. A study which explored the impact of weed management under CASI on women's labour found no additional burden; this addresses the currently limited understanding of how gender norms in the EGP affect knowledge of and responsibilities for agricultural activities, particularly in relation to the uptake of CASI practices.

There has been a substantive body of scientific knowledge of novel methods to assess institutional effectiveness in the EGP. Primary data collected from expert communities and the novel application of the Delphi and Best Worst Scaling techniques to generate the institutional mapping are particularly valuable. This represents a substantive contribution to the New Institutional Economics literature and development analysis

The program has contributed new knowledge to sustainable groundwater development in the EGP, using a food-energy-water (FEW) nexus lens. Individual projects have looked at patterns of availability and access to groundwater, local level water management solutions (i.e. CASI, aquifer storage and recovery), and the impacts of commonly used policies aiming to influence groundwater development and sustainability. Results indicate the links are not always as expected. For example, increased access to electricity has not resulted in a strong change in groundwater use or productivity in West Bengal; and water savings at the farm scale do not always result in reduced groundwater use overall. In the EGP, impacts of climate change will result in delayed monsoons and increased incidence of flooding, which makes summer crops more vulnerable to water stress (both too much and too little). Groundwater resources, which in many places are annually recharged (as at least four ACIAR SDIP studies have confirmed), are more resilient to climate change and offer assured irrigation in the dry winter months.

The weeds and soil projects identified challenges and opportunities for further research to address them.

In five years time, the scientific knowledge generated in this program will have continued to be published, with a target of more than 40 publications in total. Application of this knowledge can improve planning processes in the EGP. In particular, the scientific basis for promotion of CASI and more holistic understanding of groundwater can promote a more sustainable development pathway for the EGP.

9.2 Capacity impacts – now and in 5 years

Capacity development across a range of spheres has been a focus of the program from the start. In total, the program has supported 72,292 people (27% female) to undertake professional development and/or technical training opportunities, including short courses, study modules, and high level study tours. 1,934 people (53% female) have participated in key knowledge/dialogue/policy forums. 26 people (5 female) have been supported to undertake Masters and PhD programs.

Novel extension methods have been used to promote CASI to different stakeholders. Over 8,000 participants joined the first ever Massive Open Online Course (MOOC) covering Conservation Agriculture-based Sustainable Intensification (CASI), delivered by Bihar Agricultural University (BAU) in partnership with CIMMYT. This course provided a comprehensive overview of CASI to an audience ranging from farmers to extension officers and policy makers.

The SRFSI scaling strategy was focused on building capacity to improve the enabling environment for large-scale uptake of CASI innovations. This consisted of a tiered approach to training; experts (L1) who provided training for trainers (L2), who then delivered training to farmers and communities (L3). The focus of training was on technical elements of CASI, but also associated supporting skills like business and finance skills. The number of people trained in this activity constitutes a significant proportion of the training number provided here; and has resulted in a cadre of people trained in CASI techniques, and who can support the implementation of CASI at the local level. Building on this, the Government of West Bengal are establishing a Centre of Excellence for Conservation Agriculture (CECA) at partner university UBKV, with the aim of training 2,500 people per year in CASI approaches. This will have long term implications for supporting CA in the northeast region of India for many years to come.

In the Foresight component, one of the aims has been to help our partners to bring together the 'big picture' related to sustainable food systems, through application of Foresight processes in the EGP. This work has included engaging key stakeholders in informed dialogue on the drivers and trends for regional food, water and energy security through enhanced foresight and scenario processes. More than 200 researchers, planners, policymakers, entrepreneurs and civil society members from Bangladesh, India and Nepal came together over a series of workshops for planning, learning, and information sharing. These workshops helped build and strengthen a core group that is interested in undertaking foresight for food exercises in the region.

Regular opportunities have been provided for cross-country learning and knowledge sharing on a range of topics. Together, these approaches have built capacity to support and apply technical (e.g. CASI, groundwater management, institutional analysis) and systems approaches in the EGP that can help contribute to better regional cooperation.

In five years, with the commencement of CECA planned for 2021, an additional 12,500 people will be trained in CASI approaches over the next five years, focusing on ensuring the training sessions are gender and youth inclusive. This will build a cohort of people who can support CASI scaling in the region.

9.3 Community impacts – now and in 5 years

The program has focused at the community level in terms of understanding the impacts of systems change associated with CASI approaches. CASI farming practices increase productivity and farm incomes and have emission reduction benefits. In total, around 120,000 farmers (25% female)[2] are now using CASI techniques. As well as direct benefits for farming households, CASI also provides business opportunities in local communities.

In five years, if 5% of the Rice-Rice, Rice-Wheat, Rice-Maize and Rice-Lentil systems adopted CASI approaches, this would mean covering 0.7 million hectares, and approximately 1.2 million farmers. If 20% of the of these farming systems adopt CASI approaches, this means covering 2.9 million hectares and 4.8 million farmers. Specific benefits are detailed below with regard to economic, social and environmental impacts. Adoption at scale would reflect the impact of both phases of the program.

9.3.1 Economic impacts

At the farm level, Rice-Wheat, Rice-Maize and Rice-Lentil systems using CASI practices resulted in significantly higher gross margins of around 20%, compared to than conventional tillage, with the gross margin of the partial CASI practice also higher than that of conventional tillage in all systems (but not significantly so in the Rice-Lentil system). Average gross margins for CASI and conventional tillage in cropping systems include Rice-

[2] Number of farmers using CASI practices is reported by partners, who receive information from block level Department of Agriculture staff.

Wheat ($1,097 compared to $869), Rice-Maize ($1,965 compared to $1,672) and Rice-Lentil ($1,605 compared to $1,344). These gross margin data directly reflected the lower costs of production under CASI than under conventional tillage practices. The cumulative impacts of this adoption over the life of SDIP up to mid 2021 includes an estimated additional AUD $100 million in farm household income, and AUD$60 million in reduced production costs. Additional modelling of the risk associated with CASI adoption showed that there is more risk associated with CASI in the early years of adoption compared to conventional tillage, given low levels of experience and higher costs associated with informal lending (compared to trial data) – these risks must be managed for CASI to scale sustainably.

If 5% of the appropriate farming systems adopt CASI approaches, this means an additional AUD $520 million in farm household income annually. If 20% of the of the appropriate farming systems adopt CASI approaches, this means an additional AUD $2 billion in farm household income annually. This does not take into account additional income for service providers and those supporting the mechanisation.

9.3.2 Social impacts

In CASI systems, labour is reduced by 15% – 43% depending on the techniques used and the cropping system. In all cases, reductions in labour use are significant compared to conventional production systems. These labour savings have been demonstrated to allow households, particularly women, more time to pursue alternative productive and reproductive tasks. In addition to reduced labour, drudgery associated with land preparation, transplanting and hand weeding is also reduced.

In the program operating areas, farmers generally access CASI machinery from service providers, which opens up opportunities for small businesses to provide machinery services locally where there is sufficient interest in a community to create demand. These business opportunities also provide opportunities for women, for example in production of rice seedlings for mechanical transplanters; and to own machines as part of group assets. 445 people or groups have been supported to become micro-entrepreneurs for service provision.

9.3.3 Environmental impacts

In accounting for emissions from on-farm production inputs, compared to conventional tillage, CO_2-e emissions under full CASI were significantly reduced by 14% in Rice-Wheat systems, by 11% in Rice-Maize systems, and by 10% in Rice-Lentil systems. Total energy use was reduced by a similar amount.

Water use varied between cropping systems and depending on management. In the Rice-Rice, Rice-Wheat and Rice-Maize systems, significant irrigation use declines were observed (15%, 17%, and 25%, respectively) when CASI techniques were used. Greatest irrigation water savings (of 53%) were observed in the Rice-Wheat- Jute system. Use of irrigation water under CASI compared to CT increased in the Rice-Lentil system by 10%. In terms of total in-crop water use (irrigation and rainfall), total water use was significantly lower in the Rice-Maize (2%), Rice-Wheat (4%), Rice-Rice (8%) and Rice-Wheat-Jute (11%) systems. All cropping systems were significantly more water-productive under CASI than under conventional approaches. Based on the current adoption level of 120,000 farmers using CASI approaches, it is estimated that 60,000 tonnes of CO_2-e have been mitigated, and 63,000 megalitres of water saved within the program's lifetime.

If 5% of the appropriate farming systems adopt CASI approaches, this would mitigate an additional 155,000 tonnes of CO_2-e and reduce water use by 548 GL annually. If 20% of the of the appropriate farming systems adopt CASI approaches, this would mitigate an additional 740,000 tonnes of CO_2-e and reduce water use by 2,192 GL annually.

9.4 Communication and dissemination activities

Communications have been a major focus of the project during Phase 2. The program team have implemented a multi-faceted communications strategy that includes digital (website, social media, bi-monthly e-newsletter, webinars), print (reports and briefs) and film platforms to communicate program structure and project outputs. The program **website** was launched in June 2018 and is regularly updated. Since June 2018 it has received 20,000 pageviews from 7,500 visitors. The website contains information about SDIP, the ACIAR SDIP program and projects. It also acts as a repository for project reports and communication materials.

A series of films highlighting elements of the ACIAR SDIP program were developed and are hosted on the website and shared with partners and wider audiences through social media using ACIAR and partner accounts, and in physical meetings. Films produced include:

1. Agriculture and the food-energy-water nexus
2. Household level impacts for Sulochana Devi in Bihar
3. High Commissioner Julia Niblett meets farmer Lucky Begum in Bangladesh
4. The role of women in agriculture in the EGP
5. SRFSI: The West Bengal Story
6. Kalpana's story
7. Markets working for farmers
8. Stories of most significant change
9. Electrifying groundwater irrigation

The program has organised 12 webinars in 2020-21 to ensure continued dissemination of findings, with results from Small Research Activity projects presented by project teams. These webinars were promoted through ACIAR and other social media, open to a wider audience and received good attendance and participation from a wide range of interested parties.

A **Steering Committee** (SC) was established in early 2018 to guide the work program by informing priorities, responding to higher level research results, and ensuring its integration with regional policy and dialogue processes and other research efforts. The 12 member SC, of which 7 are women, represent the wider agricultural system, including members of national planning commissions, regional partner organisations, academia and the private sector. They have provided valuable guidance to the shape the program, and feedback suggests they are impressed by the comprehensive program of work under ACIAR SDIP, covering a range of issues relating to agriculture's contribution to the wider food system.

Linking ACIAR SDIP with existing ACIAR projects in South Asia has been pursued in several ways. The aim was to share experience and expertise in intensification of farming systems in the EGP region across a range of disciplines, scales and approaches, to understand the synergies and trade-offs across the work already being undertaken by ACIAR. Relevant project leaders have been invited to program meetings, with a workshop focused on Diversification for Sustainable Food Systems in South Asia held in December 2018 to bring together 30 researchers representing 10 research organisations from Australia and the CGIAR, including ACIAR Research Program Managers (Water and Climate Change, Crops, Horticulture, Livestock and Farming Systems) and regional staff; partners from the SDIP portfolio; and other researchers working in the EGP.

Integrating across the program has been necessary given the diverse program structure, with 20 projects in total of varying sizes and complexity. This integration was managed by having two full time staff based in the region who were dedicated to program management and regional coordination; frequent communication through newsletters and the website to share information and resources; working with existing partners across different projects at the local and regional level, and selecting new partners who work in a collegiate way. The Foresight component is being used as one way to integrate different elements of the program. For example, Professor Sucharita Sen contributed to all of the Foresight meetings, bringing her background in social geography and results from the study into the role of women in agriculture in the EGP. This helps share the findings from this study across different parts of the program. Similarly, several local partners have been engaged in work from farm, institutional and foresight levels, and they help in bringing a ground-check to the wider thinking in terms of influences in food systems. Data sharing has occurred, for example between the SRFSI and Institutions projects, where data from on-farm research trials has been re-analysed to look at different risk profiles. Responding to the key theme of climate change as a focus for SDIP, a standalone report synthesising the different pieces of work around climate change has been undertaken, with elements of field and farm level impacts on emissions, resource use and soil dynamics considered, as well as modelled performance of CA verses conventional systems under different climate scenarios, and the potential impacts of wider adoption of CA based systems across the EGP.

Public diplomacy efforts have been made to contribute to raising Australia's public profile through ACIAR SDIP activities. High Commissioners from India and Bangladesh, and Ambassador to Nepal have all visited project sites and joined high level workshops and meetings. West Bengal has been a site of success for CASI activities, and as a priority state for Australia as identified in the India Economic Strategy, can offer leverage opportunities for DFAT. Water is an established strand of the Australia-India bilateral relationship, supported by a high-level formal agreement. Australia is internationally recognised for its water resources management expertise and is an established and trusted partner in the Indian water sector. With the Indian Government launching large-scale infrastructure projects in water, Australia is well-positioned to assist India to strengthen its water governance and management systems and support increased engagement by Australian companies in the Indian water sector. India has launched the National Water Mission with an aim to improve the efficiency of water use by at least by 20%, and agriculture, industry and domestic water are key areas of focus. They have identified the use of micro irrigation, promotion of water neutral and water positive technologies, and recycling of water as key measures for increasing efficiency. This offers an opportunity for DFAT in India to explore agriculture as an entry point to engage on policy development, including through water-efficient agriculture. In terms of climate, a regional understanding of how food systems are changing can help with longer term climate smart and resilient planning and investment; and cultivating productive relationships can help position Australia as a trusted and useful partner for India's own policy objectives.

10 Conclusion and opportunities for future work

The ACIAR SDIP Phase 2 program goal has been to maximise agriculture's contribution to sustainable food systems in the EGP, for improved food, energy and water security. The program has transitioned from identifying and promoting sustainable farming technologies based on conservation agriculture, to a focus on understanding the wider context of the food system and the various external factors which influence sustainable food production. The program has worked to promote resilient and inclusive food systems supported by robust institutional arrangements, policies and strategic regional planning, in the context of a changing food system.

The program's second phase had ambitious goals in a short time frame, with work planned to be delivered from mid 2018 – mid 2020 and then extended twice to September 2021. The Covid-19 pandemic caused delays to several projects, and meant primary data collection was not possible for two of the larger projects. Importantly, the pandemic also prevented planned synthesis and knowledge sharing events which were to take place at the end of the program. These have been difficult to deliver on-line, although webinars have served the purpose of communicating individual project outputs.

Despite the pressure of time from the start, the program has delivered a wealth of information around the context for food systems in the EGP; identified effective institutional arrangements; supported an improved understanding of the scaling of sustainable farming techniques; built capacity in a range of areas from mechanisation to foresight processes; contributed evidence to the understanding of the unique food-energy-water nexus in the EGP; and identified broader constraints in our understanding of gender in agriculture. Work from several individual projects demonstrates the importance of an integrated understanding of the system as a whole for sustainable, profitable and resilient food systems to be achieved.

Although the program has covered a broad span of the food system, there are some areas that have been less well studied. This includes nutrition and dietary diversity, which has been touched on but deserves more attention. It may be possible to link with different programs and organisations with a nutrition focus in the future. Farm scale projects have focused mainly on cereals, and there is scope and demand from partners that more diversified systems be considered in new projects. Market systems have not been a major focus, apart from localised work on mechanisation; expanding this would be an important part of future project particularly when incorporating a diversified livelihood systems focus.

The ACIAR SDIP program has set the scene for future work in the region, by producing a body of work that demonstrates the potential for change from farm to regional scales. Future work can capitalise on this work by integrating the lessons and allowing time for their implementation and learning from this, to contribute to understanding the processes for transformation of food systems. Elements that need to be built on to achieve this include:

- Consolidate the lessons from different scaling approaches to draw out key elements that are needed to support food system transformation;
- Explore the capacity for implementation of policy settings, building on the work done several projects in this program;
- Refine recommendations to optimise policies that impact the food-energy-water nexus in the EGP, including a better understanding of water markets and how they respond to energy, water and food policy. Completing the primary survey developed by the University of South Australia can help to contribute to this understanding by providing farmers' experiences and preferences for institutional arrangements;
- Address the lack of studies and key data in the EGP that clearly establish a farm–to–region water balance. Time-series spatial data on actual evapotranspiration is particularly lacking. Studies at a range of scales, from farm to region, are required to determine the impact of farm-scale water saving measures on regional hydrology;
- Target research on the impact of climate change on EGP agriculture remains limited and needs to be significantly increased, especially in relation to crop heat resilience, changes to insect pest/pollinator regimes, and crop responses to elevated CO_2 concentrations. Farmers and policy makers alike need

climate smart, profitable production systems that can help them deal with climate variability and maintain food and nutrition security.

- Address soil acidification, including the different forms of nitrogen supply, and the level to which groundwater irrigation can neutralise acidification.

Several of these research themes will be explored in a follow-on project to commence in October 2021. The project will build on work done in ACIAR SDIP to define the processes and practices (technical options, scaling interventions, policy settings and implementation) that can be applied to achieve sustainable, efficient, diversified food systems at scale in the Eastern Gangetic Plains.

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