Towards phosphorus and climate smart agriculture (PACSA) in Sri Lanka

Technical Report · October 2017

4 authors:

Dana Cordell
University of Technology Sydney

Mohamed Esham
Sabaragamuwa University of Sri Lanka

Elsa Dominish
University of Technology Sydney

Brent Charles Jacobs
University of Technology Sydney

Towards Phosphorus and Climate Smart Agriculture (PACSA) in Sri Lanka

www.sab.ac.lk

Institute for Sustainable Futures

www.isf.edu.au

TOWARDS PHOSPHORUS AND CLIMATE SMART AGRICULTURE (PACSA) IN SRI LANKA

2017

Authors:

Dana Cordell[1]

Elsa Dominish[1]

Mohamed Esham [2]

Brent Jacobs[1]

[1] Institute for Sustainable Futures, University of Technology Sydney

[2] Sabaragamuwa University of Sri Lanka

ABOUT THE AUTHORS

The Institute for Sustainable Futures (ISF) was established by the University of Technology Sydney in 1996 to work with industry, government and the community to develop sustainable futures through research and consultancy. Our mission is to create change toward sustainable futures that protect and enhance the environment, human wellbeing and social equity. For further information visit: **www.isf.uts.edu.au**. ISF Research team: Dr Dana Cordell, Elsa Dominish and A/Prof Brent Jacobs.

Sabaragamuwa University of Sri Lanka (SUSL) was established in 1995 and within a short time, the university has become a center of academic excellence in higher education and has recorded significant achievements in teaching, research and the other key areas within the higher education system in Sri Lanka. For further information visit: **www.sab.ac.lk**. SUSL Research team: Prof Mohamed Esham.

CITATION

Please cite as: Cordell, D., Dominish, E., Esham, M. and Jacobs, B. (2017), *Towards Phosphorus and Climate Smart Agriculture in Sri Lanka*. Report prepared by the Institute for Sustainable Futures at University of Technology Sydney in collaboration with Sabaragamuwa University of Sri Lanka.

ACKNOWLEDGEMENTS

The authors would like to thank PhD candidate Madhuri Nanda from the Coca-Cola Department of Regional Water Studies, TERI University, India, for research assistance during the stakeholder interviews.

The authors would like to acknowledge the invaluable perspectives, knowledge and ideas offered by the 32 stakeholders interviewed for this research. From senior government staff through to family farmers, the generous time provided by all stakeholders was greatly appreciated and formed the primary data for this social research.

DISCLAIMER

PHOTOS

Cover: Vegetables for wholesale at a trading centre in Sabaragamuwa Province
1 Organic garden at an eco hotel in the Central Province
2 Vegetables for wholesale at a trading centre in Sabaragamuwa Province
3 Failed crops due to erratic rainfall and heat in Sabaragamuwa Province
4 Bags of compost derived from municipal organic waste ready for sale and distribution
5 Woman purchasing products at a local agrochemical retail outlet
6 Smallholder farming plots in the Central Province
7 Vegetables for wholesale at a trading centre in Sabaragamuwa Province
8 Children at local food shop in the Central Province

INSTITUTE FOR SUSTAINABLE FUTURES

University of Technology, Sydney
PO Box 123 Broadway, NSW, 2007
www.isf.edu.au

TABLE OF CONTENTS

GLOSSARY OF TERMS

APRA	Agricultural Research Production Assistants
CKDu	Chronic kidney disease of unknown etiology
CSA	Climate Smart Agriculture
DOAD	Department of Agrarian Development
FAO	Food & Agriculture Organisation of the United Nations
GAP	Good Agricultural Practices (FAO)
INDC	Intended Nationally Determined Contributions
NAP	National Adaptation Plan
PACSA	Phosphorus and Climate Smart Agriculture
PPP	Public-Private Partnerships
SLSI	Sri Lanka Standards Institution
TSP	Triple-superphosphate (fertiliser)
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WHO	World Health Organisation

EXECUTIVE SUMMARY

Two of the biggest global challenges for food security – phosphorus scarcity and climate change – are threatening farmers' livelihoods, agricultural productivity and environmental health. Sri Lanka's agricultural sector is comprised largely of smallholder farmers, where rain-fed rice is often a staple of the diet. Climate change projections indicate rice yields could drop by 40%, affecting the majority of farmers and increasing poverty levels by up to a third. At the same time, fertiliser subsidies, which represent 2% of government spending, are currently being scaled back in a country that is dependent on fertiliser imports. This exposes farmers to future price fluctuations like the 800% phosphate fertiliser price spike that occurred in 2008.

The goal of this collaborative research project is to contribute to building food system resilience to climate change and phosphorus scarcity in Sri Lanka, through adaptations from farm-scale through to policy-making. This report presents the first phase of the project investigating the capacity of smallholder farmers, policy-makers, industry and other food system stakeholders in Sri Lanka to adapt to these twin challenges, via a participatory, integrated, rapid vulnerability assessment framework.

The report is structured as follows:

- **Sections 1-3**: context and a conceptual framework for the analysis.
- **Section 4**: interlinked risk pathways between climate change, phosphorus scarcity and food security.
- **Section 5**: the current and potential future adaptive strategies towards phosphorus and climate smart agriculture, identified by stakeholders.
- **Section 6**: stakeholders' capacity to adapt to support a sustainable situation.
- **Section 7:** key conclusions.
- **Section 8**: recommendations for a way forward.

Most respondents –especially farmers– reported experiencing changes to the climate and water availability, including delayed monsoons and more intense drought and floods. This has led to increased incidence of pests and diseases, reduced crop yields and serious financial consequences. However, there was very little reported awareness or experienced impact of phosphorus scarcity, including how the increasing scarcity of the world's non-renewable phosphorus resources, and associated geopolitical risks, might affect Sri Lanka's security of phosphorus supply for food security.

We find that while Sri Lanka is vulnerable to these twin risks, there are many adaptive strategies already in place or planned, which although not primarily driven by climate change adaptation or phosphorus scarcity, could be strengthened to ensure phosphorus and climate smart agriculture (PACSA).

Sri Lanka's food production is in the midst of a major transformation, largely driven by the President's push for organic agriculture to create a 'toxin-free nation', including fertiliser subsidy reform, promotion of organic fertilisers and a ban on glyphosate weedicide (*Roundup*). Transformation towards PACSA is also being indirectly facilitated by pressures to improve waste management and climate mitigation measures, such as household separation of organic waste and waste-to-energy systems implemented through public-private partnerships (which will also generate organic fertilisers).

There are many win-win PACSA opportunities both on- and off-farm, such as developing crop varieties that are drought-tolerant and also less dependent on phosphorus fertiliser, diversification of crops and improved cost-effective cold storage in the food value chain to reduce food losses.

Adaption to climate change and phosphorus scarcity in Sri Lanka may be impeded by: fragmentation of current programs under numerous different Ministries and Departments, mistrust between some stakeholders in the supply chain, labour shortages, resistance to changing paddy practices and low farmer purchasing power. Further, vegetable farmers may find it harder to adapt than rice paddy farmers because rice is considered a staple for food security and is supported by fertiliser subsidies and two institutional channels for purchasing paddy at a guaranteed predetermined price.

There is a need to bring all key stakeholders on board to implement change in a coordinated and managed way – including the relevant Ministries, but also industry and farmer organisations. In addition to improving integration across sectors and actors, specific recommendations include:

- **Extending the Climate Change National Adaptation Plan** to include off-farm strategies such as food chain cold storage, and, integrate phosphorus adaptations such as low phosphorus-demanding crops.
- **Improve awareness, communication and capacity building,** among: farmers regarding the use of some organic wastes; extension services to better match knowledge with the local context and a changing climate; and relevant government departments regarding awareness of phosphorus scarcity.
- **New knowledge and research**, including: optimising the organic waste system, overcoming market impediments, the implications of phosphorus scarcity and undertaking a comprehensive phosphorus budget.
- **Improve resource efficiency**, to reduce system losses of water, food waste and phosphorus, and, diversify nutrient/water inputs to agriculture.
- **Strengthen vegetable markets**, by supporting vegetable farmers to ensure a more even playing field with rice farmers, and promoting vegetable consumption to improve nutritional security and public health.

1 INTRODUCTION

The challenge of phosphorus scarcity, coupled with climate uncertainty, has serious potential consequences for food security, that is, the future availability, accessibility and nutrition of food. The goal of this research is to contribute to building food system resilience to climate change and phosphorus scarcity through adaptations from farm to policy-making in Sri Lanka. Ultimately, this research project seeks to transform the food system (which includes farmers' practices, the agrochemical and food industry, waste managers and institutional environments) from one characterised as relatively vulnerable, inefficient/low yield, with constrained adaptive capacity and polluting, to a system that enables farmers to:

- maximise crop yields through adoption of efficient agricultural practices
- support their families
- reduce runoff to waterways; and
- create a resilient and sustainable food system in Sri Lanka.

This report presents outcomes from the first phase of analysis of the PACSA project, identifying the interlinked phosphorus-climate change vulnerability of Sri Lanka's food system, the adaptive capacity of key stakeholders and adaptive strategies in Sri Lanka. While each country's sensitivity to these global challenges is context-specific, the framework used here has been designed for potential application in other locations, for example, other diverse socio-economic countries in Asia Pacific, such as India, Fiji, Singapore & Australia.

Sections 1-3 provide context and a conceptual framework for the analysis, while **Sections 4-8** detail the analysis and conclusions.

In **Section 4** we first identify interlinked risk pathways between climate change, phosphorus scarcity and food security.

Section 5 describes the current and potential future strategies to adapt towards phosphorus and climate smart agriculture.

In **Section 6** we identify stakeholders' capacity to adapt and finally key conclusions (**Section 7**) recommendations for a way forward in **Section 8**.

1.1 Climate change, phosphorus scarcity and food security

Ending hunger, achieving food security and promoting sustainable agriculture are global priorities as established under the UN's 2nd Sustainable Development Goal (UN 2016). Importantly, this Goal seeks "*to double the agricultural productivity and incomes of small-scale food producers… including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets*" (UN 2016). Two of the most complex global threats to achieving this goal —phosphorus scarcity and climate change— are still insufficiently understood.

Increasing scarcity of the world's main source of phosphorus is one of the most under-researched and under-represented policy issues (Cordell & White 2015). Without phosphorus, we cannot produce food. Phosphorus is an essential element for crop growth in the form of fertilisers, yet, the world's main source of phosphorus - mined phosphate rock - is non-renewable and becoming increasingly scarce and expensive (UNEP 2011). Further, while all farmers need access to phosphorus fertilisers, just five countries control 86% of the world's remaining reserves (Cordell & White 2015). Morocco alone controls three-quarters of the world's phosphate, and this global share could increase to 90% by the end of the century (Cooper, et al. 2011). This leaves importing countries, from India to Europe to Australia, vulnerable to decisions of a few producing countries[1]. In 2008, the price of phosphate spiked 800%, leading to farmer riots, suicides and Senate Inquiries across the world. Although the

[1] See more at http://phosphorusfutures.net.

price has since come down somewhat, the spike indicated the vulnerability of food systems to even a short-term disruption in supply and price spikes. However, as with many natural resources, the core problem can be attributed to failures of governance rather than simply attributed to limitations in the physical resource (Pahl-Wostl 2009).

The impacts of a changing climate affect food security in a number of ways. The direct effects of prolonged droughts or delayed onset of monsoon rains on agronomic uncertainty and risk of crop failures can flow on to determine the types of crops that can be grown and the viability of cropping systems (Iizumi, et al. 2013). However, the entire food value chain, and hence, food security, can also be compromised indirectly by climate change. For example, increased post-harvest spoilage of crops is associated with erratic weather during storage, or food price spikes are associated with climate-induced crop failures in exporting countries leading to increased food insecurity among urban poor (who are net food buyers) in low income countries (Esham 2016).

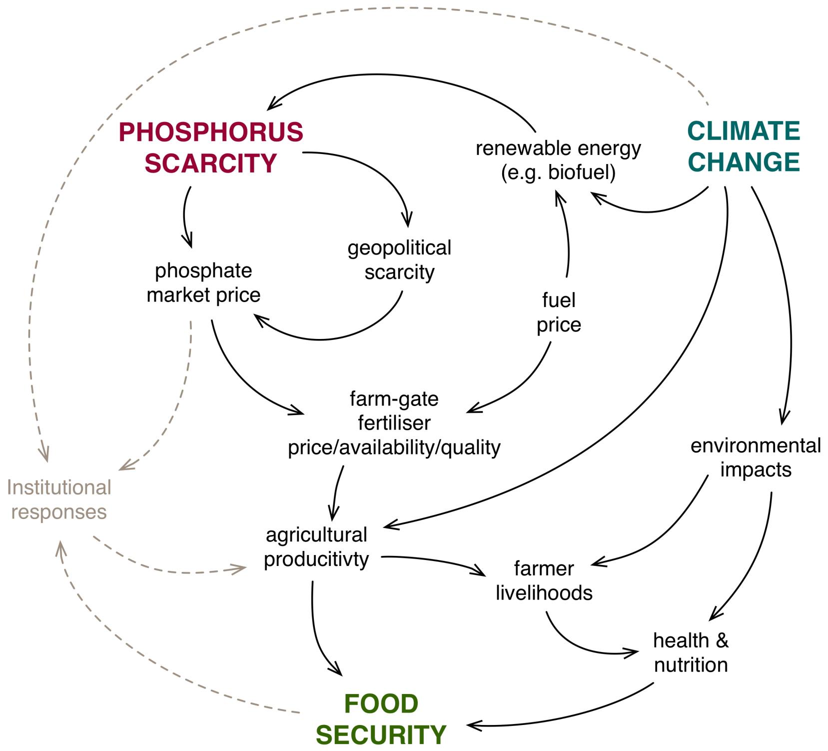

Figure 1: Conceptual visualisation of interactions between phosphorus scarcity, climate change & food security. Institutional responses are in grey dashed lines indicating they could be strengthened to improve the resilience of the food system.

These implications of phosphorus scarcity and climate change for food security have not been comprehensively or sufficiently assessed in an integrated way. Figure 1 provides a conceptual picture of some of the interlinkages between phosphorus scarcity, climate change and food security. Further, there is a need to integrate across scales. That is, complement local and short-term agricultural initiatives with strategic regional-level, medium/long-term actions that can together improve the resilience of food and farming systems. Vulnerability and adaptive capacity frameworks have been proposed to inform effective design of future governance regimes that are flexible and account for complexity (Adger 2006; Folke 2006).

This research fills three important knowledge gaps. First, existing research in the food security field has largely ignored the implications of phosphorus scarcity for food security until very recently (Cordell & White 2014). Assessment of regional phosphorus scarcity in vulnerable low-middle income countries is most lacking: efforts to-date have focused predominantly on Europe, US and Australia. Sri Lanka has no baseline phosphorus budget for the food system on which an adaptation/vulnerability assessment can be built[2]. Second, although it is widely acknowledged that small-scale family farmers make up the majority of food producers globally (FAO 2014), there remains a lack of systemic knowledge and analysis within the field of global food security into how these vulnerable groups can adapt to climate change, achieve food security and protect local ecosystem services such as soil fertility and clean, reliable groundwater resources (IFAD 2013). Third, few, if any, studies have sought to study the multi-scalar, social-ecological and inextricable links between phosphorus scarcity and climate change, and how these explicitly interact to impact food security; for example, how farmers coped with the simultaneous extreme drought and phosphorus fertiliser price spike of 2008.

1.2 The Sri Lankan food system

In common with similar nations, the low-middle income island state of Sri Lanka is highly vulnerable to the twin challenges of phosphorus scarcity and climate change. For example, with an agricultural sector comprised largely of smallholder farmers where rain-fed rice is a staple of the national diet, climate change projections indicate rice yields could drop by up to 42%, which is predicted to affect approximately 70% of farmers and increase poverty levels by up to a third (Esham 2016; Zubair, et al. 2015). At the same time, agricultural soils are largely phosphorus-deficient (Kumaragamage & Indraratne 2011), yet phosphorus fertiliser subsidies are currently being scaled back, leaving farmers heavily dependent on imported phosphate and vulnerable to future price fluctuations.

1.2.1 Food security

Sri Lanka produces about 85% of its annual food requirements domestically, with a low reliance on imports (Department of Census and Statistics 2014). However, the local food system is still intertwined with global markets. The country has almost achieved self-sufficiency in its staple food, rice (Department of Census and Statistics 2011), but, during the 2008 global food crisis, even domestic rice prices doubled in a year (Esham et al. 2017). The local market is vulnerable to adverse weather conditions that require the short-term import of rice and other essential items to make up the shortfall and control escalating prices. For example, Sri Lanka imported the largest quantity of rice in its history in 2014 when production dropped by 27% due to adverse weather conditions (Esham et al 2017)[3].

The agricultural sector plays an important role in Sri Lanka's economy with 41% of the economically active population engaged in primary agricultural production (FAOSTAT 2014). Smallholder farmers, cultivating an average landholding size of 0.87 ha, produce eighty percent of the local food requirement (Esham et al. 2017).

1.2.2 Climate change

The food system in Sri Lanka is threatened by rapidly changing and more unpredictable climatic conditions. The most important climatic parameters impacting food production are rainfall variability and temperature rise. Studies point to systematic warming taking place at

[2] Addressed in another part of this project, not presented here.

[3] In the period following this research (Oct-Dec 2016), prolonged drought caused similar widespread rice paddy failures in Sri Lanka, leading to a spike in rice prices and the government importing rice from Asian countries (pers comm, D.B.T.Wijeratne, Assistant FAO Representative (Programme) 13/2/17).

an increasing rate (Fernando et al. 2007; Zubair et al. 2010). The staple food, rice, is highly sensitive to temperature rise as it is already being grown close to the temperature tolerance threshold. Exposure of the developing spkielets (flowers) of the rice plant to temperature above 31°C reduces pollen fertility and paddy yield (Dharmarathna et al. 2014). Although the amount of annual rainfall has not significantly changed, delays in the onset of rainfall and changes in rainfall distribution have resulted in disturbance to the normal cropping calendar, frequent crop failure and yield loss (Esham & Garforth 2013). The prevalence of extreme climate events has increased in recent decades leading to negative impacts on food production, especially on rice production, resulting in the need to import significant quantities of rice to meet national requirements (Esham et al. 2017; Gunda et al. 2016). It is predicted that the predominately rice growing area, the dry zone, where nearly 72% of rice is produced will receive lesser amounts of rainfall in the coming years leading reduced rice production (De Silva et al. 2007).

Climate change impacts extend beyond agricultural production to other food system activities such as post-harvest storage, processing, distribution and consumption. However, most research on food systems in Sri Lanka has focused on climate change impacts on agricultural production and productivity, and little has been done to understand the climate change impacts on other food system activities. Available evidence for Sri Lanka shows that there is significant loss along food supply chains of both perishables and non-perishables due to poor supply chain infrastructure and technology in the food system in Sri Lanka (Esham et al. 2017).

1.2.3 Agricultural markets and food value chain

Fruit and vegetables, excluding produce consumed by farming households, are sold through traditional markets. Smallholder farmers sell their produce to assembly agents or wholesale traders at Dedicated Economic Centres established in major farming districts (Ministry of Food Security 2015). Produce is then distributed to wholesale markets in major cities and retailers including local markets or supermarkets. Some produce is also sold via direct contract to supermarkets. Organic farmers are able to sell their produce for higher prices, sold through different channels with fewer outlets.

Paddy rice is sold through a parallel market to the fruit and vegetable market. Smallholder farmers can either sell to private buyers, which make up more than 90% of the market, or to the government-run Paddy Marketing Board or Multi-purpose Cooperative Societies. These institutional buyers have a fixed purchasing price which is higher than private buyers, but farmers are often unable to meet the pre-specified quality requirements, and usually end up selling the rice to private buyers for a lower price (Senanayake and Premaratne 2016).

Sri Lanka has high post-harvest losses due to poor infrastructure and transportation channels at all stages of the supply chain, losing an estimated 30% of food before it reaches the consumer. Losses are particularly high for fruit and vegetables (up to 40%) and fish (30-40%) compared to paddy (approximately 15% losses) as they are channelled through traditional markets with many intermediaries (Esham et al. 2017). Unpredictable rainfall and extreme weather events have a serious impact on post-harvest losses and increasing under a changing climate impacts these will increase accelerate losses unless the post-harvest infrastructure is improved. At the same time, the shelf life for fruits and vegetables is expected to reduce due to higher temperatures associated with a changing climate (Esham et al. 2017).

1.2.4 Farmer productivity & livelihoods

Smallholder farmers have little control in agricultural markets as assembly agents set the prices for produce. At the same time, poor storage management limits farmers' ability to store produce (particularly rice) to hence their ability to take advantage of higher prices (Esham et al. 2017). One industry stakeholder interviewed explained that as produce exchanges hands several times between the farmer and final consumer, the intermediaries see more profits than the farmers.

Further, smallholder farmers have limited fertiliser market access and have naturally phosphorus-deficient soils leading to low crop yield (Kumaragamage and Indraratne 2011). Farmers regularly misuse or overuse fertilisers, which have been attributed to the fertiliser subsidy (Bandarage 2013, Central Bank of Sri Lanka 2014). This is supported by one government respondent who reported that in some areas the soils are saturated with excessive levels of phosphorus. Two-thirds of cropland is rain-fed (Biradar et al. 2009) which leaves farmers highly vulnerable to variations in rainfall, as well as temperature, which can decrease productivity. There are two rainfall seasons in Sri Lanka, Maha and Yala, and the delayed or uncertain start to monsoon can make planning difficult and the heightened risk crop failure (Esham & Garforth 2013).

A fertiliser retailer respondent reported that due to changing climatic conditions, cultivation was occurring in the off-season, soil quality has reduced and that the incomes of smallholder farmers were declining. These factors put upward pressure on an already vulnerable sector where incomes are extremely low. While the agricultural sector employs 41% of Sri Lankans (FAOSTAT 2014), this only represents 7.8% of GDP (Central Bank of Sri Lanka 2016). Poverty is high among households dependent on agriculture, particular smallholder farmers. Agricultural smallholdings are prevalent in areas where a high incidence of poverty is reported (Amarasinghe et al. 2005). Moreover, there is a correlation between the size of paddy holdings and poverty: that is, smallerholder farmers tend to have higher levels of poverty (Sanderatne 2004).

1.2.5 Government extension services and farmer knowledge

At least eight government ministries and departments are responsible for or influence food security in Sri Lanka. The Ministry of Agriculture has two departments dealing with agricultural extension (that is, translating scientific research to agricultural practices via farmer education and training). First, the Department of Agriculture's major functions include research, extension, production of seed and planting material, regulatory services related to plant quarantine, soil conservation and pesticides, setting imports and fertiliser recommendations. The Fertiliser Secretariat sits within the Department of Agriculture and is responsible for the quantity and quality assurance of fertiliser imports and managing the fertiliser subsidy. Second, the Department of Agrarian Development (DOAD) is responsible for formulation and implementation of agrarian law, strengthening and development of farmers' institutions, agriculture land management and water resource management.

There are Provincial departments of agriculture within Sri Lanka's nine provinces. These provinces are further divided into districts (25 in total across the country) and local divisions. There are 551 Agrarian Service Centres that operate at the local levels, managed by more than 8500 Agricultural Research Production Assistants (APRAs).

Other agriculture-related State agencies include: Department of Export Agriculture (which provides extension for spice production), Coconut Cultivation Board, Tea Smallholding Development Authority, Rubber Development Department and The Provincial Department of Agriculture & Livestock.

There are three State organisations involved in irrigation management. Mahaweli Authority (Mahaweli scheme), Department of Irrigation (major tanks) & Department of Agrarian Development (minor/village tanks with the involvement of farmer organisations). Major irrigation schemes along Mahaweli River are managed by Mahaweli Authority of Sri Lanka, while the small systems (and the larger outside of Mahaweli) are managed by the Irrigation Department. Water diversions can also occur between districts.

Farmer organisations share recommendations from the Department of Agriculture to farmers. Farmers are often part of farmer organisations that have either been established by farmers or set up by the government. Farmer organisations in paddy producing areas are mainly established by DOAD (these farmer organisations facilitate the fertiliser subsidy). The number of farmer organisations established by farmers themselves is very low compared to those set up by DOAD. The role of these organisations varies in different locations, including providing machinery and loans to farmers; some charging a fee to join the organisation.

The decision-making process on water allocation and cropping calendars is both top-down and bottom-up, decided at a pre-cultivation meeting between agencies responsible for the local reservoir and farmer organisations.

Farmers get much of their information from agrochemical retailers and fertiliser companies (who promote their own products) (Bandarage 2013). Farmer organisations reported that the Department of Agriculture provided advice on reducing fertiliser use.

1.2.6 Fertiliser markets and use

Although Sri Lanka has a high proportion of food grown locally, it has a high dependence on imported fertilisers. There is a low diversity in the types of fertilisers used and low use of organic or renewable fertilisers[4]. Fertilisers are subsidised, representing 2-3% of Sri Lanka's government annual expenditure on average, peaking at 2.7% in 2008[5] (Central Bank of Sri Lanka 2014). This leaves the country vulnerable to fertiliser price fluctuations and changes in availability on the international market. Sri Lanka has a domestic phosphate mine, but phosphate rock production is limited and is only used for plantation crops. Although there are plans for developing the mine, a government respondent noted there has been local resistance.

Fertiliser companies import phosphate based fertilisers from China and Russia, and according to a government respondent, often import when the price is low and store for future seasons. Fertiliser imports are regulated by the national Fertiliser Secretariat under the Department of Agriculture which is responsible for determining input amounts and quality assurance. In the past, the Secretariat determined the required fertiliser for the country in a given year, and fertiliser was imported only by government-owned companies. Today, the market has opened up and private companies are able to import and sell alongside the government owned company within the guidelines of the Fertiliser Secretariat. The quality of fertiliser imports has been an issue in the past, but it is no longer so according to a government stakeholder. The Fertiliser Secretariat, alongside the Finance Ministry, also manages the fertiliser subsidy, which recently changed from subsidised fertilisers to a direct payment to farmers (see section 4.1.2).

Importantly, there is no comprehensive research or knowledge on the implications of long-term phosphorus fertiliser scarcity on the Sri Lankan food system.

1.2.7 Diet and health

Nutritional security in Sri Lanka remains relatively poor, particularly for the urban poor and smallholder farmers (Esham et al. 2017). The consumption of high levels of starches and low levels of fruit, vegetables and protein are linked to an increase in non-communicable diseases including diabetes and heart disease (Jayawardena et al. 2014). Rice is the staple food contributing 33% of calories and 41% of protein requirements in diets (FAO 2012). Because of this, households are reluctant to substitute rice during price spikes, and when rice prices rise, consumers continue to buy rice because it is seen as a staple of the diet (Esham et al. 2017). In comparison, when vegetable prices increase, consumers tend to reduce the volume of purchasing and are likely to not begin buying them again even when prices reduce (pers comm, D.B.T.Wijeratne, Assistant FAO Representative (Programme), 13/2/17).

This consumer behaviour adds to their vulnerability as household expenditure on food is already high at 38% in urban areas and 50% in plantation areas. Reduced food access and low dietary diversity due to low household income can lead to child malnourishment, with stunting and wasting rates very high for the region (Liyanage 2015). Low nutritional security

[4] However, this is changing, see section 4.1.3.

[5] This increased over the 10 years prior to 2008, from less than 0.8% (Weerahewa et al 2010, see https://cip.cornell.edu/DPubS?verb=Display&version=1.0&service=UI&handle=dns.gfs/1289505412&page=record).

combined with high sensitivity to price fluctuations makes Sri Lankan households, particularly poor urban residents, vulnerable to reductions in food access (Esham et al. 2017).

In other aspects of public health, Sri Lanka has high levels public sanitation and medium access to improved water sources (WHO/UNICEF 2016).

Chronic Kidney Disease of unknown etiology (CKDu) is a serious public health concern in Sri Lanka affecting an estimated 400,000 people and resulting in 22,000 deaths in the past two decades. This included mainly male rice farmers, but also women and children casualties (Bandarage 2013). The majority of cases are in the North Central Province where nearly half the country's paddy fields are located (Wimalawansa 2014). Although first detected in the early 1990s, the disease is not well understood and there is no agreement among scientists on the causes. However, there is consensus that it not related to the common causes of kidney disease. The cause is suspected to be due to the interaction of multiple factors, including the hardness of the water and the use of agrochemicals (Jayasumana et al. 2014, Jayasumana et al. 2015, Wimalawansa 2014). A recent WHO consultation found that the role of agrochemicals in CKDu was inconclusive but recommended the promotion of sustainable farming and reduced exposure to agrochemicals (WHO 2016). Addressing CKDu is a high priority for the government and the suspected link of CKDu with agrochemicals has driven a transformation of the agricultural sector with a Presidential push to promote organic agriculture and a "Toxin-Free Nation" (Presidential Secretariat 2016, see Section 4.1.1).

2 METHODOLOGY

2.1 Conceptual framework: vulnerability and adaptive pathways

The target outcome of this research is phosphorus and climate smart agriculture (PACSA) (box 1). Three interrelated concepts guide our framework: transformational social change, transdisciplinarity and systems thinking. Transformation seeks big, deliberate and lasting changes along sustainability pathways that enhance equity and livelihoods, avoids environmental degradation and unintended consequences (Hackmann et al. 2014; Iwaniec et al. 2016). Transdisciplinarity transcends and integrates disciplines and sectors from soil agronomy to policy, and is outcomes- and future-oriented (Mitchell et al. 2015). Application of systems thinking supports the integration and analysis of biophysical and social-institutional systems in the same framework; it is cross-scalar, cross-temporal and acknowledges relationships between system actors are just as important as the actors themselves (Midgely 2003).

To analyse how PACSA can be achieved, our conceptual framework seeks to understand system vulnerability and adaptation, drawing specifically on the capitals concept (used widely to assess sustainable livelihoods e.g. Ellis 2000), coupled to an adaptive pathways approach (figure 2). The capitals concept recognises that stakeholders in the Sri Lankan food system draw on a stock of resources to achieve their goals. Goals could be: greater productivity for farmers, reduced post-harvest losses for wholesalers or widespread policy adoption for a government agency. These resources are generally grouped into a framework of five capitals (or asset classes):

Box 1: PHOSPHORUS AND CLIMATE SMART AGRICULTURE (PACSA)

Building from FAO's definition of climate smart agriculture CSA, we define phosphorus and climate smart agriculture (PACSA) as an approach that helps to guide actions needed to transform and reorient food and agricultural systems to effectively support development and ensure food security in a changing climate and phosphorus-scarce future. Specifically, PACSA seeks to:

- sustainably increase agricultural productivity and incomes;
- adapt and build resilience of food systems to and;
- reduce and/or remove greenhouse gas emissions and phosphorus losses to water, where possible.

PACSA is an approach for developing strategies to secure sustainable food security under climate change and phosphorus scarcity. PACSA provides the means to help stakeholders from local to national and international levels identify strategies across the food value chain suitable to their local conditions.

- **human capital**, e.g. levels of education, health and ability to labour;
- **social capital**, e.g. connections to community and society;
- **natural capital**, e.g. stock, flows and security of natural resources like water and fertile land;
- **physical capital**, e.g. level and type of infrastructure; and
- **financial capital**, e.g. wealth, personal income and debt levels.

People use, exchange and convert these resources to achieve their goals. For example farmers use natural capital (soil fertility, water etc.) to grow crops which they sell (financial capital) to buy fertilisers (physical capital) to replenish natural capital stocks, to buy education and health services for their families (human capital) and to participate in society through professional and personal networks (social capital).

Although livelihoods are typically assessed for households or farmers, our multi-scalar systems approach means we assess vulnerability and adaptive capacity of other sectors of the food system in addition to farming households, such as policy-makers and industry (figure 2). For example, for financial capital, this could range from farmers' access to credit through to government's financial resources to implement policy changes.

Adaptive capacity can be thought of as the ability of an individual, family or organisation to use their stock of resources in innovative ways to overcome new challenges (such as a changing climate) (Jacobs et al. 2015). One of the important limitations on the capacity to adapt is imposed by the enabling environment in which stakeholders are embedded. The enabling environment includes contextual barriers and enablers of change that are largely outside a stakeholder's control. These include government policy, institutional inertia, culture, and social norms, peer pressure, etc. Sustainable Livelihoods assessment typically uses this approach to vulnerability assessment. While there is no single conceptual framework or method for assessing adaptive capacity, four broad questions need to be answered that are generic across a range of contexts (Engle 2011):

- What are the likely or current *impacts* driving adaptation?
- *Who* needs to adapt?
- What are the *barriers* to or *opportunities* arising from adaptation?
- What appears to *enable* the adaptation processes?

Vulnerability drives the need to adapt (Pelling 2001). Vulnerability is generally agreed to be made up of three components: exposure to a hazard (largely geographical), sensitivity (the degree of damage that follows exposure) and adaptive capacity (the degree of change that is possible to avoid future exposure or damage). However, there are multiple ways (adaptation pathways) that food system stakeholders could follow to reduce their vulnerability.

Adaptation pathways approaches were developed because they allow for flexibility in planning under deep uncertainty (Kwakkel et al 2015). Adaption pathways allow decisions to be grouped or 'bundled' around system components. They also enable the separation of short-term coping strategies within an existing system, from long-term and more durable transformational change to a system (Kates et al. 2012). Decisions with the potential to result in pathways that overshoot sustainability thresholds of the system, or maladaptive pathways, can also be identified. Using adaptive pathways can assist in testing the reactions of decision-makers to changes in system drivers. The pathways chosen by an individual stakeholder would be influenced by their perception of vulnerability and their adaptive capacity.

Our assessment framework facilitates the identification of: risk pathways, vulnerable sectors and points within the Sri Lankan food system with respect to climate change and phosphorus scarcity; and, drivers of change that are highly likely to occur but where the timing of the impacts are unknown. The framework assesses the ways sectors and stakeholders are vulnerable and seeks to identify and prioritise policy approaches to build adaptive capacity at multiple-levels (see Figure 2).

Advice on good practice in vulnerability assessments suggests that a combination of top-down and bottom-up perspectives is essential, but is still rarely achieved in practice (Preston and Jones 2011). Because adaptation is often influenced by the perception of a hazard, constrained by local context and distributed across many actors in social systems, integrated approaches are best that focus on the needs of the decision-maker at the point where action can be taken. We aim to integrate a top-down with a bottom-up assessment. We draw from Earth System's Governance that employs the "5 A's" analytical themes of Architecture, Agency, Adaptability, Accountability and Allocation (Biermann et al. 2009). This 'top-down' approach facilitates analysis of how integrated governance systems can support social-ecological systems towards sustainable development. For 'bottom-up' assessment we apply a Sustainable Livelihoods approach, which allows for context-specific assessment of a region or groups' vulnerability and adaptive capacity.

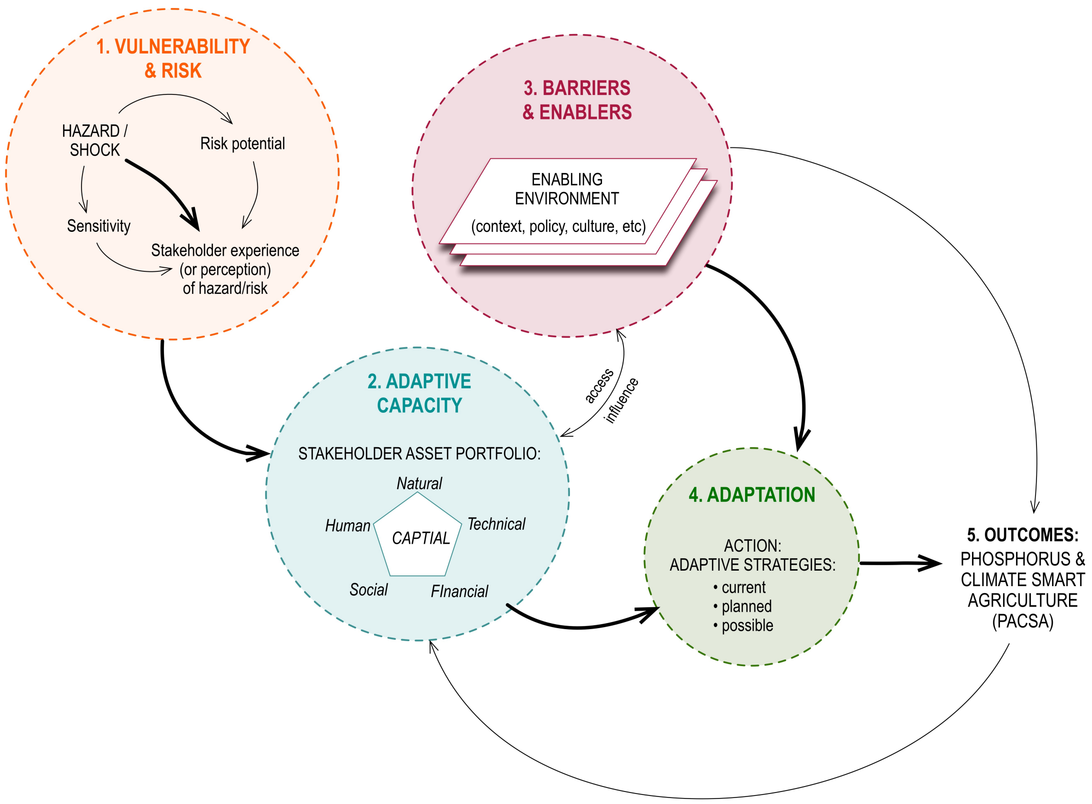

Figure 2: Conceptual framework indicating relationship between: 1. Climate change and phosphorus scarcity hazards & risks (Section 3), 2. Adaptive capacity (Section 5), 3. Enabling environment (Section 6), 4. Adaptive strategies (Section 4) and sustainable outcomes.

2.2 Method

To assess vulnerability, adaptive capacity and adaptation pathways, we undertook in-depth stakeholder interviews (social research) to obtain primary data, supplementing secondary data from academic literature and policy documents.

Interviews of 1-2 hours length were undertaken with 32 stakeholders across 16 interviews, representing:

- Farmers (4 interviews)
- Farmer Organisations (2 interviews)
- Fertiliser & agrochemical industry (2 interviews)
- National government (5 interviews)
- Provincial government (2 interviews)
- NGO (1)

The interviews took place face-to-face in the Central Province, Sabaragamuwa Province and Western Province (Colombo) of Sri Lanka during October 2016, at the start of the main growing season, *Maha*, however, the monsoonal rains had not yet arrived.

Key objectives of undertaking semi-structured interviews with Sri Lankan food system stakeholders included:

- Elicit stakeholder knowledge and perception of phosphorus and climate change risks, to themselves, their sector, or Sri Lanka's food system at large;

- Understand relationships between sectors (to inform both understanding of system vulnerabilities, potential risk pathways and potential interventions);
- Explore stakeholders' capacity to adapt to phosphorus and climate change risks, both in past, and future; and
- Better understand stakeholder priorities in Sri Lanka, to contextualize vulnerability, and seek windows of opportunity for change (potential hooks/drivers for interventions).

The guiding interview questions are provided in Appendix C. Thematic analysis was performed on interview transcripts manually (Saldana 2009) with a particular emphasis on coding to identify specific issues that integrated aspects of phosphorus scarcity and climate change vulnerabilities.

The semi-structured format of the interviews allowed gaps in literature to be filled, especially related to phosphorus scarcity, as there is more available knowledge on climate adaptation. The literature review involved a review of relevant stakeholder documents, academic literature and other research reports such as CGIAR[6] reports.

Data sources drew from a spectrum of quantitative and qualitative sources. Primary data was sought from interview data with identified key stakeholders, while secondary data was sought from: published data (e.g. fertiliser industry data), and unpublished data (e.g. data held by various Sri Lankan Ministries of Agriculture, Health and/or Environment).

[6] CGIAR is a global research partnership for a food-secure future, see: http://www.cgiar.org/

3 VULNERABILITY OF SRI LANKA'S FOOD SYSTEM TO CLIMATE CHANGE AND PHOSPHORUS SCARCITY

The impacts of a changing climate and phosphorus scarcity result in a cascade of interlinked risk pathways (Figure 3). Most respondents –especially farmers– reported changes to the weather and water availability which has led to increased pest and disease incidences, reduced crop yields and serious financial consequences. However, there was very little reported awareness of phosphorus scarcity as a challenge, nor was there much reported experience of impacts of phosphorus scarcity.

3.1 Weather and climate change risks

The predominant climatic changes already observed by farmers interviewed included increased drought, flooding and delayed monsoons. Others also noted increased sun intensity and wind, which both influence evapotranspiration, mediated by attributes of soil quality (such as soil carbon and soil texture). However, institutional stakeholders shared divergent views. One national government stakeholder did not perceive any current effects of climate change, while another thought it was a core issue currently being experienced. A fertiliser industry respondent indicated that the effects of climate change on their business were being felt primarily through increased business uncertainty. That is, climate variability created difficulty in predicting crop seasons and rainfall, which in turn affected the local demand for fertiliser and agrochemical imports. For example, the stakeholder noted "*in a normal season, farmers might choose herbicides, but if the monsoon is delayed then farmers demand pre-emergent weedicide*".

Importantly, these interconnections are non-linear (as indicated in figure 3) with positive and negative feedback loops. Further, climate impacts risks ripple through the system to influence other management decisions as well as the environment – such as agrochemical/ fertiliser inputs and water use, as described below.

3.2 Water-related risks

Water is the limiting factor in agriculture that sets the production and yield limit – fertilisers such as phosphorus are applied to optimise within yield thresholds. Farmers considered a lack of water as one of their highest priorities and identified a number of increasing water-related risks.

Farmers observed that there is a reduced availability of water from natural sources due to reduced and irregular rainfall and increased demand due to more end-users in the area. This has led to water rationing in some farming areas and restrictions on days of use which farmers reported may lead to crop failure. To address water scarcity, water diversions have taken place to supply water to new farming areas, which has adversely impacted the water supply of one farmer organisation's members.

To adapt to the reduced water availability, farmers rely on pumped water from alternative sources rather than rainfall or natural streams on which they previously depended. One farmer who previously used a natural stream to irrigate his fields now pumps water from the main stream further away. This has increased his costs as he now needs to pay for pumping instead of relying on a gravity system. However, he also described that this has also decreased his fertiliser demand. Other farmers who now pump water instead of using natural rainfall observed that this has increased pollution from diesel fuel used for pumping.

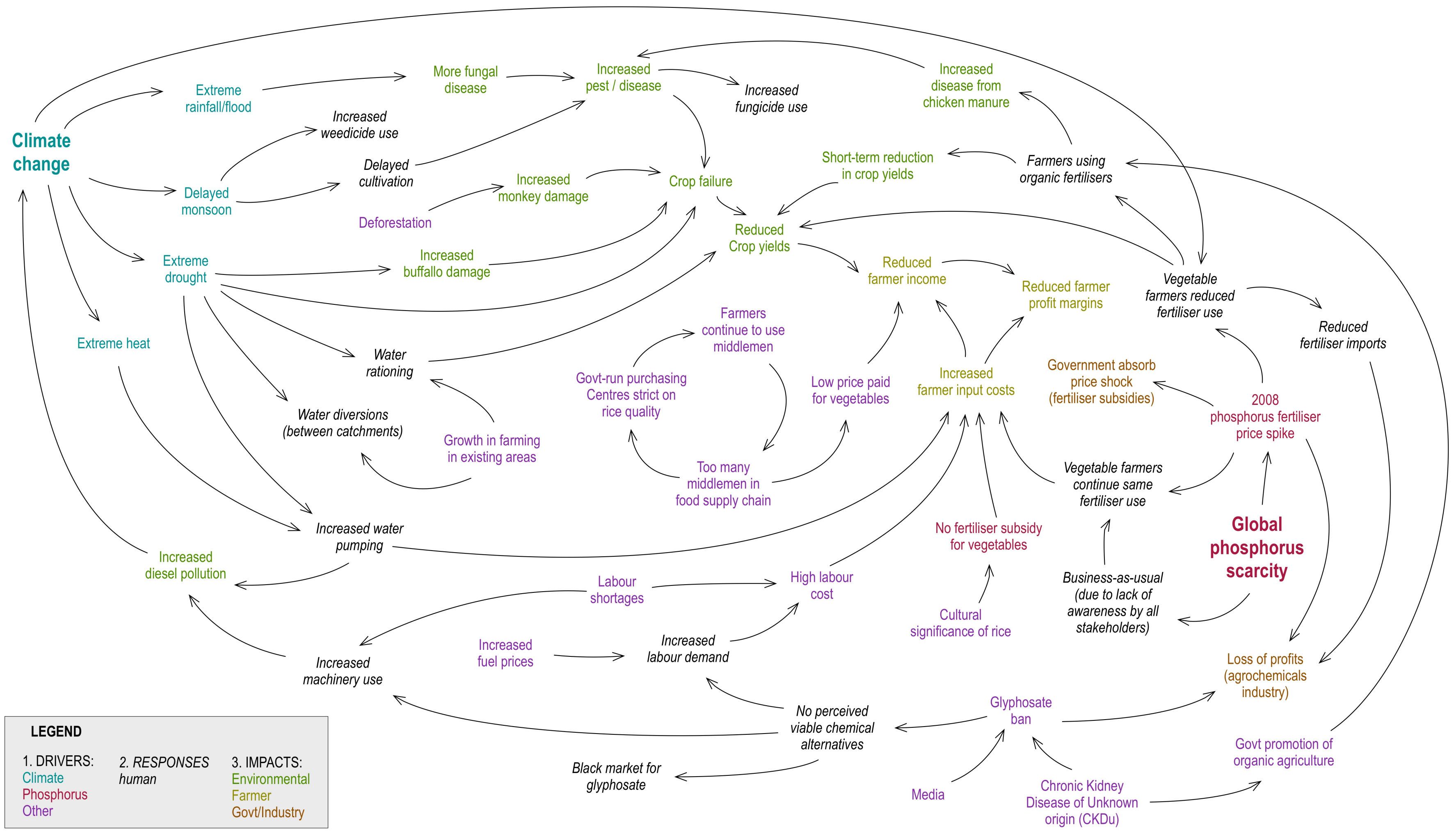

Figure 3. Interlinked risk pathways for climate change starting from the left side (blue) and phosphorus scarcity from the right side (red) leading to food system vulnerability.

3.3 Pest and disease risks

There is a complex interaction between climate and the incidence of pest and disease driven by changed timing of seasons and rainfall patterns. Farmers and industry respondents observed that there are increased pest attacks when planting is not undertaken in line with traditional seasons and that a lack of rain delays cultivation. For example, one farmer observed that if sowing is done in the off-season, there was more chance of rodents eating the seeds.

Farmers interviewed observed that drought has led to increased fungal diseases. Water scarcity has also led to an increase of buffalos damaging crops[7] and deforestation for agriculture has decreased habitats for monkeys which can be a menace for crops.

According to one respondent, using other forms of organic fertiliser to adapt to phosphorus scarcity could also impact on pest and disease. For example, one farmer observed that chances of pest infestation increased with chicken manure.

3.4 Implications of fertiliser scarcity

Fertiliser use is currently subsidised for farmers of rice and some key crops (including soy, maize, onion and chilli). However there is no subsidy for vegetables. This has implications for food security and farmer livelihoods with vegetable farmers noting that high agrochemical and fertiliser costs are a high priority for them.

Across all stakeholders interviewed, there was a lack of awareness of the longer-term global phosphorus issue with only some stakeholders aware of the 2008 price spike. An industry stakeholder who was aware of the price spike recalled that there was a decrease in demand for fertilisers from farmers.

The experience of the 2008 price spike varied for the farmers interviewed. Some vegetable farmers (with no subsidy) continued to purchase and apply fertilisers at the same rate despite the increase in price, which impacted the profit margins significantly. Conversely, another vegetable farmer felt they had no other option but to apply less fertiliser during the price spike, which affected the yield. Another noted that they did not feel the price spike, but that they were now using less fertiliser as the price had since increased. A government stakeholder noted that some farmers were not aware of the price spike as the government subsidised the fertiliser.

Agrochemical price fluctuations affect the fertiliser industry. One industry stakeholder noted Sri Lanka does not produce fertilisers but relies on imports from countries including Japan, China and India, and determines imports based on what is affordable. They thought that if prices go up again, it would definitely affect them as formulas would need to change and companies would stop importing. However, this stakeholder thought that the government would need to intervene to mitigate the risk: *“but the government will regulate, or farmers will take to the streets”*.

A government stakeholder thought phosphorus scarcity and the price spike was not discussed because Sri Lanka has a rock phosphate mine that the government plans to develop.

[7] These are wild buffalos that were previously domesticated for farming but have now been replaced by machinery.

3.5 Economic impacts

Farmers, industry and government stakeholder respondents all observed economic impacts of climate change and the associated changes in fertiliser demand, which can impact on both input costs, yield and ultimately profitability. The lack of profitability of farming is of high concern to farmers, causing many to leave the sector. Profitability can further decrease due to phosphorus and climate risks. Farm input costs were observed to be high for farmers, while the price farmers received for produce has not increased at the same time, affecting profitability. Some farmers consider machinery and the associated fuel use the highest input cost, however, farmers noted the machinery was still cheaper than using labour for the same tasks. Agrochemical costs are also one of the highest inputs and these input costs could increase due to climate risk and uncertainty.

Farmers perceived that climate change has a direct economic impact through crop losses due to changing weather or extreme weather events. Drought also reduces fertiliser demand, but leads to lower yields, whereas periods of excess rain can require increased use of agrochemicals and fertilisers. Climate change also has direct effects on costs, for example, one farmer noted increased drought can dry out the soil requiring further labour to manage the soil.

Other drivers also affect the profitability of farming. Some farmers reported a lack of trust in insurance schemes, which could insure them against climate risk. They observed that there are too many middlemen in the supply chain leading to market distortions and unfair prices for farmers. Dedicated Economic Centres were established by the government to address this; however, they are not meeting their purpose as many farmers still go to middlemen due to entrenched behaviour. The price for vegetables is low and declining, and farmers also face competition from imported produce.

4 ADAPTIVE PATHWAYS

Strategies for actors in the Sri Lankan food system to cope, adapt or transform in response to climate change and phosphorus scarcity can take many forms - from behavioural change to policy change. Indeed, many stakeholders interviewed are already adapting, including farmers, policy-makers and industry. This section details the range of current and planned adaptations (4.1) in addition to potential future adaptive pathways (4.2) offered by respondents and the literature. We also highlight the enablers of, and barriers to, adaptation that respondents perceived to be hindering or enhancing change.

Ultimately, effective adaptation to these complex challenges will require transformational change rather than incremental changes or simply 'coping' with the stresses and shocks. For example, coping strategies that seek to maintain farm viability by 'mining' soil fertility under declining farmers' terms of trade are unsustainable in the medium and long term. Further, system-wide change across the whole food system will be required, not just within an individual sector like agriculture, and include all key stakeholders. Figure 4 locates a range of adaptive strategies identified by stakeholders on a scale of incremental to transformational, and individual to system-wide changes. Ideally, for transformation to be promoted, there should be a sufficient spread of strategies in the top right quadrant of the graph. In practice, stakeholders often struggle to identify transformational strategies as they tend to go beyond their sector and experience.

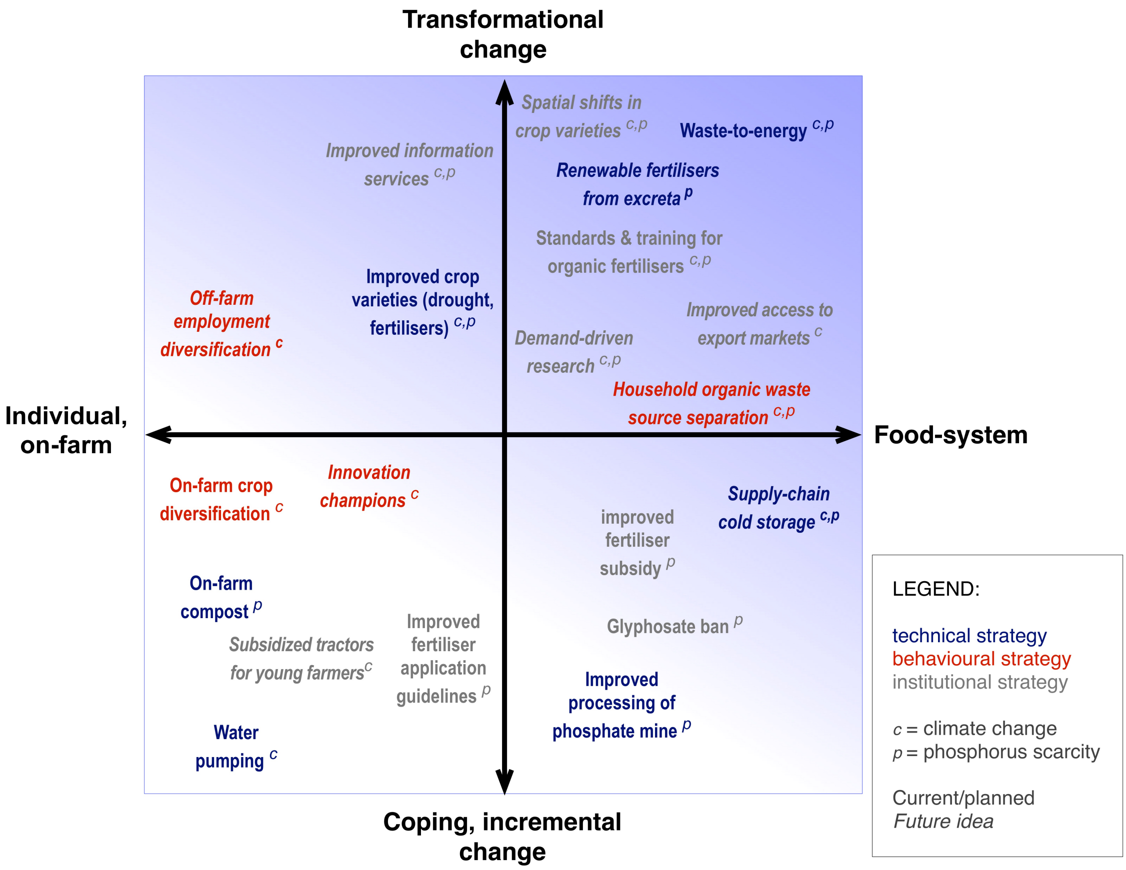

Figure 4. Adaptive PACSA strategies on a scale of incremental to transformational, and individual to system-wide, also indicating whether these are technical, behavioural, social-institutional in nature. *For full list, see Appendix B*.

4.1 Current and planned adaptation

Key adaptive strategies currently underway are largely centred around organic waste management for energy and compost, incentivising organic agriculture and reducing toxins in the environment. Importantly, these strategies are largely driven by external factors, rather than climate change or phosphorus vulnerability, as identified in Table 1 and Section 6. Table 1 lists key initiatives, including the sector initiating the change, the drivers of change, and the stakeholder groups affected by the change. The initiatives are further elaborated in the text below.

Table 1. Key adaptive PACSA strategies already underway, indicating the initiating sector, drivers and stakeholders affected.

Sector	Current key initiatives	Drivers of change	Stakeholders affected
1. Presidential Secretariat	• Task Forces e.g. "Toxin-Free Nation", including: ○ banning glyphosate ○ incentivising organic agriculture & indigenous crop varieties	• Presidential concern over Chronic Kidney Disease of Unknown origins (CKDu)	Agro-chemical industry (producers, retailers), farmers, communities at risk of CKDu
2. Ministry of Agriculture	• New fertiliser subsidy • Promoting use of organic fertilisers (e.g. Standards, extension, training farmers)	• Presidential interest in reducing chemical fertiliser use due to environmental health concerns • Reduced crop yields and crop failure, increased crop disease • Cultural significance of rice (rice receives fertiliser subsidy but not vegetables) • Financial cost to government of fertiliser subsidy is approximately 2% of government expenditure	Farmers, agro-chemical industry

Sector	Current key initiatives	Drivers of change	Stakeholders affected
3. Waste Authorities	• Waste-to-energy • Compost production and use • Household source-separation of organic waste	• 85% of waste goes to open landfill, creating health and social problems • Landfills are reaching capacity and waste generation is expected to double by 2050 • Climate mitigation commitment (reduces methane generation) • National policy for 20% non-conventional renewable energy by 2020 including waste-to-energy • Public pressure to improve waste management • Presidential push for organic fertiliser for organic agriculture	Waste industry, households, communities
4. Climate Change Secretariat	• National Adaptation Plan, including: ○ efficient farming ○ drought-tolerant crop varieties	• International agreements (UNFCCC COP) • Climate change impacts including extreme rainfall/flood, delayed monsoon, extreme drought, extreme heat • Climate change projected to affect 70% rice farmers and impacts on other farmers	Farmers
5. Farmers & Farmer Organisations	• Diversification of crops (e.g. bananas in addition to paddy) • Alternative water sources (e.g. pumping, diversions)	• Government support for adapting to changing climate • Direct coping mechanisms	Food value chain stakeholders
6. Non-profit	• Biogas digestion for energy and fertilisers	• Promoting sustainable enterprise development to address waste, agriculture and climate challenges	Hotel industry, farmers

4.1.1 Presidential Task Forces: Toxin-Free Nation

The “Toxin-Free Nation” taskforce was established by the Presidential Secretariat to remove agro-chemicals from the food chain, and to promote organic agriculture and a healthy population. Establishment of the taskforce was driven by the prevalence of Chronic Kidney Disease of unknown etiology (CKDu) in farming communities and following the World Health Organization (WHO) recommendation to reduce the use of agrochemicals in agriculture as a potential contributor to CKDu. The President established the taskforce alongside another specifically focused on CKDu which has the objective of identifying causes and undertaking prevention activities in relation to the disease. CKDu primarily affects farmers in the North Central Province where the President is from and the President aims *“to eradicate Kidney Disease, which effects the farmer community, the life blood of our country”* (Presidential Task Force on Prevention of CKDu).

The “Toxin-Free Nation” program is also driven by the desire to reduce dependency on foreign companies for fuel and fertilisers in agriculture and improve economic opportunities for farmers. It supports the Food Production National Programme (2016-18), which aims to make the country self-sufficient in food production, replacing imported food that may contain toxins currently banned in Sri Lanka with locally grown organic food.

The goal of the taskforce is to replace all agriculture produce based on imported agrochemicals with organic agriculture, including 30% indigenous varieties and to provide healthy food to citizens. It aims to address the challenge of the high cost of organic food by achieving *“the same nutrition for the same price”* (Presidential Secretariat 2016, p. 23), so farmers can obtain the same profits for organic rice as conventionally-grown rice. The taskforce plans to guarantee this for farmers and has established a fund to make sure farmers are subsidised for any shortfall in profits.

To achieve this goal, the “Toxin-Free Nation” plan includes a ten-point program of actions both on and off-farm (see Appendix A for more detail). On-farm strategies include toxin-free pest control and fertilisers, appropriate irrigation and equipment. Off-farm strategies include improved facilities for storage, transport and sale of produce, increased research and skills development and improving the legal framework for land distribution to prevent land transfer to foreign companies and to protect the intellectual property of crop biodiversity. The program also engages consumers to encourage the purchase of organic produce, improve their understanding of nutrition and to develop toxin-free home gardens including indigenous varieties.

Since inception in 2015, this program has been the driver of two major policy decisions:

1. An outright ban of the weedicide glyphosate (Monsanto’s *RoundUp*) from import and distribution. One government stakeholder noted that there had been some resistance, but it was not a significant issue, however, one industry stakeholder felt that the ban was not based on scientific evidence.
2. Changes to fertiliser subsidies, which creates the possibility for *“equal competition between the two forms of agricultural practice”* (Presidential Secretariat 2016, p. 29), outlined in Section 4.1.2 below.

The program is highly ambitious aiming to convert all agriculture to organic within three years. The current program is training 75,000 farmers over 50,000 ha with 1000 trainers.

4.1.2 Fertiliser subsidy reform

The subsidy system for fertilisers was changed in 2016 so that farmers now receive a payment directly rather than the government subsidising the cost of fertiliser via retailers at the point of purchase. Importantly, this means farmers can now purchase any type of fertiliser, either chemical or organic. The subsidy applies to paddy rice and other field crops (soy, maize, onion and chilli) but not to fruit and vegetables. Agricultural Research Production Assistants (APRA) manage the subsidy implementation by collecting data from farmers, which is then validated by farmer organisations.

The change in the subsidy system was driven by: a) a desire to decrease the administrative cost of the system, and, b) to create a favourable market environment for organic fertilisers for those farmers that want to use organic cultivation methods. Previously, the subsidies only applied to chemical fertilisers. There is a four-year action plan for major crops to cut down the import of fertiliser and increase organic fertiliser production. One government stakeholder interviewed believes that the reform does encourage farmers to use organic fertilisers, and that the subsidy change has stimulated increased production of organic fertiliser.

The first growing season the subsidy change was implemented faced many challenges, particularly with delays in payments getting to famers, as noted by a government and an NGO stakeholder.

Farmers often use more fertiliser than recommended. A disadvantage of the new scheme, according to a government respondent, is that the government does not have control of the farmers' fertiliser use, so, farmers might purchase and use more fertiliser than the subsidy provides for, using their own money.

According to another government stakeholder, there are currently no standards for organic fertiliser, such as compost from municipal waste. However, efforts are underway to develop such standards. Another government stakeholder stated the fertiliser regulations need to be updated to include organic fertiliser and illegal stocking of chemical fertilisers.

One NGO stakeholder felt the subsidy changes by the government were a positive move but believed the shift towards organic agriculture should be done slowly over time. They noted that the fertiliser subsidy was important because it subsidises the country's food, but the level of subsidy for different types of crops should be considered to make sure it was equitable. There is a need to make sure any switch to organic agriculture does not inadvertently decrease Sri Lanka's food sovereignty due to a decrease in the number of types of crops grown or a decrease in overall productivity.

One industry stakeholder was positive about the subsidy and considered that it removed the burden on fertiliser companies that existed under the old system.

While it is unclear if, or when, subsidies would be phased out completely, the government notes: "*since the farmer who engages in organic agriculture reduces the use of inputs and increases his yield simultaneously, there will be no need for this subsidy in the future at all*" (Presidential Secretariat 2016 p. 29).

4.1.3 Compost, organic fertilisers & bio-fertilisers

Significant developments surrounding compost and bio-fertiliser production in Sri Lanka are largely driven by the Presidential Secretariat's push for clean organic agriculture[8], coupled with a climate mitigation target to reduce methane generation associated with the decomposition of organic waste in landfills and dump sites. The use of compost could also: have a lower cost than commercial chemical fertilisers, buffer against climate variability for rain-fed agriculture due to improvements in soil water-holding capacity, and theoretically with sustained use, could approach the same crop yields achieved with as chemical fertilisers over the medium-term, though some farmers reported mixed-results to date.

There is a wide range of current or potential organic waste sources and products, scales of recovery, stakeholders, risks and benefits. As indicated in Table 2, sources include: municipal solid waste (mixed or source separated organic waste at the household), biogas digestion slurry and liquids, wastewater, septic tank sludge/septage, manure (cow or poultry), plant extracts for commercial bio-fertilisers, agricultural waste (including crop residues).

[8] See Appendix A. This builds on the Ministry for Agriculture's promotion of organic fertilisers over the past decade (http://www.agrimin.gov.lk/web/index.php/media-gallery/video-gallery/12-project/26-promotion-of-production)

Table 2. Potential sources of organic waste and applied forms.

Organic waste source	Form applied to farm
Municipal solid waste: • mixed and manually separated at compost plant • source separated organic waste at the household	Compost (commercial sales or informal use)
Biogas digestion by-products: • small-scale residential/on-farm and commercial • industrial scale waste-to-energy from municipal solid waste (including food) and agricultural waste	Slurry and/or liquids (currently informal, commercial planned in future)
Wastewater	Effluent (treated or untreated)
Septic tank sludge/septage	Treated sludge or septage
Animal dung	Cow or poultry manure
Agricultural waste, including crop residues	Compost (on-farm, informal)
Plant extracts	Commercial liquid bio-fertilisers

The two primary sources of organic waste are organic municipal solid waste, such as food and garden waste, and agricultural waste such as crop residues and straw. Plans for processing the former as waste-to-energy are predominantly put forth by larger companies, while the latter is often used directly on-farm by farmers or processed by smaller companies. However, there is a full suite of scales and options planned, ranging from local authorities encouraging home composting through to Public Private Partnerships (PPP) with the Provincial government (and local authorities) for large scale bio-methanisation facilities (see 4.1.4 below). There are currently 140 small-medium composting plants run by local authorities, each processing around 1000 tonnes per month. The planned large-scale facilities would also produce commercial bio-fertilisers as by-products[9]. There are also plans to upgrade dump-sites, driven by health concerns and local public pressure.

The institutional arrangements under development to support a transition to these adaptive waste-to-energy (WtE) technologies range from PPP at the Provincial and local levels, to new national standards—and possibly certification—for organic fertilisers and bio-fertilisers. The certification process was seen as important by the provincial government stakeholder interviewed in order to gain consumer confidence. As an interim measure, the government are using the UN Food and Agricultural Organisation's Good Agricultural Practices (GAP)[10] guidelines. Importantly, this will also include Provincial/local government incentivising households to segragate organic waste from other household waste fractions to ensure low contamination rates and facilitate the effective processing of organic waste into resources. For example, while organic waste is currently separated in compost yards managed by local authorities, there have been recent trials to incentivise households to source-separate organic waste at home through load-based pricing for mixed waste.

[9] The plant was officially opened in August 2017 http://www.president.gov.lk/president-lay-foundation-stone-for-waste-based-electricity-plant/.

[10] See http://www.fao.org/prods/gap/

According to the agrochemical retailer interviewed, demand for bio-fertilisers is also increasing due to its co-benefit of deterring pests. A government stakeholder further noted that plans to create special compost blends based on customer needs (e.g. paddy, vegetables) are also under way.

4.1.4 Waste-to-energy strategy

As noted in 4.1.3 above, Sri Lanka's climate mitigation commitments have shifted the focus of organic waste management from composting alone to waste-to-energy. Current and planned systems range from on-site hotel biogas systems through to large-scale gasification; however, large-scale waste-to-energy projects may face public protest if perceived in the same way as a new landfill site (see Section 6.2).

The non-profit stakeholder elaborated on a six-year biogas program that generates renewable energy and slurry for fertiliser use. The input is typically food waste from hotels or municipal solid waste with the resultant biogas slurry applied to coconut plantations and horticultural cash crops (mainly chilli). A limited number of biogas slurry trials have also included paddy cultivation. Barriers to overcome in moving from trials to implementation include the need to establish the value chain to guarantee supply and quality (e.g. fertiliser strength was initially too high), and the associated lack of scientific testing. Further, there is some psychological resistance to using biogas slurry that has been generated from human excreta as an input. However the farmers involved in the coconut plantation trials may not have noticed the slurry since the plantations are so large.

4.1.5 Other biotechnical strategies

In addition to the development of organic fertilisers and waste-to-energy, there are a range of technical strategies already in place to adapt to climate change and to a lesser extent phosphorus scarcity, by default.

Water management:

For example, in relation to water, on-farm water efficiency has increased according to one farmer organisation, which believes this has resulted in reduced consumption from 10m^3 down to 3m^3 per acre. However, the farmer organisation noted this was not sufficient to meet growing water demand and that diversions from other catchment areas were required. Another farmer noted he had actually increased his on-farm water use as a coping mechanism due to the drought.

Cold storage:

Another planned technical strategy to buffer the value chain against climate change is investing in cold storage to reduce the current 30-40% post-harvest losses.

Soil microbes:

Regarding other phosphorus adaptation strategies, a government stakeholder noted they are working on developing soil microbes that can be introduced to farm soils to increase phosphorus uptake by plant roots.

Domestic phosphate rock mining:

Further, they have been investigating how to develop the phosphate mine in the North-Central part of the country to produce triple-super-phosphate fertilisers. This is driven by government interest in reducing dependence on fertiliser imports. The agrochemical industry stakeholder believes there could be 80 years' supply of phosphorus in the domestic mine, however, in addition to technical barriers, the government is constrained in seeking investors because a court order—and public pressure—is preventing the sale of the mine to overseas investors.

Total weed killers:

The same stakeholder also saw opportunities for alternatives to glyphosate which was subject to a ban in 2015/6; for example, new organic 'total weed killers', which are currently being tested by the government. As noted earlier by many stakeholders, other alternatives to glyphosate, such as physical weed control (e.g. hand weeding and mechanisation), are not practical for farmers due to the high cost.

4.1.6 Other institutional and market-based strategies

Crop & employment diversification:

To adapt to uncertainty associated with climate change, farmers have been diversifying to grow supplementary crops officially since 2000 under the support of government extension officers. Growing bananas and vegetables in addition to rice, for example. A farmer organisation emphasised that bananas are profitable, more so than paddies since they provide continuous income.

Further, there was an excess production of paddy, which also uses more water. The fertiliser retailer stakeholder noted that he had personally shifted sectors as a coping strategy: from farming to vegetable wholesaler to agrochemical retailer.

Fertiliser application guidelines

Finally, new guidelines for application of fertilisers suited to different soil types is under development.

4.2 Potential future adaptive PACSA pathways

In addition to existing and planned initiatives, stakeholders suggested a wide range of possible future adaptive PACSA pathways, ranging from more efficient on-farm crops and technologies to more effective institutional structures.

4.2.1 Institutional & market-based initiatives

Institutional and social adaptive strategies were discussed from a strategic level through to on-farm strategies.

Gradual planned transitions:

Importantly, as stressed by the non-profit stakeholder, transitions such as the shift to organic or changing subsidies need to be done gradually in a holistic manner and through constructive dialogues, otherwise, one part of the food chain might impact another and affect the whole system. By way of example, he referred to what he saw as an emotional rather than just a scientific response to the CKDu issue, especially via the media.

Prioritising quality:

Also at the strategic level, a government stakeholder reflected that during the period when then Sri Lankan economy was developing, price was the key priority, while now as a low-middle income country, quality is also important. He provided the example of the garment industry, which used to be low-end but is now moving to high-end quality apparel.

Incentivising market access:

Several market-based initiatives were suggested by various government, industry and farming stakeholders, ranging from farmer support in the form of loan schemes for vegetable farmers, to subsidised tractors to encourage young people into farming. The agrochemical retailer also suggested improving access to export markets for farmers to increase profits. The non-profit stakeholder stressed the importance of putting a price on organic fertilisers, including biogas by-products, to incentivise use.

Off-farm diversification:

Finally, although farmers are already being encouraged to diversify their crops, it was suggested that farmers could further adapt by diversifying into off-farm pursuits such as co-operative agri-tourism experiences, for example, by renting rooms as accommodation. However it is unclear where the capital would come from to develop such opportunities.

4.2.2 Biotechnical initiatives

A suite of potential on-farm bio-technical adaptive measures was offered by stakeholders.

Improved crop varieties:

Although developments for new crop varieties are underway, some farmers and farmer organisations were not satisfied and wanted to see more drought/moisture-resistant and low-fertiliser-demanding crop varieties suited to the region.

Renewable fertilisers:

In addition, they suggested the development of appropriate renewable and alternative fertilisers and measures to increase bio-availability of soil nutrients.

On-farm infrastructure:

Another farmer's priorities for climate adaptation were to invest in tube wells to improve water security and poly-tunnels to protect staple crops (and possibly even cash crops like gerbera flowers).

Service industry:

A government stakeholder also recognised the need for new agribusiness and local enterprises to offer/sell land-clearing machinery and services to farmers to replace the weed removal role of now-banned glyphosate weedicide.

4.2.3 Knowledge-based and educational initiatives

A suggestion made by several respondents related to improved knowledge flow for/between farmers on technology, markets and climate. For example, improved seed-to-harvest technology, appropriate fertiliser types and application techniques, and market information such as prices could be provided by the media or by mobile phone messages. A government extension officer suggested off-farm knowledge initiatives like adding climate change and adaptation to the school curriculum.

Some farmers and the agrochemical industry recognised the need for non-market incentives to adapt, such as boosting the recognition and reputation of farmers to encourage youth to enter farming. They also suggested that identifying farming leaders/champions of change who are innovating and risk-taking could inspire the smaller farmers to implement more efficient practices.

4.2.4 Value-chain initiatives

Finally, greater linkage between value-chain actors was recognised, including between producers and consumers, or between farmers.

Rice and vegetable bartering system:

A government extension officer proposed a novel bartering initiative between rice and vegetable-growing farmers to address their issues. The paddy farmer organisation liked the idea and was willing to get in touch with the vegetable farmer organisation because they have excess paddy seeds and could trade these for vegetables.

Linking farmer organisations:

The government extension officer also proposed linking various farming organisations in different regions to collectively address common priority issues, for example, via an e-farming platform.

Plant doctor:

Other suggestions included a ‘Plant Doctor’ model whereby farmers can bring a sample of a sick crop into a local clinic for diagnosis and treatment by extension service providers or ‘plant doctors’.

Investigate and promote consumer demand for organic produce:

Regarding demand-supply linkages, it was acknowledged that the Ministry of Agriculture’s organic farming promotion program focused on farmers and production, not yet creating or even investigating consumer demand for the products.

4.3 Views on use of excreta as fertiliser

While most respondents generally embraced the use of compost from crop, food waste and manure, they were divided in their views on the use of wastewater or human excreta as a fertiliser[11]. Most had not thought of this option, and those who were reluctant, when probed cited health concerns or cultural barriers. Those who would be potentially supportive suggested if the technology was there and it was safe, they would be supportive. One government respondent noted the environmental importance of such a measure ‘then the cycle is complete’, while an agrochemical industry respondent offered that it is simply a marketing issue to promote it.

[11] In most interviews, respondents were not familiar with the reuse technologies of human excreta, so further information summarising experience from around the world was offered to respondents. For example, noting that today there are over 50 different technologies, from low-tech, low-cost reuse such as urine diverting toilets, through to high-tech centralized recovery systems such as struvite recovery from wastewater treatment plants).

5 CAPACITY TO ADAPT

For stakeholders to implement effective adaptive strategies, they must have key capabilities or access to resources. Importantly, a diversity of resources is required to effectively adapt, including sufficient financial, social, human, physical and natural assets (Ellis 2000). Despite the relatively high exposure and, hence, vulnerability of the Sri Lankan food system to both climate change and phosphorus scarcity, there is a surprisingly strong capacity to adapt among some groups of stakeholders. This is in part enabled by the political will at the highest Presidential level (mentioned in Section 4.1.1 and 6.1), but, also because vulnerability can drive adaptation. For example, the experience of drought can drive the use of alternative water sources, diversions or efficiency (e.g. Biazin and Sterk, 2013). The stakeholder interviews identified attributes that facilitated both strong and weaker capacities to adapt (table 3).

5.1 Strong capacity to adapt

While lack of knowledge was a strong barrier to adapt (see section 5.2), there was evidence of pockets of knowledge capital such as educated farmers conducting soil testing, enabling them to apply the recommended fertiliser rates. Further, some farmers had the necessary knowledge to implement some of the government's adaptation measures, such as growing supplementary crops (banana, etc.) and using organic fertilisers. One farmer felt confident he would know how to grow new crop varieties, if/when they become available, guided by extension officers. A farmer organisation representative noted there was a continuous flow of knowledge from the government regarding the use of organic fertilisers, which resulted in a 50% decline in use of chemical fertilisers and possibly more since the subsidy scheme was changed.

While most stakeholders were not aware of the phosphorus price spike in 2008, one of the farmer organisations remarked that fertiliser bags actually have the market price and sale price of fertiliser on them. A fertiliser retailer also noted that the government is currently developing new fertiliser application guidelines for different soil types.

The existence of social networks, relationships and trust highlighted by some stakeholders also indicated a strong capacity to adapt. The fertiliser retailer was aware that his value chain was based on mutual trust where farmers seek his advice and recommendations. He has good rapport with his farming customers in part because he used to be a farmer himself. While one of the farmer organisations recognised that while they were brought together officially over water sharing issues, they also support each other on other issues such as health and farming. One national government stakeholder also understood the importance of establishing trust and felt that there is a need to prove an adaptation on the ground with farmers: "*if it's demonstrated and farmers are engaged, then they are likely to adopt it*", and that "*farmers don't care if it is chemical or organic fertiliser, as long as it works*".

The key financial capital identified by some industry and government stakeholders was the fertiliser subsidy. The subsidy absorbs any fertiliser price shocks, buffering rice farmers. However, this can also be a vulnerability for government (and some industry groups) who foot the bill by absorbing such shocks. One industry stakeholder said they cope with price spikes by giving the agrochemical distributor a grace period to pay which is passed on to farmers. In response to the hypothetical of another price spike, a provincial government stakeholder noted that the capacity for composting could be increased by 50% to meet increased organic fertiliser demand, although he acknowledged that compost capacity was ultimately limited due to space for processing and storage.

Two non-farmer stakeholders noted that soil in the region had a high phosphorus content due to excessive fertiliser use, however, this natural capital in the form of 'legacy' phosphorus could buffer farmers in the short-term against future price spikes.

Table 3: Perceived capacity of food system stakeholders to adapt to phosphorus scarcity ([p]) and climate change ([c]).

Capital	Strong capacity to adapt	Weak capacity to adapt
Financial	• Fertiliser subsidy (for rice farmers)[p] • Pockets of informal flexible payment arrangements in value chain [p,c]	• Poor farmer incomes, profit margins, status [p,c] • Poor farmer purchasing power [p,c] • Lack of effective government safety nets for farmers (access to insurance schemes or credit) [p,c] • Donor funds not materialising for farmers [p,c] • No fertiliser subsidy for vegetable farmers [p] • Fertiliser subsidy (for government who foots the bill) [c] • Black market developing for glyphosate [p]
Social	• Mutual trust between some stakeholders (e.g. fertiliser retailer and customer) [p,c] • Government's new fertiliser application guidelines [p] • Social support networks among farmers facilitated by farmer organisations [p,c]	• Disconnect between on-the-ground implementation and policy-making, leading to lack of conducive/supportive environment [p,c] • Low trust between farmers (and food retailers) and policy-makers (perception that policy-makers have deceived in the past and could do so again) [p,c] • Agrochemical industry mistrust in government leading to resistance to glyphosate ban [p] • Farmers feeling unable to meet government crop quality standards at Economic Centres [p,c] • Farmer perception of futility: being badly stuck in the situation without knowing how to adapt to the increasing effects of climate change [c] • Farmers would not encourage their children to go into farming [p,c]
Human	• Farmer knowledge to grow new supplementary crops and produce compost as advised by government (e.g. bananas) [c] • Educated farmers conducting soil testing [p]	• Inappropriate experience of extension service providers and training on efficient composting [p,c] • Lack of timely market information (e.g. price of vegetables) [p,c] • Miscommunication regarding new fertiliser subsidy scheme (some farmers thought the subsidy was reduced) [p] • Lack of awareness and information of phosphorus scarcity and implications [p] • Lack of data collection on organic fertiliser production [p]
Physical	• On-farm organic fertiliser production/use [p] • Capacity to increase compost generation [p]	• Lack of on-farm crop storage facilities [c] • Lack of technology to process phosphate from the mine into triple super phosphate fertiliser [p]
Natural	• High soil phosphorus content (short-term) [p] • High biodiversity and climate regions	• N/A

5.2 Weak capacity to adapt

Factors contributing to weaker capacity to adapt towards PACSA largely centred around the perceived lack of financial and informational resources for farmers, in addition, to lack of trust or confidence between sectors. For example, most farmers interviewed directly or indirectly alluded to the poor financial status of farmers, explaining that the average farmer has low financial/educational status, poor income, and low profit margins. Further, they identified the weak purchasing power of farmers to influence commodity price, in part due to a lack of on-farm storage facilities and the need for cash, meaning farmers have to sell crops straight away. They felt that intermediaries are still setting the price and potentially exploiting farmers despite new options to sell through government-run Economic Centres. Some farmers felt that although they would prefer to sell through the government Centres, they could not easily meet the government's high quality standards and, hence, resorted back to old routes.

Further compounding this is a perceived lack of support. Some farmers felt it was difficult to take risks and adapt as there are no effective safety nets (such as sound insurance schemes or a lack of access to credit for fertilisers). Vegetable farmers also do not have access to the fertiliser subsidy scheme and one farmer felt that in the case of future fertiliser price spikes, he would have no other option but to continue the same application regime. To emphasise the point, some farmers said they would never encourage their children to go into farming due to lack of profit margins.

Some farmers and farmer organisation representatives highlighted the disconnect between grass-roots implementation and policy-making whereby they believed policy-makers were not providing a conducive or supportive environment for farmers who cannot sustain themselves if productivity levels on their farm dropped. Another farmer said that while donor funds were also meant to be forthcoming, they had not seen any finances yet.

The huge investment cost associated with new technology was highlighted by both farmers and the agrochemical industry as a barrier preventing them from adapting. For example, farmers would require significant financial capital in order to purchase poly-tunnels or combine harvesters, or to transport bulky manure to the farm gate, or for infrastructure for high-tech banana plantations. The agrochemical industry stakeholder also noted, "*creating new molecules is a huge investment*", meaning they wouldn't be able to easily adapt by developing new climate-smart products unless they had capital investment.

While the glyphosate ban has important potential benefits for public health and the environment, the lack of perceived viable alternatives for week management means there may be a black market developing.

Many stakeholder respondents commented on the lag in viability and effectiveness of current organic fertilisers compared to sustainability advances in other sectors. One farmer remarked, "*for energy you have solar, for cars we have hybrids, but for agriculture what options do we have?*". While many farmers interviewed thought that the use of organic fertilisers was certainly increasing, they were concerned that organic fertilisers (including compost) could not fully replace chemical fertilisers due to limited yields. Some postulated that the transition to organic fertilisers was limited because some seed varieties were better suited to chemical fertilisers while other respondents were concerned that shifting to organic agriculture (and organic fertilisers) would increase the risk of pests. Some government stakeholders also noted from a capacity perspective, compost generation to meet growing demand might be constrained by land space, need for donor support, and high levels of contamination. The provincial government stakeholder also noted they were not allowed to transport waste from other areas as an input for composters.

Some stakeholders identified a range of knowledge stocks and flows that are lacking and, hence, disempowering stakeholders from adapting. For example, the fertiliser retailer (who used to be a farmer), acknowledged there was little market information making it hard for farmers to adapt such as knowing prices of vegetables such as cabbage during drought periods to make informed decisions on whether to use fertilisers. Also, because vegetable farmers are not eligible for the fertiliser subsidy, their knowledge and effective use of organic fertilisers is of paramount importance, especially during times of high fertiliser prices. Yet some of the farmers and farmer organisations felt that government extension on organic fertilisers was insufficient; they wanted improved training because although they were following government recommendations, they felt the on-farm compost-making process was inefficient. Another farmer also felt some government agricultural advisers had inappropriate experience for his local vegetable-growing area as advisors might have come from a paddy-growing region.

None of the stakeholders interviewed were aware of the longer-term global phosphorus scarcity issue or its implications for Sri Lanka (relative to their awareness of climate change), indicating a lack of information and knowledge on the issue.

A government stakeholder acknowledged, in hindsight, that the new fertiliser subsidy program had a few teething problems, such as farmer resistance. This was in part due to how the subsidy reform was communicated which may have given farmers the wrong perception that the financial subsidy was reduced (which was not the case).

A related theme of trust was also alluded to by some stakeholders. For example, one farmer noted that although he had access to online climate information, such as weather predictions, he did not trust the reliability of the government’s Meteorological department. The fertiliser retailer suggested it was difficult to easily trust the government because different politicians had deceived people in the past.

Two government stakeholders also acknowledged there has been strong resistance by the agro-chemical industry to the glyphosate ban associated with the Presidential Secretariat’s “Toxin-Free Nation” Action Plan. This sensitive topic appears to be shrouded in a sense of mistrust and stakeholder interests. Both stakeholders referred to an incident where many scientists publicly protested against the ban (e.g. in the newspaper). It was suggested by some respondents that the position of these scientists may not be entirely independent from the agro-chemical industry.

Finally, other indications of weaker capacity to adapt included the lack of technology to process phosphate rock into triple-super-phosphate fertiliser from the government-owned local mine. There was also the perception among some farmers that climate change is so unpredictable that it is a challenge to adapt, and that they are badly stuck in the situation if the effects of climate change should become more severe.

5.3 Stakeholder responsibilities

Respondents were asked who they thought was responsible for facilitating adaptation towards PACSAand what roles they might play. Perhaps unsurprisingly, non-governmental stakeholders (including industry, farmers and farmer organisations) thought the government was responsible. Specifically, farmer and farmer organisation respondents thought it was government’s role to incentivise farmers to change practices towards more phosphorus and climate smart agriculture (including future generations who are currently disinterested) and to provide technological options (including improved crop varieties). Some stakeholders recognised that State government also needs further capacity development. Both industry respondents thought the government should also provide favourable regulatory environments to support, for example, new renewable fertiliser product development.

One government respondent indicated that they have given an open invitation to the private sector to develop improved on-farm bio-technical strategies and that the private sector was already playing a role in research development, in addition to research institutes and universities. He noted that farmers, NGOs and researchers have also been doing work on the ground for a long time. He further offered that ultimately farmers are the real decision-makers, for example, choosing which fertilisers (organic or chemical, etc.) they will use. While most of the farmers and farmer organisations wanted to see more support from government and researchers, one farmer organisation acknowledged that their structure allowed them to mobilise and approach policy-makers to discuss their priority needs, rather than remain as passive recipients.

6 ENABLING ENVIRONMENT

The broader political, cultural and biophysical environment in Sri Lanka provides a backdrop that can either hinder or enable PACSA adaptation.

6.1 Enablers of adaptation

Currently, the single biggest enabler of change towards PACSA is political will at the highest level, specifically the President's key aspiration of a "Toxin-Free Nation" and implementation actions taken towards this goal. The "Toxin-Free Nation" program is primarily driven by President's concern over Chronic Kidney Disease of Unknown origins (CKDu). The population most vulnerable to the disease are farmers in the North-Central Province of Sri Lanka where the President's family has originated from (see Section 4.1.1).

Whilst food security has been high on the national policy agenda for the past few decades, the government's "Toxin-Free Nation" Task Force is unintentionally enabling adaptation to phosphorus scarcity by actively discouraging the use of chemical fertilisers, and simultaneously incentivising the use of organic fertilisers through policy, agricultural extension and communication. For example, organic fertilisers have been encouraged through the new fertiliser subsidy scheme (see Section 4.1.2). The use of organic fertilisers (compost) can also enable better adaptation to, and mitigation of, climate change due to the water-holding capacity of compost which reduces the reliance and sensitivity to monsoonal rainwater or scarce water sources an, reduces methane greenhouse gas emissions by allowing the organic waste to decompose aerobically rather than anaerobically in a landfill or dump site.

At the same time, the production and use of compost is also driven by national and local plans to improve waste management and recycling rates. According to one government stakeholder, most waste (approximately 85%) currently goes to open landfill sites creating health and environmental impacts. In addition, landfill sites are already reaching capacity with waste generation expected to grow over the coming decades. Sri Lanka's climate mitigation agreement under the United Nations Framework Convention on Climate Change (UNFCCC) process is a further driver for waste management as it includes mitigation through household source segregation, compost production and waste-to-energy and includes a 20% target for non-conventional renewable energy (see Appendix A).

Table 4 indicates key policy, biophysical, economic and socio-cultural drivers that are influencing or enabling adaptation.

Table 4. Key drivers of change in Sri Lanka's broader political, socio-cultural, biophysical context that are influencing or enabling adaptation.

Theme	Driver of change
Policy drivers	• Presidential concern over Chronic Kidney Disease of Unknown origins (CKDu) and establishment of taskforce to identify causes and prevention activities • Presidential push for organic agriculture, organic fertilisers • Presidential ban on agro-chemical glyphosate (Monsanto's RoundUp weedicide) associated with CKDu • Fertiliser subsidy change driven by desire to increase administrative efficiency of the system and stimulate organic fertiliser use • Climate Change Secretariat's Climate Change National Adaptation Plan • Climate mitigation commitment under international agreements (UNFCCC) • National policy for 20% non-conventional renewable energy by 2020 including waste-to-energy
Biophysical drivers	• Climate change impacts including extreme rainfall/flood, delayed monsoon, extreme drought, extreme heat • Climate change projected to affect 70% rice farmers and impacts on other farmers • Reduced crop yields and crop failure, increased crop disease • 85% of waste goes to open landfill, creating health and social problems • Landfills are reaching capacity and waste generation is expected to double by 2050 • Desire to reduce fertiliser imports driven by excessive phosphorus levels in soil
Economic drivers	• Agrochemical input costs are increasing (e.g. fertilisers) for both farmers and government (e.g. government absorbed price shock of 2008 phosphorus fertiliser price spike through subsidies program) • Fertiliser subsidies represent approximately 2% of Sri Lanka's government expenditure • Labour shortages and high labour costs in agriculture • Low farmer income due to increased fuel prices, labour costs, profits of middlemen in supply chain, low prices for vegetables to farmers; no fertiliser subsidy for vegetable farming
Socio-cultural drivers	• Cultural significance of rice as the staple of the Sri Lankan diet (hence rice receives fertiliser subsidy but not vegetables) • Politicised issue of changing fertiliser subsidies as paddy is considered 'sacred' • Politicised nature of CKDu with high levels of CKDu in rural rice-farming areas • Emphasis in "Toxin-Free Nation" taskforce on growing traditional varieties (particularly of rice) • Public pressure to improve waste management[12]

[12] the high profile of recent waste management/landfill disasters as well as widespread prevalence of dengue fever have also attracted public attention and pressure.

Whilst the large number of Ministries in Sri Lanka (40 Ministries of which about 8 have direct involvement with agriculture) can impede change, the new Presidential Task Forces (see section 4.1.1) are working closely with the Ministries to develop the associated national plans. The Task Forces act as a coordinator and delegate responsibilities to the relevant Ministries, including Social Services, Agriculture & Irrigation, Finance, Defence and Environment. Structurally, the Ministry of Environment sits directly under the President, thus making the President the Environment Minister.

There are also social enablers of change occurring from the bottom-up. For example, some stakeholders noted that people “revere” monks and Buddhist clergy and often look to them for political and community leadership. This was the case for protests against any potential sell-off of the government-owned phosphate mine. The openness of younger farmers to innovative ideas was also referred to by a non-profit stakeholder. For example, the stakeholder noted these farmers’ willingness to try waste biogas slurry from food waste in traditional paddy farming, which ultimately withstood floods better than the surrounding paddy fields.

A farmer organisation stakeholder offered that farmers believe compost will be good for soil health in the long-term. According to a local government stakeholder, those who are already using traditional farming methods (without the use of pesticides and chemical fertilisers) are more receptive to government advice on technology transfer and will find the transition to organic farming easier because they have the knowledge and demonstrated results (which in turn may influence neighbouring farmers). Further, traditional farmers may be more willing to transition to organic because they can get a higher price for their produce with minimal effort to change any practices. The industry stakeholder also believes there is space in the market for a ‘slow-release’ NPK fertiliser (which organic bio-fertilisers can offer) to meet the new demand potential.

6.2 Barriers to adapting

Respondents cited a wide range of barriers hindering shifts towards PACSA. These included strong socio-cultural perceptions, such as ‘paddy is sacred’, meaning there can be strong resistance from farmers to trying more climate-smart and phosphorus-efficient paddy farming practices. At the same time, some farmers felt disempowered: there was often a perception among farmer respondents that the government needs to step in and support/stimulate their changed practices to be more climate-smart, etc.; that it is the key role of government, and there is little they themselves can do. They felt policies are often made top-down without looking at the needs of farmers. Some of the farmer and farmer organisation respondents also saw the unwillingness of the rich/elite farmers to join or engage with farmer organisations (because they didn’t require the support network) as hindering the diffusion of innovation and, hence, their own possibilities for adaptation.

Other social barriers included feeling discouraged as the younger generations are not wanting to become farmers as the work is perceived as too tedious and poorly paid. Farmers were also concerned about the new fertiliser subsidy scheme, both because they perceived it to provide less financial support and because it required them to have bank accounts which many of them did not already have. One government respondent thought that farmers were over-applying fertilisers because they perceived it would lead to increased yields.

Several government and non-profit stakeholders thought the biggest barrier to waste management (including organics recycling) was community perceptions. For example, people do not like the smells associated with dumpsites and landfills, and therefore communities may also oppose waste-to-energy if they think it is just another dumpsite. A non-government stakeholder also thought community perceptions of biogas as a ‘*poor-man’s energy source’* may impede progress on technology adoption. Another social barrier identified by a government stakeholder was the perception of immigrant or low socio-economic status labourers as unreliable workers. According to one respondent, absenteeism is a significant issue because they are typically employed as casual labour to avoid being subject to labour rights legislation triggered by permanent employment.

Labour shortages—and the resultant high labour costs—in the country were also hindering on-farm adaptations according to several government and farmer stakeholders. For example, high labour costs limit the viability of compost as an alternative to chemical fertilisers due the labour intensiveness of compost use.

Finally, there were mixed views on the transition to organic agriculture. Many opposed the strict plan arguing either that diversity of sustainable agricultural systems is needed (organic being just one type) or that it is too early to transition to 100% organic because the essential support infrastructure is not in place. The risk is therefore that yields can be low and unable to meet demand, especially risky in times of crop failure (as evidenced for rice in 2014 and again in 2016/17).

7 KEY FINDINGS

This research sought to investigate the vulnerability of Sri Lanka's food system stakeholders to both climate change and phosphorus scarcity, and, their capacity to adapt. Box 2 highlights the key findings.

The study found that the Sri Lankan food system is vulnerable to both risks and is indeed already experiencing the impacts of climate change in terms of delayed monsoons, extreme drought/floods and flow-on impacts reducing farmer productivity due to disease, pests, and water scarcity. In relation to phosphorus scarcity, while most stakeholders were not aware of the risks, the government budget for fertiliser subsidies (which already represents around 2% of expenditure) took a blow during the 2008 fertiliser price spike reaching 2.7% of expenditure (Central Bank of Sri Lanka 2014). Vegetable farmers were impacted by the increase in fertiliser cost, while paddy farmers were protected by the government subsidy and did not feel the impact. The analysis found that climate change and phosphorus scarcity risks are interrelated within the food system in a complex, non-linear web of causal links and feedback loops that together can, and are, reducing productivity and farmer incomes, exacerbated by other external drivers such as labour shortages and unnecessarily long supply chains.

At the same time, the study found that significant transformations are already underway that, by default, promote phosphorus and climate smart agriculture, such as the promotion of organic fertilisers and scheduled waste-to-energy projects. However, these adaptive strategies are largely not driven by climate change adaptation nor phosphorus vulnerability, rather, they are being driven by health concerns over CKDu, climate mitigation and waste management targets.

Vulnerability often drives adaptation in the form of coping, maladaptation or transformation. For example, the removal of subsidies can drive efficiency. While there is some existing level of coping mechanisms in addition to knowledge, awareness, and experiences related to climate change, there is negligible awareness or adaptation in Sri Lanka in response to phosphorus scarcity. This was evident from both the literature review and social research.

Further, the climate change discourse and actions related to food security have largely targeted agriculture, ignoring risks and opportunities in other components of the food value chain, such as food spoilage due to extreme weather during transport, and the adaptive opportunity that cold storage transport could provide to reduce food waste.

In addition to ad-hoc farmer coping strategies, such as pumping water to replace rain-fed fields, planned climate change adaptation has largely been driven by national implementation of international agreements (such as the UNFCCC). No comparable formal driver to directly address phosphorus scarcity was found through this research. However, indirectly there is a national driver to reduce dependence on fertiliser imports and promote organic fertilisers through national food security policies.

Further, few existing adaptation strategies explicitly address both climate change and phosphorus scarcity. Therefore, there is a need to make links explicit between phosphorus and climate change, to co-adapt to the twin challenges through a coordinated approach that ensures strategies promote PACSA and avoid mal-adapting.

The evident disconnect extended beyond climate change and phosphorus scarcity: whilst there are many initiatives underway, there is a degree of fragmentation between national food security programs and policies (including the "Toxin-Free Nation" and Food Production National Programme) and climate adaptation policies (National Adaptation Plan (NAP) and Readiness Plan for Implementation of Indented Nationally Determined Contributions (INDCs)). This is, in part, because climate change policies sit under the authority of Ministry of Mahaweli Development and Environment whereas the food security policies have been developed under the Presidential Secretariat and many line ministries. There are numerous ministries and departments involved in these related areas stressing the need for a more coordinated implementation.

Within the national climate change policies, food security is considered an important part of climate change adaptation. The focus is on agriculture and on-farm strategies including resilience of crops to changes in heat, drought, extreme weather events and pests. While still focusing on on-farm needs, some strategies are more transformational, for example, adjusting cropping calendars, developing communication systems for farmers and research capacity in the NAP and updating agricultural zones in the INDC. However, these policies do not consider the links between climate change and fertiliser inputs or address links to phosphorus vulnerability.

Box 2: KEY FINDINGS: HIGHLIGHTS

- Sri Lanka's food system is vulnerable to both climate change and phosphorus scarcity – together these can and are reducing productivity and livelihoods.
- Vegetable farmers may find it harder to adapt than rice paddy farmers because rice is considered a staple for food security and is supported by fertiliser subsidies and institutional channels for purchasing paddy at a guaranteed price.
- Farmers and other stakeholders are already feeling the impacts of delayed monsoons and more extreme droughts and floods. Vegetable farmers were impacted by the 2008 fertiliser price spike as they were not buffered by the fertiliser subsidy.
- Significant transformations are already underway, including incentivising organic agriculture, promotion of organic fertilisers, fertiliser subsidy reform, on-farm diversification of crops, a ban on glyphosate weedicide, organic waste household separation and waste-to-energy. However, these have been driven by health concerns (Toxin-Free Nation program), climate mitigation and waste management.
- Unlike climate change, there are no formal programs or agreements directly addressing phosphorus scarcity. No stakeholders interviewed were aware of global phosphorus scarcity or the risks facing Sri Lanka's food system.
- Adaption to climate change and phosphorus scarcity is impeded by: fragmentation of current programs under numerous different Ministries and Departments, mistrust between some stakeholders in the supply chain, labour shortages, resistance to changing paddy practices and low farmer purchasing power.
- There is a need to bring all key stakeholders on board to implement change in a coordinated and managed way – including the relevant Ministries but also industry and farmer organisations.
- Relative to other low-middle income countries in the region, Sri Lanka has good access to services and infrastructure that are essential for transformation, including: water and sanitation, health services, transport, education and natural resources such as highly biodiverse regions.

Policies and programs directly targeting food security do not explicitly address phosphorus scarcity or climate change, but, many of the strategies address both vulnerabilities. Unlike with climate change adaptation, the food security policies take a whole food system approach, including on- and off-farm adaptations. Strategies that address both phosphorus and climate change include improving storage, transport and sale of produce to prevent losses and developing new organic fertiliser products and standards. Promoting toxin-free pest control and fertilisers through changes to the fertiliser subsidy and banning glyphosate address phosphorus scarcity although they are driven primarily by health concerns. However, the link with climate change in these strategies needs to be made more explicit as it has the potential to impact the success of strategies within both programs.

In practice, the stakeholder interviews identified the focus of the Presidential “Toxin-Free Nation” Program has been on banning glyphosate, reforming the fertiliser subsidy and training farmers to produce and use compost. Strategies for preventing post-harvest losses require more focus.

While this Program has already driven bold changes towards sustainable agriculture, not all stakeholders are on board. For example, stakeholders had various opinions on the implications of the promotion of organic agriculture for food security. Perceptions of the benefits of organic agriculture and best strategy vary greatly: while the President is pushing for 100% organic, some food security and sustainability stakeholders were more cautious of such an ambitious and singular approach. Gradual and holistic transitions may be required to avoid mal-adapting and to ensure stakeholder buy-in and coordination between sectors.

Additional planned strategies include creating new guidelines for soil specific fertiliser application, improved processing from the Sri Lankan phosphate mine and connecting producers and consumers through a National Consumer Network. Stakeholders interviewed also suggested an array of possible future PACSA strategies such as improved knowledge for farmers on technology (including fertilisers) and markets, establishing links between farmer organisations, off-farm diversification (e.g. agro-tourism), new local enterprises or subsidies for equipment (including replacing glyphosate use), improved access to export markets and extending the fertiliser subsidy to other crops.

The literature supplemented these suggestions, including demand-driven organic food markets and research and diversifying sources of fertiliser inputs such as using human excreta. There was a lack of knowledge and awareness around the use of human excreta as a source of phosphorus among interviewed stakeholders.

Interestingly, this research also identified that the vulnerability situation for rice and vegetables was almost a tale of two crops. Paddy systems and rice are considered ‘sacred’ and a staple for food security, attracting fertiliser subsidies and leaving markets relatively inelastic. While vegetable production, on the other hand, is not recognised or valued as important nutritionally or economically, and is not supported by fertiliser subsidies, leaving vegetable farmers much more exposed to future climate change or phosphorus shocks such as extreme weather or global fertiliser price spikes. Further, the government has established two channels for purchasing paddy at a predetermined price, while vegetable farmers are price-takers and must sell to middlemen on the open market, regardless of prices offered.

Factors limiting Sri Lankan stakeholders’ capacity to adapt to both climate change and phosphorus scarcity shared many universal aspects typical to many countries. For example, low farmer purchasing power and incomes, mistrust between sectors, and stakeholder perceptions on their lack of ability to create change which perpetuates their sense of futility. Stakeholders interviewed were not always able to identify resources they already possessed that would enable them to adapt. However it was clear from the literature that relative to other low-middle-income countries, Sri Lanka has a relatively good access to physical and social infrastructure such as access to water, sanitation and transport, health services and education, in addition to highly biodiverse regions for such a small island state. While persistent manual labour shortages was seen by many stakeholders as limiting the capacity to adapt to phosphorus scarcity and climate change, new human resources were emerging at the professional level; the Ministry of Defence is transitioning from armed forces to civil services so this group of personnel has the capacity to implement key services such as new water infrastructure. Similarly, extension services provided by the government are widespread, indicating strong social capital, yet it is unclear whether these services are appropriately targeted and utilised.

8 A WAY FORWARD

To overcome the impediments, fill gaps and harness opportunities identified in the key findings in Section 7, a way forward is proposed. First, a key recommendation is to improve connections within the whole food system. That is, linking, bridging and bonding social capital and coordination between actors, across scales and between phosphorus scarcity and climate change (Woolcock 1998). Table 5 identifies six key scales for improving system connections to enable adaptation towards phosphorus and climate smart agriculture.

Table 5: Six scale-explicit recommendations to overcome fragmentation towards more effective phosphorus and climate smart agriculture.

Scale/system	Recommended strategy	Specific recommendations
National	National strategy to share disparate knowledge, identify synergies/inter-linkages, overcome institutional fragmentation and clarify roles and responsibilities in a transformed food system.	Make explicit how non phosphorus and climate change initiatives like "Toxin-Free Nation" link to PACSA (to avoid mal-adaptation). E.g. through workshop bringing together key stakeholders, co-run/owned.
Food system	Ensure PACSA adaptive strategies address: • all sectors in the food system • the whole value chain as a system • producer-consumer dynamics.	• Improved cold storage • Explore market demand opportunities and dynamics of value chain, to complement supply-side initiatives like training farmers to use compost • Linking waste managers and agrochemical industry.
Farming regions	• Farmer-to-farmer knowledge-sharing, bartering, social networks • Improve government extension-to-farmer relationships	• Link paddy and vegetable farmers, or farmer organisations with each other, or risk-taking innovation champions with other farmers • Ensure extension officers have the appropriate knowledge sets (through train-the-trainer).
Farm	On-farm adaptive strategies address both phosphorus scarcity and climate change	Drought-tolerant and low fertiliser-demanding crops
Phosphorus scarcity and climate change nexus	Ensure inter-linkages between climate change and phosphorus scarcity are clear, in terms of vulnerability and adaptive strategies that address both issues.	Benefits of waste-to-energy for climate adaptation (reducing on-farm water demand), phosphorus (renewable fertilisers), climate mitigation.
Organic waste system	Optimise and integrate organic waste management, resource recovery and fill gaps.	Whole-system modelling, assess risks and benefits, perceptions of different options and sources Investigate use of wastewater/excreta as a future potential source.

A national strategy should aim to optimise the food system within the environmental thresholds set by climate change. The strategies identified in this research, in addition to other possibilities, need to be further investigated with key food-system stakeholders to explore their desirability, feasibility and effectiveness.

8.1 Specific recommendations

In addition to the recommendations identified in Table 5 above, there is a suite of potential priority PACSA initiatives emerging from this study which could be explored further and that explicitly seek to integrate climate change and phosphorus adaptation where possible.

8.1.1 Extending the Climate Change National Adaptation Strategy (NAP)

This project identified several PACSA recommendations building on Sri Lanka's key climate change adaptation policy mechanism - the National Adaptation Strategy:

- identify off-farm climate adaptation strategies in the food system (to complement on-farm strategies), such as improved cold-storage which reduces food waste associated with more extreme heat during transit;
- integrate phosphorus adaptive strategies with existing climate adaptation options (identified in table 6, p.49 of the NAP), specifically:
    - **Germplasm improvement** – investigate low-phosphorus crop varieties, in addition to proposed drought and pest-tolerant varieties;
    - **Promotion of resource efficient farming systems** – promote low-phosphorus demanding crops in addition to proposed low-water demanding crops
    - **Information management and communication** *system* – including phosphorus tracking (e.g. phosphorus fertiliser price) in addition to proposed weather forecasts;
- Engage Sector Cells within individual Ministries and Agencies to explore the coordinated implementation of PACSA strategies.

8.1.2 Improved awareness, communication and capacity-building

Build social and knowledge capital in key identified areas of weakness including:

- **Farmers**: Overcoming farmers' negative perceptions and miscommunication regarding organic waste and organic fertilisers (including compost from waste-to-energy, biogas slurry, human excreta, etc.);
- **Extension services**: ensuring an appropriate knowledge set to match changing climate and adaptive strategies;
- **Government**: Raise awareness of phosphorus scarcity among local, provincial and national government (particularly key Ministries of Agriculture, Mahaweli & Environment) and other key food system stakeholders to inform implementation of adaptive responses;
- **Government**: bottom-up knowledge from farmers to government of key concerns, perceptions, needs;
- **Households**: organic waste separation – needs, benefits, process;
- **Consumers**: health (e.g. promoting vegetable consumption), transparent food chain; and
- **All**: Need a national conversation on organic agriculture: risks, benefits, optimisation; clarify roles and responsibilities with stakeholders.

8.1.3 New knowledge and research

Address knowledge deficits to allow system actors to make better evidence-based decisions and improve their management of risk (this could be all along the supply chain):

- identifying and **overcoming market failures** and removing impediments (e.g. supporting vegetable production, e.g. through subsidy equity, market access, etc.);

- **optimising the organic waste system** (modelling of resource flows, scenarios, assess benefits, risks and trade-offs) including the suite of sources for potential use on-farm including municipal organic waste (food & garden), agricultural residues, cow and poultry manure, wastewater, biogas slurry and liquid, septic sludge. The new fertiliser subsidy program requires APRA's to collect data from farmers on which fertilisers they will use with the subsidy (organic, chemical, etc.) and volumes - this can provide valuable data for such analysis;
- Further investigate the **implications of phosphorus scarcity** for food security in Sri Lanka to inform evidence-based policy responses and adaptation measures; and
- undertake a comprehensive **phosphorus budget** through the Sri Lankan food system to identify largest stocks, flows and areas of loss. The preliminary analysis undertaken in this research indicates compost alone is not enough to meet Sri Lanka's nutrient demand.

8.1.4 Improved resource efficiency

Use resources more efficiently under increasing climate risk and to reduce system losses – water and nutrients, including:

- **water use efficiency** – particularly on-farm as farmers are already struggling to cope with extreme drought and delayed monsoons that are leading to crop failure and reduced crop yields. e.g. compost can increase the water-holding capacity of soils, thereby buffering against extreme climate variability;
- **reducing food losses** from farm-gate to fork;
- **reducing phosphorus losses** from mine to farm to fork and increasing on-farm phosphorus use-efficiency through improved soil management, improved crop types, and alternative fertilisers;
- **diversification of agricultural input sources** to buffer against resource shortages, scarcity and price fluctuations. Specifically, continue to diversify nutrient/phosphorus sources instead of heavy reliance on imported fertilisers.

8.1.5 Strengthen vegetable markets

Ensure strategies explicitly support vegetable markets along with rice markets. This is important for nutritional security, farmer livelihoods, and national food security during periods of extreme events that may destroy rice crops, but not vegetable production. Interventions might consider:

- comparable **subsidies or financial incentives** applied equally to vegetables and rice;
- campaigns to **promote vegetable consumption** (building on FAO recommendations, pers comm D.B.T.Wijeratne, Assistant FAO Representative (Programme), 13/2/17);and
- streamlining or **shortening vegetable supply chains** to increase farmer agency when selling and to reduce spoilage/losses.

9 REFERENCES

Adger (2006) *Vulnerability*, Global Env Change, 6(3), August 2006, Pages 268–281

Amarasinghe, U., Samad, M., & Anputhas, M. (2005) *Spatial clustering of rural poverty and food insecurity in Sri Lanka*. Food Policy, *30*(5), 493-509.

Bandarage, A. (2013) *Political economy of epidemic kidney disease in Sri Lanka*. Sage Open, *3*(4), 2158244013511827.

Biazin, B. and Sterk, G. (2013) *Drought vulnerability drives land-use and land cover changes in the Rift Valley dry lands of Ethiopia*. Agriculture, Ecosystems & Environment, 164, pp.100-113.

Biermann et al (2009) *Earth System Governance: People, Places and the Planet.* Science and Implementation Plan of the Earth System Governance Project. ESG Report 1. Bonn, IHDP: The Earth System Governance Project.

Biradar, C. M., Thenkabail, P. S., Noojipady, P., Li, Y., Dheeravath, V., Turral, H., et al. (2009) *A global map of rainfed cropland areas (GMRCA) at the end of last millennium using remote sensing*. International Journal of Applied Earth Observation and Geoinformation, 11(2), 114-129. doi: http://dx.doi.org/10.1016/j.jag.2008.11.002

Central Bank of Sri Lanka (2014) *Annual Report 2014, Chapter 2. National Output and Expenditure*, online: http://www.cbsl.gov.lk/pics_n_docs/10_pub/_docs/efr/annual_report/AR2014/English/6_Chapter_02.pdf

Central Bank of Sri Lanka (2016) *Annual Report 2016, Chapter 2. National Output and Expenditure,* online: http://www.cbsl.gov.lk/pics_n_docs/10_pub/_docs/efr/annual_report/AR2016/English/6_Chapter_02.pdf

Cooper, J., Lombardi, R., Boardman, D., and Carliell-Marquet, C. (2011) *The future distribution and production of global phosphate rock reserves*, Resources, Conservation and Recycling, 57 (2011) 78–86.

Cordell, D. & White, S. (2014) *Life's bottleneck: sustaining the world's phosphorus for a food secure future*, Annual Review of Environment and Resources, Vol. 39:161-188.

Cordell, D. & White, S. (2015) *Tracking phosphorus security: indicators of phosphorus vulnerability in the global food system*, Food Security, Springer, Feb 2015, Vol 7, Issue 2, p.337-350.

DCS (2014) *Food Balance Sheet, 2012/2013*, Colombo, Department of Census and Statistics, Sri Lanka.

DCS (2011) *Self-sufficiency rate of rice 2005-2010*, Colombo, Department of Census and Statistics, Sri Lanka.

De Silva, C., Weatherhead E., Knox J. et al (2007) *Predicting the impacts of climate change: a case study of paddy irrigation water requirements in Sri Lanka*. Agricultural Water Management, 93:19–29.

Dharmarathna, W. R. S. S., Herath, S., & Weerakoon, S. B. (2014) *Changing the planting date as a climate change adaptation strategy for rice production in Kurunegala district, Sri Lanka*. Sustainability science, 9(1), 103-111.

Ellis (2000) *Rural Livelihoods and Diversity in Developing Countries*. Oxford University Press, Oxford.

Engle, N.L. (2011) *Adaptive capacity and its assessment*. Global Environmental Change, 21(2), pp.647-656.

Esham, M, (2016) *Climate change & food security: A Sri Lankan Perspective*, Institute for Sustainable Futures, University of Technology Sydney.

Esham, M., & Garforth, C. (2013) *Agricultural adaptation to climate change: insights from a farming community in Sri Lanka*. Mitigation and Adaptation Strategies for Global Change, 18(5), 535-549.

Esham, M., Jacobs, B., Rosairo, H. S. R., & Siddighi, B. B. (2017) *Climate change and food security: A Sri Lankan perspective*. Environment, Development and Sustainability, 1-20.

FAO (2014) *The State of Food and Agriculture: Innovation in family farming*, Food and Agriculture Organization of the United Nations, Rome, ISSN 0081-4539.

FAOSTAT (2014) *Statistical Database from Food and Agriculture Organization*. http://faostat3.fao.org/download/T/TP/E. Accessed 24 January 2016.

Fernando, M.T.N., Zubair, L., Peiris, T.S.G., Ranasinghe, C.S., & Ratnasiri, J. (2007) *Economic value of climate variability impacts on coconut production in Sri Lanka*. AIACC Working Paper No. 45.

Folke (2006) *Resilience: The Emergence of a Perspective for Social-Ecological Systems Analyses*. Global Environmental Change, 16: 253-267.

Gunda, T., Hornberger, G.M. & Gilligan. J.M. (2016) *Spatiotemporal patterns of agricultural drought in Sri Lanka: 1881–2010*. International Journal of Climatology 36: 563–575.

Hackmann, H., Moser, S. & St Clair, A. (2014) *The social heart of global environmental change.* Nature Climate Change 4:653-5.

IFAD (2013) *Smallholders, food security, and the environment*, International Fund for Agricultural Development and United Nations Environment Programme, Rome.

Iizumi, T., Sakuma, H., Yokozawa, M., Luo, J-J., Challinor, A.J., Brown, M.E., Sakurai G. & Yamagata, T. (2013) *Prediction of seasonal climate-induced variations in global food production,* Nature Climate Change, 3, 904–908

Iwaniec, D., Metson, G., Cordell, D. (2016) *P-FUTURES: Towards urban food & water security through collaborative design and impact*, Current Opinion in Environmental Sustainability, v20, June 2016, p.1–7, Special Issue on co-design and co-production of transformative knowledge.

Jacobs, B. Lee C. and O'Toole D. (2014) *Integrated regional vulnerability assessment of government services to climate change*, International Journal of Climate Change Strategies & Management, 6 272–295.

Jacobs, B., Nelson,R., Kuruppu,N., and Leith,P. (2015) *An adaptive capacity guide book: Assessing, building and evaluating the capacity of communities to adapt in a changing climate*. Southern Slopes Climate Change Adaptation Research Partnership (SCARP), University of Technology Sydney and University of Tasmania. Hobart, Tasmania.

Jayasumana, C., Gunatilake, S., & Senanayake, P. (2014) *Glyphosate, hard water and nephrotoxic metals: are they the culprits behind the epidemic of chronic kidney disease of unknown etiology in Sri Lanka?*. International journal of environmental research and public health, 11(2), 2125-2147.

Jayasumana, C., Paranagama, P., Agampodi, S., Wijewardane, C., Gunatilake, S., & Siribaddana, S. (2015) *Drinking well water and occupational exposure to Herbicides is associated with chronic kidney disease, in Padavi-Sripura, Sri Lanka*. Environmental Health, 14(1), 6.

Jayawardena, R., Thennakoon, S., Byrne, N., Soares, M., Katulanda, P., & Hills, A. (2014) *Energy and nutrient intakes among Sri Lankan adults*. International Archives of Medicine, *7*(1), 34.

Jones, R. N., & Preston, B. L. (2011) *Adaptation and risk management*. Wiley Interdisciplinary Reviews: Climate Change, 2(2), 296-308.

Kates, R.W., Travis, W.R. and Wilbanks, T.J. (2012) *Transformational adaptation when incremental adaptations to climate change are insufficient*. Proceedings of the National Academy of Sciences, 109(19), pp.7156-7161.

Kumaragamage, D, and Indraratne, S.P (2011) *Systemic approach to diagnosing fertility problems in soils of Sri Lanka*. Communications in Soil Science and Plant Analysis, 42 (22), pp. 2699–2715.

Kwakkel, J.H., Haasnoot, M. and Walker, W.E. (2015) *Developing dynamic adaptive policy pathways: a computer-assisted approach for developing adaptive strategies for a deeply uncertain world*. Climatic Change, 132(3), pp.373-386.

Liyanage, K.D.C.E. (2016) *Nutrition Security in Sri Lanka*, Procedia Food Science, Vol 6 pp. 40-42.

Midgely, G. (2003) *Science as Systemic Intervention: Some Implications of Systems Thinking and Complexity for the Philosophy of Science*, Systemic Practice and Action Research, Vol.16, No.2, April 2003.

Ministry of Food Security (2015), Dedicated Economic Centres, online: http://www.mtdec.gov.lk/

Mitchell, C., Cordell, D. & Fam, D. (2015) *Beginning at the end: A transdisciplinary perspective of desired outcomes in sustainability research*, FUTURES, Special Issue on Transdisicplinarity. Futures v65 ,86–96

Moore M-L, Tjornbo O, Enfors E et al. (2014) *Studying the complexity of change: toward an analytical framework for understanding deliberate social-ecological transformations*. Ecology & Society, 19:10pp.

Pahl-Wostl (2009) *A conceptual framework for analysing adaptive capacity and multi-level learning processes in resource governance regimes*. Global Environmental Change, 18: 354-365.

Pelling, M. (2011) *Adaptation to Climate Change: From Resilience to Transformation*, Routledge, London.

Presidential Secretariat (2016) *A Toxin-Free Nation: Three Year Plan*. The President Office. Colombo.

Presidential Task Force on Prevention of CKDu (no date), *National Programme for the Prevention of Chronic Kidney Disease of Uncertain Etiology in Sri Lanka 2016-2018*. Development and Special Projects Division, Presidents Office, Colombo.

Saldana, J. (2009) *An introduction to codes and coding*. The coding manual for qualitative researchers, pp.1-31. Sage Los Angeles, CA.

Sanderatne, N. (2004) *Livelihoods and Poverty in Sri Lanka*. CEPA.

Senanayake, S.M.P. & Premaratne, S.P. (2016) *An analysis of the paddy/rice value chains in Sri Lanka*, Australia South Asia Research Centre working paper, online: https://acde.crawford.anu.edu.au/publication/asarc-working-papers/8377/analysis-paddyrice-value-chains-sri-lanka

Smith, M.S., Horrocks, L., Harvey, A. and Hamilton, C. (2011) *Rethinking adaptation for a 4 C world*. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 369(1934), pp.196-216.

UN (2016) *Sustainable Development Goal 2: Ending Hunger*, in: Transforming our world: the 2030 Agenda for Sustainable Development, online: https://sustainabledevelopment.un.org/sdg2

UNEP (2011) *Phosphorus & Food Production*, UNEP Yearbook: Emerging issues in our global environment, UNEP. http://staging.unep.org/yearbook/2011/pdfs/phosphorus_and_food_productioin.pdf

WHO (2016) *International Expert Consultation on Chronic Kidney Disease of Unknown Etiology*, Colombo, Sri Lanka 27–29 April 2016, World Health Organization, Country office for Sri Lanka.

WHO/UNICEF (2016) *Joint Monitoring Programme for Water Supply & Sanitation: estimates on the use of water sources and sanitation facilities: Sri Lanka* https://washdata.org/data

Wimalawansa, S. J. (2014) *Escalating chronic kidney diseases of multi-factorial origin in Sri Lanka: causes, solutions, and recommendations*. Environmental Health and Preventive Medicine, 19(6), 375-394.

Woolcock, M. (1998) *Social capital and economic development: Toward a theoretical synthesis and policy framework*. Theory and Society, 27(2), pp.151-208.

Zubair, L., Hansen, J., Yahiya, Z., Siriwardhana, M., Chandimala, J., Razick, et al (2010) *Impact assessment and adaptation to climate change of plantations in Sri Lanka*. International Rice Institute, IRI, Technical Report.

Zubair, L., Nissanka, S., Weerakoon, W. et al (2015) *Climate change impacts on rice farming systems in northwestern Sri Lanka*. In *Handbook of Climate Change and Agroecosystems: The Agricultural Model Intercomparison and Improvement Project (AgMIP) Integrated Crop and Economic Assessments, Part 2*. C. Rosenzweig, and D. Hillel, Eds., ICP Series on Climate Change Impacts, Adaptation, and Mitigation Vol. 3. Imperial College Press, 315-352.

APPENDIX A

Key Sri Lankan policy documents and their objectives, coverage, relevance to PACSA, gaps, effectiveness.

1. National Adaptation Plan for Climate Change Impacts in Sri Lanka (NAP)

Climate Change Secretariat, Ministry of Mahaweli Development and Environment, 2015

Coverage/relevance	Gaps and current level of implementation
• Follows on from National Climate Change Adaptation Strategy for Sri Lanka 2011-16 and the National Climate Change Policy (NCCP) adopted in 2012 • Food security identified as one of nine vulnerable sectors (as well as export agricultural sector[13]) • Priority actions for food security include: develop tolerant crop varieties and breeds to heat, drought, floods and resistant to disease and pests; water efficient farming methods; cropping calendars adjusted to climate forecasts; system for communicating climate information to farmers; and develop research institute capacity of above. • Cross cutting needs include: policy review for options to mainstream adaptation activities; policy recommendations; strengthen Climate Change Secretariat; develop inventory of international donors, schemes, training and research; create National Adaptation Fund; network of research agencies, research grant program and repository of research materials; identification of vulnerable assets; and training for government and non-government employees.	• Identified adaptation needs and suggested actions in the "Sector Action Plan – Food Security" are all focused on on-farm needs, e.g. resilience of crops to changes heat and water stress and extreme weather events, ,minimising the impact on food security due to changes in precipitation and minimising risk of crop and health damage from biological agents. • The plan does not consider adaptation needs for the whole food system, for example to address potential increases in post-harvest losses. • Phosphorus adaptation is not considered, for example actions could include low-phosphorus demanding crop varieties and phosphorus efficient farming methods • The Climate Change Secretariat is responsible for coordination and facilitation of the NAP, and activities are implemented by the relevant Ministries. Implementation is a challenge, as the ministries need to agree to undertake the proposed actions and take a proposal to the treasury for funding. Communication between the secretariat and various ministries is also a challenge, for example information is not always shared on the status of implementation by ministries.

[13] see National Adaptation Plan for priorities in this sector.

2. Readiness Plan for Intended Nationally Determined Contributions (INDCs)

Ministry of Mahaweli Development and Environment – Sri Lanka, 2016

Coverage/relevance	Gaps and current level of implementation
• Plan to implement Sri Lanka's country commitments to address climate change, according to the Indented Nationally Determined Contributions (INDCs). Sri Lanka is a signatory to the Paris Agreement in April 2016, after the climate deal at 21st Conference of Parties (COP21) in Dec 2015. • Plan contains strategic policies and readiness to implement INDCs for mitigation, adaptation, loss and damage and means of implementation. The readiness phase is from 2017 until implementation begins in 2020 with targets for 2030. • Mitigation targets are to reduce GHG emissions by 20% for energy[14] sector, and for 10% in other sectors (transport, industry, forests, waste). Waste strategies include household source separation, compost production, waste-to-energy and improve solid waste management strategies. • Adaptation strategies are for health[15], food security (agriculture, livestock and fisheries), water, coastal areas, biodiversity, tourism and urban planning. • Agriculture strategies include: crop resilience to pest through Integrated Pest Management (IPM), development/ introduction of tolerant varieties to climate damages, updating agricultural zones to identify climate zones, enhance land and water practices.	• Mitigation strategies for waste management need to consider social license for new developments of waste-to-energy or compost production, and, behaviour change strategies or incentives for implementation of household source separation • Adaptation strategies for agriculture are focused on on-farm adaptations, such as crop resistance to pests and climate damages. Gaps include consideration of fertiliser inputs (particularly phosphorus) and links with climate change adaptation. • The plan includes updating agricultural zones based on climate. • The strategies do not consider the whole food system, such as food losses along the value chain that could increase under climate change.

[14] Energy strategies include installing new renewable energy, demand side management and target of 60% renewable energy.

[15] CKDu is mentioned in health but does not mention changing from chemical to organic fertiliser.

3. A Toxin-Free Nation: Three Year Plan

Presidential Secretariat, 2016

Coverage/relevance	Gaps and current level of implementation
• Supporting program of the "National Food Production Program" (2016-18) • Goal is to replace agriculture based on imported agrochemicals with organic, natural agro-culture and provide healthy food to citizens. This will cover all the main agricultural produce and include 30% indigenous varieties. • Driven by the link between agrochemical use and CKDu and desire to reduce dependency on foreign companies for fuel and fertilisers in agriculture. • Addresses the challenge of high cost of organic foods to consumers. Reasons identified that organics are more expensive in Sri Lanka: fertiliser subsidies are exclusively for chemical fertilisers, higher labour requirements and high labour costs, comparatively low yields impacting farmer income and national food security (especially rice self-sufficiency). Changes in the environment mean that it is not possible to undertake natural agriculture as it was done in the past. • Aims to have "The same nutrition for the same price", that is the entire country should be able to fed on organic rice and farmers should obtain the same profits for organic rice as conventional. • Ten-point program: 1. Toxin-Free pest control 2. Toxin-free fertiliser 3. Irrigation appropriate to natural agriculture 4. Agricultural equipment appropriate for sustainable agro-culture 5. Facilities for yield purchase, preparation and storage 6. Safe transport and sale of produce 7. Land for those farmers engaged in sustainable agro-culture 8. Research into sustainable agro-culture and skills development 9. Protection of intellectual property rights related to biodiversity 10. Cooking techniques and intelligent consumption patterns	• Plan takes a broader view of food system, including strategies for storage, transport and sale of food, consumer practices, broader reform around rights to land and biodiversity. • The current program is training 75,000 farmers over 50,000 ha in organic agriculture with 1000 trainers. • First action implemented was to ban the weedicide glyphosate from import and distribution, based on the link with CKDu. • Fertiliser subsidy has been changed to provide the subsidy direct to farmers for both chemical and organic fertilisers, enabling the farmer to choose between the two types of agricultural practice. • Future stages for point 1 and 2 are to create a program to promote biological agents to control pests based on indigenous herbal extracts, replacing current varieties with traditional varieties more resilient to pest, disease and weed attacks. Plans to agricultural practices such as promoting planting to replenish nitrogen in the soil. • Need more focus on increasing risks and adaptation needs under climate change (e.g. potential need for more fertiliser or weedicide with changing weather patterns) • Stakeholders interviewed focused on the changes to the fertiliser subsidy and glyphosate ban when discussing the Toxin-Free Nation plan, rather other aspects of the plan.

4. Food Production National Programme 2016-2018

Presidential Task Force on National Food Production, 2015

Coverage/relevance	Gaps and current level of implementation
• Addresses the problems of: increasing food demand, cost of importing food that could be produced locally, farmer poverty and poor health, environmental degradation, competition for land, lack of technology and youth working in agriculture, issues with quality of food and adherence to food standards, adverse impacts of climate change, productivity not sufficient. • Main objective of the program is to make the country self-sufficient in food and end food importation. • Other objectives include: Ensure availability of high quality foods, ensure food security by management of food stocks, introducing a crop production program, increase productivity, coordination between stakeholders, high quality inputs and building a healthy nation. • Program strategies include: crop production program (for agricultural crops including rice, vegetables, fruits and spices), and livestock, fisheries and plantation crop development. • Crop production program includes strategies for improving inputs (seeds, fertilisers, equipment) including promoting organic fertiliser, farmer empowerment, marketing, natural resource management and climate change adaptation, public and private sector partnership, youth and women participation, knowledge management, traditional knowledge, research, educating consumers on healthy food practices, ensuring food security, irrigation infrastructure, legal frameworks and monitoring committees supervise progress.	• The program considers aspects of the whole food system and is broader than on-farm needs, for example includes marketing, educating consumers, and considering national level food security. • The plan is mainly targeted at increasing food production to make the country self-sufficient, but does not adequately address strategies for minimising food waste, for example in post-harvest losses. • The program promotes organic agriculture and fertiliser, but does not include promotion or support for enterprise development of renewable sources of organic fertiliser, standards or training. • Plan does not include strategies to improved information sharing for farmers. • Phosphorus adaptation is not considered, for example actions could include low-phosphorus demanding crop varieties and phosphorus efficient farming methods.

5. Promotion of Production and Use of Organic Fertiliser

Ministry of Agriculture, 2012

<table>
<tr><th>Coverage/relevance</th><th>Gaps and current level of implementation</th></tr>
<tr><td>

- Aim of project: Increase sustainable crop production, improvement of long-term soil fertility for better farmer livelihood, alleviating rural poverty and reduce foreign exchange drain on chemical fertiliser imports.

Relevant short-term objectives:

- Identification and utilization of new sources of organic materials.
- Compost production using freely available organic waste materials such as urban waste, industrial waste, animal waste, domestic waste.
- Increase production of high quality organic fertiliser by introducing correct technologies.
- Increase organic fertiliser production at different levels such as large, medium and small scales.
- Quality control of organic fertiliser production through implementing SLSI standards.
- Generate more employment opportunities by promoting commercial organic fertiliser production.
- Increase organic fertiliser marketing system.

Expected outputs:

- Increase food crop production by 50%.
- Increase farmer income by 50%.
- Increase organic fertiliser production by 400%.
- Increase use of organic manure and organic fertiliser by 100%
- Cut down chemical fertiliser imports per year by 25%.
- Save 25% expenditure on fertiliser imports.
- Utilise waste materials and freely available organic manure for crop production.

See: http://www.agrimin.gov.lk/web/index.php/project/12-project/26-promotion-of-production

</td><td>

- Unclear if there are clear roles and responsibilities for coordination and implementation across relevant agencies to achieve these target outputs. For example, the Fertiliser Secretariat wasn't fully aware of the project or responsible for implementation of activities related to the Secretariat.
- Many activities are currently underway, such as the Department of Agriculture training farmers to produce their own compost onsite.

</td></tr>
</table>

6. National Programme for the Prevention of Chronic Kidney Disease of Uncertain Etiology in Sri Lanka[16] 2016-2018

Presidential Task Force for Chronic Kidney Disease Prevention, Presidential Secretariat, 2016

Coverage/relevance	Gaps and current level of implementation
• National Plan is a 3-year programme carried out by Task Force with participation of ministries, departments, government and non-government organisations at from national to village levels. • Recommendations from the consultation held with World Health Organisation are considered in preparation of the plan. • 8 main focus areas: 1. Behavioural development for disease prevention 2. Early detection of patients 3. Supply of clean drinking water 4. Patients care 5. Welfare of patient, family and community 6. Healthy diet and nutrition 7. Establishment of an active database 8. Survey, research and policy preparation. • Healthy diet and nutrition includes focus on: recommendations for correct fertiliser use and compost, promoting organic farming, education on agricultural practices, control pesticide use and promote integrated pest management, traditional farming knowledge, establishments of a sales network for healthy food.	• Implementation is underway with actions targeting the 8 main focus areas. • Priority given to 11 districts in 2016 with 14 other districts in 2017/18.

[16] Excerpt from report: CKDu first detected in 1990's and now prevalent in 11 districts with around 20,000 patients. Contributing factors include agrochemical use, heavy metals in groundwater, dehydration and fluoride; Mission of the Task Force is the ensure eradication of CKDu through exchange of knowledge, disease prevention and care of patients. Role of taskforce is to prepare national policy and, coordinate among government ministries, departments and organisations, support legal and policy intervention, facilitate, supervise and monitor progress.

APPENDIX B

Strategies towards PACSA identified by stakeholders (B1 and B2) and from the literature (B3)

B1. Current/planned adaptive strategies

** = implemented or in progress*

- Drought and pest tolerant crop varieties (National Adaptation Plan)
- Low-water demanding crops (National Adaptation Plan)
- New fertiliser subsidy*
- Promotion of organic fertilisers* (standards, extensions training, goals)
- Incentivising organic agriculture* (extension, etc.)
- Banning glyphosate*
- Organic total weed killers (alternative to glyphosate)
- New guidelines for soil-specific fertiliser application
- Soil microbes to improve crop nutrient uptake
- Waste-to-energy* (biogas, incineration, gasification)
- Compost (on-farm to commercial bio-fertilisers)
- Household source separation*
- Diversification of crops* (e.g. bananas (ideally that is not also climate-sensitive) to cope during short-term climate adversity (or as a longer-term strategy))
- Alternative water sources* (e.g. pumping, diversions)
- Investing in cold storage (on-farm)
- Deterring rodents with seeds off-farm*
- Shifting sectors as coping mechanism* (e.g. farming to veg wholesaler to agrochemical retailer)
- Improved processing from phosphate mine
- National Consumer Network (empowering consumers)
- Encouraging increased vegetable consumption

B2. Future ideas to adapt

- Gradual and holistic transitions (to avoid mal-adapting and coordination between sectors)
- Shift focus from product price, to quality too (e.g. as per transition in garment industry)
- Loan schemes for vegetable farmers
- Subsidised tractors for young farmers
- Improved access to export markets
- Putting price on organic fertilisers (to incentive use)
- Off-farm diversification (e.g. agro-tourism)
- Crop varieties that are drought-resistant, low-fertiliser demanding, and region-specific
- Renewable and alternative fertilisers
- Increasing bioavailability of soil nutrients
- Tube wells to access deeper water
- Poly-tunnels to protect crops
- Agribusiness/local enterprises for land-clearing machinery (replacing glyphosate use)
- Improved knowledge on technology (seed-to-harvest, fertiliser types & application techniques), markets (prices from media or via SMS)
- Adding climate change & adaptation to school curricula
- Boosting recognition/reputation of farmers (e.g. to encourage youth into farming)

- Identifying champions of change (innovative farming leaders) to inspire smaller farmers to implement adaptive and efficient practices
- Bartering initiative between paddy and vegetable farmers
- Linking different farmer organisations to collectively address priority issues
- 'Plant doctor' to diagnose and treat crop ailments
- investigating market/consumer demand for organic products
- extend fertiliser subsidy to other staple crops (especially vegetables)

B3. Other potential adaptation strategies (from the literature)

- addressing knowledge deficits that allow system actors to make better decisions and improve their management of risk (this could be all along the supply chain)
- use resources more efficiently (under climate risk and reduce system losses – water and nutrients)
- diversify sources of inputs to agriculture (P is a classic example- excreta is missing),
- improved infrastructure, e.g. storage and transport, waste management
- improved information services and market intelligence
- downscaled climate modelling (finer resolution)
- building social capital in multiple forms (bridging, bonding, linking)
- demand/problem driven research – e.g. crop and animal genetics, animal welfare under heat, farming systems
- diet and human health (linked to local production by small holder horticulture), environmental impacts
- Investment in post-harvest supply chain infrastructure**:** reduces storage spoilage; Improve smallholder adaptive capacity; and Increases fruit/veg shelf-life
- Well-managed information and knowledge-management systems: e.g. access to timely data on weather or fertiliser prices (e.g. via SMS)
- Upscale CSA currently practiced by some farmers, e.g. water efficient practices
- Improved crop varieties/strains that are more water/drought/flood tolerant, low-P and low-water demanding, and more pest-resistant
- Move from incremental adaptation to transformational changes – e.g. predicted temperature rises are above tolerable limits for rice and maize, therefore some farmers may need to shift to e.g. quinoa
- Smallholder farmers: seek off-farm employment to diversify (ideally that is not also climate-sensitive) to cope during short-term climate adversity (or as a longer-term strategy) – e.g. additional sectors
- Investment in appropriate biogas or other food-energy-water technologies (multiple benefits: generates local energy, generates local renewable fertiliser, reduces greenhouse gas emissions, reduces waste to landfill (for solids), reduces nutrient and pathogen pollution of waterways (for excreta) – and overcome perceptual barriers (biogas is poor man's energy source)
- Explore appropriate renewable fertiliser from excreta (in addition to compost/manure) including social research
- Extend the National Consumer Network to include knowledge/awareness and perceptions of healthy food, including vegetables
- altered farming systems
- agricultural adjustment

APPENDIX C

The following questions informed the semi-structured interviews with different stakeholders. They were not asked in order, rather they were used as a guide.

FARMERS

- CONTEXT:
    - Who consumes the produce? (household, local market?)
    - Why is this a good place to farm?
    - What inputs are used and from where? - fertilisers (subsidized)? Water (rain, irrigation, etc.)? Energy? Chemicals?
    - What quantities of fertiliser are used? How do you decide when to purchase/apply fertilisers? Who recommends?
    - Are you a member of any farmer co-ops or other groups?
    - What are your key priorities, what are pressures you are currently dealing with? (how has/is this changing?)
    - How do you interact with other sectors (up or down the supply-chain, or regulators) – including with government departments.
- RISKS:
    - Have you noticed any changes to weather in the local area?
    - Are you aware of the P-CC risks to you or your sector and the Sri Lankan food system more broadly? How do you understand/perceive them? [If necessary, researchers to provide statements on general risks, e.g. phosphorus price spikes]
    - Have you experienced these P-CC risks? How did you respond?
    - If these happened again, would you do anything differently?
    - Are there other risks you are worried about? (Particularly issues that could be amplified by CC – e.g. pests/diseases/weeds/ resource/water conflicts.)
- ADAPTIVE CAPACITY & ADAPTATION:
    - Do you think you have the resources (knowledge/networks/tech/finances) to respond/adapt to these risks? How could this be financed?
    - Where do you currently get your information about climate change and how to adapt?
    - P: Have you used or would you use compost, manure, wastewater/excreta, biogas as fertilizer alternatives? Why/why not? (What's stopping you? What would it take?)
    - Whose responsibility is PACSA?

POLICY-MAKERS

- CONTEXT:
    - What are your department's key priorities, what pressures are you currently dealing with? (how has/is this changing?)
    - How are your department's priorities decided? What is your governance process and engagement with stakeholders?
    - How do you interact with other sectors and departments in the food supply-chain (farmers, other govt. agencies, industry, CSOs?)
- RISKS:
    - Are you aware of the P-CC risks to your sector and the Sri Lankan food system more broadly? How do they understand/perceive them? [If necessary, researchers to provide statements on general risks, e.g. phosphorus price spikes]
    - Have you experienced these P-CC risks? How did you respond?
    - If these happened again, would you do anything differently?
    - What about food supply chain impacts of CC?
    - Are there other risks you are concerned about?
- ADAPTIVE CAPACITY:
    - Do you have the resources (knowledge/networks/tech/finances) to respond/adapt to these risks? Where could the finances come from?
    - Where do you currently get information about climate change and how to adapt?
    - Adaptation: have you considered subsidy transitions? How might this happen?
    - Is there a policy statement on CC or adaptation or food security?
    - What are the 3 biggest barriers to implementing change in their department?
    - P: would you support the use of local renewable fertilisers, such as compost, manure, wastewater/excreta, biogas? Why/why not? (What's stopping you? What would it take?)
    - Whose responsibility is PACSA?

AGROCHEMICAL INDUSTRY

- CONTEXT:
    - What are the key fertiliser products you sell, where do they come from? (imports from?). Which have largest market? Is this changing?
    - How does the fertiliser supply chain work? (from imports to farm gate)?
    - What are your key priorities, what pressures are you currently dealing with? (how has/is this changing?)
    - How do you interact with other sectors in the food supply-chain (farmers, government departments, industry, CSOs?)
- RISKS:
    - Are you aware of the P-CC risks to your sector and the Sri Lankan food system more broadly? How do they understand/perceive them? [If necessary, researchers to provide statements on general risks, e.g. phosphorus price spikes]
    - Have you experienced these P-CC risks? How did you respond?
    - If these happened again, would you do anything differently?
    - Are there other risks you are concerned about?
- ADAPTIVE CAPACITY:
    - Have weather-related events affected your business? Have you made any changes to your business to deal with weather-related events?
    - Do you think a transition from fertiliser subsidy is a good idea?
    - How would a transition away from fertiliser subsidies affect your sector?
    - P: would you consider developing renewable fertilisers, sourced from local inputs such as compost, manure, wastewater/excreta, biogas? Why/why not? (What's stopping you? What would it take?)
    - Do you have the resources (knowledge/networks/tech/finances) to respond/adapt to these risks? Where could the finances come from?
    - Where do you currently get information about climate change and how to adapt?
    - What are possible P-CC opportunities that you see?
    - Whose responsibility is PACSA?

NGO

- CONTEXT:
    - What are your organisation's key priorities, what pressures are you currently dealing with? (how has/is this changing?)
    - How do you interact with other sectors and departments in the food supply-chain (farmers, government, industry, CSOs?)
- RISKS:
    - Are you aware of the P-CC risks to the Sri Lankan food system more broadly? How do they understand/perceive them? [If necessary, researchers to provide statements on general risks, e.g. phosphorus price spikes]
    - Have you experienced these P-CC risks? How did you respond?
    - If these happened again, would you do anything differently?
    - What about food supply chain impacts of CC?
    - Are there other risks you are concerned about?
- ADAPTIVE CAPACITY:
    - Do you have the resources (knowledge/networks/tech/finances) to respond/adapt to these risks? Where could the finances come from?
    - Do you think a transition from fertiliser subsidies is a good idea? Why/Why not? How might this happen?
    - P: would you support the use of local renewable fertilisers, such as compost, manure, wastewater/excreta, biogas?
    - Whose responsibility is PACSA?

WASTE MANAGERS

- CONTEXT:
  - Where does the organic waste come from? (markets, households) and where does it go? How much compost/recycling?
  - What are your organisation's key priorities, what are pressures you are currently dealing with? (how has/is this changing?)
  - How do you interact with other sectors in the food supply-chain (farmers, government departments, regulators, industry, households, CSOs?)
- RISKS:
  - Are you aware of the P-CC risks to your sector and the Sri Lankan food system more broadly? How do they understand/perceive them? [If necessary, researchers to provide statements on general risks, e.g. phosphorus price spikes]
  - Have you experienced these P-CC risks? How did you respond?
  - If these happened again, would you do anything differently?
  - Have they experienced any weather–related disruptions to waste management? What do they do?
  - Are there other risks you are concerned about?
- ADAPTIVE CAPACITY:
  - Do you have the resources (knowledge/networks/tech/finances) to respond/adapt to these risks? Where could the finances come from?
  - Do you think a transition from fertiliser subsidies is a good idea? Why/Why not? How might this happen?
  - P: would you consider developing renewable fertilisers, sourced from local inputs such as compost, manure, wastewater/excreta, biogas? Why/why not? (What's stopping you? What would it take?)
  - What are possible P-CC opportunities that you see? (e.g emissions reduction or waste to energy)
  - Whose responsibility is PACSA?