

A Holistic Lens on Rice Value Chain Pathways in Senegal;

Application of “The Economics of Ecosystems and Biodiversity for Agriculture and Food” Framework

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Acronyms and abbreviations

AE	Agroecology
ANB	Autorité Nationale de Biosécurité
ANCAR	Agence Nationale de Conseil Agricole et Rural
ANSD	Agence Nationale de la Statistique et de la Démographie, République du Sénégal
ANSTS	Académie Nationale des Sciences et Techniques du Sénégal
ARAA	Agence Régionale pour l'Agriculture et l'Alimentation
ARM	Agence de Régulation des Marchés
ARN	Association des Riziers du Nord
AquaStat	FAO's Information System on Water and Agriculture
ASCOSEN	Association des Consommateurs du Sénégal
ASPRODEB	Association Sénégalaise pour la Promotion du Développement par la Base
AWD	Alternate Wetting and Drying
BAU	"Business As Usual"
BNDE	Banque Nationale pour le Développement Economique
BRVM	Bourse Régionale des Valeurs Mobilières
CADI	Centre d'appui au Développement Local
CCGA	Changing Course in Global Agriculture
CEDEAO	Communauté Economique des Etats de l'Afrique de l'Ouest
CIRIZ	Comité Interprofessionnel du Riz au Sénégal
CNCAS	Caisse Nationale de Crédit Agricole du Sénégal
CNB	Comité National Biosécurité
CNCR	Cadre National de Concertation des Ruraux
CNIS-GDT	Cadre National d'Investissement Stratégique pour la Gestion Durable des Terres
COMEX	Commerce Extérieur
CRAFS	Cadre de Réflexion et d'Action sur le Foncier au Sénégal
CORAF/WECARD	West and Central African Council for Agricultural Research
CRES	Consortium pour la Recherche Économique et Sociale
CSO	Civil society organisation
DA/DISEM	Direction de l'Agriculture, Division des Semences
DADL	Direction d'Appui au Développement Territorial
DAPSA	Direction de l'Analyse, de la Prévision et des Statistiques Agricoles, République du Sénégal
DCI	Direction du Commerce Intérieur

DP	Direction de la Planification, Ministère de l'Économie, des Finances et du Plan, République du Sénégal
ECOWAS	Economic Community of West African States
EIA	Energy Information Administration
ENDA	Environnement et développement du tiers monde
FAO	Food and Agriculture Organization of United Nations
FAOSTAT	FAO Statistical Database
FENAB	Fédération Nationale des Agriculteurs Biologiques du Sénégal
FFS	Farmer Field Schools
FNDASP	Fonds National de Développement AgroSylvoPastoral
GA	Grande Aménagement
GDP	Gross Domestic Product
GDSP	Groupe du Dialogue Sociale et Politique
GEF	Global Environment Facility
GHG	Greenhouse gas
GM	Green manure
GOANA	Grande offensive pour la nourriture et l'abondance
GoS	Government of Senegal
GDSP	Social and Political Dialogue Group
IFAD	International Fund for Agricultural Development
IFC	International Finance Cooperation
IPM	Integrated Pest Management
IMF	International Monetary Fund
IPCC	Intergovernmental Panel on Climate Change
IPPM	Integrated Production and Pest Management
ISRA	Institut Sénégalais de Recherches Agricoles
ITPGRFA	International Treaty on Genetic Resources for Agriculture and Food
MAER	Ministère de l'Agriculture et de l'Équipement Rural, République du Sénégal
MCC	Millennium Challenge Cooperation
MEDD	Ministère de l'Environnement et du Développement Durable
MEPA	Ministre de l'Élevage et des Productions Animales
MRA	Market Regulation Agency
MSAS	Ministère de la Santé et de l'Action Sociale
OECD	Organization for Economic Co-operation and Development
OMVS	Organisation pour la Mise en Valeur du fleuve Sénégal
PIP	Périmètre Irrigué Privé
PIV	Périmètre Irrigué Villageois
PNAR	Programme national d'autosuffisance en riz
POAS	Plans d'occupation et d'aménagement des sols
POGV	what is this?
PAA	Purchase from Africans for Africa
PPB	participatory plant breeding

PRB	Programme Régional de Biosécurité
PSAOP	Programme des Services Agricoles et Organisations de Producteurs du Senegal
RTS	Radio Télévision Sénégalaise
SAED	Société Nationale d'Aménagement et d'Exploitation des Terre du Delta
SCPZ	Crop processing zone
SDG	Sustainable Development Goals
SOM	Soil organic matter
SOC	Soil organic carbon
SODAGRI	Société de Développement Agricole et Industriel du Sénégal
SRI	System of Rice Intensification
SSA	Sub Saharan Africa
TaFAé	Task Force multi-acteurs pour la promotion de l'Agroécologie au Sénégal
T21-iSDG	Threshold21-iSDG
TEEB	The Economics of Ecosystems and Biodiversity
TEEBAgriFood	The Economics of Ecosystems and Biodiversity for Agriculture and Food
UEMOA	Union Economique et Monétaire Ouest Africaine
UN	United Nations
UNACOIS	Union National des Commerçants et Industrielsdu Sénégal
UNDP	United Nations Development Program
UDP	Urea Deep Placement
WAAPP	West Africa Agriculture Productivity Program
WARDA	now: Africa Rice
WDI	World Development Indicators
WEO	Women's Economic Opportunity
WGI	Worldwide Governance Indicators
WHO	World Health Organization
WPP	World Population Prospects (by UN)

1. Introduction

The Economics of Ecosystems and Biodiversity (TEEB¹) is a global initiative focused on drawing attention to the economic benefits of biodiversity including the growing cost of biodiversity loss and ecosystem degradation. TEEB presents an approach that can help decision-makers recognize, demonstrate and capture the values of ecosystem services and biodiversity. Within the global initiative, studies have been undertaken to investigate the application of the concept to different sectors. The ‘TEEB for Agriculture and Food’ (TEEBAgriFood²) study seeks to review the economic interdependencies between human (economic and social) systems, agriculture and food systems, and biodiversity and ecosystems. In doing so, it addresses the economic invisibility of many of these links while exploring how biodiversity and key ecosystem services deliver benefits to the agriculture sector and also beyond, itself being a key contributor to human health, livelihoods and well-being.

The first major output of TEEBAgriFood is a ‘*Scientific and Economic Foundations*’ report³, which addresses the core theoretical issues and controversies underpinning the evaluation of the nexus between the agri-food sector, biodiversity and ecosystem services and externalities including human health impacts from agriculture on a global scale. As part of this research, authors have developed an Evaluation Framework⁴ that provides broad categories of all interactions that may exist within a given ‘eco-agri-food system’.

The overall purpose of the Framework is to provide a clear and common starting point for future assessments that seek to carry out holistic evaluations in line with the systems view advocated by TEEBAgriFood. These ‘Framework-testing studies’ will generally have the following features:

- broad and systemic in nature,
- reflect the contributions of all four capitals (natural, produced, human and social), and
- examine connections along the full value chain, including production, processing & manufacturing, distribution, marketing & retail, and consumption.

The TEEB Secretariat has invited reports on regional narratives and perspectives on the relevance and application of the TEEBAgriFood Framework to the agriculture and food sector in Africa.

Objectives and aims of this study

This study has been carried out to contribute to the further development and refinement of the Framework, through the lens of farming approaches to rice in Senegal. It has been formulated to explore the agricultural policy landscape in the region, and in particular the extent to which these policies influence the way in which *inter alia* ecosystems and biodiversity, livelihoods and equity, and nutrition and health are captured.

¹ www.teebweb.org

² www.teebweb.org/agrifood

³ www.teebweb.org/agrifood/home/scientific-and-economic-foundations-report

⁴ www.teebweb.org/agrifood/home/evaluation-framework/

The specific aim has been to set out an approach to assess the various types of interventions in the agriculture and food sector of rice production in Senegal that might be used to capture these values so that hitherto invisible value-additions are recognized and accounted for in decision-making, leading to better livelihood outcomes. The study utilized an approach based on first, stakeholder consultation to develop a robust understanding of the issues facing rice production, and second, a systems model simulation to compare the outcomes- many of which otherwise remain invisible – on the Sustainable Development goals relevant to livelihoods in Senegal.

Development of the discourse on rice production issues in Senegal

Agriculture is central to the economy of Senegal; 70% of the population work in the agriculture sectors, contributing 17% to overall GDP. Almost half of the land in Senegal is under agriculture, although much of this is in extensive livestock grazing. Only 17% of the land area of Senegal is arable (FAOSTAT, no date). Agriculture in Senegal is dominated by very small family farms, occupying 95% of the country's agricultural land, and representing 80% of the population. Ranked 164th out of 189 countries on the Human Development Index (HDI) in 2017, food insecurity remains a constant concern in Senegal. The two largest crops by production value in Senegal are cash crops, sugar cane and groundnuts. The third largest is rice (FAOSTAT 2018).

Ensuring and improving food security is a high priority for the Senegal government, as national food production does not meet Senegal's needs. The production of major staple food crops covers barely 30% of consumption needs, with the remaining 70% being imported- mostly rice, wheat and maize. This dependence on global markets exposes households to price fluctuations and greater vulnerability.

Agriculture in Senegal is negatively impacted by land access problems, deterioration of soils, forests and water resources (in quality and quantity), and the high use of pesticides (DYTAES, 2019). In recent years, groundnut yields have begun to decrease due to a combination of poor soil conditions and climatic factors; yields in 2018 were 5% lower than in 2015 (FAOSTAT).

There has been a long history of efforts to identify alternative agricultural pathways in Senegal marked by multiple local initiatives on the part of NGOs, farmer organizations, some private sector partners, and also through national level platforms (FAO and Biovision, in draft). Actions have focused on integrated and sustainable land management, water and soil conservation practices, crop associations, biological control of plant pests, organic conservation methods for agricultural products and agroforestry. In particular, a growing focus on agroecology as a viable alternative has arisen on several levels:

- the socio-economic level (consumer awareness on products' origin, promotion of healthy food and enhancing local economy through short circuits markets);
- the environmental level (promotion of organic fertilizers, biocides);
- and at the political level (public authorities have manifested their interest in agroecology, as part of the political discourse and agenda) (FAO and Biovision, in draft)

Notably, in 2019 the Senegalese government placed agroecological transition among the five major initiatives of the Priority Action Plan of the second phase of the Plan Senegal Emergent Vert (2019-2024), the key national policy framework. Also in 2019, a coalition - called “la Dynamique sur la Transition Agroécologique_au_Sénégal” (DyTAES) - of producer organizations, civil society organisations, researchers, consumers, local authorities and sectoral ministries was created as an umbrella initiative to support the government’s commitment and to move towards an effective agroecological transition.

Given the ongoing dialogue taking place in Senegal on the shape and form of agricultural development, particularly as it pertains to the most important crop from the standpoint of food security – rice – it seems highly appropriate to focus a study, applying the TEEBAgriFood framework on rice value chains, comparing alternative development pathways between agroecological approaches and “business as usual”.

Role of rice in the agriculture sector of Senegal

Rice is the most consumed cereal in Senegal and a critically important staple food crop (Colen *et al.* 2013). In 2009, the average consumption of rice was 71.5 kilogram per person per year, which results in a total consumption of 984,000 tons of rice per year (Maclean *et al.* 2013). Senegal is one of the largest consumers of rice in West-Africa (Maclean *et al.* 2013). However, as noted above, a considerable portion of rice comes from imports, estimated at around 80 percent in 2005 to provide the needed quantities for domestic consumption though possibly declining more recently to around 60% (USDA 2017). In any case, this makes Senegal the second largest rice importer in Sub Saharan Africa (SSA) (Brüntrup *et al.* 2006), and also makes Senegal one of the largest net importers of food in the world (Stads & Sene 2011). Figure 1 shows the rice import and production trend from 1999 to 2016, with import exceeding production in each year. Self-sufficiency in production is a goal and a challenge for the Government of Senegal.

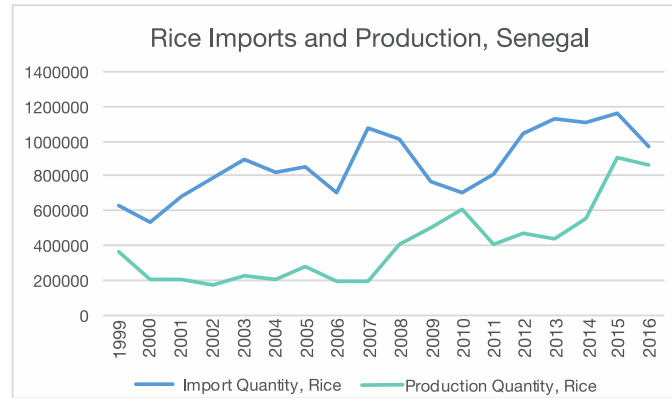


Figure 1. Rice imports and production, Senegal (FAOSTAT)

Rice has long been a valued crop in Senegal, with increasing importance over the last decades. Since the 1980s, the country has emphasized rice production through subsidies, extension, and infrastructure, but has failed to compete commercially with imported rice (Dermont & Rizzotto 2012). This is partly due to the government’s focus on urban populations and their efforts to import cheap rice from Asia (Khouma *et al.* 2012), which considerably undercuts local production.

About 20 percent of the total area of Senegal is arable land of which rice production occurs on about five percent in 2010 (Maclean *et al.* 2013). The area of rice cultivation in Senegal almost doubled from 86,252 hectares in the year 2000 to 135,129 hectares in 2012. But not only the area of rice cultivation increased in Senegal - the amount of rice production augmented three-fold from 2000 to 2012. In 2012 paddy rice production on a national level was 630,654 tons, while in 2000 this was 202,293 tons (FAOSTAT, n.d.). This means that the average yield almost doubled from 2.34 tons per hectare in 2000 to 4.67 tons per hectare in 2012, although it has declined to 4.21 in 2017. Senegal is recognized for having one of the largest production increases, from 2010 to 2017 in West Africa, along with Benin and Côte d’Ivoire. Although overall regional rice production increased by 25% from 2010 to 2017, rice consumption was up by 35%, a more rapid increase than expected. As a consequence, regional self-sufficiency declined from 59% to 54%. Senegal is one of four countries, over this time, that has increased its rice self-sufficiency (by 4%) (Styger & Traoré 2018).

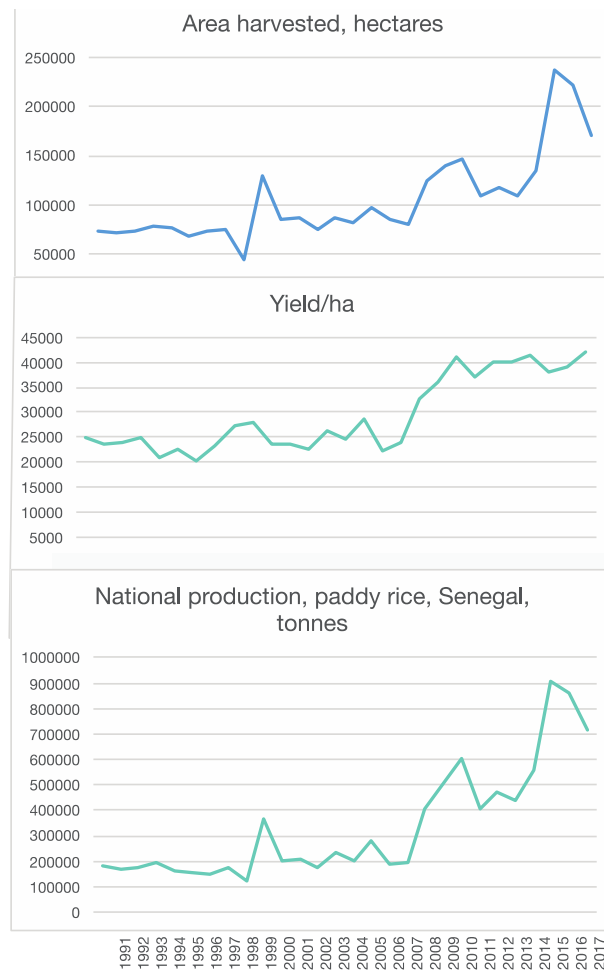


Figure 2. Area harvested, yields and national production trends of paddy rice in Senegal, 1990-2017 (FAOSTAT)

Yet, according to Maclean *et al.* (2013), average yields varied widely over the past twenty years (Figure 2). In irrigated systems, the potential yield is nine tons per hectare in the wet season and 12 tons per hectare in the dry season, indicating a pronounced yield gap between actual and potential yield in Senegal (Wopereis *et al.*, 1999), which could be addressed with different management practices. Since 2007, rice harvested area has increased dramatically by expansion of dry-season rice cropping in the Senegal River valley. The average on-farm yields are reaching 5.4 tons per hectare in the wet season and 6.8 tons per hectare in the dry season (Saito *et al.*, 2015).

Rice consumption in sub Saharan Africa has been growing rapidly (Diagne 2010). It is a staple that takes less time and energy to prepare than other staples such as cassava and bananas. These are important considerations as women are participating increasingly in the labor market. Rice has a long shelf life and is relatively easy to store and handle, of great utility as urban household

members are consuming food increasingly away from home. At the same time, rice production is seen as a source of greenhouse gases due to its methane emissions, and as larger user of water resources, with considerable evaporative water losses

Thus, there are strong imperatives facing the rice sector in Senegal: to increase domestic production and processing of rice, in a sustainable manner. Several substantial donors have proposed that investments should be made in large scale rice production and processing. However, there are a number of alternative pathways to that goal. For example, increasing rice production by conventional high-input methods could ramp up yields, but there are increased costs related to greater fertilizer, pesticide and water use. Large-scale rice value chain projects may propose equally large rice mills, but the opportunity to process rice in smaller units may enable greater use of rice by-products such as for livestock feed and promote greater equity through community ownership. Different pathways have different implications for employment in the agriculture and food sector. By using a holistic framework to review the possible pathways, many diverse aspects can be brought into focus at the same time, looking at impacts on not just economic/produced capital but also social, human and natural.

2. Dimensions of rice beyond yields

The contribution and impacts of rice – like any and all agricultural products - to the livelihoods of people has far greater significance to human (and the earth's) welfare than is captured by yields or production statistics alone. We introduce a few of these considerations here, but they are as well the overall focus of this report.

Rice is produced around the world by millions of small-scale family farmers, often through complex social relationships. The act of growing rice remains, in most countries, labour-intensive, with “green infrastructure” built and maintained by generations of farmers, working together. Rice paddies, sculpting the land, often serve as a form of water storage and supply and erosion control. Water supply for rice comes from rivers and streams; irrigation flows through the same ancient river ways. Flooded fields provide an environment that controls weeds, but the water is not then entirely used or transpired by the rice crop, nor is it all evaporated. Water is let out of the field during the growing season, adding it back to downstream flows; thus, rice crops are not nearly as water-consuming as they are often perceived to be (Bouman 2009; Mutters,n.d.).

With its long history of cultivation and selection under diverse environments, rice has acquired a wide adaptability enabling it to grow in a range of environments, from deep water to swamps, irrigated and wetland conditions, as well as on dry hill slopes. Probably far more than any other crop, rice can grow under diverse geographical, climatic and cultural conditions. The quality preferences of rice consumers, over millennia, have resulted in a wide diversity of varieties specific to different localities. Rice has a unique center of origin in West Africa, for the African rice species (*Oryza glaberrima*). According to Cubry et al (2018), the *Oryza glaberrima* was domesticated in the inner Niger Delta. This Africa rice species has been partly replaced by higher-yielding Asian rice, but it nonetheless persists, particularly in upland environments. African rice is hardy and pest-resistant crop, well adapted to a variety of African conditions (Linares 2002) and often preferred for its nutty taste. African rice holds unique cultural values; for instance, it is sacred to the Jola people in the Casamance region of Senegal⁵, and is a heritage variety in the United States, having been brought to the New World by slaves (Carney 2009). The genetic traits of African rice have been used in breeding programs to develop NERICA, the “New Rice for Africa” (Sarla et al. 2005).

When irrigated rice is grown under organic conditions, it creates its own “agricultural ecosystem of unrivaled complexity” (Settle et al. 1996). Underlying the seemingly simple structure of the

⁵ According to Davidson (2015) Jola people have long depended on rice, and believe that their hard work in the rice paddies is part of a covenant with their supreme deity for which they are rewarded with rain

rice paddy monoculture, in smallholder and family farmer fields systems, is a complex system of built-in natural controls. Food web interactions among insect pests of rice and their numerous natural enemies in paddy fields – in the absence of high pesticide applications - can be very complex, often resulting in low but stable insect populations. In most early-season tropical rice fields, abundant populations of generalist predators can be found in (Settle *et al.* 1996). These generalist predators are likely to be supported, in the early season, by feeding on abundant populations of detritus- feeding and plankton-feeding insects, whose populations consistently peak and decline in the first third of the season. The abundance of alternative prey gives the predator populations a "head start" on later-developing pest populations, thus enabling them to strongly suppress pest populations and generally lend stability to rice ecosystems by decoupling predator populations from a strict dependence on herbivore populations. These and other observations support management strategies that promote the conservation of existing natural biological control through a major reduction in insecticide use, and the corresponding increase in habitat heterogeneity.

Rice fields harbour a surprisingly rich level of biodiversity, thought to be amongst the greatest of any tropical rainfed system (Halwart & Gupta 2004). Around 600 or more species of organisms – from insects, fish, reptiles and amphibians – have been recorded in rice fields in Thailand, Cambodia and Indonesia (Halwart & Gupta 2004; Gregory and Guttman 1996; Settle *et al.* 1996), although similar studies have not been carried out in Senegal. Since rice is typically grown in flooded conditions, rice fields often function as surrogate ecosystems for wetland-dependent bird species.

When paddy rice is cultivated without heavy inputs of agricultural chemicals, it is possible to integrate fish or duck rearing along with the rice. In a careful review of the literature, Halwart & Gupta (2004) documented fish production yields in rice-fish systems all over the world. The analysis demonstrates that, although higher rice yields were not always obtained with the introduction of fish, the majority (80%) resulted in higher yields of 2.5% or more, and a significant contribution of fish protein to farmers' diets. Efforts to integrate fish with rice in the Casamance region of Senegal have shown considerable promise (Petersen *et al.* 2006).

Rice consumption in sub Saharan Africa has been growing rapidly (Diagne 2010). It is a staple that takes less time and energy to prepare than other staples such as cassava and bananas. These are important considerations as women are participating increasingly in the labor market. Rice has a long shelf life and is relatively easy to store and handle, of great utility as urban household members are consuming food increasingly away from home.

Thus, there are strong imperatives facing the rice sector in Senegal: to increase domestic production and processing of rice. Several substantial donors have proposed that investment should be made in However, there are a number of alternative pathways to that goal. For example, increasing rice production by conventional high-input methods could ramp up yields, but there are increased costs related to greater fertilizer, pesticide and water use. Large-scale rice value chain projects may propose equally large rice mills, but the opportunity to process rice in smaller units may enable greater use of rice by-products such as for livestock feed and promote greater equity through community ownership. Different pathways have different implications for employment in the agriculture and food sector. By using a holistic framework to review the possible pathways, many diverse aspects can be brought into focus at the same time, looking at impacts on not just economic/produced capital but also social, human and natural.

As we pursued the methodology outlined below, the alternative pathway of agroecology was the most often invoked by stakeholders and the literature. To clarify what is meant, we follow the definition as provided by the Food and Agriculture Organization of the United Nations (FAO): “**Agroecology** is the science of applying ecological concepts and principles to manage interactions between plants, animals, humans and the environment for food security and nutrition. All over the world farmers already apply this approach, which has a fundamental pillar in traditional and local knowledge.” (<http://www.fao.org/agroecology/knowledge/practices/en/>)

3. Application of the TEEBAgriFood Framework

“The Economics of Ecosystems and Biodiversity for Agriculture and Food” (TEEBAgriFood) initiative (<http://www.teebweb.org>) seeks to review the economic interdependencies between human (economic and social) systems, agriculture and food systems, and biodiversity and ecosystems. TEEBAgriFood has developed a framework supporting the evaluation of different agri-food systems across the food value chain, from production through consumption. In contrast to the commonly used metrics such as levels of productivity, the TEEBAgriFood Evaluation Framework supports a broad scope of evaluation, across human, social, economic and environmental dimensions. The use of the Framework is advocated to recognize the key elements that should be evaluated in any given assessment, and to ensure transparency by highlighting the aspects that should not be overlooked. The Framework is intended to be used in an open and transdisciplinary manner, where questions, options and relevant variables are all determined in participatory manner.

The initiative acknowledges that agriculture and the way agricultural production is performed affects all areas of development and itself is affected by those areas. Thus, a dynamic approach is proposed, particularly seeking to reveal the invisible, non-market stocks and flows through agricultural food value chains and their impacts and interdependencies.

Steps undertaken in this TEEBAgriFood application to rice in Senegal

The TEEB Foundations study proposed five key families of application for the TEEB framework: agricultural management systems, business analysis, dietary comparison, policy evaluation and national accounts for the agriculture and food sector. This particular contribution focuses on the agricultural management system of rice in Senegal, but also considers the implication of different national policies relevant to rice management.

As per the guidance provided in Chapter Six of the TEEB Foundations Report, we outline the key steps undertaken in this study, and where more information about each can be found.

Steps	
Purpose of evaluation	As stated in the objectives, this study is intended to contribute to the further development and refinement of the Framework, through the lens of farming approaches to rice in Senegal. It explores the extent to which agricultural management approaches and policies influence the way in

	which <i>inter alia</i> ecosystems and biodiversity, livelihoods and equity, and nutrition and health are captured, and all values may be captured and accounted for in decision-making, leading to better livelihood outcomes.
Entry point and spatial scale	The entry point is rice production and value chains in Senegal, including all forms of rice cultivation, from non-irrigated upland rice to lowland paddy rice. The spatial scale is throughout the rice growing regions of Senegal, as detailed in Table 1.
Scope of the value chain	The rice value chain, from production, processing, distribution and consumption is covered.
Focus on specific stocks, flows, outcomes and impacts	Figure 7 presents the comprehensive set of stocks and flows within the rice sector of Senegal, and the modeled impacts on key indicators of the four capitals: natural, human, produced and social. Annex 3 provides indication of where impacts and dependencies have been identified in rice production systems.
Evaluation technique	A broad scope of evaluation is used, across human, social, economic and environmental dimensions. The impact of implementing a coherent set of policy responses on several relevant development outcomes in Senegal is analyzed through a system dynamics model.
Data Collection	The study utilized an approach based on first, stakeholder consultation to develop a robust understanding of the issues facing rice production. Data relevant to each of these issues was collected via literature reviews and expert knowledge, and used to fine tune a systems model simulation to compare the outcomes of two contrasting agricultural management and policies. Many of the outcomes on the Sustainable Development goals relevant to livelihoods in Senegal, uncovered through this process, are ones which otherwise remain invisible – such as

	unemployment rates and under 5 mortality rates.
Findings	The results of the simulated agroecological scenarios indicate significant possible improvements by 2050 in all selected SDG indicators, linked to the four dimensions of capital, when compared by to “business as usual”. The results illustrate the interlinked nature of the system and reveal that the changes implemented in agriculture spread and diffuse through the whole system. Improvements in the agroecological scenario with respect to several indicators increase over time due to the reinforcing action of a set of positive feedback loops. The value of such a comprehensive, long-term analysis, and a holistic impact assessment that reviews the interdependencies between different dimensions of capital is highlighted, reinforcing the aims of the TEEB AgriFood initiative.

In applying the framework, it has been possible to build off two in-depth, existing studies which have provided a basis of data and a structure for understanding the interactions between key variables in the TEEBAgriFood Framework. As a feeder study for the TEEBAgriFood initiative, an intensive study of positive and negative externalities in the Philippines, Cambodia, Senegal, Costa Rica and California were documented (Bogdanski et al. 2016; TEEB AgriFood 2016), which identified and documented benefits and costs of rice production systems, across multiple dimensions.

The TEEBAgriFood Economic and Scientific Foundations report makes a strong case that systems thinking should be a guiding principle in the application its Evaluation Framework. The Millennium Institute has been carrying out work with the government of Senegal to develop a systems dynamics-based model to support national development planning around the Sustainable Development Goals, structured to analyse medium-long term development issues at the national level; and integrating the economic, social, and environmental aspects of development into a single framework. It is a quite large model with over 3600 state variables and several thousand feedback loops, covering more than 55 sectors. The sectors particularly relevant to this analysis have been developed fully, as described in section 6. A detailed description of the model, the structure of the sectors and the interlinkages can be found in the Threshold 21 (T21) iSDG Model documentation (MI 2016).

Dynamics within and between sectors are captured by the model. Thus, outcomes of scenarios or policy decisions that are analysed by the model are the results of the interlinked structure of the system itself. The model became functional for the first time in 2010 and was since then continuously improved (for example concerning agriculture and recently to include the SDGs). A simplified summary diagram of the agriculture sector (in Figure 5) conveys the level of complexity and interaction, within just this one sector.

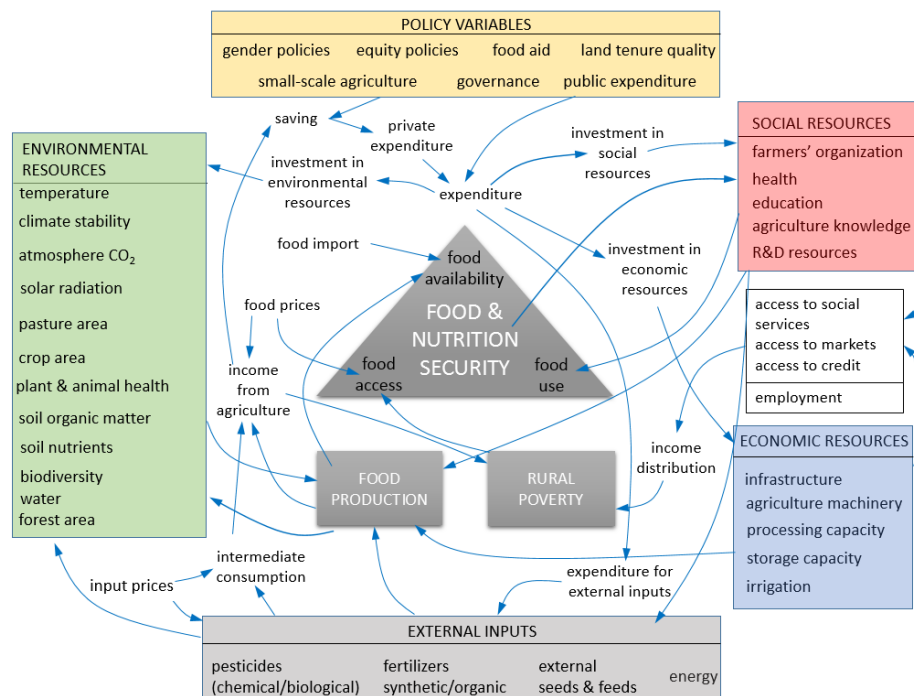


Figure 3. Simplified summary diagram of the interactions included within the Agriculture Sector of the T21-iSDG in Senegal (MI 2014)

4. The Eco-Agri Rice Food System in Senegal from multiple perspectives: farmer, researcher, civil society, governance/think tank)

Research methodology

Two research methods are combined in this study.

- 1- To carry out the present analysis, information has been collected about the current status of as many of the stocks and outcomes presented in the TEEBAgriFood framework, across the rice value chain. Stakeholders from four different groups – a female farmer, two researchers, a civil society representative, and people who have been interacting in an agriculture/governance think tank - were then asked to reflect on the predominant issues for each of the aspects considered. (it should be noted that this is not a comprehensive multistakeholder consultation; individuals presented their own perspectives, not ones derived from extensive consultation with their communities. Moreover, the perspective of intermediaries in the food value chain – such as millers and traders – was not represented, due to the limitation of resources.
- 2- From the articulation of these stakeholders, prevailing issues, possibly policy interventions have been formulated (Section 5), and the outcomes of such interventions, as opposed to “business as usual” evaluated using the T21-iSDG model (Section 6).

Following this rice value chain in the sections below, we review first the current status of issues related to rice, and current rice policy in Senegal. Within each issue area, we present a farmer perspective on alternate pathways, a civil society perspective, a researcher perspective and a governance/think tank perspective (while acknowledging that each of these are perspectives of individuals, not intended to represent consultation with entire sectors or the viewpoint of institutions). We then focus, in the subsequent section a systems model of the agriculture sector in Senegal, propose modeling modifications to reflect these alternate pathways, and analyze the results.

The structure of the current rice value chain in Senegal is mapped in Figure 4, and the alternative value chain suggested by stakeholders in Figure 5 as an initial overview of the directions in contrast taken by this study.

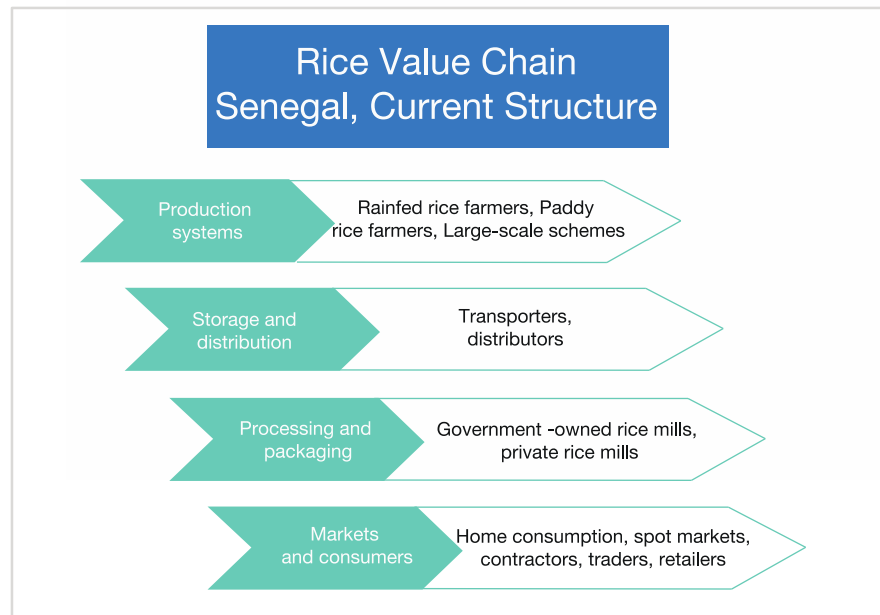


Figure 4. Rice value chain in Senegal, current structure

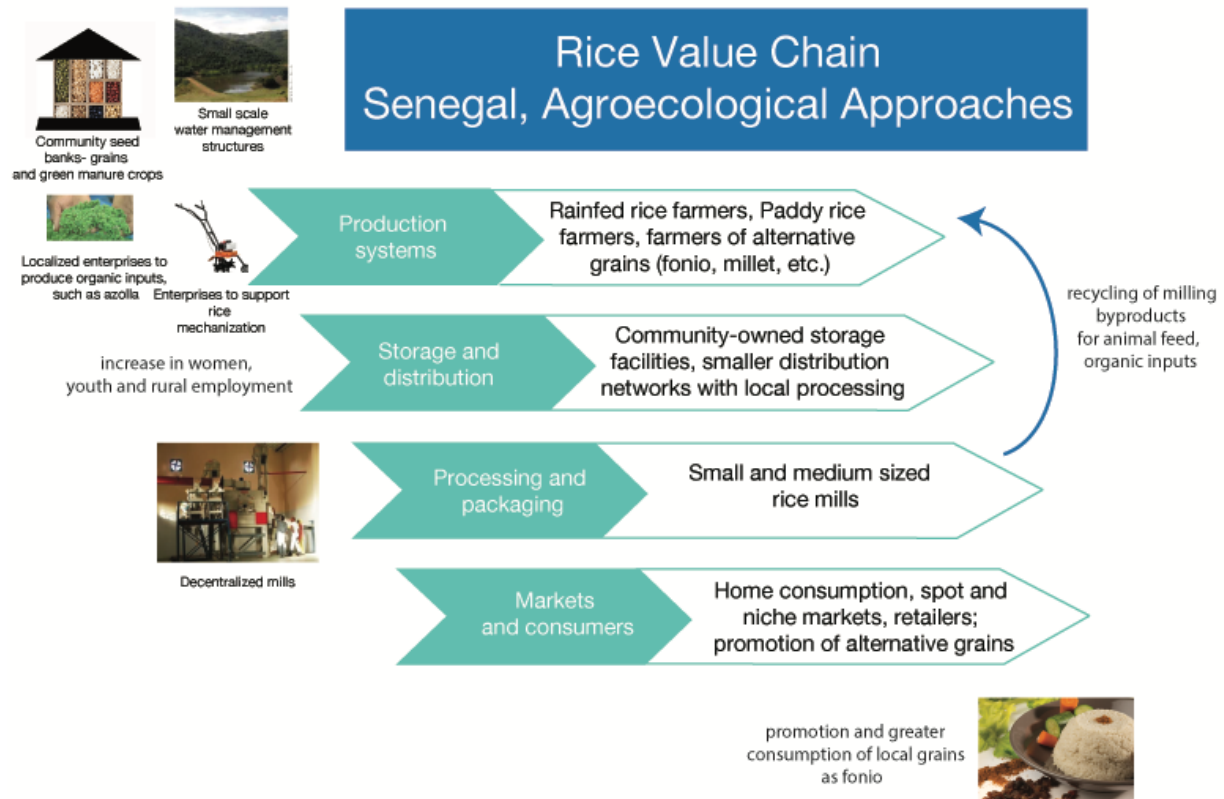


Figure 5. Agroecological rice value chain in Senegal

Dimensions of rice production

4.1. Farming systems issues

Current status: Rice farming systems in Senegal are highly variable depending on region (Table 1). Where irrigated rice cultivation is prominent there is a much higher input of resources, e.g. mechanization, herbicides and fertilizer use, compared to rainfed rice farming systems. In Saint-Louis and Dagana even two growing seasons per year are possible and yields are by far higher compared to rainfed systems.

Table 1. Rice farming systems in Senegal according to region (source: Wolfe et al. 2009)⁶

Characteristic	<i>Saint-Louis</i>	<i>Matam</i>	<i>Fatick</i>	<i>Kolda</i>	<i>Ziguinchor</i>
Rice as staple food	Primary	Primary	Secondary (millet being primary)	Secondary (maize being primary)	Primary
Season	Jun/Aug-Oct/Dec Jan/Feb-Apr/May	Jun/Aug-Oct/Dec	Jul/Aug-Sep/Oct	Jul-Oct	Jul-Oct
Varieties	High-yielding (improved)	High-yielding (improved)	Local varieties (partly improved)	Local varieties	Local varieties
Farming environment	Irrigated lowland	Irrigated lowland	Rainfed lowland	Rainfed lowland	Rainfed lowland/upland
Plot size	Large (>1 ha)	Medium (>0.25 ha)	Small (<0.1 ha)	Small (<0.1 ha)	Small (<0.1 ha)
Main cultivators	Men	Men & women	Women	Women	Men & women
Land preparation	Mechanized	Mechanized	Manual	Manual	Manual
Fertilizer dosage	High	High	None to minimum	Low	None to minimum
Herbicide use	Common	Common/None	None	None	None
Harvesting	Mechanized, manual	Manual, mechanized	Manual	Manual	Manual
Threshing	Mechanized	Manual, mechanized	Manual	Manual	Manual
Average yield	>5 t/ha	>4 t/ha	1-2 t/ha	1-2 t/ha	1-2 t/ha
Destination	Consumption, sale	Consumption, sale	Consumption	Consumption	Consumption

Farming system issues from a researcher perspective: Rice production in Senegal is not without its challenges. Rice yields are largely challenged by infestation from weeds and birds. Also, Senegal faces water scarcity, which affects rice production as well. Finally, rice fields with high

⁶ Since this table was published, several newer trends may be changing rice farming systems in these regions. Now the NERICA varieties for rainfed ecologies are introduced in all regions. An irrigated scheme occurs in the Kolda Region, while the subsidies- farmers may have increased usage of inputs and mechanization in Fatick region. Yields in rainfed regions are low, but where irrigation is possible, the yields may increase to 2-6 t/ha. (M. Diagne and R. Gaud, pers. comm.)

salt content and deficits of Nitrogen (N) are limiting growth factors to which not all farmers have easy access for solutions.

Alternative practices: To respond to these challenges, the predominant agroecological rice farming system in rice is SRI, System of Rice Intensification, or variations on its approach including the Rice Integrated Crop Management (RICM) that allows small-scale farmer to significantly increase their yield and income depending on their resource endowment (Kebbeh and Miézan, 2003). The combination of simple changes in agronomic practices, which became known as SRI, was developed during the 1980s by a Jesuit priest in close collaboration with farmers in Madagascar. SRI is an agroecological rice production methodology that allows farmers to increase rice productivity while using less seed and water, and fewer purchased agrochemical inputs. SRI rice fields are thought to adapt better to climate change and give off fewer greenhouse gas emissions. SRI does not rely on new varieties, fertilizers, pesticides, or infrastructure to raise yields. Rather, it is a knowledge-based crop management approach that allows plants to better express their genetic potential, which leads to improved plant growth and productivity. Since 2000, SRI has spread to many countries; it is estimated that 10-15 million farmers apply SRI methodologies in more than 55 countries of Asia, Africa and Latin America (Styger & Traoré 2018).

In conventional management practices, (a set of conventional practices as described by Krupnik *et al.* 2010) rice seeds are planted in a wet seedbed, within a layer of 1-4 cm of water. After 21 to 23 days the rice plants are transplanted into paddies in the wet season and after 24 to 25 days in the dry season. In the System of Rice Intensification (SRI) rice seeds are sown in a damp seedbed sown with a higher plant density, having a layer water of 0-1 cm. After 11 to 13 days in the wet seasons the rice plants are transplanted. In the dry season this is 14 to 15 days. Transplanted rice plants suffer less from weed competition and from limitations in land leveling, but direct seeded rice plants can be sown with a higher plant density. Fertility and weed management are timed according to transplantation or seeding day.

Although SRI was originally developed for irrigated rice, for which full water control is possible, SRI practices have been successfully adapted to rainfed rice production. This has been especially true in West Africa, where most rice is grown in rainfed systems. Although conditions across West Africa may not always allow perfect implementation of the four principles (of early, quick and healthy plant establishment, reduced plant density, Improved soil conditions through enrichment with organic matter, and reduced and controlled water application), applying these principles, combined with an understanding of the synergies created, can go far to optimize crop management.

The System of Rice Intensification has gained critiques - along with its popularity - from rice scientists. For example, the reports of “super-high” rice yields have been widely condemned as faulty by researchers at a number of international institutions. Other critics highlight the risks and disadvantages that should be considered alongside the potential benefits of SRI’s principles, such as greater weed growth and high labour requirements, which is not always available to farmers in Senegal (Krupnik & Sarr 2008). In addition, SRI requires strict control over water/water regime for irrigation and drainage, and strict timing is necessary. Besides that this is not always available or feasible it also requires levelled land (Stoop, 2003). As Krupnik and Sarr (2008) state: “Where farmers cannot enact all of these principles, they are encouraged to adapt and alter parts of the system to fit site-specific agronomic, economic and cultural needs. SRI should consequently not be thought of as a pre-packaged technology; rather it represents an integrated rice production approach that encourages farmers to experiment with and optimize their management of soil, nutrient, water and biological relationships while attempting to maximize the efficient use of scarce natural resources”. This is essential to keep in mind as there might be circumstances in Senegal in which SRI is difficult to apply, for instance direct seeding is rather important in the SRV, there is a lack of equipment for mechanical transplanting, and rice straw and other rice by products are in various cases used for animal feeding.

Challenges to apply in the case of Senegal come from the importance of direct seeding in the SRV, the lack of equipment for mechanical transplanting and the use the rice straw and other rice by products for animal feeding (M.Diagne, pers.comm.) However, extensive experience in its implementation, and highly positive outcomes in Senegal comes from the West Africa Agriculture Productivity Program (WAAPP) -- executed in 13 West African countries, led by the West and Central African Council for Agricultural Research (CORAF/WECARD), and funded by the World Bank (Styger & Traoré 2018).

Farming system issues from a civil society perspective: The problem of rice production can be summarized as the interaction of multiple constraints closely linked to climate change, such as water deficit, salinization and acidification of cropland. The main causes of these constraints are: drought, very high evaporation, deforestation, topography and relative proximity to the sea. Salinization, soil degradation and impoverishment have made ecosystems vulnerable. These combined impacts have negatively affected agricultural activities in general and rice cultivation in particular and contributed significantly to the impoverishment of populations (AGRIDAPE, 2013). Rice cultivation, practiced in the lowlands, is under serious threat from the effects of climate change, particularly from drought and land salinization.

SRI, as a rice production technology, has demonstrated its value in comparison with control plots. The results have shown that it increased yields by 50 to 100% and often more, with a reduction in the amount of water, seeds and fertilizers used (AGRIDAPE, 2013). Having always believed that

permanent flooding and mineral fertilizers such as NPK and Urea were essential for rice production, SRI has shown to producers that not only is it possible to produce rice without mineral fertilizers, but that they can at least double yields. This success, recorded on a relatively small scale within Senegal, has led to a great popularity of this system among the population in the experimental areas.

Proposed policy response (synthesis of responses from stakeholder inputs): Faced with this situation, it is becoming urgent to provide a response at the highest level and to reinforce transitions to more sustainable rice production at all levels, particularly at the local level. To combat the phenomena of salinization, soil degradation and impoverishment and revitalize agroecological rice cultivation, projects and programmes must support and expand the initiation of producers to the principles of the SRI, and set up a series of hydraulic structures that can support the need to manage water on SRI principles. The successes achieved in the experimental areas have been very well received by farmers who are increasingly adopting this innovative method of rice cultivation.

4.2. Land tenure issues

Current status: Land tenure in Senegal is governed by legislation giving municipality leaders control over land allocation and management. Rural councils have considerable discretionary power over land allocation. The primary means of accessing land is through inheritance, leasing, borrowing, land purchase, and allocations – all from local rural councils. Customary law, religion, and political party membership can perpetuate inequities to land access. The central government is allowed to reclassify territorial lands as pioneer lands in order to regain control. Reclassification may occur when commercial players are interested in obtaining quality farmland, especially in the Senegal River valley (USAID 2010). There are instances when rural councils collude with commercial interests at the expense of poorer farmers in areas where land is highly productive and valuable. Finally, there is no formal expropriation and compensation procedure for expropriated land taken for projects such as irrigation development (USAID 2010).

Land tenure issues from a farmer perspective: To promote the local rice value chain, local communities need to commit to allocating arable land for agroecological systems. At the moment, some cities and their leaders declare themselves agroecological and promote at the local level policies favorable to agroecological production. Efforts that will result in the creation of sustainable food systems at the local level. These lands must be registered with their market value for their holders to use them to have access to credit. Other challenges to access to land for agroecological systems, are the customs in some communities that do not give land ownership to either youth or women Participatory research and promotion of initiatives to

redistribute rice fields for the benefit of women and young people is a possible as a strategy to promote agroecological rice farming in a sustainable way.

Land tenure issues from a researcher perspective: Land tenure considerations have strong youth and gender equity components. Around 80 percent of Senegal's population is younger than 35. The droughts of the 1970s and 1980s impacted heavily on rural incomes, and one of the major consequences of this has been the flight of young men towards cities, where they seldom find jobs, leaving disproportionately large numbers of women in the countryside. Thus, a major challenge to agriculture in Senegal is to sustain the sector by increasing investment in farms, and to attract young people back, capable of absorbing the information needed to use new approaches, such as SRI (Seck *et al.* 2005). An essential component of this is ensuring land tenure rights to youth and women, as a fundamental basis for securing equity and building new, diverse socio-professional communities in the agriculture sector.

Land tenure issues from a civil society perspective: Rice cultivation in the off-season (for other crops) predominates in rice production. This system may lead to the extension of cultivation areas to the detriment of pastoral rangelands or protected areas. Conflicts arise as a result of the encroachment of cultivated land into pastoral areas.

Until 1987, most of the developments in the Senegal Valley were large and medium-sized state-funded schemes. They were developed by peasant farms set up and supervised by SAED, which had held the Delta lands classified as a pioneer area since 1965. With liberalisation policies, the pioneering area of the Delta was transferred in 1987 to the land areas managed by local authorities. The disengagement of SAED and the reduction of the State's investment resources have favoured the development of private perimeters developed by individual promoters or organised as family or collective enterprises on land affected by the rural councils (Enda Pronat, 2017).

Despite their importance, the vast majority of the affected areas are not as yet developed. For the areas developed by the State and especially those developed by the private sector, the cultivation rates per season are very low. The developed areas are partially exploited due to degradation resulting from lack of maintenance, poor development, soil salinization and lack of a drainage system. For the entire left bank of the Senegal River, the area under cultivation increased from 47,467 in 2006 to 73,844 in 2013, according to SAED.

Proposed policy response: Develop and apply land management policies, particularly on the part of local government, that recognizes legal land ownership by women and youth, and explicitly allocates land for agroecology. Such policies should consider those conditions which would enable the women and youth to economically develop the land provided to them, such as finance

(addressing access to credit), and mechanization (addressing labour demand). The explicit registration of land designated for agroecology, with credit policies aligned could enable farmers-including women and youth, to have access to credit.

Digitalisation of land registration could also help to monitor the land distribution and use for agriculture by the government or the local communities (M. Diagne, pers.comm.).

4.3. Research and development on the production level

Current status: Rice production has benefited from a relatively high level of national and international research. Much of this research has been on irrigated, high-input systems, even though the total irrigable area in Senegal is small (Masters 2007). The acreage of irrigated rice in Senegal in 2008 was estimated at 53,000 hectares, out of a total of 125,000 hectares under rice cultivation (Senegal Ricepedia, <http://ricepedia.org/senegal>).

Research and development issues from a farmer perspective: There has been a lot of research in the field of agroecology but agroecological practices have not been scaled up. To develop the local rice sector, research needs to begin by identifying needs by producers as barriers to scaling up, working with research institutions, conducting participatory research including producers, capitalizing on results, and to popularize them.

Research and development issues from a civil society perspective: From 1996/97, SAED, in partnership with the Caisse Nationale de Crédit Agricole du Sénégal (CNCAS) and WARDA (now Africa Rice), developed and implemented the "Riz de Qualité" program as part of its technical programs, which took into account factors for improving productivity and quality. However, this programme, as it has so far been developed, does not promote agroecological practices, soil fertility restoration, nor biodiversity and environmental protection. Indeed, this programme is mainly based on an intensification of technical approaches requiring the following:

- compliance with the crop calendar and fertilization recommendations;
- the use of high-performance rice varieties (Sahel 108, Sahel 202, Sahel 201 and IR 1529) characterized by their short and medium cycle (105 - 120 days) ⁷and a yield potential (9-10 t/ha);
- the production of rice of a quality that ensures a good processing coefficient during processing (or milling rate, as the more common technical term) and makes it possible to produce the three categories of rice (broken, intermediate and whole);

⁷ Update from reviewers: Only Sahel 108 is a short duration variety. S108, S201 and S202 were released in 1994. From 2005, 21 other improved varieties were released including a short duration variety (Sahel 134) and 3 aromatic varieties (Sahel 177, Sahel 328 and Sahel 329). A hybrid variety was also released in 2017. (M. Diagne, pers.comm.)

- the improvement of processing performance;
- the promotion of local rice by putting rice millers producers and rice plants in contact with the distribution channel.

While all these have value, the research supporting agroecological rice production, or systems of rice production that favors small-scale family farmers has not been supported.

Research and development issues from a researcher perspective: There are many research gaps that should be addressed to foster more holistic rice production systems. For example, the application of green manure in rice production systems is a key measure to both sustain fertility and address pest issues (see below) yet the research and management techniques developed for synthetic inputs are not adequate for effective GM use. Conventional inputs deliver readily known and adjustable levels of nutrient, and have well documented, consistent patterns of availability or action. As Cherr *et al.* (2006) notes, “Green manures, however, are biological organisms affected by the cropping environment, regularly confounding direct control by farm managers”. As with many agroecological inputs, green manure provides multiple services (for example, nutrient supply, pest and weed control, and increase of soil organic matter), thus its management and calculation of benefits is inherently complex (Cherr *et al.* 2006).

Another research gap, in supporting more organic forms of cultivation, is in balancing the trade-off between using the organic matter such as rice straw to improve the structure of the soil and rice productivity, and the need to feed livestock. In rice production farmers are recommended to not export the straw outside the field to increase the availability of the potassium, nonetheless most do not follow this recommendation. Research might look at the larger system, including the needs of animal agriculture, to seek solutions (M. Diagne, pers. comm.)

As noted above, rice in West Africa has been the focus of considerable research, particularly with respect to irrigated, high-input systems, even though the total irrigable area In Senegal is less than half of total rice production acreage (Masters 2007). The alternative crops that may fare better in arid environments such as millet and fonio have not received sufficient research support, nor has agroecological approaches in general such as the effect and potential of water saving strategies (Djaman et al., 2018). Also, on-farm trials are essential to adapt research outcomes to local agronomic, social and economic circumstances (Krupnik & Sarr, 2008).

Proposed policy response: Research funding is a sustainability and national security issue that involves state policies and expenditure. The latter must strengthen the seed sector, and support farmers to better save their seeds and improve certain farming practices in rice seed production and conservation. It must also subsidize organic fertilizers to facilitate access to these products for producers, so that they can restore the fertility of their soils. This would help to safeguard the

farmers' seed capital. These research directions should be supported by advocacy towards decision-makers and awareness raising for the public. For example, fairs can be organized for the general public so that the SRI technique and agroecological intensification can be mastered and scaled up.

4.4. Training and education

Current status: BAU promotes increased diffusion of crop management options to reduce yield gaps, through agricultural extension agents.

Training and education issues from a farmer perspective: Increased farmer training of integrated and agroecological crop management options to reduce yield gaps in both irrigated and rainfed systems is needed. There are many agroecological farms in Senegal that provide trainings which are not officially recognized by the ministry of education For example, the work of Kaydara School Farm in Senegal has led to concrete benefits for the community and for the environment (see <http://www.fao.org/agroecology/database/detail/en/c/1055842/>). As another example, ENDA Pronat worked with other CSOs to develop a partnership with Cheikh Anta Diop University to introduce a professional license and Master on agroecology. It is important to support the development and the official recognition of knowledge provided by the agroecological farms. Agroecology must be included in Senegal's national agricultural and education policies. In this way academic training and the ongoing training of agricultural extension agents will also include agroecology and they will be able to support farmers with the needed skills.

Training and education issues from a civil society perspective: The State must, on the one hand, demand more integration of SRI and agroecological intensification into agricultural training curricula. And on the other hand, SRI's outreach programmes should be multiplied in collaboration with all stakeholders. As part of SRI and sustainable food system development programmes, the financial capacities of civil society organizations should be strengthened to help them better disseminate SRI and agroecological intensification in a comprehensive manner, with a good monitoring and evaluation system.

It is now essential to strengthen: (i) training on agroecological intensification and SRI in schools and in the field with the farmer-school field approach (participatory action research) and functional literacy; (ii) awareness-raising on environmental issues and risks involved with the conventional rice production system; (iii) farmers' organization to rebuild local seed capital and advocate for the enhancement of farmer seed.

Training and education issues from a researcher perspective: Support for agricultural extension services is back on the agenda of donors; for example, the World Bank Programme des Services

Agricoles et Organisations de Producteurs du Senegal (PSAOP) has sought to increase smallholder agricultural productivity, production and incomes, through increasing access to agricultural services and empowering producer organizations, through technology transfer (World Bank 2006). This support is in the form of a loan, which the government of Senegal must pay back, presumably through the greater revenues from agricultural productivity resulting from the program, with significant impacts on Senegal's balance of payments.

However, the standard technology transfer approach has shown its weaknesses, in assuming a one-way flow of information and techniques, without respecting the expertise and understanding of challenges of farmers. An increasing corps of people focusing on effective farmer training are recognizing the value of a very different approach, that of farmer-led research in farmer field schools and farmer-researcher networks. The depth of understanding that can be developed on context-specific challenges and solutions by beginning with farmer experiences and fostering co-creation of knowledge between farming communities, scientists and extension agents (Nelson *et al.* 2016) is increasingly being acknowledged and used to structure training and education. Strong social relations and social cohesion among farmers is thus essential for scaling up of agroecological practices (Jenkins 2015).

Proposed policy response: Policy must recognize the value of participatory research, that fosters and supports interaction between actors involved – noting that interaction is essential not only between researchers and farmers, but also among farmers, if a significant societal impact is sought from research and education.

Thus, policy measures must support:

- the development and the official recognition of knowledge provided by the agroecological farms;
- research on scaling up agroecology, identifying needs by producers as barriers to scaling up, working with research institutions, conducting participatory research including producers, capitalizing on results;
- increase farmer training of integrated and agroecological crop management options (including systems of rice intensification in both lowland and upland rice);
- include Agroecology in Senegal's national agricultural and education policies so that academic training and the ongoing training of agricultural extension agents includes agroecology and they will be able to support farmers with the needed skills.

Research funding is a sustainable national security issue that involves the state. The latter must strengthen the seed sector support fund and help farmers to better save their seeds to improve certain farming practices in rice seed production and conservation. It must also subsidize organic

fertilizers to facilitate access to these products for producers, so that they can restore the fertility of their soils. This would help to safeguard the farmers' seed capital. This must be supported by lobbying, advocacy towards decision-makers, the organisation of information fairs for the general public so that the SRI technique and agroecological intensification can be mastered and scaled up to the scale of large rice crates.

4.5. Traditional knowledge

Current status: In the current agricultural research and extension work of the Government of Senegal, there is little recognition of traditional knowledge, including preservation and dissemination of techniques used by women who are producing and processing indigenous rice in ecologically-friendly ways (as has been supported by a New Field project in Burkina Faso). Research priorities on both intensification of rice production and poverty reduction do not consider traditional knowledge; for example, the specific agricultural objectives in PSRP include modernizing equipment, supporting markets, improving access to lands, increasing agricultural research, and improving the management of the agricultural sector. (GTF website)

Traditional knowledge issues from a farmer perspective: Traditional knowledge in agroecology is the basis of everything, it affects all areas of production. But it needs to be documented, capitalized and shared among producers. It is important to support more exchanges between producers and capitalization among agro-ecological rice producers between producers in Senegal and those in countries like Burkina Faso and Benin

Traditional knowledge issues from a civil society perspective: Civil society must do more to advocate with international policy makers and institutions for the recognition of traditional knowledge and farmers' rights, based on the International Treaty on Genetic Resources for Agriculture and Food (ITPGRFA). As noted by the farmer perspective above, it is important to support more exchanges among agroecological rice producers, between producers in Senegal and those in countries like Burkina Faso and Benin and also from countries in Southeast Asia (Cambodia).

Traditional knowledge issues from a researcher perspective: Considerable research has documented the contribution of traditional knowledge in rice cultivation in Senegal. Much of the scientific literature has focused on the Jola people; as noted by Linares (2009):

“The Jola have been among the most skilled rice producers of West Africa for centuries, growing both upland and flood rice in the inundated valleys and mangrove-lined river channels (marigots) lying along the flood plains and the tributaries of the Casamance River. They have produced mostly for home consumption, but their history tells us something

about the gendered development of farming skills in complex rural economies. Numbering approximately 400,000 persons, they live in numerous scattered communities located in the southwestern corner of Senegal known as Lower Casamance. Initially, they grew only the indigenous African species of rice known as *Oryza glaberrima*, then shifted to introduced varieties of the Asian species *Oryza sativa*. Their sophisticated rice-growing technologies include bunding the rice parcels to retain rainwater, cutting down the mangrove and then flushing out the salts, carving out deep fields surrounded by tall walls, and building sturdy dikes to keep the brackish marigot water out of their fields. Farmers in some communities raise fish in ponds along the tall dikes. The Jola distribute and circulate rainwater and fresh water from uphill springs among various categories of rice fields by cutting through, or plugging up, the bunds. Everywhere, they transplant the seedlings from numerous rice varieties into flooded fields, or direct-seed (i.e., broadcast the seed) into upland fields.”

This intricate system of production is however under threat from current pressures. As Linares (2009) notes, severe droughts have impacted rice-growing systems in Senegal and adjacent countries for several decades. The migration of young men to cities has caused severe labor shortages, leading to the neglect and eventual collapse of the dikes protecting the mangrove-recovered fields. Brackish water has invaded and destroyed some of the best-yielding fields.

As can be seen, the contributions of traditional knowledge to rice production in Senegal is not archival material from the past; their vibrancy and life is very much in the present. As documented by Linares (2009), skilled Jola women farmers in the Casamance region of southern Senegal work to maintain their complex system of irrigated and upland production. They have made use of their “traditional” knowledge and farming skills to shift crop repertoires and techniques so as to embark on market-gardening, thus innovating in response to new needs and perceived opportunities (Linares 2009). In a project coordinated by the Institute for Development Studies, traditional oral communicators are presently involved in promoting agroecology to the wider public through community radio broadcasts while farmer organisations establish local schemes for multiplying traditional peasant seeds so that traditional varieties are more widely available. Farmer groups are establishing a network of organisations and stakeholders to take actions for agroecological transitions and have begun farmer exchanges to share technical expertise (Taylor 2017).

It is important to make a case why traditional varieties may be replaced. The intention is not to discard landraces; in fact these varieties co-exist along side the improved varieties. New varieties have been created to address a certain productivity-limiting factors such as susceptibility to

disease, salinity, etc. The combination of the two may answer many needs (Africa rice researcher, pers. comm.).

Proposed policy response: (see above, and also with seeds and genetic resources) Dissemination of technology without state involvement (e.g. farmer to farmer propagation, dissemination of best practices, support the development and the official recognition of knowledge provided by the agroecological farms etc.)

4.6. Irrigated rice production - General

Current status: Irrigated rice is the most productive form of rice production. in the Sahel region as a whole, irrigated rice produces 8.5% of regional rice production, although irrigation potential is estimated to be much greater, estimated at more than 3 million ha along the Senegal, Niger, Black Volta, Chari, and Logone rivers (Maclean *et al.* 2013).

Seventy percent of the total rice production in Senegal is irrigated and takes mainly place in the Senegal River Valley. The Government of Senegal (GoS) has played a major role in the development of the irrigation infrastructure in the Senegal River Valley. The two main schemes managed by the government are the Large-Scale Irrigation Schemes (Grande Aménagement, GA) and the Village Irrigation Schemes (Périmètre Irrigué Villageois, PIV). The Large-Scale Irrigation Schemes cover areas over 1000 hectares including both canals and drainage networks. The Village Irrigation Schemes are smaller (15-50 hectares) and only consist of canal infrastructure (no drainage canals). The government remained mainly involved in developing irrigation infrastructure until 1994. Thus, the state has played a lead role in developing and managing irrigated rice schemes, with over 75% of the areas currently under parastatal control (Bogdanski *et al.* 2016).

Because of disengagement of the GoS in the nineties, private investments formed the Private Irrigation Schemes (Périmètre Irrigué Privé, PIP). These schemes cover areas of maximum 500 hectares and they have no drainage facilities (Wolfe *et al.* 2009).

The technical potential of irrigated rice has attracted large public investments in West Africa over the last century: the first irrigation schemes were constructed in the Sahel in the 1920s. Under the introduction of privatization policies, rice investment schemes are increasingly being managed by actors from the private sector (Maclean *et al.* 2013). Investment in agribusiness rice schemes call for rehabilitation of irrigation systems in disuse and building of new systems to yield an average cropping intensity of at least 1.5 rice crops per year in these schemes. Yet many challenges remain within high-input rice cultivation, including its negative externalities. Many farmers in Senegal also confront basic production challenges under conventional production: the

late arrival of inputs or delay in harvesting of the previous crop often leads to important yield losses. Weed infestation, in particular in direct-seeded fields, and bird damage are also major constraints.

At the same time, Senegal has also a strong tradition and component of irrigated rice production from smallholder and family farmers, both in the Senegal River Valley and in the Casamance region of southern Senegal. Many studies have documented that investment in infrastructure could facilitate, not simply large agri-business schemes, but greater community and family farmer control over water for rice production. For instance, the implementation of SRI in non-improved lowlands has been constrained by the impossibility of water control, as plots were not leveled and were exposed to sudden flooding after heavy rainfall. The creation of bunds along contour lines as well as leveling the plots for better water management would be appropriate investments along these lines (Styger & Traoré 2018).

There are many ecosystem services provided by irrigated rice systems that should be recognized in an accounting of costs and benefits. For example, groundwater recharge is a provisioning ecosystem services provided by rice paddies. When rice fields are flooded, standing water percolates through the soil and recharges the groundwater. Although a significant part of the water flows back into river or drainage channels, around seven percent recharges the underground aquifers (Bogdanksi *et al.* 2016; Abdullah 2002).

Sensitive management of irrigated rice production systems may also have benefits for the moderation of extreme weather events, as described below under the researcher perspective.

Irrigated rice production issues (general) from a farmer perspective: Community-based rice cooperatives are an alternative approach to organization of irrigated rice production systems. However, local rice cooperatives at the community level are not common. Rice is produced by households, once harvested, the rice is stored in family granaries. Scaling up local rice needs to do action research in the production areas on the type of storage and its agroecological community management.

In addition, there is strong need to support to small scale irrigation infrastructure; it is important to encourage dikes and bunds in the lowlands to retain and manage the "surplus" rainwater and control salt accumulation. Some experiments have been started in this direction both in Senegal and other west African countries like Burkina Faso.

Irrigated rice production issues (general) from a civil society perspective: In the Senegal River Valley, where there is a relatively abundant water resource, access to irrigation water for family farms and its management is still a concern in rice fields, because the efforts made by the State

in the development of irrigation infrastructure are insufficient in this region, and even less so in other regions. In some places, in the middle Valley (for example in the department of Podor), large pumping stations are temporarily nonfunctional and/or with limited irrigation capacity in time and space. Family farms that do not have enough financial resources to equip themselves with a pumping system within their reach are condemned to produce under tense conditions of access to water with very high hydraulic costs to bear.

Canal maintenance work is not regularly carried out in major rice developments schemes because of a lack of rigorous monitoring on both the SAED and operator sides, resulting in loss of pressure and pumping system efficiency.

Drainage networks in large rice development schemes are major sources of pollution of the river water where they are directly connected, but also of the groundwater through the infiltration of floodwater from rice plots. These drains, which are loaded with chemical fertilizer and pesticide residues, constitute major health risks of contamination of people and local animal and plant biodiversity. Unfortunately, this major public health risk is not yet taken seriously by the various rice promotion programmes.

Irrigated rice production issues (general) from a researcher perspective: As discussed earlier, rice farmers in Senegal are facing challenges such as yield losses by weeds and birds and water conflicts (Hathie *et al.* 2013. In irrigated rice systems, farmers use pesticides, which might end up in waterways affecting water quality. Also, mineral fertilizer input can cause eutrophication of waterways. Although needed to improve rice yields, fertilizer and pesticides are not accessible to all farmers.

To provide water to the irrigated rice paddies, irrigation infrastructure is needed, including pumps and other machinery which might be costly. The irrigation infrastructure is mainly managed by farmers themselves and therefore requires strong social relations and trust.

The primary agroecological alternative to conventional rice production is SRI, Systems of Rice Intensification, an agroecological methodology for increasing the productivity of irrigated rice by changing the management of plants, soil, water and nutrients. This production approach is described above, here we note the scientific documentation of its benefits: increased yields of 20-50% or more, a reduction in seed use of 80-90%, and up to 50% water savings (<http://sri.ciifad.cornell.edu/aboutsri/FAQs1.html>).

The infrastructure of irrigated rice farms in Senegal is mainly managed by the farmers themselves, without state involvement. This is an important aspect to appreciate, as it requires strong social relationships and levels of trust. In other regions, the scope for expanding

irrigation infrastructure to serve multiple purposes has been explored, such as “Perimeter Engineering” This approach recognizes that the “green infrastructure” created by communities managing water together may serve, not just to function for weed control in rice, but also as landscape elements that capture floodwaters during the rainy season, and thus recharge groundwater that may be used during drier periods. This is the concept behind the “Ganges Water Machine” (<http://wle.cgiar.org/blogs/2013/05/21/>), a long debated concept to find a solution to water issues in the Ganges River Basin in India, where 80% of the monsoon-driven river flow occurs during a four month period. While rice systems do serve in this capacity already, the logistics of optimizing such functions across an entire river basin – remain challenging. It is unlikely that this can be accomplished simply by farmer training, as a social investment in creating such a system of bunds and dikes is needed. The direct effects of such an investment would be to increase employment (initially for a few years, and ultimately for continued maintenance), increase productivity due to ability to manage water levels, provide resilience (protect against drought and floods), and allow greater fish or duck cultivation in rice paddies.

Proposed policy response:

- Implement agro-livestock integration (see also recycling) we will mention that for rice, the integration more specifically refers to fish-rice integration, but that with this assumptions concerning agro-livestock, we represent the AE principle and also the impact (through better use of by-products of livestock for crops (manure) and by-products of crops (animal feed) for livestock, use of animal force for crops production etc. all together increasing yield)
- Implement and invest in climate change adaptation (e.g. local seed use, moisture management, research, restore habitats etc.)
- Diversify production and increase income
- Support the construction of dikes and bunds in the lowlands to retain / manage the "surplus" rainwater and control salt
- Enhance the provisioning of ecosystem services (including pollination and soil health e.g. through polycropping, intercropping, crop rotation, multi-layer farming etc.) by enabling the implementation of sustainable land management supporting specifically small-scale production, processing and storage in a holistic way (including training, awareness, research but also access to equipment and credit, investment in small scale mills and community storage options, as well as support of marketing of AE products) (see also synergy)

- Experiment with drainage water treatment systems through the introduction of plant species for wastewater filtration; such experiments need to be carefully developed so that any introduced species will not infest farmers' fields.
- Support small holders to implement small-scale irrigation, along with possible interlinked benefits of perimeter engineering.

4.7. Irrigated rice production - Seeds and genetic diversity

Current status: Seed is often difficult for farmers to obtain; farmers save seed for replanting but are not assisted to do so. Seed is being developed through conventional breeding programs, focusing on input-responsive seed (commercially produced) and high inputs to improve yields. The development of the rice seed sector is anticipated to occur primarily through private sector actors.

Irrigated rice production- seeds and genetic diversity issues from a farmer perspective:

Development of the rice seed sector is needed through community seed banks:

In order to develop the rice seed sector and cover community needs, it is important to have seed banks at the very local level. This will only be possible, if there is a:

- 1) An inventory of local / traditional / peasant seeds;- of relevance to rainfed systems.
- 2) A research on technical itineraries (next to peasant knowledge);
- 3) An awareness raising of the communities based on the results of the research and finally
- 4) develop a commercial valuation system.

A scale up of pilot projects in seed production and conservation is needed.

Irrigated rice production- seeds and genetic diversity issues from a researcher perspective:

Farmer participation in agricultural research is increasingly seen as a pathway to increase the relevance of improved seeds developed to benefit farmers' communities. This is well acknowledged by many in the crop breeding community with however some criticism that there are higher costs of participatory plant breeding (PPB) compared to conventional breeding. Mangione *et al.* (2006) have shown that there are no relevant differences between the participatory and the non-participatory plant breeding programs, and that in fact decentralized-participatory breeding programs reach the same level of development of the breeding material three years earlier than a centralized– non-participatory breeding program. Participatory may be capable of generating more information due to the use of more trials at each site, improving selection efficiency.

The scope for encouraging greater participatory breeding to meet the tastes of different populations has been somewhat explored in Senegal. Farmers do not always readily take up improved varieties, which may be explained by the fact that these varieties are not adapted for farmers' needs, preferences and conditions. In the upland rice/groundnut cultivation zone of Senegal, Kanfany *et al.* (2016) invited 29 farmers (both men and women) were invited to participate in a breeding selection process. The rankings of farmers were not according solely to yields, but rather related to characteristics of earliness, moderate height, yield, and termite tolerance.

With respect to the development of seed systems, despite the existence of UNIS (Union Nationale Interprofessionnelle Semence), there is no proper planning of the needs of the different type of seed (foundation, certified), the control system is weak, and there is a lack of specialized funding for seed commercialization, and lack of seed storage, A new business model for seed production and distribution is needed (M. Diagne, pers. comm.)

Irrigated rice production seeds and genetic diversity issues from a civil society perspective: Research (ISRA, AfricaRice), private seed operators and the control service provided by DISEM constitute the backbone of the certified seed production system in Senegal. The current availability of certified rice seed under the community seed production programmes initiated by producers and supported by ANCAR, in partnership with ISRA, DA/DISEM, CARITAS, POGV, ASPRODEB, has made it possible to satisfy, in part, the producers' requests, but not for traditional varieties. Indeed, the latter mainly use certified rice seeds listed in the official catalogue to the detriment of traditional varieties left out by the State's research and agricultural programmes (Enda Pronat, 2018).

Certified rice seeds are sometimes more productive but have very limited agronomic capacities (low genetic diversity), specific to an area or environment, thus limiting their capacity to adapt. In addition, they require the application of a fairly expensive technological package based on synthetic chemical fertilizers and pesticides that are not always available to producers. In addition, R3 certified seed ages over time and loses its productive capacity, becoming no longer suitable for propagation for certification.

Another researcher perspective, from AfricaRice, notes that is important to make a case why traditional varieties are replaced. The intention is not to throw them away; in fact these varieties co-exist along side the improved varieties. The new varieties are indeed called improved because they are created to address a certain challenge. It is not just about productivity, but the productivity-limiting factor such as susceptibility to disease, salinity, etc. Reliance on traditional varieties alone will not lead to the food security/sovereignty. They can continue to be grown, and

even be marketed according to the consumer needs and preferences. However, we should not forget the idea why new varieties are called for in the first place (AfricaRice, pers.comm.)

Proposed policy response: Develop and support community seed banks at the local level, including research, inventories, and awareness raising and small-scale seed enterprises. Strengthen seed systems overall.

4.8. Irrigated rice production - Water management practices

Current status: Mean paddy yields are currently about 4.5 t/ha but vary widely from as low as 1 t/ha, rising to 4–6 t/ha (Maclean *et al.* 2013).

Irrigated rice production- water management practices issues from a farmer perspective: New ways of assisting farmer communities to store and manage water are being identified. For example, a water-gathering and storage system put in place through FAO's "1 million cisterns for the Sahel" programme focuses on vulnerable rural communities in arid and semi-arid regions of five countries affected by climate shocks. Women, their families and local masons have been trained to build cisterns for year-round water storage. The cisterns hold water harvested from a collection area such as the rooftop of a hangar or shed. The beneficiaries and masons were paid for their work while the farmers received training in resilient agricultural practices (FAO 2019).

Irrigated rice production- water management practices issues from a researcher perspective: According to de Vries *et al.* (2010), in irrigated lowland rice cultivation areas in Senegal the recommended water depth is 10 to 15 centimetres permanently flooded. Although, it should be noted that depending upon how irrigation water is distributed, water management may be modified. There is a positive correlation between water depth and plant performance. However, irrigation is costly, and water is becoming scarcer in Senegal. Alternate wetting and drying (AWD) in which fields are not continuously flooded has been proposed as an alternative to save water. AWD is also applied under the System of Rice Intensification (SRI) until the reproductive stage, including a shallow water depth.

The dependence on water of the rice farming sector is a huge challenge as freshwater resources are becoming increasingly depleted due to competing water uses from the residential and industrial sector and as rainfall is increasingly erratic due to climate change and variability. According to FAO water experts any evidence-based on "water use efficiency" should be multiple scale and based on sound water accounting (Perry & Steduto 2017). If there is not a sound water accounting framework, one will miss a number of trade-offs, for instance:

- More water efficient means less storage benefits and less groundwater recharge.

- It also means less of a number of ecosystem services linked to biodiversity, micro-climate, connected wetlands, part of the landscape feeding off “water losses” (such as the very productive wooded areas/trees, etc.).
- Water saving regimes will increase the weed biomass as flood irrigation is practiced to suppress weeds. Weed pressure is a major constraint for rice yield.
- An important term when considering the trade-offs between water quantity and food production is water productivity. This describes rice yield divided by the total water input. Under water saving rice cultivation systems, water productivity increases, yet there may be the possibility of saltwater intrusion. Rice production in Senegal can be severely affected by saltwater intrusion.
- Under water saving systems major water savings can be achieved. However, without proper weed management yields will suffer from weed competition. Weed control under water saving regimes is found to be very effective to keep yields on a certain level.

The primary approach to addressing water in rice cultivation in a holistic manner is the System of Rice Intensification (SRI), as described earlier. SRI has been documented to lead to increased yields, often by 50% or more, while using 90% less seed, 30-50% less water and less agro-chemicals, and can be implemented in both irrigated and rainfed lowland systems. The average SRI yield for irrigated rice in Senegal was 6.6 t/ha compared to 4.23 t/ha for conventionally grown rice (N=292 sites), a 56% increase. For rainfed lowland systems, SRI yields averaged 4.71 t/ha, compared to 2.53 t/ha for conventional rice (N=441), an 86% increase. The estimated total additional quantity of rice produced with SRI compared to conventional rice during the 2015/2016 growing season alone was 31,458 tons of paddy, or 20,113 tons of milled rice, representing a value of 10.07 million USD dollars. (Styger & Traoré 2018).

Irrigated rice production - water management practices issues from a civil society perspective:

The summary nature of some developments, particularly those encountered in initiatives to extend village irrigated perimeters, makes water management more difficult rather than easier. A better leveling of the plots would allow a more rigorous management of the water brought in. However, the use of public works machinery entails a cost that individual farmer cannot bear.

Rice cultivation recharges the groundwater until it is flush with the surface, causing salts to rise to the surface at the same time as creating a dynamic water concentration (Salvignol 1993). Indeed, the conventional system of permanent flooding of rice plots is at the origin of irrigation water losses, which not only lead to the degradation of facilities and high pumping costs, but also to the rise of groundwater on the surface. The rice plot flooding system can incur three types of foreseeable losses in the irrigating channels (Salvignol 1993):

- losses by infiltration, however, the design of channels with stiff stabilizing elements makes them these losses low;
- direct losses, they consist of a flow through the groundwater, so they end up in the drains;
- losses due to overflows. they are real and have been noted. They are difficult to quantify but seem to be the main factor explaining the increase in water consumption and losses.

Changing attitudes, while far from easy, seems to be the basis for significant improvements. It is indeed necessary for farmers to stop believing that all the water entering their plot is used only for rice growth.

For the efficient management of irrigation water and in order to increase water productivity, the intermittent irrigation technique such as SRI advocated by a large number of research and development organizations is very little known to farmers. It is a water-saving technology, in contrast to conventional rice irrigation, where rice fields are kept flooded throughout the growing and development season. SRI and intermittent irrigation techniques alternate watering and drying, which makes it possible to directly reduce the quantity of irrigation water intended for rice fields.

Another way of improving the situation would be to act directly on the rise of the groundwater table. To this end, crop diversification, by limiting excessive groundwater recharge, would be a solution.

Proposed policy response: Greater support should be allocated to water-saving rice farming systems such as Alternate Wetting and Drying (AWD) and Systems of Rice Intensification. Both greater investment in research and on-farm training is needed.

Water resource-use efficiency should be increased (e.g. replace inefficient with efficient irrigation equipment and support research and on-farm trainings on water saving practices)

- Decrease of expenditure for (inefficient) irrigation equipment frees money for other purposes
- Increase of expenditure for efficient irrigation equipment
- Support small-scale irrigation equipment
- Set up a training support fund for pump operators and operators as part of the extension of the SRI to better adapt the volumes of irrigation pumped to needs (optimal irrigation). Training activities must be strengthened in this direction.

4.9. Irrigated rice production - Fertilizer management practices

Current status: Conventional fertilizers are mostly imported, except for phosphate that is mined in the country. To maintain and increase soil fertility and thereby increase yield, chemical fertilizers are generally applied. However, nutrient use efficiencies are rather low in Senegal. Fertilizers are subsidized by the Government of *Senegal*. Subsidised fertilizer is about half the price of non-subsidised fertilizer (Osinski & Sylla 2018); The total subsidies for Senegal is 72.6 million, where 30 % is allocated to fertilizers.

Most fertilizers have been subsidized at 50 percent, meaning the government pays for 50 percent of the farmer's fertilizers through government-approved and registered tenders and the farmer purchases the remainder of their fertilizer through the private market (Bumb *et al.* 2011). Farmers are responsible for obtaining their fertilizer from the suppliers' warehouses, and 80 percent of the fertilizers on the market are government approved tenders (ibid).

Irrigated rice production - fertilizer management practices issues from a farmer perspective: Agroecological producers should be encouraged to produce, collect and market their own natural fertilizers (cow dung, dead leaf humus, compost, etc.); At the same time, it is necessary to advocate for increased access to natural fertilizers subsidized by the government. Alternatively, community-based compost production experiences must multiply and scale up.

Irrigated rice production - fertilizer management practices issues from a researcher perspective: Rice requires about 20 kg of nitrogen per ton of the harvested crop. About half of this is recycled into the soil in the crop residue; therefore about 10 kg of nitrogen is removed per ton of harvested grain. A 6-ton rice harvest removes about 60 kg of nitrogen from the soil, equivalent to 300 kg of ammonium sulfate fertilizer.

Chemical fertilizers ending up in waterways may cause eutrophication; these negative externalities of fertilizers are well documented. Blooms of phytoplankton (including cyanobacteria) are widespread, mainly caused by phosphorous (P) inputs (in combination with environmental factors, like changes in light and temperature). Lakes and tributaries along the Senegal River are subject to these P inputs, while they are used by the local populations as freshwater supplies (for example as drinking water for the capital Dakar). Nitrogen (N) fertilizer application proves to be profitable in irrigated rice cultivation systems in Senegal to increase yield. However, N is applied in relatively low application rates and the timing of N applications is not optimal. Although application rates of N are low and it is not the main cause of eutrophication in Western Africa, N use efficiencies of rice plants are sub-optimal, resulting in losses of N (Bado *et*

al. 2011). Bado *et al.* (2011) stated that response to N by rice in Senegal can be increased by improving weed control as the presence of weeds increases N loss (Bogdanski *et al.* 2016).

In addition, Senegalese farmers are constrained by the high costs of chemical fertilizer and sometimes lack accessibility at the right time (Krupnik 2012). This is also a matter of low recovery rates of applied nutrients; e.g. farmers apply too high quantities, at an suboptimal time in the growing stages of the rice plants and mode of applications (Haefele, 2002). Practices to replace, reduce and/or complement chemical fertilizers are recommended. For instance, the use of organic and alternative inputs, such as green manure, could reduce the need for chemical fertilizers. Alternatives include:

- Increase optimization and recovery of applied (chemical) fertilizer. Fertilizer applications that are too high and not applied at the critical stages of plant growth will result in low recovery rates. This will cause not only run-off, followed by its negative impacts, it will also result in lower yields. Fertilizer application is recommended to be done in 2 or 3 splits at the planting stage, early tillering stage and panicle initiation stage. Also the dosage is key to efficient application of fertilizer (Haefele, 2002). A tool has been developed, which is called 'RiceAdvice' which can advice farmers in the recommended dosage and timing of fertilizer.
- Green manure applications. Although Green Manure incorporation is thought to incur high costs of labor, costs of fertilizer purchase and application can be higher and therefore less accessible for African smallholder farmers. Hence, farmers can benefit from the use of GM, yet specific numbers on costs are not available. This is explored more thoroughly below.
- The application of Azolla could possibly reduce fertilizer use; however, yields will only remain high when applying at least 60 kg N ha⁻¹. (Bogdanski *et al.* 2016). If Azolla was substituted for ammonium sulfate, nearly all of the money required to purchase the 300 kg of ammonium sulfate fertilizer could theoretically be used to pay farm labor to grow azolla, or to gain a greater return on family labor (Lumpkin & Pluecknett 1985).
- The use of rice straw amendments to add Nitrogen (N) to rice fields.
- Urea Deep Placement (UDP): Granules or briquettes are made of urea and applied to or within the soil just after transplantation of rice. The briquettes are placed close to the roots (Bogdanski *et al.* 2016). This practice also serves to mitigate Greenhouse Gas (GHG) emission from fertilizer application. There may be additional labor or capital costs associated with this technology (AfricaRice, pers. comm.)
- Residue management: explored more thoroughly below.

Green manure details: Ndoye *et al.* (1996) and Rinaudo *et al.* (1983) both studied the input of Green Manure (GM) *Sesbania rostrata* on rice yield. Rinaudo *et al.* (1983) argued that *S. rostrata*

as green manure showed to be a suitable substitute for chemical N fertilization, as they found significant increases yield using GM (571 g m⁻²) compared to the N fertilizer input of 60 kg ha⁻¹ (381 g m⁻²). Ndoye *et al.* (1996) compared the input of the GM with a mineral fertilizer input of 92 kg ha⁻¹ on one site and 105 kg ha⁻¹ on another site in Senegal. Yields under the GM system were significantly higher, with no chemical fertilizer input. In Fangote, the average yield over seven years under GM was 3.9 Megagram per hectare (Mg ha⁻¹), compared to 2.0 Mg ha⁻¹ with fertilizer input. In Oussouye the average over 6 years under GM was 4.1 Mg ha⁻¹, compared to 2.1 Mg ha⁻¹ with fertilizer input (Bogdanski *et al.* 2016). Although Green Manure incorporation is thought to incur high costs of labor, costs of fertilizer purchase and application can be higher and therefore less accessible for African smallholder farmers. Hence, farmers can benefit from the use of GM, yet specific numbers on costs are not available (Ndoye *et al.* 1996).

Azolla details: Riara *et al.* (1987) studied the effect of Azolla crops on yields in irrigated rice cultivation. One Azolla crop is equivalent to 30 kg N ha⁻¹. The highest yield was found for a combination of fertilizer input and Azolla (60 kg N ha⁻¹ + 2 Azolla crops gives 8 t/ha), then for an application of 120 kg N ha⁻¹ (gives 7.2 t ha⁻¹) and third when implementing 4 Azolla crops (5.9 t ha⁻¹). Azolla could possibly reduce fertilizer use, however, as the results show: yields will only remain high when applying at least 60 kg N ha⁻¹. Ndoye *et al.* (1996) also considered the high labor costs of Azolla implementation, which could double the costs of labor. Azolla is a fast growing aquatic pteridophyte which fixes atmospheric Nitrogen by forming a symbiotic association with the Blue-Green Algae, *Anabaena azollae*. Azolla is an efficient Nitrogen fixer. It is grown in lowland rice fields because flooded habitat is suitable for it. Under favorable field condition, it fixes atmospheric nitrogen at a rate exceeding that of the Legume-Rhizobium symbiotic relationship. It increases the rice yield equivalent to that produced by 30-60 kg N/ha. As green manure in water logged soil, it enhances the rapid mineralization of nitrogen. It reduces the NH₃ volatilization losses through its influence on floodwater pH that leads to the conservation of urea-N in the system to improve the efficiency of N fertilizers. It significantly improves the physical and chemical properties of the soil including improvement in soil microbial activities. It helps in addition of Organic Matter and release of cations such as Magnesium, Calcium and Sodium. The total N, available P and exchangeable K in the soil and N-uptake by rice can be improved. Therefore, Azolla application is considered as a good practice for sustaining soil fertility and crop productivity irrespective of some limitations. (Subedi & Shrestha 2015)

Externalities Runoff of nutrients, especially phosphorus, leading to eutrophication causing taste and odour in public water supply, excess algae growth leading to de-oxygenation of water and fish kills. Leaching of nitrate to groundwater; excessive levels are a threat to public health. Specific to Senegal: In the lower Senegal River Delta region, there is a rapid expansion of irrigated rice cultivation. There is an increased input of nutrients into water systems causing

environmental damage by eutrophication. Blooms of phytoplankton (including cyanobacteria) are widespread, mainly caused by phosphorous (P) inputs (in combination with environmental factors, like changes in light and temperature). Lakes and tributaries along the Senegal River are subject to these P in-puts, while they are used by the local populations as freshwater supplies (for example as drinking water for the capital Dakar) (Quiblier *et al.* 2008).

Irrigated rice production - fertilizer management practices issues from a civil society perspective:

Producers forced to use certified rice seed often face situations of limited access to the recommended mineral fertilizers, as the latter are generally not sufficiently available in sufficient quantities, especially for urea. Therefore, the recommended spreading schedule is not respected, and the applied rates are generally not sufficient. As a result, many unfortunate producers end up with very low yields because the use of organic amendments and the introduction of legumes are not part of their fertilization practices.

Proposed policy response: Reduce mineral fertilizer and increase natural fertilizer use (e.g. soil fertility enhancement) (see also synergy)

- Increase of natural fertilizer use (by increasing subsidies, encourage producers to produce, collect and market their own natural fertilizers supporting the implementation of alternative approaches (such as the use of organic fertilizer derived from the Non-Sewerage Sanitation System along the fecal sludge Management treatment facilities) and training on its production, see training on SLM)

Decrease of mineral fertilizer use (by decreasing subsidies)

4.10. Irrigated rice production - Residue management

Current status: After harvest of the rice grains, rice straw remains in the field as residue. In the Senegal River Valley, 80 percent of the rice straw residues are burned. A reason for the burning of rice straw is that cattle are wandering around rice fields, releasing their dung in the fields. As dung contains seeds, cattle are seen as a major vector for dissemination of wild rice (which is considered as weed). Straw residues are burned, so cattle do not spend too much time in the field grazing on these residues. The remaining 20 percent of the rice straw residues are either fed to animals or buried in the field as fertilizer. A different situation happens in the Casamance region, where almost no rice straw is burned. The residues are either left in the field for grazing or the straw is buried to improve soil fertility. Burning rice straw in the field can emit substantial amounts of air pollutants, which has a negative impact on the environment and human health (Bogdanski *et al.* 2016).

Irrigated rice production – residue management issues from a researcher perspective: Soil fertility (soil nutrient level as well as SOM and SOC) could be improved by leaving rice straw residues in the field, resulting in a potential yield increase (Haefele *et al.* 2004). Rice cropping systems in Senegal are becoming more and more intensive. Yields have not reached optimum quantities and in general in West Africa yields are even decreasing due to, among other things, a decrease in soil organic carbon (SOC). Decomposition of the residues in flooded rice systems in Senegal results in increasing SOC status. However, Greenhouse gas (GHG) emissions (methane and nitrous oxide) increase when rice straw is incorporated in the soil compared to fields without rice straw amendments (Bogdanski *et al.* 2016).

Rice crop residues could be used as feed for animals. In times of drought, biomass may be very limited and nutrition is a major concern in cattle production in Senegal. All rice residues fed to livestock compete with soil fertility. However, synergies are found between soil residues fed to cows and food production as well. Livestock production seems to increase (milk, beef) as well as productivity during ploughing time (more hours of work per day). In addition, the quality and quantity of dung improves which as well can be added to the field again to improve soil fertility. This system is usually only viable however, when farmers have both crops and livestock.

Alternatively, farmers could use rice straw for energy. Households in Senegal highly depend on biomass energy. A trade-off needs to be considered between the use of rice residues to improve soil fertility, animal food or to use it as a source of biomass energy. In depth research is needed to see the amount of field residues which could potentially be removed without affecting soil fertility. In addition, currently rice husks are used as biomass energy. Many Africans households lack access to energy. Up to 90 percent of households in Senegal use biomass fuels, such as fuel wood or residues, as source of energy (UNEP RISO 2013). Under certain circumstances, rice husks and straw could be used as an energy source (Alesbury 2013), for instance as green charcoal as suggested in the pilot study done by the International Biochar Initiative (n.d.). These studies refer to pilot projects however and are not readily being employed in the country. There is no evidence that rice straw is used as energy source in Senegal (Bogdanski *et al.* 2016)

Irrigated rice production - residue management practices issues from a civil society perspective: Community management rules, if adopted, could result in a better valuation of harvest residues.

Proposed policy response: Support the implementation of the land use and development plans (POAS) already designed.

Support local initiatives for better management of agro-pastoral areas with a view to better integration of agriculture-livestock systems, in order to better valorization of crop residues.

4.11. Irrigated rice production - Management of greenhouse gas emissions

Current status: In Senegal, the emission of methane and nitrous oxide gases from lowland rice production is one of the contributors to global climate change. The major GHG emissions in Senegal are Carbon dioxide (CO₂), Methane (CH₄) and Nitrous Oxide (N₂O). Total GHG emissions (CO₂, CH₄ and N₂O) per year from agriculture in Senegal were approximately 186 Gigagram (Gg) in 1991, of which methane emissions in rice contributed 58.7 Gg. Hence, rice counted for 31.5 percent of total GHG emissions (CO₂, CH₄ and N₂O) in agriculture in Senegal. Total methane emissions from agriculture in Senegal were 142.9 Gg, so rice contributed over 40 percent of methane emission, at the time of this calculation (Bogdanski *et al.* 2016)

Irrigated rice production – management of greenhouse gas emissions from a researcher perspective: Several farm management practices in rice fields influence GHG emissions. Rice in Senegal is mainly grown under flooded conditions (de Vries *et al.* 2010). Methane is produced under these anaerobic conditions in waterlogged soils and consequently wetlands (like rice fields) are the major sources of methane production. Methane production and emission in cultivated wetlands (mainly rice fields) increases by submersion and rice straw residue incorporation (organic matter addition) (Le Mer & Roger 2001). Yet, it should be recognized that rice straw burning emits GHGs as well, increasing air pollution (Gaihre *et al.* 2013). Addition of N by organic or mineral fertilizer has also an impact on GHG emissions as it mainly increases N₂O emissions from the soil (Velthof *et al.* 2002).

Measures to mitigate greenhouse gases in Senegal rice production systems include:

1. Urea Deep Placement (UDP) reduces GHGs emissions compared to conventional application of urea in flooded rice fields. In addition, rice yields seem to increase as well under UDP. Exact numbers of this practice in Senegal are not available, but the data available from other West-African countries showing a synergy between climate change mitigation and food production when using UDP.
2. Alternate wetting and drying, in which rice fields are not permanently flooded, reduces methane emissions from rice fields. Over-drying could cause drought stress to rice plants and dry conditions increases weed competition. However, de Vries *et al.* (2010) concluded that alternate wetting and drying is possible in Senegal with little or no yield reduction. In this case, climate change mitigation will increase while food production is sustained.
3. Under the System of Rice Intensification (SRI) fewer fertilizers are used and rice fields are not permanently flooded. This results in lower methane emission, but nitrous oxide emissions could be higher. Yields will increase under SRI practices. Green manure amendments (used in SRI) – especially with high levels of C – increase methane

production. Site-specific research is needed to see whether there is a negative impact of SRI on GHGs emissions in Senegal.

Straw incorporation is a common long-term practice to improve soil fertility in croplands worldwide. However, straw amendments often increase methane (CH₄) emissions from rice paddies, one of the main sources of anthropogenic CH₄. Intergovernmental Panel on Climate Change (IPCC) methodologies to estimate CH₄ emissions from rice agriculture assume that the effect of straw addition remains constant over time.

Recent research results (Jiang *et al.* 2019) suggest that model projections may have overestimated CH₄ emissions from rice agriculture and that CH₄ emission estimates can be improved by considering the duration of straw incorporation and other management practices (Jiang *et al.* 2019)

Irrigated rice production - management of greenhouse gas issues from a civil society perspective:
A point of view shared with that of the researcher.

Proposed policy responses:

- Limit or even eliminate the subsidy of synthetic fertilizers to reduce or eliminate the use of mineral fertilizers, especially urea.
- Set up a participatory action research program on the technique of alternating wetting and drying, scaling up among family farmers.
- Popularise and disseminate the technique of alternating wetting and drying in irrigated rice growing basins.

4.12. Irrigated rice production - Pest and weed management

Current status: Rice cultivation systems in Senegal, like elsewhere, face damage by pests and diseases. The conventional approach to suppress pests is the use of pesticides (insecticides, fungicides, herbicides), even though the positive effect of insecticides on rice yields is not proven according to Settle *et al.* (1996). The quantities of pesticides used in Senegal, on all crops, has risen considerable over the last decades (Figure 6). Over the past 15 years pesticide use per hectare in the Senegal River Delta alone has increased four to fivefold, while the area under rice cultivation has only doubled. Jepson *et al.* (2014) outlined an approach to pesticide risk assessment in West Africa, which found that in Senegal in 2007 and in 2010, no irrigated rice perimeters met acceptable levels of pesticide risk to both human and wildlife health.

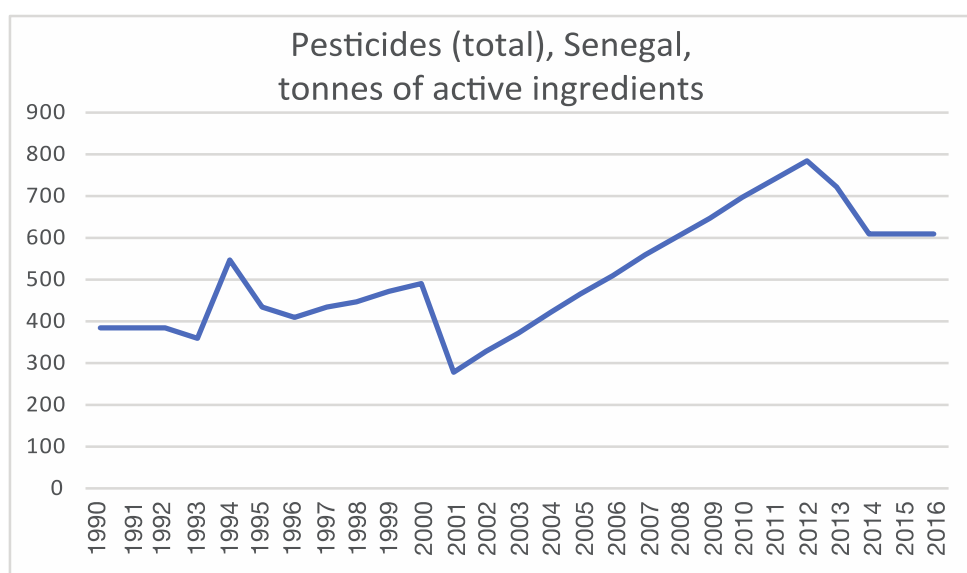


Figure 6. Tonnes of pesticides applied, Senegal (FAOSTAT)

Table 2. Pesticide use in Senegal

Target crop	Year	Insecticides applied, t/yr	Herbicides applied, t/yr	Total, t/yr	Source
Rice, Senegal River Valley	2001-2002	31.3	154.7	186.0	Sow <i>et al.</i> 2008
All crops	2001	198.22	75.62	282.02	FAOSTAT
All crops	2016	249.74	270.1	609.79	FAOSTAT

Irrigated rice production - pest and weed management practices issues from a researcher perspective: There is very limited damage by insects on rice plants in Senegal, such as stemborers (Settle & Garba 2011). The biggest current challenges are weeds and birds (Rodenburg *et al.* 2014). Pesticides may be over- and misused in Senegal (IW:LEARN, n.d.). Through pollution of the Senegal River watershed, by spraying pesticides without protection and by eating treated rice, these pesticides may also have dangerous impacts on human health and biodiversity.

As noted above, the positive effect of insecticides on rice yields is not proven (Settle *et al.* 1996; Settle & Garba 2011). Problems caused by insect pests, such as stemborers, appear relatively limited in West Africa (Settle & Garba, 2011). Weeds, on the other hand, do cause major problems in rice cultivation, affecting rice yields (Labrada 2003; Ongley 1996). De Vries *et al.* (2010) showed a significant increase in yield when using herbicides to control weeds in rice

cultivation in two sites in Senegal. They found an increase in rice yield in the wet season of 2.8 t ha⁻¹ (146%) and an increase of 4.4 t ha⁻¹ (215%) in the dry season under flooded conditions.

However, the application of herbicides (and any pesticides) do tend to have clear impacts. The use of agrochemicals leads to contamination of surface water and biota; dysfunction of ecological system in surface waters by loss of top predators due to growth inhibition and reproductive failure; public health impacts from eating contaminated fish. Pesticides are carried as dust by wind over very long distances and contaminate aquatic systems 1000s of miles away (e.g. tropical/subtropical pesticides found in Arctic mammals). Some pesticides may leach into groundwater causing human health problems from contaminated wells.

Residue analysis showed that detectable quantities of pesticides enter villages in Northern Senegal through irrigation channels and drains. Applications of the pesticide Carbofuran have been commonly used in rice production systems in Senegal, to control stem borers (even if not needed, or effective). This pesticide is known for its hazardous effects on non-target species who use rice fields as (feeding) habitat, such as fish, frogs, wildlife, invertebrates and macroinvertebrates – and also impacting the birds who feed on them. Research has shown that the exclusion of Carbofuran use in rice fields increases on average the biomass of aquatic micro invertebrate per hectares by 444% (Mullie *et al.* 1991).

Various alternative management practices have the potential to decrease pesticide use, in particular the use of herbicides. The best biological control alternatives to herbicides appears to be not to apply alternative biologically-sourced toxins, but to improve plant nutrition, such as through Azolla fertilizers. Thus, some management practices to control weed in rice fields in Senegal that have been commonly identified include (Bogdanski *et al.* 2016):

- (1) An increased rice plant density, a rice crop with a more rapid crop canopy closure or a more competitive rice cultivar to reduce the weed;
- (2) A manual weeding treatment combined with Azolla always increases yields, while decreasing weed biomass. Yields even pass yields of only herbicide use (although this difference is not proved to be significant at 5 percent).
- (3) No weeding only using Azolla gives a significant increase of rice yield of 1.7 tons per hectare compared to a system without Azolla and no weeding.

To reduce pesticide use, while limiting the damage by insects, the Integrated Production and Pest Management (IPPM) project has been carried out in Senegal. In this program sustainable intensification is promoted by the use of Farmer Field Schools (FFS). Farmers build new skills and knowledge to increase yields by using ecological methods. The program helps farmers to modify and adapt their own set of good farming practices. This is mainly done by showing field

experiments, e.g. experiments on the influence of natural enemies on pests. Farmers build new skills and knowledge to increase yields by using ecological methods. Settle & Hama Garba (2009) stated that there are already over 5,000 hectares of rice land in Senegal under the IPPM program. After implementation of IPPM in rice cultivation in Senegal, pesticide use was reduced by 100 percent (FAO 2008a and b). In addition, the yield increased by almost a quarter under the IPPM project compared to the conventional system (pesticide use).

There is not as yet a solid way of accounting for the cost of pesticide externalities, although a good model has been provided by a study of pesticide externalities in Thailand (Table 3). Some sources of information for carrying out such studies on rice in Senegal include a study on the externalities from pesticides (from desert locust spraying in 2003-2005 in Senegal (Leach *et al.* 2015), using the same detailed Pesticide Environment Accounting system as used in the Thailand study (Leach & Mumford 2008). It provides a potential approach for assessing the externalities of pesticides applied to rice in Senegal, should the resources exist to do so. With respect to rice, a study carried on negative externalities in rice production systems applied contingent valuation to assess the costs of a range of externalities for rice in the Philippines (Cuyno *et al.* 2001). Within Africa, Maumbe & Swinton (2003) assessed the costs of health impacts from pesticide applications in cotton production in Zimbabwe, as did Ajayi *et al.* (2011) among smallholder farmers in the cotton zones of Côte d'Ivoire. These approaches could serve as templates for an assessment of pesticide externalities in rice systems in Senegal.

Table 3. Calculation of costs of pesticide externalities in Thailand (Praneetvatakul *et al.* 2013)

Cost category	Million USD
1. Health costs due to acute pesticide poisoning	
a) Registered cases	0.13
b) All cases	2.79
2. Pesticide contamination of:	
a) fruit	155.25
b) vegetables	72.88
3. Costs related to the BPH (brown plant hopper, rice pest) outbreak in 2010	15.77
4. Budget for research related to pesticide issues	38.85
5. Budget for R&D on agricultural production inputs (related to pesticides)	0.48
6. Budget of the Q-GAP program	60.34
7. Food safety standards	5.89
Total	352.7

Irrigated rice production - pest and weed management practices issues from a civil society perspective: Set up a participatory action research program to investigate integrated pest

management techniques that have proven their effectiveness, on the scale of a locker in a farming environment.

Vulgarize the integrated pest management techniques that have proven effective in irrigated rice growing basins.

Proposed policy response: Reduce pesticide use and increase integrated pest management (see also resilience)

Set up a participatory action research program to investigate integrated pest management techniques that have proven their effectiveness, on the scale of a locker in a farming environment.

Popularize and disseminate the integrated pest management techniques that have proven effective in irrigated rice growing basins.

4.13. Rice production - Addressing salinization

Current status: In several parts of Senegal rice cultivation is threatened by salinization, which mainly occurs in the Senegal River Valley. Farmers often dry-till their soil and thereafter irrigation-drainage cycles are applied to flush the salts out of the field. To further remove salts from the field some farmers apply puddling. Puddling refers to tillage while the soil is flooded. Puddling is combined with irrigation-drainage cycles as well (Bogdanski *et al.* 2016).

Rice production – addressing salinization issues from a researcher perspective: Rice production in Senegal can be severely affected by saltwater intrusion, especially in the Senegal River Valley. Salts end up in the topsoil from saline groundwater when the rice field is not cultivated (capillary rise) and additional salts are added through the irrigation water. In addition, under flooded conditions the salts are dissolved and transported downwards from the topsoil. In general, rice plants are able to survive under certain saline and flooded conditions, yet rice production is threatened and limited by high levels of soil salinity. Many farmers dry till their fields and to wash out the salts from the soil, farmers flush their rice fields with fresh water. The results showed that puddling decreased the soil salinity level significantly. If rice fields are not flushed, eventually fields have to be abandoned due to high salt content of the soil (Raes *et al.* 1995). Though, two trade-offs need to be taken into account. First of all, the salt content in the drainage water was in the first three drainage cycles (after puddling) three to eight times higher for the puddling compared to the baseline treatment. Secondly, data on yield was not given in the research, yet rice seed establishment was poor in the puddling system (Hafele *et al.* 1999; Bogdanski *et al.* 2016).

It is noted that salt tolerant varieties are becoming available (AfricaRice, pers. comm.)

Rice production – addressing salinization issues from a civil society perspective: Same perspectives as provided in the "water management" section.

Irrigated rice production- mechanization

Current status: In 2004, there were 645 tractors in Senegal; so, the baseline at present is close to zero. (AUC/FAO 2017; Mrema *et al.* 2017). The need for greater agricultural equipment has been expressed from many perspectives. It is critical, however, to understand where the demands for greater mechanization currently apply, as discussed below.

Irrigated rice production- mechanization issues from a farmer perspective: In traditional rice fields, small tillers or polycultures are needed. They must be of human dimension so that an average peasant family can acquire / manage them.

Irrigated rice production- mechanization issues from a researcher perspective: As currently undertaken, crop establishment in irrigated rice in Senegal involves limited mechanization. There is for instance machinery available for mechanical weeding (Rodenburg & Johnson, 2013). Also, hydro tillers are used for wet tillage to flush out salts from irrigated rice fields (Haefele *et al.* 1999).

A focus on mechanization in rice production concentrates on harvesting and post-production stages. Traditionally rice is harvested manually with a knife, which is very labour intensive. Advocates for rice agribusiness argue for providing farmers with access to agricultural equipment for harvest and postharvest activities, oriented toward commercial large-scale production. Also, the possibility of increasing rice yields in the Senegal River Valley through double rice cropping, would be very much dependent on machinery availability (combine harvester and tractor). The number of such machines are limited; and the scope for maintenance is a major constraint. Once broken, they cannot be easily repaired locally, as most of the machines are imported with no spare parts. (Brosseau *et al.* 2018)

In the Casamance area of Senegal, the smallholder traditional rice systems suffer from severe labor shortages as young men and women leave the countryside to find work in the cities. Linares (2009) notes that:

“If Jola rice-growing systems are to avoid stagnation or gradual decline, serious efforts need to be made to mechanize agriculture. Unfortunately, however, this

enormous task would require substantial financial and technical inputs that are well beyond the reach of the Senegalese state.”

Thus for both conventional and agroecological rice systems, there is a need for greater investment in appropriate mechanization.

Irrigated rice production - mechanization issues from a civil society perspective: Despite the development and supervision of rice growing areas by development projects, the introduction of heavy equipment such as tractors and combine harvesters to support rice growing development has not been as successful as expected. Indeed, in most rice growing areas, tillage, harvesting activities are still not mechanized due to the high cost of maintaining equipment that is difficult for promoters and producer organisations to bear.

It should just be noted that even when there is a sufficient quantity and diversity of agricultural equipment available in rice production area, producers do not always use the services of machinery providers for economic reasons.

Proposed policy response: There is a need for greater investment in appropriate mechanization. In particular, farmers should be provided with access to agricultural equipment for harvest and postharvest activities. For agroecological farmers, this equipment should be developed and scaled toward the needs small scale producers, such as small tillers or harvesters for use in traditional/small-scale rice fields. Given the challenge of the cost of mechanization, greater support is needed to enable farmers’ organizations to invest together in machinery, and for private contractors to be able to rent and repair these.

4.14. Rice production - Inputs and subsidies

Current status: Subsidies for inputs such as fertilizer, seed, machinery, and fuel have been a mainstay in agricultural development in Senegal since 2004. The amount of subsidies provided has expanded as well, increasing from 75 million in 2001 to 36 billion ten years later (Seck 2015). The subsidies have been credited with enhancing productivity in groundnuts, millet, sorghum, and maize, but not rice particularly (GFC website). Development of a coherent input subsidy policy is greatly needed. Most of fertilizers have been subsidized at 50 percent, meaning the government pays for 50 percent of the farmer’s fertilizers through government-approved and registered tenders and the farmer purchases the remainder of their fertilizer through the private market (Bumb *et al.* 2011). Farmers are responsible for obtaining their fertilizer from the suppliers’ warehouses, and 80 percent of the fertilizers on the market are government-approved tenders (ibid). The total subsidies for Senegal is 72.6 million US dollars, where 8.3 % (\$ 6.03 million) is allocated for all types of seeds. (Seck 2015).

Irrigated rice production - inputs and subsidies issues from a researcher perspective: An agroecological approach to subsidies would be to recognize the value of investment in farmers, but to phase out subsidies for agrochemical inputs and reorient these resources to support farmer-to-farmer training, farmer researcher networks and training on agroecological farm management. Such a reorientation could contribute substantively to increased employment in green industries around agroecological rice: seed banks, green manure production, rental of small-scale machinery for harvesting and threshing, community-owned rice mills.

Irrigated rice production - inputs and subsidies issues from a civil society perspective: One of the major handicaps is undoubtedly the availability of appropriate inputs at the needed time (with respect to the crop calendar) and accessibility of fertilizers (high prices), more particularly Urea.

Proposed policy response: Development of a coherent input subsidy policy that fosters agroecological approaches and regenerative rather than high-input agriculture

Or abolish the subsidy for chemical fertilizers and leave it to private operators and the market to make the necessary trade-offs. The State, through its decentralized structures, would then be more useful as a market regulator and a control body for fertilizer distribution channels.

4.15. Rice production - Agricultural credit

Current status: Currently, systems of agricultural credit are limited, and through short credit duration lead to a “vicious cycle” of “short pay-back to finance service > delayed credit attribution > delayed planting > delayed harvesting > delayed pay-back to finance service, etc. (Brousseau *et al.* 2018). Such delays in credit have many knock-on effects, including delayed sowing, and reduced yields (Tanaka *et al.* 2018).

Irrigated rice production - agricultural credit issues from a farmer perspective: For agroecological rice production, credit is non-existent in Senegal. Farmers' organizations must work with financial institutions such as the “Caisse Nationale de Crédit Agricole” and other micro finance institutions to draw- up credit lines for the benefit of producers or traders of agroecological products only.

While majority of family farmers produce food primarily for home consumption, yet they struggle to market the little surpluses that they have. There aren't any niche markets for agroecological produce. In the absence of facilities for storage facilities and capacities to add value, farmers are forced to sell their produce in the local markets with low returns. Specialised (organic) and distant markets insist on value addition and certification, that are beyond the affordability of a small farmer. Thus agricultural credit could make a large difference in facilitating storage facilities and value-added enterprises.

Irrigated rice production - agricultural credit issues from a researcher perspective: A study analyzing the rice value chain in Senegal sought to identify if it is structured to implement technical changes and integrate new functions, leading to increased value added, as rice value chains in Asia have often done (Soullier 2017). The study found that while many aspects of the Senegalese value chain are in step with what is taking place in Asia, a significant difference is tied to the absence of credit. In Senegal, many of the transactions along the rice value chain are “spot transactions”. When farmers participate in contracts, they do so to secure agricultural financing, in credit markets where such financing is not obtainable due to the indebtedness of small-scale producers to the national agriculture bank. Two types of contracts are common- production contracts and marketing contracts. The impacts of such contracts on small scale farmers are different. The production contract has a positive impact on the income of producers who were excluded from bank credit. It nevertheless includes implicit interest and insurance costs, meaning that these producers make less profit than those financed by the bank. The marketing contract is a financial device which has no impact on agricultural practices, yields, product quality and income. It nevertheless slightly improves food security by mitigating price seasonality. The study author calls for the design of an appropriate insurance system for agricultural credit which should also include mechanization and address the needs of small-scale processors in the modernization through the promotion of semi-industrial technics and the opening up of operating and equipment loans.

A special issue of LEISA India on Agroecological Value Chains (LEISA India 2018) outlines some of the challenges and possibilities of building safe, sustainable agroecological value chains that ensure farmer prosperity. They describe the formation of farmer producer organizations in India that assist farmers with sustainable production methods and work together to add value by grading and branding. Farmers working together have been able to collectively market their products and enhance their bargaining power. Similar initiatives have and can be initiated and encouraged on rice value chains in Senegal, possibly through infusions of agricultural credit.

Irrigated rice production - agricultural credit issues from a civil society perspective: Irrigated agriculture as carried out by small scale and family farmers in the Senegal River Valley does not receive enough medium-term agricultural credit. There is a lack of optimal support for the investment needs of farmers and businesses over a period of time that meets the requirements of irrigated agriculture. This is largely due to the fact that demand is mainly for short-term needs, yet short- and medium-term credit is hard to obtain. Private investment in credit institutions is extremely limited due to the existing structures and systems.

The dominant element of the production system in the valley is still the subsistence family farm. The agricultural sector is primarily subsistence and marginally commercial, where accumulation

is insignificant. Presently this sector constitutes the basis of basic food production and the basis for the emergence of individual agricultural enterprises since they hold most of the land allocated. Existing credit institutions are not serving this sector effectively.

Proposed policy response: There is an urgent need for the State to clearly define the type of agriculture it intends to develop at the national level, and to confirm that in the Senegal River valley agricultural development should proceed through the normal stages of a self-sufficient family agriculture before trying to institutionalize the industrial agriculture model advocated by the structural adjustment programmes. Credit structures should support family farmers and their entrepreneurial aspirations.

The relevance of the rice systems set up in the context of large dam projects must be questioned, since they have very high production costs and only offer low incomes. There is insufficient thought on alternatives to the technical packages prescribed by the development offices, while options exist that could reduce production costs and should be tested locally. These include improving plot fertility management (organic manure, limestone, green manure), hydraulic control (water blade management), better equipment for producers for cultivation, harvesting and post-harvest, and reducing irrigation costs.

Support financial organizations to extend credit and micro-credit to provide preferential terms to producers or traders of agroecological products, and other producers or traders otherwise contributing to resilience. Particular areas needing support are for mechanization, storage facilities, and processing capabilities.

4.16. Diversification, integration of fish with rice

Current status: Over 90% of the world's rice is grown under flooded conditions, providing an environment not solely for the crop alone but also for wide range of aquatic organisms. Many rural households depend on monotonous diets that are too high in carbohydrates and too low in animal source foods and micronutrient-rich fruits, fish and vegetables. Access to a diversified diet is often constrained by lack of purchasing power, limited expertise and limited availability. Experience has shown that more diversified farming systems that contain horticultural or aquacultural components are one way to improve households' availability and access to such animal source foods, fruits and vegetables. While high external input production systems, usually monocultures, may increase rice yield (compared to more diverse, yet lower external input systems), they bear the risk to lead to monotonous diets that are high in carbohydrates and low in animal source foods and micronutrient-rich fruits, fish and vegetables (trade-off). More diverse, yet less external input systems may lead to higher dietary diversity and better nutrition, with potential trade-offs in yields of rice- but also potential synergies for increased yields.

Diversification may occur along many lines; two that we consider below are integration of vegetables, and incorporation of fish in rice paddies.

Irrigated rice production - diversification, integration of fish with rice issues from a researcher perspective:

Diversification with vegetables: in a case study exploring trade-offs and synergies for improving irrigated rice systems in the Senegal River Valley (Brouseau *et al.* 2018) many farmers have desired crop diversification through the integration of (more) vegetables, with the hope that this could lead to greater income, less risks and increased food security. However, vegetable cultivation posed a potential risk to the objective of households to be self-sufficient in rice, since rice and vegetable cropping calendars could overlap, with both occurring between the end of the cool dry season and the start in the hot dry season. Other constraints included credit arrangements, and small land sizes. A simulation of possible farmer decisions showed indicated the following trade-offs in the Senegal River Valley, farm profit can be increased with reduced household leisure time and increased N losses, and rice production could be increased by cultivating rice in the hot dry season in the fields currently dedicated to vegetables. The latter option can reduce farm profit and N loss but increase household leisure time (Brouseau *et al.* 2018).

Fish-rice integration: In a careful review of the literature, Halwart & Gupta (2004) documented fish production yields in rice-fish systems all over the world. The analysis demonstrates that, although higher rice yields were not always obtained with the introduction of fish, the majority (80%) resulted in higher yields of 2.5% or more, and a significant contribution of fish protein to farmers' diets.

Efforts to integrate fish with rice in the Casamance region of Senegal have shown considerable promise (Petersen *et al.* 2006) In the rice culture zones of Senegal, environmental changes have caused some rice farmers to diversify and integrate fish culture in their farming operations. As described by Diallo (1998):

“After two decades of drought, mangrove areas on the foreshore have expanded and surface and groundwaters have become increasingly salinized. To protect their rice fields against the inflow of saltwater, farmers built fishponds along the foreshore area to produce fish. The fishponds range from 500 to 5 000 m² (30 cm deep with 1 m deep peripheral canal). During the first rain, the gates of the rice fields and fishponds are opened to allow the rainwater to wash away any salt that may have accumulated. Then the gates are closed and the rainwater and surface runoff are collected for both the rice planting and fish growing operations. After the rice has been planted from mid-August to mid-September, the seaward gates are

opened during the spring tides. Coastal fish attracted by the flow of freshwater come into the ponds and are trapped. No attempt is made to control the species and the number of fish that enter. The rice fields and fishponds are fertilized with cattle and pig manure and ash. The fish are fed rice bran, millet bran and sometimes termites. The fish are harvested either when the rice is about to mature or just after the rice has been harvested from December to January, when the fish have been growing from 120 to 150 days. Harvesting is done during low tide by draining the pond with a basket locally known in Senegal as “etolum” placed at the end of the drainpipe. In Basse Casamance, Senegal, rice–fish alternating with fish only culture results in fish yields ranging between 963-1 676 kg· ha⁻¹ in ponds fertilized with animal manure and fed farm by-products, and 590 kg· ha⁻¹ from the rice field.”

Irrigated rice production - diversification, integration of fish with rice issues from a civil society perspective:

The intensification of rice cultivation and the development of irrigated diversified crops other than rice must be compatible: on the one hand with the sustainability of cultivation and production systems, and on the other hand with the preservation of natural resources.

Care should be taken to ensure that the issue of intensification is addressed, as it will only be sustainable if it improves or maintains fertility in its broadest sense, paying particular attention to ensuring that it does not contribute to causing or accelerating the degradation of the environment. Hence, the relevance of rice and fish farming and the association of other crops in rice fields with a low water level (e. g. sorghum and some forage crops tolerating root asphyxia relatively better according to Saglio & Pradet 1983, Follin 1993). These crops are unfortunately not well known to farmers.

The constraints to diversification are many and varied depending on whether one is dealing with small village or private perimeters, or medium to large perimeters. Significant challenges are noted in the diversification of crop calendars, technical routes and water management. Crop calendar problems are very complex. The results of Amediane *et al* in 1993, in the specific case of small village perimeters, make it possible to classify constraints into five groups according to whether they are due to: production systems, types of irrigated perimeters, or macroeconomic, cultural or technical problems. Constraints to diversification can also be: insufficient farm size to achieve self-sufficiency, lack of available labour and, almost generally, lack of cash flow.

However, the most serious constraints are neither climatic nor purely technical: they most often relate to the collective organisation of perimeters, access to credit and inputs, the poor state of pumping equipment, not to mention the existence of incentive or non-incentive sectors. Indeed, the absence of attractive diversification channels other than tomatoes and onions, whose

markets are not spread over a long period of time and are saturated too quickly, is a major constraint.

Proposed policy response: The State must undertake guarantees of market outlets, prices and financing for diversification, which currently are too uncertain to allow farmers to take the risks of engaging in any farming systems in which productivity remains uncertain until the harvest. This risk to farmers should be addressed by programmes that help farmers to face uncertainty.

4.17. Rainfed lowland or upland rice production - General

Current status: Rainfed rice systems are mainly found in the Casamance region (Kolda and Ziguinchor regions), in the south of Senegal. Although 90 percent of the inhabitants of Senegal live in this area, and the region covers a large area of harvested rice in Senegal (over 75,000 hectares), only 30 percent of the rice of Senegal is produced in this area. During the 2009 rainy season, rainfed rice growing occupied 72,000 ha, representing 30% of national production. Production, harvesting, and processing operations in rainfed systems are done manually and mostly by women. Farmers generally lack access to seed of improved varieties, such as. NERICA (New Rice for Africa). Drought, weed infestation, and low soil fertility are major constraints in rainfed upland systems, with yields usually from 1 to 2 t/ha. In rainfed lowland systems, yields are usually clearly higher, up to 3 t/ha, because of more favorable soils and moisture conditions. Plots are small (<0.1 hectares) and rice production is extensive as low amounts of fertilizer are applied and no herbicides are used. Lowland rainfed rice plots are seasonally flooded, while upland rainfed rice plots fully depend on rainfall (Wolfe *et al.* 2009). Seed is often difficult for farmers to obtain; farmers save seed for replanting but are not assisted to do so. Rainfed lowland or upland rice production is not a focus for commercial production/agribusiness.

Rainfed lowland or upland rice production - general issues from a researcher perspective: The rainfed systems face challenges related to weed infestation, drought and low soil fertility. Most of the rice production in rainfed systems is done manually and often by women. Mechanization levels are low, pesticides are hardly used, and water management is difficult as water input is harder to control compared to irrigated rice systems and floods are easier taking place. Average yields are therefore quite lower compared to irrigated rice yields.

Members of the research establishment have, in reference to GOANA program mentioned below, brought attention to the newer program PRACAS (2014) where rice is an important component (M. Diagne pers.comm.).

Rainfed lowland or upland rice production - general issues from a civil society perspective: Salinisation is the most widespread problem in all lowland rainfed rice growing areas. The fight

against the chemical degradation of the land in the rice growing valleys of Casamance due to the rise of fluviomarine waters was carried out from the 1970s onwards with the implementation of several anti-salt dams that enabled the rehabilitation, defense and development of the several valleys located along the Casamance River and its tributaries. However, it should not be forgotten that the lowland is not completely isolated from the hydrographic network and that the salt water table circulating under the anti-salt dike cannot be entirely eliminated. Therefore, maintaining previously rehabilitated soils is particularly difficult in the driest years, when freshwater meteorological inputs are greatly reduced. Even poor water management or improper maintenance of structures can negatively affect the salt balance in the valley.

This partly explains why, despite the various development aid actions that have addressed the problems of lowland rice cultivation since the 1960s, most of the socio-economic, environmental and technical limitations and bottlenecks that condition valley management have not found long-term solutions, while there has been a marked decline in lowland rice cultivation in favour of upland rice, which, also thanks to the introduction of improved varieties (in particular upland NERICA varieties), has seen significant development in recent years (DRZ, 1999).

However, it should not be forgotten that, after the launch of GOANA [Grande offensive pour la nourriture et l'abondance], rainfed rice production in Senegal achieved significant results, increasing from 40,000 ha to about 80,000 ha (+95%) and covering 30% of national rice production in 2008 (PNAR 2009). This confirms the good development potential of rainfed rice in view of national food self-sufficiency objectives.

Proposed policy response: Development programmes must be designed to ensure that water flow, always in relation to desalination processes, is well controlled to prevent land upstream of the anti-salt dike from being denied water and, on the contrary, to prevent the land closest to the dam from being excessively submerged. This therefore requires the construction of additional infrastructures (dikes) to retain runoff water (surface and groundwater) to slow its movement, maintain an optimal water level for rice cultivation by regulating its height or to create water supply areas.

The adoption of appropriate cultivation techniques is necessary to ensure salt mobilization and the improvement of physical and chemical soil fertility in lowland rice fields. Examples in agroecology include the use of manure and ploughing in ridges.

At the same time, it is necessary to adopt measures to control erosion and subsequent silting of valleys on plateau and slope areas. These interventions may include the adoption of conservation agronomic techniques (e.g. ploughing and contour seeding, mulching, etc.), the construction of small structures (or buffer zones) to control water flows (half-moons, isohypsal hedges, stone

barriers, filter dikes, etc.) or larger-scale defensive measures in situations of major risk (e.g. if the slope is greater than 2%). All these efforts involve integrated actions at the territorial level to raise awareness and empower people to protect the land, both productively and naturally.

The development of lowland rice cultivation also strictly depends on the capacity and willingness of the beneficiaries to organize themselves for the management and maintenance of the structures (anti-salt dam and related developments). In this respect, water control must be ensured by the farmers themselves within the communities of the villages focused on the rehabilitated valley and organized into a management and monitoring structure (e.g. valley committees).

4.18. Import vs. domestic production

Current status: Rice is Senegal's staple crop, and since the 1980s, the country has emphasized rice production through subsidies, extension, and infrastructure, but has failed to compete commercially with imported rice (Dermont and Rizzotto 2012). This is partly due to the government's focus on urban populations and their efforts to import cheap rice from Asia (Khouma *et al.* 2012, GFC website).

Import vs. domestic production from a farmer perspective: It is recognized today that the Senegal has made a strategic mistake by focusing on rice to ensure the country's food security. Promotional efforts must be made towards speculation such as millet, maize and fonio. In Senegal, there are many experiments to introduce cereals other than rice into Senegalese diet. But the results are still mixed because of a lack of political will of the State of Senegal which does not support these efforts of food education.

Import vs. domestic production from a researcher perspective: While the Government of Senegal has invested considerable resources on rice production, there are strong arguments to be made for focusing on other crops to more realistically attain food security in Senegal, such as millet. Millet is far more drought resistant than other major staples as rice and sorghum, a critical characteristic to rural communities where soil fertility is poor and rains are unpredictable. Millet is currently grown on about 1 million hectares or one-third of Senegal's arable land. In the Senegalese regions of Kaolack, Kaffrine and Fatick, where most of the country's millet and peanut are grown, typically on sandy soil. Millet is interchanged with peanuts from one year to the next, a vital relationship as peanuts help to fix nitrogen in the soil. (GAIN 2011)

Import vs. domestic production issues from a civil society perspective: The rice sector in Senegal does not seem to benefit from a good image. Rice cultivation is perceived to be "too expensive" because it requires, in large part, irrigation by pumping and mechanized tillage. Equipment is

deteriorating and the practice of renewing or repairing needed equipment is not yet well-developed. The price of rice produced domestically is even not competitive compared to imported rice.

The disruption of the marketing system and the liberalization of imports are among the many constraints facing local rice. The main causes are: uncontrolled marketing channels, difficult access to inputs (including credit), lack of organisation of rice producers, poor production and uncontrolled imports of Asian rice.

Proposed policy response: Allocate greater resources in research, farmer training and education to the production of alternative, more drought resistant grains such as millet and fonio, based on an appreciation for traditional knowledge with these crops

Take measures to promote local rice by structurally improving the functioning of the internal market: reorganisation and organisation of the marketing circuit, inclusion of rice in the special registers (such as exists for onions), and support for a generalised reduction in production factors.

4.19. Employment

Current status: In Senegal, 46 per cent of people work in agriculture. Two thirds of Senegal's population is under the age of 18 and approximately 200,000 young people enter the job market each year fighting for around 30,000 formal jobs. Most informal jobs are in agriculture in rural areas, but the sector is lacking in productivity—it generates only around 16 percent of GDP—hindering the creation of much needed jobs and prospects of improved livelihoods.

Employment from a farmer perspective: Agroecological jobs are virtually non-existent. Formalizing the sector, starting with a redistribution of land, would create jobs for young people and women.

Employment from a researcher perspective: A case study from Senegal features a women's union that suggests one pathway to increasing employment in the agroecology sector. The farmers union, representing over 1,800 women across all age groups, cultivates around 300 hectares of land. They welcome young people and helps them to learn new skills in the union. As a group, they invested in a small rice milling facility and the rice they produce gets delivered locally, but also to the capital city, Dakar. They named their product Riz Reine (Rice Queen) and built it up to be a trusted brand (Glatzel 2018).

While increasing employment is extremely important, labour can nonetheless be quite a constraint for rice farmers in Senegal. Agroecological practices, such as SRI, can increase labour

requirements which is not always accessible to farmers (Krupnik *et al.* 2010). This can especially be a concern for women, as they also have domestic work to do (USAID 2010).

Through policies supporting smaller, community-based rice mills, seed banks, and the provisioning of biological inputs such as natural green manure, employment in the sector could be increased. All of these are relatively labour-intensive over conventional alternatives, but interventions requiring investments that are labor-saving may not have such comparative value where labour is more readily available than monetary resources. Agroecology can provide more work opportunities, including dignified, meaningful work for smallholder rural producers, particularly since it encourages experimentation, ongoing learning and sharing with peers (Bezner Kerr *et al.* 2018).

Employment issues from a civil society perspective: Development of the irrigated rice value chain, with public and private investment in development and mechanization, paves the way for the emergence of professions and service providers in maintenance and care, management, logistics, operation of machinery, etc. However, land policy is a fundamental aspect to be taken first into account, since young people often face severe constraints in accessing the resources that permit them to participate in the value chain. Population growth and the fragmentation of land ownership due to inheritance are holding back many young people in their desire to engage in lucrative agricultural activities (IPAR 2014). In the Senegal River delta, the relative mobility of land through the rental or sale of land (even if these are illegal transactions under the law) facilitates young people's access to land, thus resulting in their greater involvement in agricultural production. However, these young people generally have not received the appropriate training and are not prepared to apply agroecological practices required in a productive and sustainable rice farming system.

Proposed policy response: It is necessary to rethink agricultural policy, particularly its job creation component, by promoting initiatives that connect agroecological production systems and social organization, enabling farmers to find their rhythm and develop as true agricultural entrepreneurs. Job creation can be carried out through knowledge- and labor- intensive agroecological production and the formalization of the sector (see culture and food traditions). A coherent vocational training policy targeting young people, a promotion of mechanized and digital services, and integrated into an agri-environmental development policy for the value chain will make it possible to achieve a sustainable qualitative leap. A renewed rice cultivation, with well-trained young people and a good command of agroecological practices, should make it possible to achieve the sustainable objective of food sovereignty in rice.

4.20. Equity

Equity issues from a farmer perspective: In Senegal, women and young people are the most active in the agroecology sector. The formalization of the agroecology sector would enable them to develop their income and their leadership within farmers' organizations and communities.

Equity issues from a researcher perspective: “The Senegal River basin countries and the rest of West Africa have a relatively similar development history after independence. Their economies have not developed in pace with the other comparable developing regions. On the contrary, the GNP per capita halved between 1979 and 1995. In terms of human development, the region has developed far more slowly than other regions of the world have done. Food security remains a serious problem, and the food self-sufficiency has decreased in the region. It seems that the rural areas are challenged to produce the food for their own use, but are unable to feed the rapidly growing cities, which in turn must import part of their food. With this, it is reasonable to speculate that the problems in Senegal River development arise from broad development and regional, politics related issues. Also, it is clear that, in order to improve the situation along the river, strong actions are needed to boost the area’s macro-economy. In the light of this, the strong emphasis on hydropower generation and large-scale irrigation is understandable. However, improving human development in fields such as education and health is equally important in order to transfer the benefits of growth in the national economy to the inhabitants along the river. This should be the case in the rural villages especially, which now have lost their traditional livelihoods due to the river development schemes. A crucial mechanism in distributing the created wealth is due to developing the local markets and economic structures so that they are linked to the growing urban economic activities. The future may see major trade-offs between the national and local stakeholders. Turning these into equitable solutions requires integration between different institutions and stakeholders, as well as all the environmental components along the river. Perhaps the biggest challenge is to get the two poles of development, national and local, to mirror their goals and actions in the same landscape, most importantly to get all stakeholders to express their views and affect the development options (Varis *et al.* 2008).

In addition, although over 50% of rice area in Senegal are cultivated by women, gender gaps are found as well. Women are often seen as being the last one to access innovation and also gender gaps have been found between access to agricultural knowledge. Also adoption rates of improved practices are different between men and women (Zossou *et al.*, 2017; Addison and Ohene-Yankyera, 2018). In addition, according to cultural norms in Senegal, women do not sell rice, they save seeds from the previous year, they hardly invest in rice cultivation (no external

inputs like chemical fertilizer), and they do not grow rice as cash crop (Sullivan, 2002). It is thus key to include women in extension opportunities and training.

Equity issues from a civil society perspective: There is no equity in support for inputs (seeds and fertilizers) and investments (agricultural equipment). Indeed, most of the current subsidies benefit large farmers.

Proposed policy response: Empower people, especially women and young people at household, community levels and beyond by building knowledge, through collective action and creating opportunities for commercialization (e.g. by promoting their participation in producer groups)

The Ministry of Agriculture and its branches should objectively exploit the results of the analysis of the effects of subsidies and their contribution to the rice value chain and develop a recovery plan that secures and develops the potential of small family farms. The Social and Political Dialogue Group (GDSP) also provides a legal framework for discussing and validating proposals made in this regard to correct the imperfections mentioned above.

4.21. Environmental impact

Current status: Rice represents a significant share of these impacts, given the high carbon-intensity of rice production methods (e.g. paddies are major emitters of Envimethane), combined with high quantities of rice wastage.

The cereal milling industry is acutely exposed to the impacts of climate change throughout the value chain where a lack of access to inputs, extension, equipment, technical guidance and development has led to underperformance and created vulnerabilities. Climate change in Senegal is predicted to manifest as a decrease in the amount of rainfall—however with increased intensity, increased temperatures, and sea-level rise. Drought and saline intrusion threaten water supplies, while sea-level rise along with coastal erosion threaten infrastructure (UNDP 2016, UNIDO 2017 climate change impacts in Senegal).

These changes, combined with population growth, could lead to a 30% reduction in per capita cereal production in 2025. However, this scenario is mitigated by the fact that in Senegal, maize and rice seem to be less negatively affected than other crops by the changing climate conditions, and their yields could potentially increase (Jalloh 2013).

Environmental impact issues from a farmer perspective: It has been established that agroecological practices have the potential to protect the environment through the rational

management of water and soil. They allow the regeneration of soils, knowledge that needs to be popularized on a large scale.

Environmental impact issues from a researcher perspective: The various agroecological rice farm practices that have been discussed here have the potential to have a lower impact on the environment compared to conventional practices (e.g. AWD, SRI, IPM, etc.). These practices have shown to have positive effects on water quality, water quantity, GHG emissions and habitat provision. However, it should be noted that limited research is done in Senegal to study environmental impacts of agroecological practices in rice systems. In addition, research on the trade-offs and synergies between environmental impact and other aspects such as food production, or cultural values is key.

Environmental impact issues from a civil society perspective: Some irrigated areas have rudimentary drainage systems or none at all; this leads to excessive salinity levels on farms. In the Senegal River Valley, poor water quality in some areas affected by saline intrusion and drainage water discharged into the river and Lake Guiers contribute to the increase in the salinity of these waters.

In terms of environmental pollution, a study by the Organisation for the Development of the Senegal River (OMVS) estimates that more than 150,000 tonnes of minerals are discharged into the Senegal River and its dependencies each year. In addition, the use by large farms of chemical pesticides to control granivorous birds should be considered.

Proposed policy response: Include in future agriculture sector letters and SAED's next Mission Letter, participatory action research and the development of plants for the treatment of contaminated water (e. g. with *Sesbania rostrata*), strengthen control over pesticides and even move towards a ban on their import.

4.22. Fair pricing

Fair pricing issues from a researcher perspective: Ensuring fair prices paid to farmers for rice at mills/hulling operations is critical to building a strong, sustainable rice value chain. The study of rice value chains in Rwanda highlighted the fact that investment in modern mills was undercut by farmers not willing to sell their rice to the mills, due to the lower prices they were offered compared with other buyers. As a result, only about 10% of the paddy being produced is processed in modern mills. The rest is going to seed, feed, losses, hand pounding, or husking by small hullers (Stryker 2010).

Fair pricing issues from a civil society perspective: The current or expected performance of the local rice market is influenced by interactions with the imported white rice market. The characteristics of imported rice (quality, price) induce changes in the market shares of the different rice categories and partly explain the relative competitiveness of local rice. Deficiencies are noted, mainly the lack of market and price control, the lack of promotion and communication measures on local rice (quality, price, availability, etc.), the lack of a technical basis for setting the price of paddy and white rice, (farm production account, cost of processing white rice).

On the basis of the average production cost estimated at 80 FCFA/kg of paddy, the paddy price fixed by CIRIZ varies from 125 FCFA to 130 FCFA, the producer's margin estimated at 45 FCFA/kg of paddy is very sensitive to the price applied. If the price of paddy differs significantly from the official price, the producer's profitability is severely affected. This situation is made more fragile by the relatively small volumes on which the majority of these producers operate (with the exception of the few large producers). The margins of the other players are also not high enough. This undoubtedly explains the strong pressure that these downstream actors exert on producers to reduce the official price of paddy. Only productivity gains (increased yields and lower production costs) could reasonably lead producers to accept lower prices.

Proposed policy response: It is therefore important to look at the cost structure in the imported white rice value chain, to learn more about the actors involved and the distribution of their margins, and to consider incentives and other protective measures that can contribute to better promotion of local rice. Reduce production costs, which today range from 76 to 82 CFA francs/kg of paddy depending on the type of perimeter thanks to the economies of scale achieved.

4.2. Rice processing

4.2.1. Processing infrastructure and investment

Current status: The cereal milling industry in Senegal mainly serves the domestic market, providing important staples and critically contributing to the country's food security. Dakar has 95% of Senegal's industry including the major cereal mills. (UNIDO 2017).

Two diametrically different visions have been proposed for processing infrastructure and investment in Senegal; to invest in larger-scale agribusiness schemes or to invest in supporting smaller-scale family farmers to participate more fully in rice value chains, particularly in the processing stage.

Characteristics of larger-scale agribusiness schemes: These have been described by Adesina, through the African Development Bank Group. Adesina advocates for the creation of staple crops processing zones across Africa (SCPZs): vast areas within rural areas set aside and managed

for agribusiness and food manufacturing industries and other agro-allied industries, enabled with right policies and infrastructure. He notes “I am convinced that just like industrial parks helped China, so will the SCPZs help to create new economic zones in rural areas that will help lift hundreds of millions out of poverty through the transformation of agriculture- the main source of their livelihoods- from a way of life into a viable profitable business that will unleash new sources of wealth,” he said. (African Development Bank Group 2018). This approach is also reflected in proposed programs of the Islamic Development Bank’s Rice Regional Value Chain Program, which proposes to invest in the following key areas:

- 1) Infrastructure development: investments in socio-economic infrastructure (such as land development, irrigation canals, rural roads, market infrastructure, etc.). This is expected to increase productivity and projects and enhance smallholder access to markets
- 2) Research and Development/Science and technology: support to the national agriculture research systems in ten countries of West Africa and the Consultative Group on International Agricultural Research institutions (CGIAR) such as Africa Rice to develop and disseminate appropriate seed technologies and systems
- 3) Development of Value Chains: The program will facilitate and build public-private-partnerships. IsDB together with other development partners will closely work with relevant institutions in the beneficiary countries develop in-put/output value chains that would generate rural employment and contribute to interregional trade and cooperation in Africa.
- 4) Capacity building to enhance enabling policy environment: for the program will support capacity building of beneficiary countries to create conducive and enabling environment. that would make economies competitive and attract private sector investment.

The program will support (i) improving productivity and quality of paddy and milled rice; (ii) increasing efficiency of local rice processing and marketing; (iii) enhancing capacities to develop and promote adoption of integrated innovative practices and use of technologies. In addition, the program will promote sustainable innovative practices and principles of on and off farm production and post-farm gate processes while addressing the needs of both men and women to enhance household income and create rural employment and entrepreneurship opportunities for young people and women farmers.

Characteristics of agroecological approaches to the rice value chain in Senegal: In contrast to the larger-scale agribusiness schemes described above, agroecological approaches stress the following:

- Biological inputs

- Small scale mechanization
- Businesses to rent and maintain machinery
- Farmer to farmer training
- Small scale irrigation and community water management systems,
- Aquaculture industries (supply of fish fingerlings, fish processing plants)
- Community threshing, dehulling and sorting. (Diagne et al. 2017)
- Recycling of residues on farm and from mill
- Storage facilities on farm or in villages
- Farmer unions formed creating better bargaining prices for farmers
- Community-owned and small to medium sized mills,
- Transportation systems rationalized to reduce costs and ensure even distribution of milled rice between rural and urban areas,
- Agroecologically produced rice and traditional rice marketed to consumers with a preferential price.

Processing infrastructure and investment issues from a researcher perspective: In recent developments in a number of African countries, the liberalisation of rice marketing and milling has led to the introduction of small rice hulling operations (Stryker 2010). These have proven to be less expensive and more economically efficient than larger, often state-owned mills. As Stryker (2010) notes, “West Africa is filled with examples of how the introduction of small rice hullers contributed to higher prices for producers, lower prices for consumers, and greater market efficiency. For example, in the Office du Niger in Mali, small-scale hullers competed very well with large, inefficient and costly rice mills owned by the state. This led to liberalization of rice marketing and expansion of rice production and processing. In Rwanda and other countries, small to medium-sized modern mills (0.2-3.5 t/hour) were found to be profitable and provide multiple community benefits; and can continue to be profitable paying a proper market price for rice to farmers.”

An additional benefit of smaller decentralized mills is that by-products can be utilized, instead of turned to waste. As noted by Stryker (2010): “The by-product of processing most rice in small hullers is usually a mixture of husks, bran, and some broken grains. This is a relatively good animal feed, especially for ruminants, and can contribute to food security through the livestock sector. Other uses are as organic fertilizers or use in breweries or other sectors”.

Processing infrastructure and investment issues from a civil society perspective: In the Senegal River Valley, there are 458 private rice threshers that process nearly 77% of paddy rice, 28 functional rice mills or mini-rice mills offer rice that is popular with consumers (SAED, 2018).

Proposed policy response: Support for smaller and medium sized decentralized mills and storage facilities managed by the communities (providing benefits, such as capacity for milling by-products to be allocated to other uses, such as animal feed, field fertilizers, breweries or other sectors, reduction of transportation costs, higher prices for producers, lower prices for consumers, greater market efficiency and availability at the community markets)

An agricultural and industrial policy that is concerned with job creation should propose specific strategies to support these small businesses in order to develop them towards quality standards and support those that are capable of growing. Unfortunately, policy options are often more favourable to large-scale foreign private investment and do not necessarily create jobs.

4.2.2. Ownership of processing facilities

Ownership of processing facilities issues from a farmer perspective: Support peasant organizations and local traders to create mills at the community level to avoid transportation costs and provide lower prices on produced rice and allow availability at the community markets.

Ownership of processing facilities issues from a researcher perspective: Promoting cooperative and community ownership over mills. (Although, from other researcher perspectives, such vertical integration should consider the current role of millers, and how this would impact them (AfricaRice, pers.comm.).)

Ownership of processing facilities issues from a civil society perspective: Processing facilities are privately owned. About 70% of the local rice is supplied by artisanal huskers and only 30% is produced by so-called modern rice mills (MRAs). Hence the difficulty in guaranteeing quality rice in time and space. This has a negative impact on consumer appropriation of rice.

Proposed policy response: as above, Support for smaller and medium sized decentralized mills and storage facilities managed by the communities. The State, with the support of development NGOs and donors, must implement a material support training programme for manufacturers of artisanal huskers and service providers to improve the quality of rice processing.

4.2.3. Use of rice by-products

Use of rice by-products issues from a farmer perspective: Support for promoting by-products. These smaller mills also provide the capacity for rice milling by-products to be allocated to other uses, such as animal feed, field fertilizers, breweries or other sectors.

Use of rice by-products issues from a researcher perspective: The major by-products of rice are rice husk and straw, which have various potential uses. Risk husks could be pressed into briquettes, which can be used as green charcoal (Bogdanski et al., 2016). This could provide an alternative fuel source to fuel wood, as many Senegal households lack access to energy sources (Alesbury, 2013). Rice straw is either left in the field for grazing of cattle or buried into soil to improve soil fertility (UNFCCC, n.d.); however, researchers note that while burying straw is recommended, it is not yet a common practice. Too often, farmers burn rice residues (M. Diagne, pers. comm.).

Use of rice by-products issues from a civil society perspective: Much of the rice straw is burned on site before cultivation - due to the difficulties of removing it from the fields. According to ARORA (1976), the straw/paddy ratio is 1.44 and falls to 0.6 with the mechanization of rice harvesting. Thus, the tonnages of rice straw also varies considerably depending on the regions and harvesting techniques used. The feed value of rice straw varies from year to year, depending on the varieties grown, cultural practices, dates and harvesting methods. As both a ballast element and an energy source, it is a good carrier for molasses, capable of covering 30 to 70% of the animals' energy needs.

The by-products of rice processing in rice mills are rice husks, husker sounds, cone flours and basic flours. Cone meal is probably the most interesting by-product for animals. They are rich in protein, fat, and carbohydrates. They are highly digestible and have an energy value close to 1 UF/kg MS (Djoudeitingar, 1993). However, it should be noted that part of the rice produced in Senegal is exported to Mauritania to feed dairy cows (Tiviski network). There is a lack of policy on the price of by-products. The latter are dependent on the law of supply and demand (FAO, 2014). Mauritians sometimes buy basic flours before the rice is even planted. Basic rice flour is used to feed poultry or ruminants. It is now estimated that a quarter of the basic rice meal produced in the valley is used to feed poultry. Rice mills use different channels to market rice products. The most modern (i.e. those producing basic flour of very good quality) establish contracts with industrialists and sell part of the production to small wholesalers and breeders (Lambaré, 2015). These volumes are highly variable throughout the year. Livestock farmers buy mainly when pasture resources decline, and they supplement animals to save them.

Proposed policy response: as above: Support for smaller and medium sized decentralized mills and storage facilities managed by the communities (providing benefits, such as capacity for milling by-products to be allocated to other uses, such as animal feed, field fertilizers, breweries or other sectors,

Support and encourage the integration of agriculture and livestock into the PNAR (Programme national d'autosuffisance en riz) to improve the value of rice by-products and complete the cycle from production to consumption. This should be reflected in the field by a broad awareness campaign accompanied by a broad communication campaign and a strong partnership between processors, breeders and farmers. There is a need for a pricing policy for agro-industrial by-products

4.3. Rice distribution

4.3.1. Transportation

Transportation issues from a researcher perspective: Reduced transportation costs can result from smaller and medium sized decentralized mills. When rice marketing and milling was liberalized in many African countries, this led to the introduction of small rice hullers, who could process rice more inexpensively than large state-owned mills, and also showed a substantial savings in the cost of transporting rice to mills (Stryker 2010).

Transportation issues from a civil society perspective: Transport remains essential because of the distance between production and consumption areas. The means of transport must be adapted to the needs, in sufficient number.

Proposed policy response: The Senegalese government's challenge to rapidly increase local rice production must be accompanied by all the support logistics it requires in terms of storage, transport and infrastructure. It is necessary to strengthen the appropriate infrastructure linking rice fields, processing units and distribution sites to ensure that the market is supplied correctly but also to optimise logistics costs and reduce transaction costs, through collection points for example. Measures should be developed to Improve operators' access to logistics (packaging, transport, storage), financial information and services.

4.3.2. Continuity of supply

Current status: Many challenges exist in the current rice food value chain around the lack of storage facilities, and its impacts on the continuity of supply.

Continuity of supply issues from a farmer perspective: Even though the rice mills are decentralized, it will be necessary to have storage facilities that are managed by the communities themselves. Only in this way will the sector be formalized, well managed and more importantly to avoid food insecurity.

Continuity of supply issues from a researcher perspective: Investment in storage facilities which may be less need if rice mills are decentralized. Lack of ready availability of local rice throughout the year may also be a problem.

Proposed policy response: The ARM should adjust the quota on rice imports according to the production quantities expected in the period, to even out the continuity of supply and support local production more effectively.

4.3.3. Rice markets-general

Rice markets-general- from a farmer perspective: Policies are needed that ensure that:

- 1) There are prices and rice qualities for all income levels and
- 2) The different qualities of rice that consumers are used to, are produced and present on local markets on a permanent basis.

In Senegal, it is very common to buy a brand of rice that you cannot find the next week on your local market. This brings the need of support from the banks and the government to local rice producers and traders, to provide credit that can stabilize rice markets.

Rice markets-general- from a researcher perspective: Markets have a major role in shaping consumer preferences (Hawkes 2002). In many locations, they are the key place where consumers are exposed to information and products that shape food preferences and ultimately choices (Clary *et al.* 2017). “Markets and other economic institutions do more than just allocate goods and services; they also influence the evolution of values, tastes and personalities” (Bowles 1998). Studies analyzing the challenges facing local rice in urban markets indicate that local rice has a poor market share as it is perceived as being of inferior quality; however it also has a lower price, certainly of interest to poorer consumers (Faimohe *et al.* 2018). Policies are needed that explicitly seek to maintain a diversity of rice on the market, of both high quality and broken rice markets, for different consumers, and rice reflecting local consumers’ preference. Various policy measures proposed include encouraging investment in quality upgrading, imposing tariffs to increase the cost-competitiveness of West African rice relative to imported rice, while still leaving open the market windows for low-cost, broken rice markets.

Rice markets-general- issues from a civil society perspective: Facilitate contractual agreements between traders, processors and agricultural producers.

Proposed policy response: Increase the potential of territories to sustain their peoples by reconnecting food habits and culture as well as food production and food consumption (e.g.

ensure that rice production matches the food preferences of consumer and promote the cultural value of rice in Senegal).

4.3.4. Organization of marketing

Organization of marketing from a researcher perspective: Better organization of marketing is needed, and the creation of cooperative groups in charge of buying, processing, and selling milled rice.

Organization of marketing issues from a civil society perspective: Improving product distribution is a very important factor in increasing competitiveness.

Proposed policy response: Support farmers institutions and community-based cooperatives improving access to training, markets, inputs, capital, information, research, storage and processing options on a community level as well as the organization of marketing (e.g. document, capitalize and share traditional knowledge among producers, support agroecological community management and more exchanges between agro-ecological producers in Senegal and those in countries like Burkina Faso and Benin.

A trade promotion policy must be developed that covers the entire country and all local cereals (rice, millet/sorghum, maize and fonio), promoting the diversity of local cereal-based food products associated with rice. The image of local rice can be further enhanced, accompanied by the trademarks of local processors. A multi-pronged competitive strategy against imported rice and its by-products is needed. The aim is to communicate intensively on the entire range of food products that can be produced from local cereals (including rice), highlighting food aspects in terms of quality, hygiene and nutritional benefits.

4.3.5. Credit in the value chain

Current status: Traders in cities may be reluctant to carry local rice due to a lack of credit from wholesalers, whereas trading terms between retailers and wholesalers for imported rice consist of well worked out agreements

Credit in the value chain issues from a civil society perspective: The market regulation system put in place has enabled the financial sector to become more involved with credit in the value chain, alongside the Caisse Nationale de Crédit Agricole du Sénégal (CNCAS), the operations of the Banque Nationale pour le Développement Economique (BNDE), the Bourse Régionale des Valeurs Mobilières (BRVM) and other institutions that have created positions as value chain managers. Between 2015 and 2016, the quantities marketed by BNDE and BRM under the platform

increased from 10,633 to 15,069 tonnes, more than 65% of which was whole rice for a total financing of CFAF 5.9 billion (source: ARM).

Credit in the value chain, issues from a researcher perspective: In understanding the dynamics around the rice value chain in Senegal, and the ways that credit influences this, there is a need to include the crop insurance program as a strategy for risk management. This was initiated in the country since 2008, and started in 2012 in the Senegal River Valley (Sandmark et al. 2013). The rice insurance product is an indemnity-based named-peril insurance for rice against granivorous birds, nocturnal birds, and rainfall. Initial engagement with farmers in Senegal was problematic (Muller 2012). Senegal was the only country where Government provides subsidies for insurance, but farmers were reluctant to participate, questioning the levels of protection and cost. Greater affordability may come at the cost of insuring only against extreme climate hazards (Muller 2012).

Proposed policy response: Communicate more with banks on the functioning of the value chain. Better knowledge of it by financial institutions would also allow processors and producers to access more and cheaper financing.

Support financial organizations to extend credit and micro-credit to provide preferential terms to producers or traders of agroecological products only, and other producers or traders otherwise contributing to resilience.

4.4. Rice consumption

4.4.1. Consumption patterns and policies

Current status: Senegal, along with Madagascar, Sierra Leone, Guinea, Guinea-Bissau are the only countries (with populations greater than 1 million) outside of Asia where rice contributes more than 30% of caloric intake. Of these five African countries, in Madagascar and Sierra Leone rice composes greater than 30% of the total crop harvested domestically, but in Senegal, along with Guinea and Guinea-Bissau there is a strong discrepancy between domestic demand and consumption of rice, and domestic production, with important implications for food security. `

In Senegal, the share of calories consumed per person from rice increased from 20% in 1961 to 31% in 2007. Rice is growing in popularity with consumers, as it requires less preparation time and less energy to cook than most other staples, including beans, cassava, banana and potato. These savings are key as women participate more in the labor market, and more food is

consumed away from home. Other desirable attributes of rice are its relative ease of storage and handling, and its long shelf life.

Consumption patterns issues from a researcher perspective: A recent study looked at the degree to which national policies promote nutrition, and not just food security in Senegal (Lachat *et al.* 2015). Through interviews with those responsible for formulating food and nutrition policy, respondents mainly perceived their contributions to the improvement of nutrition to be related to the increase of food supply and diversity. Policy makers focused less on social or cultural aspects of food habits, such as practices, perceptions, and community participation or empowerment. Items that related to postharvest handling, storage, and marketing of agricultural produce were less frequently included in the policy documents. In particular, activities to expand market access of nutrient-rich foods were absent from the food security policies reviewed. The respondents noted that the current agricultural programs in which they were involved had no explicit nutritional goals and as such did not include nutritional indicators. Yet, the reduction of postharvest losses, organization of nutrition education and promotion, improvement of storage, and expansion of markets and market access are areas that offer considerable scope for improvement and explicit focus in policies.

The PAA program in the Kédougou region of Senegal, over the period 2013 to 2016, offers examples and lessons for programmes to address nutrition and sustainable agriculture at the same time. As the project and its outcomes were manifold, we cite the findings of a recent assessment (Diagne *et al.* 2017):

“The Kédougou region registered the highest poverty rate in Senegal – 71.3 percent in 2011 compared to 46.7 percent of the national average (ANSD, 2011) –and a prevalence rate of food insecurity of 33 percent (SE-CNSA, 2013) *In a pilot project financed by Brazil and implemented by WFP and FAO, children in 200 schools in the Kédougou region were provided school lunches with locally produced rice, through the PAA program.* Around 1,000 small producers sold half their total production - 250 tonnes of paddy rice to school feeding programmes last year, increasing their income. The project built bridges between agriculture and education by using school canteens as markets for rice produced by small producers in areas where the beneficiary schools are located. The Senegalese government supported the initiative and hopes to eventually make school feeding a central pillar in a national policy that promotes local cereals as a way generate additional income for local producers, while improving child nutrition. Additional benefits accrued as well: school canteens created through the project proved to be a powerful tool to attract and retain schoolchildren rather than leaving school. The project succeeded to strengthen the capacity of producers through a series of training sessions and regular surveillance by means of field

visits. Producers were trained in the technical aspects of rice crop management, organizational dynamics and security reserve policies. They also received agricultural pre-harvest and post-harvest equipment (seed kits, fertilizer and rice dehusking equipment). Several farmer unions were formed during the course of the project in the area. The average yield was estimated at 2.5 mt/ha in 2012/2013 and 3.2 mt/ha in 2015/2016 against 0.8 mt/ha in 2011/2012, a respective increase of 1.7 mt/ha. On average, the quantity of paddy rice produced by the beneficiary producers has almost doubled from 422 kg to 808 kg, with stronger growth among women producers. The increase in production has not lowered the price for producers of paddy rice. One of the major goals of the project in supporting producer organizations was developing their negotiating capacity; paddy rice prices paid to beneficiary producers were higher than those recorded in other regions of the country, as in the Senegal River Valley. The income of beneficiary producers has grown rapidly as a result of increased production and better prices for the producer. This allowed producers to increase their food expenses, but also their health and education expenses. The food security of beneficiary producer households has improved greatly; producers have sold their grain surpluses after setting up security reserves. The project has brought other benefits to producers: the time spent on working on land preparation for cropping has in fact decreased; women, in particular, benefited from this and were able to increase the amount of time devoted to other agricultural activities, and thus improving their yields more than the men could. In addition, they could use the time they save for their well-being and that of their households.

With respect to school canteens, it is questionable whether they will continue to function normally after the withdrawal of PAA. The number of schools benefiting from canteens dropped from 180 to 90 in two academic years, and by the end of November 2016 no school was running its canteen. The continuity of operating school canteens is a battle that is far from being won. Moreover, schools benefiting from PAA Senegal have not learned how to source directly from local producers to the extent that dealings between the two categories of beneficiaries has not been tested by the project. However, buying local products to feed the students is PAA Africa's pioneering idea. WFP was directly responsible for purchasing rice from producers; the schools received rice directly from WFP and were not in direct relation with the producers. How can the concept then become functional if the project ends before the concept is tested?"

Consumption patterns issues from a civil society perspective: Rice is a strategic cereal for Senegal, given its prominent place in the eating habits of Senegalese people and its weight on the country's trade balance. With an estimated demand of 3000 tonnes of rice per day, or an estimated consumption of 78 kg/year per capita, Senegal is one of the largest rice consumers in

West Africa. However, the tragedy is that the State, through its National Rice Self-Sufficiency Programme (PNAR), has put more emphasis on the quantity to be produced without worrying about the disastrous consequences of the conventional production system promoted against the environment and human health. The local rice consumed is treated with dangerous chemical herbicides. Beyond the availability of food, it must be safe for human, animal and environmental health.

Proposed policy response: Increase public awareness of the potential for sustainable rice farming systems, including agroecological practices, to protect the environment through the rational management of water and regeneration of soils

Encourage the procurement by public services of agroecological rice (Hospitals, schools, armed forces, prisons, etc.)

Reconnect producers and consumers by strengthening short food circuits and local markets, including small scale production and processing (see culture and food traditions)

Focus on social or cultural aspects of food habits, such as practices, perceptions, and community participation or empowerment.

Increase the level of consumer awareness of their right to access agroecological rice that guarantees their health and that of biodiversity. Substantial investments, preferably those running on renewable energies, are needed to increase machining capacities with a relatively low carbon footprint, through small and large industrial units, in order to meet mass production.

4.4.2. Local demand vs. imported

Current status: Locally produced, often rainfed rice tends to be considered of lower quality, with impurities mixed within and not of uniform grain size and color (Campbell *et al.* 2009). Consumers perceive that local rice requires time for cleaning and sorting, and requires longer cooking time due to lack of uniformity. Imported rice is widely available in cities around the year, while local rice is consumed when harvested, more in rural areas close to production areas.

Local demand vs. imported issues, from a farmer perspective: Local rice production must match the food preferences of the Senegalese consumer. To replace imported rice, agroecologically produced local rice must contain less impurities, broken and easy to prepare. Hence the importance of selecting seeds, testing them and producing them in order to achieve their permanent availability on the market.

Local demand vs. imported issues, from a researcher perspective: An analysis of rice value chains in West African countries found the primary disadvantage of local rice over imports is due to the poor quality of milling, and a lack of policy support for investment in mills that are capable of producing a rice that is competitive in the market (Stryker 2010). Lack of product uniformity is perceived by consumers in West Africa to lead to longer cooking times and unpredictable preparation requirements, as the cleaning and sorting of this rice prior to cooking is thought to take longer and be more laborious. Credit arrangements also impact the choice of local versus imported rice: Traders in urban areas are reluctant to carry local rice because of lack of credit from wholesalers, whereas credit is generally available from importers and the wholesalers to whom they sell. Senegalese consumers, however, more than consumers in other West African countries show preferences for local, valued Senegal River Valley rice over imported rice due to its taste characteristics, even if impure and poorly sorted. Well-branded rice, designating place of origin, local fragrant rice, also received price premiums. (Diagne et al. 2017; Demont et al. 2012, Rutseart et al 2018) The investment of the government of Rwanda in good quality, but medium sized mills of 1-3 t/hr is proposed as a viable solution in West Africa, where rice may be milled more locally but also of better quality, to compete with imported rice. Fair prices paid to farmers needs to be an important part making such value chains work. In more isolated areas, small mills are seen as appropriate, giving ownership to the co-operatives and individual owners the sense that they are able to make productive investments that capture some of the value added in the commodity chain.

Local demand vs. imported issues from a civil society perspective: Senegalese rice imports amounted in 2015 to 1,159,333 tonnes, representing a value of more than FCFA 226 billion (COMEX 2015). Taking into account the efforts made in recent years and the progress made, national production reached, in 2015, 906,348 tonnes of paddy, more than three-quarters of the level of imports (source: PNAR). The market regulation system put in place has made it possible to guarantee a strong involvement of importer-distributors in the marketing of local rice, to ensure a "quality" rice to consumers with certification by a third-party holder. To this end, a marketing platform is being set up to promote the proper marketing of Senegalese rice. This is made up of the services of the Ministry of Commerce (DCI, ARM, etc.), the services of the Ministry of Agriculture (PNAR, SAED and SODAGRI), UNACOIS, the Association des Riziers du Nord (ARN) representing the rice mills approved by SAED, 11 rice importers (import at least 2% of rice), banks (BNDE, BRM and CNCAS) and third-party holding and quality certification companies etc. (ARM 2015). However, this platform has some shortcomings such as: not all modern rice mills put their production in the platform, the quantities put on the market under the scheme are very small (-30,000T) compared to the production potential of the mills), quality certification is expensive for the rice mills, the absence of a marketing contract upstream of the chain, and the rice processing plants do not always know the buyers.

Proposed policy response: Promotional efforts towards greater diversity in cultivation and consumption of crops (for example promoting other grains such as millet, maize and fonio instead of focusing on rice only, but also the diversity within rice: high quality and broken rice to match the food preferences of the Senegalese consumer).

Support for decentralized small and medium sized mills, and community ownership where possible. Fair prices must be paid to producers.

Strengthen the Market Regulation Agency (MRA) in its mission to overcome extroversion and be less dependent on the outside world. This could be achieved by consolidating the rice marketing platform, and translating the corrective measures validated within it into regulatory texts validated by the legal authorities in order to promote the correct disposal of local rice. Open the platform to other merchants who wish to integrate.

4.4.3. Cultural importance

Current status: Rice is critically important in the cultural life of Senegal; the country's national dish is rice with fish (thiébou-djène).

Cultural importance issues from a farmer perspective: Locally agroecologically produced rice plays a very important role in the cultural celebrations of local communities in Senegal. Examples during birth, death, funerals, weddings and initiation ceremonies during which the young person moves into adulthood. Even in areas like Casamance where rice and fish (thiébou-dieune) is not the national dish, all dishes are rice-based. This situation must remain as such for the rice culture to continue to be practiced ensuring the food security of the communities.

Cultural importance issues from a researcher perspective: As described earlier under traditional knowledge, indigenous varieties of Africa rice holds unique cultural values; such as being sacred to the Jola people in the Casamance region of Senegal (Linares 2009). Both the genetic traits of Africa rice and the traditional practices of rice cultivation hold greater interest for researchers and farmers, working together to improve farming systems based on local knowledge. Farmers in Senegal seem highly affected by influences from other farmers in the neighborhood, such as traditional common practices of an area or specific actions of neighbours. When adapting agroecological practices this is thus key to take into account: that cultural norms and practices are valued and readily shared in and between many Senegalese communities.

Proposed policy response: Promotional efforts towards greater diversity in cultivation and consumption of crops (for example promoting other grains such as millet, maize and fonio

instead of focusing on rice only, but also the diversity within rice: high quality and broken rice to match the food preferences of the Senegalese consumer).

Increase the potential of territories to sustain their peoples by reconnecting food habits and culture as well as food production and food consumption (e.g. ensure that rice production matches the food preferences of consumer and promote the cultural value of rice in Senegal)

4.4.4. Food security/food sovereignty

Current status: About one in five people do not consume adequate diets in Senegal (WFP 2014). Only five percent of food consumed is from the household's own production; a large majority of food consumed in both rural and urban settings is purchased from the market. Cereals contribute about two thirds of the caloric energy supply (FAO 2010). Rice is the largest share of cereal consumption, though millet, sorghum, wheat, and corn are also consumed. Over time the share of calories from rice increased from 20% in 1961 to 31% in 2007 (GRISP).

Fish, livestock, and milk are the main sources of animal protein.

Food security/sovereignty issues from a researcher perspective: Locally produced, lower quality rice has an important role to play in contributing to food security. With its comparatively lower price, it remains a formidable resource for food insecure families. In addition, the by-product of rice milled is usually a mixture of husks, bran and some broken grains, serving as an animal feed for ruminants, and can contribute to food security via the livestock sector. The small scale of informal hullers and small rice mills allows them to be owned and operated by a number of small entrepreneurs, creating income and employment, and — though this — improved food security. Finally, availability of a large number of small rice-processing units creates an environment in which competition flourishes, ensuring that costs to consumers are minimized (Stryker 2010).

As noted above, food security policies often neglect important measures for nutritional security. In particular, in the policies of Senegal, a greater attention to the reduction of postharvest losses, storage, nutrition education and promotion, and expansion of markets and market access are areas that offer considerable scope improving nutrition security (Lachat *et al.* 2015).

Food security/sovereignty issues from a civil society perspective: According to the principles of food security/sovereignty, the availability of food resources as well as their accessibility must be preserved in a stable manner over time. Food must be available over time (from one period to another) and in space (from one region to another). It is therefore necessary to take into account future conditions. Food security must therefore be sustainable. This means ensuring that rice

production systems can continue to produce in the future as they do today or evolve in ways that will not be dead ends. But considering that availability, accessibility and stability are the three indispensable pillars of food security, considering also the fact that conventional rice cultivation is reaching a dead end, food security/food sovereignty will only be achieved through the agroecological rice cultivation system. And in addition to these three dimensions of food security, the local rice produced must be safe for health and in line with the population's eating habits.

Proposed policy response: Respect the need for a diversity of rice types (broken as well as pure, traditional varieties) for different consumers. Increase a focus on promoting alternative grains such as millet and fonio.

in the policies of Senegal, a greater attention to the reduction of postharvest losses, storage, nutrition education and promotion, and expansion of markets and market access are areas that offer considerable scope improving nutrition security. It is noted that in other countries, the lower rice grades are used for the production of rice-based products (rice-based products (noodle, fortified rice, etc), In Senegal, as consumers have a preference for broken rice, it might be that whole grains could be used more in this way (Diagne, pers. comm.).

In the context of political and social dialogue, civil society must call on the State to reform, with the support of stakeholders in the value chain, the national rice self-sufficiency programme, the conclusions of which should give great importance to agroecology, which is now President Macky Sall's fourth priority, according to his statement for his second term of office.

4.4.5. Governance across the food value chain

Current status: Senegal is a lower middle-income country with an agriculture sector accounting for 17.5 percent of the GDP. Although the contribution of agriculture to the economy is lower than the average in sub-Saharan Africa (24 percent), the sector remained the primary means of livelihood for 69 percent of the workforce in 2013. The government aims to make agriculture an engine of economic growth, as stated in the Agro-Sylvo-Pastoral Orientation Law (LOASP) voted in 2004, which constitutes the legal framework for the development of agriculture in Senegal for the next 20 years. The adoption of this law resulted in the formulation of several operational programmes such as the National Agricultural Development Programme, the National Livestock Plan and the Grand Agricultural Offensive for Food and Abundance (GOANA) (FAO 2015).

Senegalese producers and the agriculture sector in general are confronted with a number of challenges that must be addressed by public authorities. Since the 2007-2008 food price crisis, the government has been implementing important measures to support production and the main focuses have been the improvement of risk management and the increase of domestic rice

production. Other important matters have received less attention such as fisheries management and the poor structuring of value-chains. As for the land policy, identified by the LOASP as a priority for agricultural development and modernization, the document should be completed by the end of 2015 (FAO 2015)

Governance issues in the value chain from a farmer perspective: Any agroecological policy must:

- 1) Subsidize agro-ecological inputs such as fertilizers and their large-scale local production to reduce their cost;
- 2) Through the decentralization policy in Senegal, adopt laws that regulate the access to land of agro-ecological producers;
- 3) Make sure within the framework of the ECOWAS common agricultural policy that the neighboring states of Senegal also adopt an AE policy.;
- 4) Protect the domestic rice with a higher Common External Tariff (CET) and
- 5) Encourage the consumption by public services of agroecological rice (Hospitals, schools, armed forces, prisons, etc.)

Governance issues in the value chain from a researcher perspective: Governance over food value chains rarely account for externalities, both positive and negative. In Rwanda, in addition to taxes on imports, the government provides substantial subsidies on production by paying for irrigation infrastructure and subsidizing the transportation of fertilizer. These subsidies amount to close to 30% of total on-farm production costs. Rice production is financially profitable everywhere, partly because of the subsidies involved. It is economically profitable in most, though not all, locations in competition with rice imports. But these policies do not account for externalities, nor support agroecological approaches. While there are substantive negative externalities to conventional rice production and food value chains, there are also significant positive externalities within agroecological approaches as described here, including:

- Greater use and enhancement of the ecosystem services of natural pest control and natural fertility maintenance
- Maintenance of rice ecosystems that enhance biodiversity (fish, frogs, birds, insects)
- Smaller-scale irrigation and community water management systems that make more efficient and fair use of water than large-scale schemes
- Fostering of small-scale enterprises around mechanization, seeds, fisheries and biological inputs, increasing employment opportunities particularly for the youth
- Greater social cohesion with farmer to farmer training and collaboration around production, harvesting and storage, sorting, resulting in higher adoption rates of agroecological practices and better bargaining prices for farmers
- Recycling of rice by decentralized mills, to return to crop fields

- Greater economic prosperity for rural communities through community ownership of small scale milling operations
- Increased food security through more even distribution of milled rice between rural and urban
- Support for traditional values and cultural and diet diversity through valuation of traditional rice varieties.

Few means have been identified to value these positive externalities, which build on the conventional values of rice as commodity with a particular yield and price.

Governance issues in the value chain from a civil society perspective: Despite FNDAPS' efforts to professionalize the rice sector, there is still work to be done. Consultation is needed with all development stakeholders by prioritising and involving professional agricultural organisations.

Proposed policy response: Prevent the depletion of natural resources through land and natural resource governance. A national policy to promote the rice value chain must be built on the basis of past policy reviews. These assessments must not be a matter for technicians alone: they must result from participatory and inclusive national and decentralized exercises involving all stakeholders, including farmers. They must be based on the actions developed at each link in the value chain and the governance of the rice sector, the investments made, the financing mobilized, their amounts and sources, the objectives targeted, the results achieved and not achieved, the strengths and weaknesses identified, quantitative and qualitative indicators understood and controlled by all the actors in the sector. The national policy for promoting the rice value chain must focus on the problems identified at each link in the value chain and the governance of the sector and clearly outline the solutions recommended and the measures taken (Ngalane 2004).

5. Another Road Taken: Articulation of Coherent Policy Responses to a New Agricultural Paradigm

Systems of food production around the world are at a crossroads; the current system results in food and nutritional insecurity in many regions of the world, alongside epidemics of obesity in the same and other regions. The natural resource base to sustain food production is being severely impacted by practices that degrade ecosystem functions and cause losses of biodiversity, making it less able to contend with the impacts of climate change. Concerns continue to mount over the political and economic dimensions of the food system, with instability and uncertainty in the governance of land, water and other natural resources, the growing concentration of power in the hands of input suppliers and food retailers, and the difficult working conditions for many workers along the food value chain (IPES, 2016ⁱ; von Braun and Birner, 2017). These concerns are reflected with a wealth of detail in the elucidation of issues along the rice food value chain in Senegal, in the previous section.

Increasingly, there have been global calls of a new agricultural paradigm, addressing such issues in a coherent manner; many of these calls focus on agroecological approaches, seen as counter to “business as usual” industrial agriculture, and capable of building food systems that substantively contribute to achieve global food security and nutrition (FSN) (Caron et al 2018, De Schutter, 2010; FAO 2018b, HLPE 2016, 2017a 2017b), while generating many positive externalities.

In line with the aims of the “The Economics of Ecosystems and Biodiversity for Agriculture and Food” (TEEBAgriFood) initiative, the narrative descriptions of the rice food value chain in Senegal in the previous section reveal interdependencies between human (economic and social) systems, agriculture and food systems, and biodiversity and ecosystems. Acknowledging that agriculture and the way agricultural production is performed affects all areas of development and itself is affected by those areas, this section articulates the convergent policy responses proposed in the previous section, to be used in an integrated and comparative scenario analysis using a comprehensive simulation model (Section 6).

The first, “Business as Usual” scenario is comprised of current policies and practices in the rice Sector in Senegal. The contrasting scenario, comprising an alternative development path, stem from the set of policy responses outlined by the different stakeholders in the previous section. Despite varied perspectives, the policy responses proposed in the previous section have many areas of convergence and can be grouped within the structure the ten elements of Agroecology (FAO 2018a). By grouping the proposed policy responses into the ten elements of Agroecology, it is more likely that a coherent articulation of policy measures can be identified and analysed at

once, as single policy measures, given the many interactions between policies, will not have the same impact as a more holistic approach.

Thus, in this section we have summarized and grouped the proposed policy interventions Senegalese agriculture as proposed within the stakeholder consultation in and more specifically their application in the rice sector, with the aim to then be able to assess the impact from applying the proposed policy measures across the rice value chain, on several relevant development indicators, covering the four types of capital and several aspects of the SDGs, and in comparison to a continuation of “business as usual”. The two approaches are further characterized in Figures 5 and 6.

Policy Interventions

Efficiency

1. Increase water resource-use efficiency (e.g. replace inefficient with efficient irrigation equipment)

This includes for example:

- Decrease of expenditure for (inefficient) irrigation equipment frees money for other purposes
- Increase of expenditure for efficient irrigation equipment
- Support small-scale irrigation equipment

2. Support the construction of dikes and bunds in the lowlands to retain / manage the "surplus" rainwater and control salt

Recycling

3. Reduce mineral fertilizer and increase natural fertilizer use (e.g. soil fertility enhancement)

This includes for example:

- Increase of natural fertilizer use (by increasing subsidies, Encourage producers to produce, collect and market their own natural fertilizers supporting the implementation of alternative approaches (such as the use of organic fertilizer derived from the Non-Sewerage Sanitation System along the fecal sludge Management treatment facilities) and training on its production, see training on SLM) (also applicable under synergies)
- Decrease of mineral fertilizer use (by decreasing subsidies)

Synergies

1. Implement agro-livestock integration (for example, integration of fish with rice)
2. Implement measures to use biological approaches to pest and disease management; Reduce pesticide use and increase integrated pest management (e.g. botanical extracts for pest management) (also applicable under diversity)

Diversity

3. Diversify production on farm levels, including
 - Promotional efforts towards greater diversity in cultivation and consumption of crops (for example promoting other grains such as millet, maize and fonio instead of focusing on rice only, but also the diversity within rice: high quality and broken rice to match the food preferences of the Senegalese consumer).
4. Employ measures that respect the contribution of farmers, particularly from marginalized groups, and support ways of increasing the base salary of farmers and farmworkers.

Resilience

5. Implement and invest in climate change adaptation (e.g. local seed use, moisture management, research, restore habitats⁸ etc.). this includes for example:
6. Enhance the provisioning of ecosystem services while ensuring the social foundation for inclusive and sustainable development by enabling the implementation of sustainable land management supporting specifically small-scale production, processing and storage in a holistic way

This includes for example:

- Training, awareness raising, research but also access to equipment and credit, investment in small scale mills and community storage options, as well as support of marketing of AE products,

⁸ We use investments in adaptation for agriculture in a rather broad sense that include covering of adaptation cost for agriculture, water supply and natural ecosystems (UNFCCC 2007), respectively agriculture, extreme weather events and water supply / flood protection (UNEP 2014a). Based on the mentioned adaptation cost literature these adaptation investment needs sum up to around 33-42% of total adaptation investment needs.

- Support financial organizations to extend credit and micro-credit to provide preferential terms to producers or traders of agroecological products only, and other producers or traders otherwise contributing to resilience.

Co-creation of knowledge

7. Dissemination of knowledge and technology without state involvement (e.g. farmer to farmer propagation, dissemination of best practices, support the development and the official recognition of knowledge provided by the agroecological farms etc.)
8. Support farmers institutions and community-based cooperatives improving access to training, markets, inputs, capital, information, research, storage and processing options on a community level as well as the organization of marketing

This includes for example:

- Increase farmer training of integrated and agroecological crop management options (including systems of rice intensification in both lowland and upland rice), and include Agroecology in Senegal's national agricultural and education policies so, that academic training and the ongoing training of agricultural extension agents includes agroecology and they will be able to support farmers with the needed skills
 - Participatory research; Support the development and the official recognition of knowledge provided by the agroecological farms; Support research on scaling up agroecology, identifying needs by producers as barriers to scaling up, working with research institutions, conducting participatory research including producers, capitalizing on results, and to popularize them
 - Document, capitalize and share traditional knowledge among producers, support agroecological community management and more exchanges between agro-ecological producers in Senegal and those in countries like Burkina Faso and Benin.
9. Increase public awareness of the potential for agroecological practices to protect the environment through the rational management of water and regeneration of soils

Responsible Governance

10. Prevent the depletion of natural resources through land and natural resource governance, including reforestation to sustain rice watersheds
11. Develop and apply land management policies, particularly on the part of local government, that recognizes legal land ownership by women and youth, and explicitly allocates land for

agroecology, including registration of land designated for agroecology with market values, so that land holders have access to credit

12. Empower people, especially women and young people at household, community levels and beyond by building knowledge, through collective action and creating opportunities for commercialization (e.g. by promoting their participation in producer groups)

Circular Economy

13. Support production and subsidize the provision of small tillers for use in traditional/small-scale rice fields
14. Support for smaller and medium sized decentralized mills and storage facilities managed by the communities (providing benefits, such as capacity for milling by-products to be allocated to other uses, such as animal feed, field fertilizers, breweries or other sectors, reduction of transportation costs, higher prices for producers, lower prices for consumers, greater market efficiency and availability at the community markets)

(It is noted that this intervention is to some degree inspired by policy in Rwanda, focusing on medium sized mills and organizing business models around these mills. Such value chain developments may be key to the success of this intervention) (Diagne, pers. comm.)

15. Reconnect producers and consumers by strengthening short food circuits and local markets, including small scale production and processing (see culture and food traditions)
16. Encourage the procurement by public services of agroecological rice (Hospitals, schools, armed forces, prisons, etc.)

Culture and food traditions

17. Increase the potential of territories to sustain their peoples by reconnecting food habits and culture as well as food production and food consumption (e.g. ensure that rice production matches the food preferences of consumer and promote the cultural value of rice in Senegal)

Human and social values

18. Job creation through knowledge and labor intensive agroecological production and the formalization of the sector (see culture and food traditions)

19. Develop and support community seed banks at the local level, including research, inventories, and awareness raising and small-scale seed enterprises

6. System dynamics model and scenario definition

In line with the aims of the “The Economics of Ecosystems and Biodiversity for Agriculture and Food” (TEEBAgriFood) initiative, the narrative descriptions of the rice food value chain in Senegal in the previous section reveal interdependencies between human (economic and social) systems, agriculture and food systems, and biodiversity and ecosystems. Acknowledging that agriculture and the way agricultural production is performed affects all areas of development and itself is affected by those areas, this section provides the results of an integrated scenario analysis using a comprehensive simulation model.

In order to elaborate this analysis, the set of convergent policies identified by stakeholders and summarized in the section above is simulated with the Senegalese Threshold21-iSDG (T21-iSDG) simulation model. The model addresses the challenge of policy impact assessment in the multi-disciplinary, interconnected and complex nature of development. The fact that policies in one sector have an effect on several other sectors and indicators, but not necessarily in a linear way, highlight the need for integrated planning across sectors to develop coherent policies (O’Connor et al. 2016). The 2030 Development Agenda with the 17 SDGs emphasizes this need. A survey of existing modeling tools for integrated assessment (UN 2015) indicates the inability of the best-known global modeling frameworks to provide a comprehensive perspective on the SDGs; to our knowledge the T21-iSDG model is the only scenario tool for national planning addressing the 17 Goals (OECD 2016). By integrating the social, economic and environmental dimensions of sustainable development into one framework, the T21-iSDG model enables broad, cross-sector, long-term analyses of alternative policies for improving development. Hence, the fundamental advantage of the model is that it integrates these different dimensions of development and is consequently able to represent the complex net of interlinkages, side-effects and feedbacks. However, to be able to do that, the details within each dimension and sector that are integrated in the model have been reduced. That means that the model provides the framework for assessing, with a macro perspective, the overall impact across sectors and spheres, while the

detailed definition and design for example of the proposed policies is a task of the agricultural experts as addressed in the previous section.

It should be noted that Section 6.2 below gives a very high-level model presentation with indication about where to find further information (for the whole model especially the "T21 iSDG model documentation" [MI 2016] and for the agricultural sector the report "T21-Senegal: Agriculture, Food and Nutrition, and Rural Poverty Scenarios" [MI 2014]). A detailed description of the model, the structure of the sectors and the interlinkages can be found in the Threshold 21 (T21) iSDG Model documentation (MI 2016).

Using the simulation results of the model, we assess the impact of policy changes on a vast amount of development indicators. For this study, we present a selection of those indicators that represent areas of each of the four capital dimensions (natural, human, social, and produced), as recognized within the TEEB AgFood framework and that are used at the same time for the assessment of the Sustainable Development Goals (SDGs), considering the importance of these SDGs that should guide the development efforts of the world at least over the next decade.

We present and compare the results for the selected indicators under two different scenarios. In the *Business As Usual* (BAU) scenario we assume that current policies are continued into the future; while in the *Agroecology* (AE) scenario we mapped the policy recommendations made by stakeholders against the Ten Elements of Agroecology, identified by FAO adopted by member countries in 2019 (FAO 2018a 2019). We found strong resonance between the policy recommendations made here and the Ten Elements and have used them as an overall structure for comparison between current status and a possible future, with the input from stakeholders defining explicit measures within each element. In sum, a comparison is made between:

- Conventional agriculture scenario / BAU (business-as-usual scenario) assuming no major changes in external conditions and a continuation of current government policies.
- Agroecological / sustainable agriculture scenario assuming the application of the policy responses identified above, within the structure of FAO's Ten Elements Agroecology in the agriculture of Senegal.

Simulating the model allows us to assess the impact of the two scenarios, and to identify the individual contributions of each policy as well as synergies emerging from policy interactions. To ensure that we assess the mid-term impact, we present the results for 2050. Our explorative scenarios are not to be taken as precise forecasts – which are not feasible over the time horizon we consider – nor are they meant to be final. They have been designed and analyzed with the purpose of informing a comprehensive policy process by facilitating the identification of effects,

impact, challenges and coherent strategies for improving development. Figure 8 visualizes the approach used in this chapter in a schematic way.

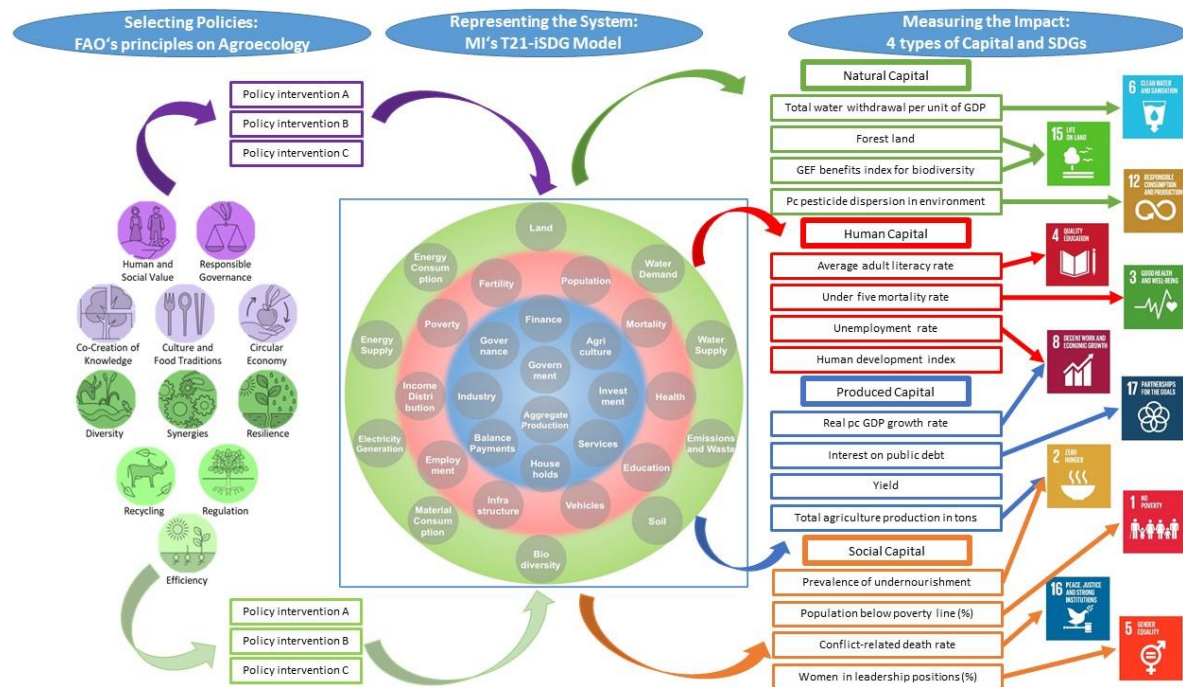


Figure 8. Schematic visualization of the approach used for the analysis

As the graphic indicates, the policy responses identified by stakeholders in the section above have been grouped within the ten agroecological principles by FAO, to clarify differences between these interventions and “business as usual”, in the two comparative scenarios. We simulate these scenarios using the T21-iSDG model that represents the system with all the relevant interactions, so that the changes diffuse along the causal relations, feedbacks etc. and affect the areas of interest, which are the natural, produced, human and social capitals which can be linked to the 17 SDGs of the current development agenda. To measure these changes, we identified indicators for the four types of capital that are also used for measuring the SDG.

Hence, section 6.1 outlines the methodology used to analyze the two scenarios and includes a description of the T21-iSDG simulation model, the scenarios, and the key indicators used to assess performance. In section 6.2 we analyze simulation results. In section 6.3 we summarize and discuss the findings, before drawing our conclusions.

6.1. Scenario description and methodology

To answer our central question – the assessment of the impact of the agroecological rice interventions on human livelihoods, specifically on the four dimensions of capital – we analyze the two scenarios, the Business As Usual (BAU) and Agroecology (AE) scenarios.

Table 4 presents the policies and assumptions characterizing each scenario. Based on the insights of the interviews / the interventions identified in this report, a key set of policy interventions – structured around FAO’s Ten Elements of Agroecology - have been identified that were translated into actions and assumption in the model. However, since agroecology constitutes a holistic approach, where principles and interventions are interlinked, the table also indicates that several interventions can be assigned to various elements. The two columns on the right-hand side of 4 indicate the level of implementation in the two scenarios. The BAU column presents the current state of practice (that would be continued into the future) and the value is estimated using the last historical data point available or estimates from local experts⁹. The AE column shows the absolute value (not the changes compared to BAU) that is assumed to be implemented in 2020 (unless otherwise indicated). To maintain the internal logic of the scenarios, the scenarios assume the application of the production approaches not only for rice but also for all crops. It should be noted that the interventions are applied to all crops, but the impact can vary. In the model, we distinguish between 10 different crops (cereals, fruits, fibre crops, pulses, tubers, treenuts, vegetables, sugar crops, oilcrops, other crops) [MI 2014]. The partly differing impact, especially on water nutrients etc. is based on the historical observed behaviour of the last 25 years). We apply the interventions to all crops, since it is also more realistic, that government and farmers do not only change for one crop only, but for the whole agricultural sector. This means that the impact of the change for one crops is then only a part of the whole impact (as is estimated using proxies as per Table 7).

The proposed AE scenario in this study is characterized by a change of farming techniques (e.g. implementation of agroecological approaches) and the inherent social and economic consequences (e.g. food autonomy or job creation), that is supported by a shift of government expenditure. These changes in government expenditure are primarily in the realm of investment in irrigation, with a reduction of overall expenditure, while investing in higher efficiency, targeting smallholders towards key aspects of agroecology (e.g. sustainable land management etc.). In the

⁹ In the continuous process of customization of the model to Senegal in collaboration with the Senegalese government, these data are derived by using several sources and adjustment calculations to ensure coherency and consistency between them. Data was collected from national and local sources (such as Agence Nationale de la Statistique et de la Démographie [ANSD], Ministry of Agriculture, Direction de l'Analyse, de la Prevision et des Statistiques Agricoles [DAPSA], and Consortium pour la Recherche Économique et Sociale [CRES]) as well as international sources and databases, including the World Bank (World Development Indicators [WDI]), the United Nations (UN), the Food and Agriculture Organization of United Nations (FAO) including FAOSTAT and AQUASTAT, the International Monetary Fund (IMF), Energy Information Administration (EIA), and the United Nations Development Program (UNDP) (see also Millennium Institute 2014). The calculation of the distribution within the agricultural budget is mainly based on data provided by the Senegalese Government (Gouvernement de la République du Sénégal 2013a, 2013b, 2011).

BAU scenario (continuation of the current status), government makes a considerable investment in water management through enlarging the area equipped for irrigation, but not specifically in the increase of efficiency. In the AE scenario, we reduce investment in irrigation but focus with this investment the increase of efficiency. Hence, in AE scenario, we reduce expenditure, and the area equipped with irrigation is not increased as fast as in BAU, but efficiency increases faster. Such a change in investment results in reducing total government expenditure of around 0.6% of GDP (the policies of this list sum up to 2.69% of GDP in the BAU and 2.07% in the AE scenario), thus alleviating national indebtedness. (It should be noted that the estimated expenditure for BAU is based on data from the government reflecting high investments in the recent years for irrigation, and subsidies for fertilizer, pesticides and seeds.

Table 4 – Policy assumptions for the ten agroecological principles and their evolution in the Agroecology (AE) scenario compared to the Business-As-Usual (BAU) scenario¹⁰

FAO principles on Agroecology	Intervention	Policy / Assumption in T21-iSDG	BAU	Agro-ecology ¹¹
			Value of assumption ¹²	
Efficiency	Increase resource-use efficiency (e.g. replace inefficient with efficient irrigation equipment) This includes for example:	Expenditure for agriculture water efficiency and irrigation equipment (% of GDP) ¹³	1.85%	0.15%
	- Decrease of expenditure for (inefficient) irrigation equipment frees money for other purposes¹⁴ - Increase of expenditure for efficient irrigation equipment - Support small-scale irrigation equipment			
	- Support the construction of dikes and bunds in the lowlands to retain / manage the "surplus" rainwater and control salt			
	Reduce mineral fertilizer and increase natural fertilizer use (e.g. soil fertility enhancement)	Natural fertilizer use per ha harvested area (ton/ha/year)	0.03	0.63
Recycling	This includes for example:	Expenditure for natural fertilizer subsidies (% of GDP) ¹⁵	0%	0.13
		Expenditure for mineral fertilizer subsidies (% of GDP)	0.135%	0.005%

¹⁰ The parameters presented in the final two columns have been the result of extensive data searches and discussions between the modeler and the agricultural experts involved in this study. Explanation of policy variables is included in an annexed table (Annex 1). Data has been documented in a separate excel spreadsheet. This table includes all the interventions that are simulated and presents the expenditure that is assumed to be used in the two scenarios for the interventions (for example in BAU 1.85% of GDP for irrigation equipment, and in AE 0.15% of GDP for increasing ag water efficiency)

¹¹ The column indicates the level that is adopted in 2020 and persists until 2050, if not indicated differently.

¹² The labelling for these two columns is to be found in the policy/assumption column (e.g., "Expenditure for agriculture water efficiency and irrigation (% of GDP) for the first row following and so on).

¹³ Calculated through simulating the irrigation coverage (as ha of irrigated land taking into account construction and maintenance cost) and use for the different scenarios the different assumptions about the investment by the government (as % of GDP)

¹⁴ In the AE scenario we invest less money for enlarging the area of irrigation (instead of 1.85% in the BAU only 0.15% in AE, but the money that we invest (the 0.15%), we invest in increasing the efficiency)

¹⁵ Based on the assumption that the money spent in BAU for mineral fertilizer subsidies is spent in AE for natural fertilizer subsidies and that this leads to the indicated changes in natural fertilizer use (from 0.03 ton/ha/year in BAU to 0.63 ton/ha/year in AE)

FAO principles on Agroecology	Intervention	Policy / Assumption in T21-iSDG	BAU	Agro-ecology ¹¹
Synergies	- Increase of natural fertilizer use (by increasing subsidies, Encourage producers to produce, collect and market their own natural fertilizers supporting the implementation of alternative approaches (such as the use of organic fertilizer derived from the non-sewerage sanitation system along the fecal sludge management treatment facilities) and training on its production, see training on sustainable land management) - Decrease of mineral fertilizer use (by decreasing subsidies)			
Diversity	Diversify production and increase income	Base salary for farmers ¹⁶	75%	82%
Resilience	Reduce pesticide use and increase integrated pest management (e.g. botanical extracts for pest management) This includes for example:	% of harvested land using biological pest control	0%	0.1%
		Expenditure for chemical pesticide subsidies (% of GDP)	0.135	0.013
	- Increase of biological pest control and integrated pest management (by providing training and extension services, see training on sustainable land management) - Decrease of chemical pesticide use (by decreasing subsidies)			
	Implement agro-livestock integration, (both integration of fish with rice, and rice crop-livestock integration)	% of arable land used for agro-livestock	0%	33%
		% of pasture land used for agro-livestock	0%	7%
	Implement and invest in climate change adaptation/mitigation (e.g., improved varieties tolerant to stresses, AWD techniques, moisture management, research, restore habitats ¹⁷ etc.)	Expenditure for climate change adaptation in agriculture (% of GDP)	0.01%	2050: 0.12%
	Enhance the provisioning of ecosystem services while ensuring the social foundation for inclusive and sustainable development by enabling the implementation of sustainable land management supporting specifically small-scale production, processing and storage in a holistic way This includes for example:	Expenditure for sustainable land management (% of GDP)	0.013%	0.85
Circular and Solidarity Economy	- Training, awareness raising, research but also access to equipment and credit, investment in small and medium sized mills and community storage options, as well as support of marketing of AE products, more specifically:			
	- Increase farmer training of integrated and agroecological crop management options (including systems of rice intensification in both lowland and upland rice), and include Agroecology in Senegal's national agricultural and education policies so, that academic training and the ongoing training of agricultural extension agents includes agroecology and they will be able to support farmers with the needed skills			

¹⁶ The % indicates the minimum salary relative to average salary.

¹⁷ We use investments in adaptation for agriculture in a rather broad sense that include covering of adaptation cost for agriculture, water supply and natural ecosystems (UNFCCC 2007), respectively agriculture, extreme weather events and water supply / flood protection (UNEP 2014a). Based on the mentioned adaptation cost literature these adaptation investment needs sum up to around 33-42% of total adaptation investment needs.

FAO principles on Agroecology	Intervention	Policy / Assumption in T21-iSDG	BAU	Agro-ecology ¹¹
	- Participatory research; Support the development and the official recognition of knowledge provided by the agroecological farms; Support research on scaling up agroecology, identifying needs by producers as barriers to scaling up, working with research institutions, conducting participatory research including producers, capitalizing on results, and to popularize them			
	- Support production and subsidize the provision of small tillers for use in traditional/small-scale rice fields			
	- Support for smaller and medium sized decentralized mills and storage facilities managed by the communities (providing benefits, such as capacity for milling by-products to be allocated to other uses, such as animal feed, field fertilizers, breweries or other sectors, reduction of transportation costs, higher prices for producers, lower prices for consumers, greater market efficiency and availability at the community markets)			
	- Increase public awareness of the potential for agroecological practices to protect the environment through the rational management of water and regeneration of soils			
	- Promotional efforts towards greater diversity in cultivation and consumption of crops (for example promoting other grains such as millet, maize and fonio instead of focusing on rice only, but also the diversity within rice: high quality and broken rice to match the food preferences of the Senegalese consumer).			
	- Support financial organizations to extend credit and micro-credit to provide preferential terms to producers or traders of agroecological products only, and other producers or traders otherwise contributing to resilience.			
	- Encourage the procurement by public services of agroecological rice (Hospitals, schools, armed forces, prisons, etc.)			
	Reconnect producers and consumers by strengthening short food circuits and local markets, including small scale production and processing (see culture and food traditions)	Waste share reduction due to small scale mills	0%	20%
		Processing share increase due to small scale mills	0%	20%
	Support farmers institutions and community-based cooperatives improving access to training, markets, inputs, capital, information, research, storage and processing options on a community level as well as the organization of marketing This includes for example:	Expenditure for farmers organization (% of GDP)	0.556%	0.656%
Responsible Governance	- Document, capitalize and share traditional knowledge among producers, support agroecological community management and more exchanges between agro-ecological producers in Senegal and those in countries like Burkina Faso and Benin. The activities are strongly connected to the policies listed under sustainable land management)			
	Prevent the depletion of natural resources through land and natural resource governance	Expenditure for additional reforestation (% of GDP)	0%	0.15%
	Develop and apply land management policies, particularly on the part of local government, that recognizes legal land ownership by women and youth, and explicitly allocates land for agroecology, including registration of land designated	Land tenure quality ¹⁸	0.69	0.9

¹⁸ We use the indicator “Land Rights and Access Indicator” provided by Millennium Challenge Cooperation (2019) using data from International Fund for Agricultural Development (IFAD) and International Finance Cooperation (IFC) that evaluates whether and to what extent governments are investing in secure land tenure.

FAO principles on Agroecology	Intervention	Policy / Assumption in T21-iSDG	BAU	Agro-ecology ¹¹
	for agroecology with market values, so that land holders have access to credit			
Co-Creation and Sharing of Knowledge	Dissemination of technology without state involvement (e.g. farmer to farmer propagation, dissemination of best practices, support the development and the official recognition of knowledge provided by the agroecological farms etc.)	Average knowledge dissemination about sustainable agriculture by organized farmers (person/farmer/year)	0	0.4
Culture and Food Traditions	Increase the potential of territories to sustain their peoples by reconnecting food habits and culture as well as food production and food consumption (e.g. ensure that rice production matches the food preferences of consumer and promote the cultural value of rice in Senegal)	Proportion of population below food poverty line with access to non-marketed food	55%	57%
Human and Social Value	Job creation through knowledge and labor intensive agroecological production and the formalization of the sector (see culture and food traditions) This includes for example:	Proportion of adult population with partial employment	40%	50%
	Develop and support community seed banks at the local level, including research, inventories, and awareness raising and small-scale seed enterprises			
	Empower people, especially women and young people at household, community levels and beyond by building knowledge, through collective action and creating opportunities for commercialization (e.g. by promoting their participation in producer groups)	Women's economic opportunity index ¹⁹	0.387	2030: 0.595
		Report of the gender gap in employment in relation to gender gap in education ²⁰	0.22	2030: 0.15
		Education gender bias (secondary, tertiary)	70%, 60%	2050: 85%, 70%
		Voice and Accountability (scale -2.5 to 2.5) ²¹	0.253	2030: 0.742

6.2. T21-iSDG model: representation of the system

The T21-iSDG model (MI 2016) was constructed starting from the well-vetted, time tested and validated Threshold²¹ (T21) model that has evolved over the past 30 years through research and application by the Millennium Institute (Barney 2002; Pedercini et al. 2017). The model for Senegal was customized for the first time in 2009 in collaboration with the Government of Senegal (Gouvernement de la République du Sénégal 2014). Since then, the model has been

¹⁹ We use the indicator “Women’s Economic Opportunity” (WEO) Index created by the Economist Intelligence Unit (2012) to measure progress in the economic advancement of women. It draws on data from a wide range of international organizations, including the UN, the IMF, the Organization for Economic Co-operation and Development (OECD), the World Health Organization (WHO), the FAO, and many others.

²⁰ A value less than one means that the disparities in employment rates are lower than in completions of education; and a value greater than one vice versa.

²¹ We use the indicator “Voice and Accountability” that captures perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media. It is one of the six broad dimensions that are used for the Worldwide Governance Indicators (WGI) provided by the World Bank (Kaufmann et al 2017).

continuously updated and used²², as well as significantly enlarged and improved, for example in the areas of agriculture and SDG assessment²³.

The T21-iSDG model is a System Dynamics based model for comprehensive and participatory development planning. The model integrates economic, social, and environmental factors, and represents the important elements of complexity – feedback relationships, non-linearity and time delays – that are fundamental for effectively addressing development issues. The model can be customized to country-specific conditions, and simulates the medium- and long-term consequences of alternative policies at the national level. Hence, it allows for easy comparison to reference scenarios, so to serve as a participatory tool in consensus building and policy discussions (Pedercini 2005; Pedercini and Barney 2010; UNEP 2014b). Figure 9 provides a conceptual overview of the T21-iSDG model structure, which includes 30 interacting sectors.

²² Several studies and reports elaborated within the intensive collaboration with the directorate of planning in the Directorate General for Planning and Economic Policy (Ministry of Economy, Finance and Plan in Senegal) can be found at the homepage (www.plandev.sn/publications.html), such as the analysis of the progress towards the SDGs (Direction de la Planification et al 2017).

²³ These improvements have been facilitated amongst others by the “Changing Course in Global Agriculture” (CCGA) project that is a joint project of Millennium Institute and Biovision Foundation, and implemented in Senegal in collaboration with the Ministry of Agriculture and the Ministry of Economy, Finance and Plan, see <http://www.biovision.ch/en/projects/international/ccga-changing-course-in-global-agriculture/>.



Figure 9 - Conceptual overview of T21-iSDG Sectors

Economic activities (blue circle) take place within society (red circle), from which social resources are drawn to generate economic value, and within the broader natural environment (green circle), which contributes sources and sinks of natural resources, emissions, and waste. All sectors interact dynamically; a change in one sector leads to impacts over time on all other sectors. This feedback-rich structure endogenously determines the behavior of the model, as economic, social, and environmental indicators respond to the accumulation or decay of resources over time. For detailed information about the model structure and individual sectors, please refer to MI (2016).²⁴

In addition to these key sectors, the T21-iSDG-Senegal is enriched by 19 special sectors that were developed and specifically included to better represent development dynamics particularly interesting for long-term planning in Senegal. The table below lists the special sectors of the T21-iSDG-Senegal. Most special sectors are suitable for analyzing agricultural and rural development aspects and its social and environmental impacts. A simplified summary of this structure

²⁴ For further information, see also <https://www.millennium-institute.org/isdg>.

concerning agriculture is presented Figure 3 of this report. For detailed information about this part of the model, please refer to MI (2014).

Table 5 - T21-iSDG-Senegal: Special Sectors

Society	Economy	Environment
S1. Urbanization	S6. Ag Social Factors	S20. Ecological Footprint
S2. Migration	S7. Ag Economic Resources	S22. Land Degradation
S3. HIV/AIDS	S8. Ag Insurance	
S4. Health Resources	S9. Ag Seeds	
S5. Nutrition and Food Security	S10. Ag Accounts	
	S11. Ag Inputs and Emissions	
	S12. Livestock	
	S13. Fishery	
	S14. Forestry	
	S15. Mining	
	S16. Telecommunications	
	S17. Decentralization	

Policy Implementation Mechanism

The T21-iSDG model for Senegal explicitly represents the causal structure that links policy interventions to eventual impacts on key performance indicators. Following a results chain approach (UNDP, 2009), budgetary interventions in the model are introduced in the form of additional investment allocated to specific activities. Over time, those activities are implemented and produce specific outputs and outcomes, which subsequently generate broader impacts on key performance indicators. For instance, increasing investment for training of farmers in sustainable land management causes an increase in the number of farmers being enrolled in training programs, gradually building capacity in that area. Over time, that leads to more sustainable land management practices, and to other positive impacts on a variety of socio-economic indicators.

Validation

The model underwent an intensive validation process involving structural and behavioral validation tests (Barlas 1996). Structural validation involved direct verification of structural assumptions and parameters. Behavioral validation involved the assessment of the model's ability to replicate the historical behavior of the main indicators for the period from 1990 until

now²⁵. The residual error from comparison with historical data is analyzed and broken down by component using Theil's statistics (Sterman 1984) to verify the model's ability to capture medium and longer-term trend in data. For this assessment a database of more than 1000 variables relating to all spheres and sectors was elaborated using national and international sources⁹ and adjusting them if necessary to ensure coherency and consistency between them. Nevertheless, the model's results inherently embed a high degree of uncertainty, due to the long time horizon of the simulation, and the large number of indirectly estimated parameters. Over such long time horizon, in fact, a large variety of unforeseeable changes can take place, and a large number of parameters might take on different values than those observed in the past, driven by elements outside the scope of the model. Consequently, simulation results are not to be taken as exact forecasts (no model can accurately forecast long-term development trends) but as reasonable and coherent projections, based on a set of clear and well-grounded assumptions.

6.2. Key indicators: measurement of the impact

We first present the impact of the interventions on key indicators and explain then (in Figure 9) how these indicators are connected to the interventions in rice / agriculture.

To assess the more direct effect of the scenarios described above, we first present two key production indicators in the cereal sector (cereal yield and cereal production in tons). In a second step, we evaluate the impact of the policy changes on the whole system by analyzing the performance of a sub-set of indicators listed in Table 6. They were selected based on the following criteria: coverage of four types of capital, interesting and relevant results, and relevance for the SDGs. We included the SDG relevance as criteria since they are the goals for the current overall development agenda and also because basing our choice on the results of the extensive discussions about appropriate indicators to measure the achievement of these goals increases our confidence of a meaningful selection. Only four indicators per dimension of capital have been selected from a longer list to increase readability and clarity of understanding of this report.

Table 6 – Selected key indicators to measure the impact of the scenarios on the four types of capital

²⁵ The data set used for calibration and corresponding simulation results for the BAU scenario are available upon request.

Type of Capital	Indicator	Source for historical data	SDG relevance (No. of indicator ²⁶)
Natural Capital	Total water withdrawal per unit of GDP ²⁷	AquaStat ²⁸ , WDI ²⁹	SDG 6 (6.4.1)
	Forest land ³⁰	FAOSTAT ³¹	SDG 15 (15.1.1)
	GEF benefits index for biodiversity	WDI	SDG 15 (15.5.1)
	Per capita pesticide dispersion in environment ³²	FAOSTAT ³³ , ANSD, WPP	SDG 12 (12.4.2)
Human Capital	Completion rate secondary school (age 20-24)	Barro, Lee (2013)	SDG 4 (4.1.1)
	Under five mortality	WPP ³⁴	SDG 3 (3.2.1)
	Total crops employment	ANSD, DP	
	Unemployment rate	WDI, ANSD, WPP ³⁵	SDG 8 (8.5.2)
Produced and Financial Capital	Real per capita GDP ³⁶	WDI, ANSD, WPP	SDG 8 (8.1.1) ³⁷
	Interest on public debt as share of export	WDI, DP	SDG 17 (17.4.1)
	Cereal import dependency ratio	FAOSTAT	
	Total cereal production in tons	FAOSTAT, ANSD/MAER	SDG 2 (2.3.1)
Social Capital	Prevalence of undernourishment	WDI	SDG 2 (2.1.1)
	Population below poverty line	WDI	SDG 1 (1.1.1)
	Conflict-related death rate	WHO (2019)	SDG 16 (16.1.1)

²⁶ Number of indicators in “Final list of proposed Sustainable Development Goal Indicators” (UN 2016).

²⁷ This metric is based on the identification of indicators by the UN for measuring the SDGs (UN 2016)

²⁸ FAO (2019a)

²⁹ World Bank (2019)

³⁰ To understand how this is captured in the model: for example in 2050, more than 35% of yearly deforestation is reduced in AE scenario compared to BAU in the, while reforestation mainly only exists in AE scenario since there is no significant investment in BAU for that, while the AE scenario includes investment in reforestation.

³¹ FAO (2019b)

³² As per results with the application of SRI, a 100% reduction in pesticides had been shown to have no impact on productivity; this is clearly an assumption, but backed up by documentation in Senegal and beyond. Thus the AE scenario models a 100% reduction, whereas BAU continues current trends.

³³ Using total pesticide use (FAOSTAT) we apply a pesticide dispersion rate of 35% to calculate pesticide dispersion and divide it by total population (ANSD, WPP) to derive the per capita amount.

³⁴ UN (2017)

³⁵ We calculate unemployment rate by dividing total employment (WDI) by labor force using the labor participation rate (WDI) and total population (ANSD, WPP).

³⁶ In the model, growth rate has no effect on productivity but is rather calculated using the simulated production (that is affected by capital, employment and total factor productivity). However, of course such an increase in production leads to higher household and government revenue and allows for example more investment (see positive feedback loop that has been previously).

³⁷ Although it is proposed to use as indicator for measuring the SDG the annual growth rate of real per capita GDP, we analyze the amount of real per capita GDP since the growth rate mainly gives an indication about the change with regard to the last year while our interest in this long-term analysis concerns the long-term development.

	Women in leadership position	WDI	SDG 5 (5.5.1)
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7. Results of scenario simulation: Impact on four types of capital

In this section we present the results of the scenarios described above for the selected key indicators. We first describe the direct effect on cereal yield and production and explain the reasons for change, before providing an overview of the impact on the four dimensions of capital in 2050. This is followed by an analyses in detail of the results for each of the selected indicators pointing also to the causal relations. Finally, we summarize the identified causalities in a causal diagram.

Direct effect on cereal yield and cereal production: The more direct effect of the changes of the simulated policies is illustrated in Figure 9 (below) presenting for two key production indicators in the cereal sector the data for 2017 (blue column) and the simulated results for 2030 and 2050 for the BAU scenario (red column) and AE scenario (green column).

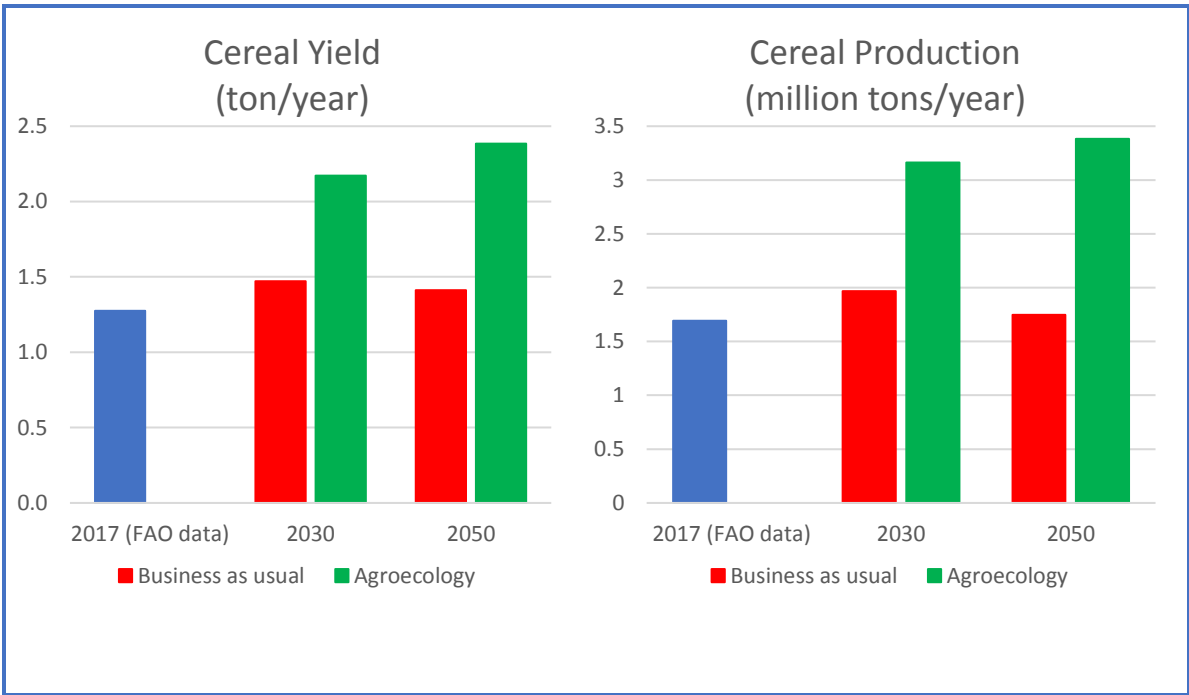


Figure 10 - Cereal yield & production in 2017, 2030 and 2050 (FAO data, simulation results for BAU and AE scenario)

Systemic effects: First of all, the comparison reveals that the proposed policy changes generate a significant improvement in the AE scenario compared to the BAU scenario, increasing yield by

around 48% in 2030 and around 69% in 2050, and cereal³⁸ production by around 61% in 2030 and around 93%, in other words nearly doubling production, in 2050. One important factor is the strong increase in public expenditure for sustainable land management that includes investment for training, awareness raising, and research but also for access to equipment and credit, in small scale mills and community storage options (decreasing for example the waste share), as well as support of marketing of AE products³⁹. These options for increased public investment are made possible, in part, as the government turns from investing, and then servicing, large debts for large scale agribusiness schemes, to investing in smaller scale projects that deliver water efficiency infrastructure to rice growing communities; the amount saved on debt payments frees up resources for such investments⁴⁰. These policies in combination with higher expenditure for farmers' organization, knowledge dissemination from farmer to farmer, increased use of natural fertilizer and biological pest control as well as improvements in land tenure lead to higher productivity, additional employment and more sustainable food production. In addition, harvested area is increased by around 14% in 2050 in the AE scenario compared to the BAU scenario, one of the main reasons being a reduction of land degradation and land abandonment caused by the increase of land that is sustainably managed and the increase of jobs. It is assumed that due to an increase of area sustainably managed (for example driven by training), land degradation decreases, increasing harvested area, with no increase in deforestation. Agriculture production is further increased by agro-livestock integration and investment in agricultural adaptation, reducing the negative impact of climate change on agricultural productivity especially in the long term.

Secondly, the results point to the fact that the improvement increases over time, both for the results in the AE scenario comparing today with 2030 and 2050, and for the difference in performance between the two scenarios comparing 2030 and 2050. The policies in the AE scenario activate some positive feedback loops that continuously reinforce the original improvement. One of these important feedback loops concerns investment: the increase of agriculture production leads to an increase of household revenue that also allows an increase of investment in other sectors, leading to higher production there, contributing to a higher GDP, and allowing for more investment in the three sectors, reinforcing the growth of GDP⁴¹. Another key example refers to the importance of governmental services: the increased GDP also leads to

³⁸ As noted previously, cereals is simulated as one of ten crop categories in the existing model for Senegal and thus is an umbrella proxy for the impacts due to changes in rice production (see Table 7). Modelling specifically rice would not have been possible within the scope / resources of this study.

³⁹ In this exercise, the impact of the measures is based on expert knowledge / literature. We do not assume a certain stable increase of productivity of each measure but instead a reasonable change in the variable affected by the interventions. For example, training increases the 'harvested area sustainably managed' with its positive effects on soil nutrient balance.

⁴⁰ Amounts of these investments (expenditure as % of GDP) are described in Table 4.

⁴¹ The specific changes in public investment between the two scenarios are described in Table 4. All the changes described in this analysis are due to the combination of these described interventions. For private investment, for example, the combination of all policies lead to an increase of around 9% in the AE scenario compared to the BAU scenario in 2050.

higher government revenue enabling more government investment, for example in education, health, infrastructure, increasing productivity and consequently GDP. Hence, the AE scenario generates effects that diffuse to the whole system, improving even indicators that are rather indirectly linked to agriculture and this improvement grows over time due to the activated reinforcing feedback loops.

Third, the simulation results indicate an important insight concerning the trend of the production: while yield and production continue to increase in the AE scenario until 2050, the observed improvement in the BAU scenario in 2030 (compared to the current data of 2017) decreases until 2050. This is mainly caused by the negative effect of climate change on agriculture productivity decreasing yield by around 20% in 2050 in BAU scenario while the investment in climate change adaptation in agriculture in the AE scenario decreases the negative impact of climate change and mitigates this reduction. In addition, we observe a slight decreasing trend of harvested area starting around 2030 that is caused by both the decreasing return on investment in agriculture reducing demand for cultivating agriculture land, and land degradation and abandonment⁴². The policies implemented in the AE scenario reduce the decrease of harvested area by addressing both factors. For example, the increase of sustainable land management results in a decrease of land degradation and abandonment, and the joint implementation of several policies (see above and below) increase agriculture production to a higher degree than investment leading to higher return on investment.

Hence, while we encounter impeding and counteracting growth factors in the BAU scenario, we can alleviate those in the AE scenario so that the activated positive feedback loops increase the initiated improvement over time, pointing to the higher degree of sustainable growth in the AE scenario compared to the BAU scenario. Comparing the two scenarios, better long-term results are attained for the key indicators (Table 6) using even less public resources for agriculture (see Table 4) pointing to the fact that the proposed interventions of AE scenario are more effective than those in BAU scenario. For a better understanding, Figure 11 provides a visualization of the described causalities summarizing not only the causal relationships that we identified in this section but also those that are outlined when analyzing the impact.

⁴² Within the model, the relative return on investment is calculated that affects the agricultural land demand and consequently additional conversion to agriculture land. It should be noted that In both scenarios the relative return on investment (current ROI compared to first positive ROI, as production compared to capital) is decreasing for the agricultural sector. However, the decrease is smaller in the AE scenario than in the BAU scenario (because of higher production in the AE scenario).



Figure 11 - Causal diagram summarizing the main causal relations that explain the observed changes in the AE scenario compared to the BAU scenario

Example for interpretation: The simulation results indicate that in 2050, the cereal import dependency ratio is 21% lower in the AE scenario compared to the BAU scenario. Applying the share of rice to cereal production in tons, it is calculated that if only rice production is changed (implementing the AE principles only for rice) cereals import quantity reduces by 9% (compared to BAU scenario). (Figure 12).

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Table 7. Impact on key indicators in 2050 as change in the % in the Agroecological (AE) scenario compared to the Business as Usual (BAU) scenario

Type of Capital	Indicator	Total Change in Key Indicator in AE scenario compared to BAU scenario in 2050	Proportion of change attributable to rice sector	Change in Key Indicator due to changes in Rice Production
Natural Capital	Total water withdrawal per unit of GDP	-8%	0,141 ¹	-1%
	Forest land	25%	0,141 ¹	4%
	GEF benefits index for biodiversity	24%	0,141 ¹	3%
	Percent pesticide dispersion in environment	-100%	0,660 ²	-66%
Human Capital	Population (age 20-24) completed secondary school	11%	0,199 ³	2%
	Under five mortality	-9%	0,199 ³	-2%
	Total crops employment	10%	0,199 ³	2%
	Unemployment rate	-12%	0,199 ³	-2%
Produced Capital	Real percent GDP growth rate	98%	0,199 ³	20%
	Interest on public debt as share of export	-78%	0,199 ³	-15%
	Cereal import dependency ratio	-21%	0,422 ⁴	-9%
	Total cereal production in tons	93%	0,422 ⁴	39%
Social Capital	Prevalence of undernourishment	-40%	0,141 ¹	-6%
	Population below poverty line	-29%	0,199 ³	-6%
	Conflict-related death rate	-25%	0,199 ³	-5%
	Women in leadership position	14%	0,199 ³	3%

¹ Rice production / total crops production (in tons in 2017 based on FAO data)

² Total pesticide use for rice / Total pesticide use in 2001 (Data for rice from Sow et al., and FAOSTAT: 186 / 282 = 66%).

³ Production Value for rice / Production Value for total crops (Gross Production Value in constant 2004-2006 1000 I\$ for 2016)

⁴ Rice production / cereals production (fonio, maize, millet, rice, sorghum) (in tons in 2017 based on FAO data)

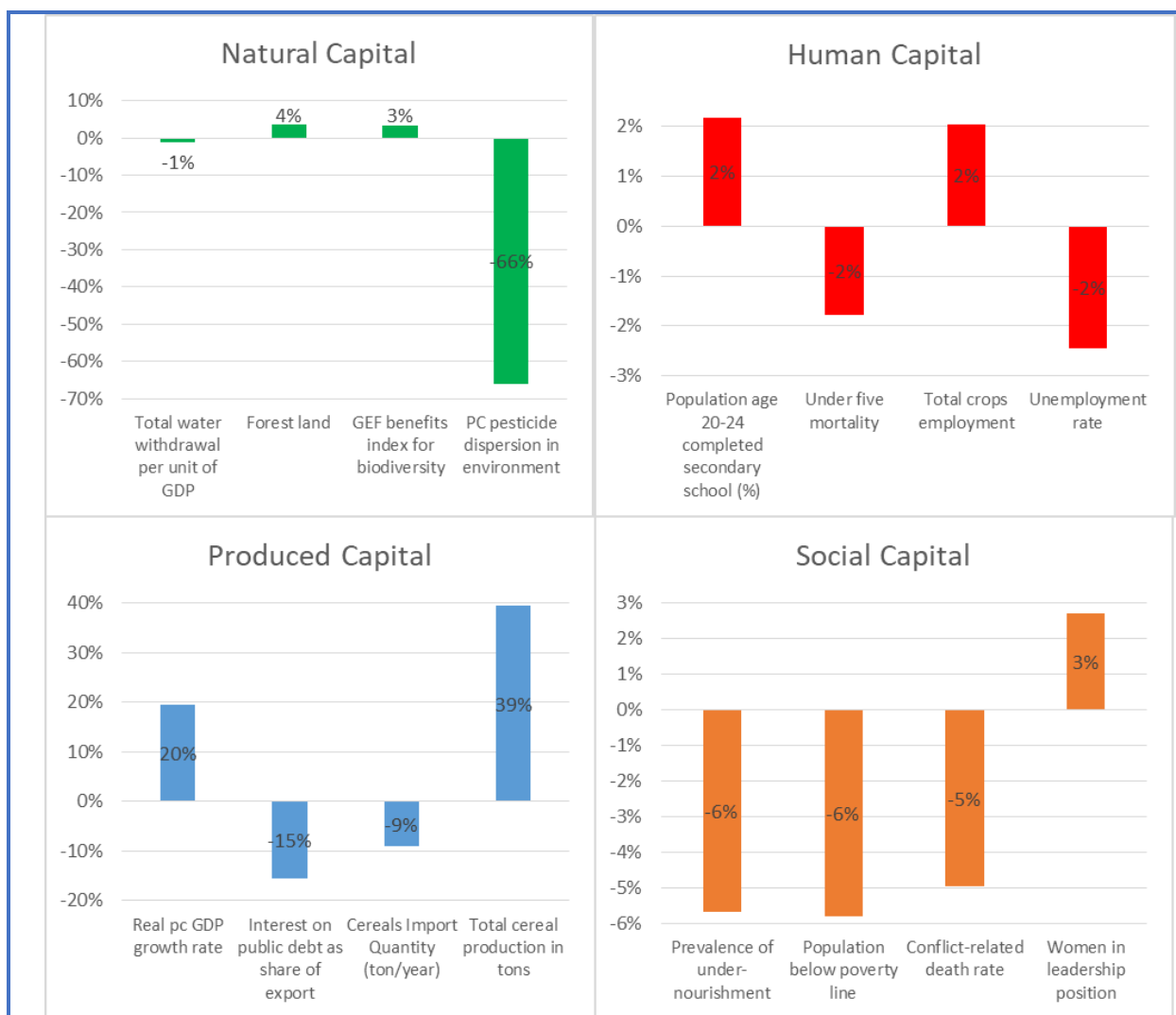


Figure 12. Impact of changes in rice production on key indicators in 2050 as change in the % in the Agroecological (AE) scenario compared to the Business as Usual (BAU) scenario.

8. Conclusions and limitations

Conclusions: Our analysis estimates the impact of different agroecological policies and their combinations on several relevant development indicators in Senegal, covering the four types of capital (natural, produced, human and social, see TEEB 2018) and several aspects of the SDGs. Further, our approach and framework help to create a better understanding of the interconnectedness of the rice system with its various sectors, indicators and causalities, thus facilitating the identification of synergies among interventions and impeding factors that can make policies less effective. In these ways, our analysis and the use of the T21-iSDG model contribute to the understanding of the interdependencies between human (economic and social) systems, agriculture and food systems, and biodiversity and ecosystems. Hence, it contributes to the TEEBAgriFood initiative providing additional quantitative evidence supporting some of the key findings of the TEEBAgriFood study (TEEB 2018) and providing an example of effective and coherent strategies to contribute to sustainable development, in the agricultural sector and beyond. Below is a summary of our findings, a discussion of limitations, and finally a set of recommendations for policy makers and practitioners.

- 1) ***The agri-food system is highly interlinked with other sectors:*** The results illustrate the interlinked nature of the system and reveal that the changes implemented in agriculture spread and diffuse through the whole system. Analyzing the reasons for changes, we identified a complex net of interactions and dependencies that we summarize in a causal diagram that visualizes the main relations (see section 3.4), and Figure 13 below. In Senegal, all the proposed policies contribute to the changes, while their impact on the different indicators varies. For example, one very important policy for the changes in cereal production (produced capital) is the government expenditure for sustainable land management combined with greater investment in the dissemination of knowledge among farmers, while the fundamental change in pesticide dispersion (natural and human capital) is mainly due to the strong reduction of subsidies for chemical fertilizer. An important contribution to the improvement of completion rate in secondary school (human capital) is generated by the empowerment of women (supporting gender equality in land tenure rights, employment and education), whereas other policies are especially relevant for the reduction of poverty (social capital), such as the job creation through knowledge and labor intensive agroecological production and the formalization of the sector in combination with the diversification of production improving income and its distribution.
- 2) ***AE interventions are highly effective:*** The implementation of the proposed policies generate a significant improvement of all selected indicators for the four dimensions of capital in the AE scenario compared to the BAU scenario, increasing for example yield for cereals on average by around 48% in 2030 and around 69% in 2050, respectively cereal production by around 61% in 2030 and around 93%, in other words nearly doubling production, in 2050 (Figure 10). However, as shown in Table 7, of course the scale of change in the indicators differs and ranges in 2050 from around 8% [total water withdrawal per unit of GDP] to 100% [percent pesticide dispersin in environment] absolute change when assuming that AE is

applied to all crops, and 1% to 66% absolute change for the same indicators when assuming AE is applied to rice only. Searching for reasons for the different intensity of change in the indicators from the BAU values, the simulation results suggest that the more indirect the relationship the lower the difference (in relative and not necessarily in absolute terms). This explains why we find the highest difference (assuming only changes in the rice sector) on average for the selected indicators of the natural capital with around 17% and produced capital with around 16%, while the mean change for the chosen indicators of social capital is around 5% and for human capital around 2% compared to the BAU scenario (although of course the selection of other indicators could change the mean values). In any case, the simulation results indicate remarkable changes for the more direct indicators such as pesticide dispersion in the environment that can be reduced by around 66% or cereal yield and production, as mentioned above, but also concerning more indirectly related indicators, such as the indicators for human capital that are improved by around 2% only by the changes in rice production.

To better comprehend the inner workings of the model, reference can be made to the causal loop diagram of Figure 13, which shows why adoption of AE causes changes in the indicators within the 4 forms of capital. The figure is not all encompassing but shows some of the key causal chains embodied in the simulation model. The indicators are shown in italics (the names of the indicators are shortened for space).

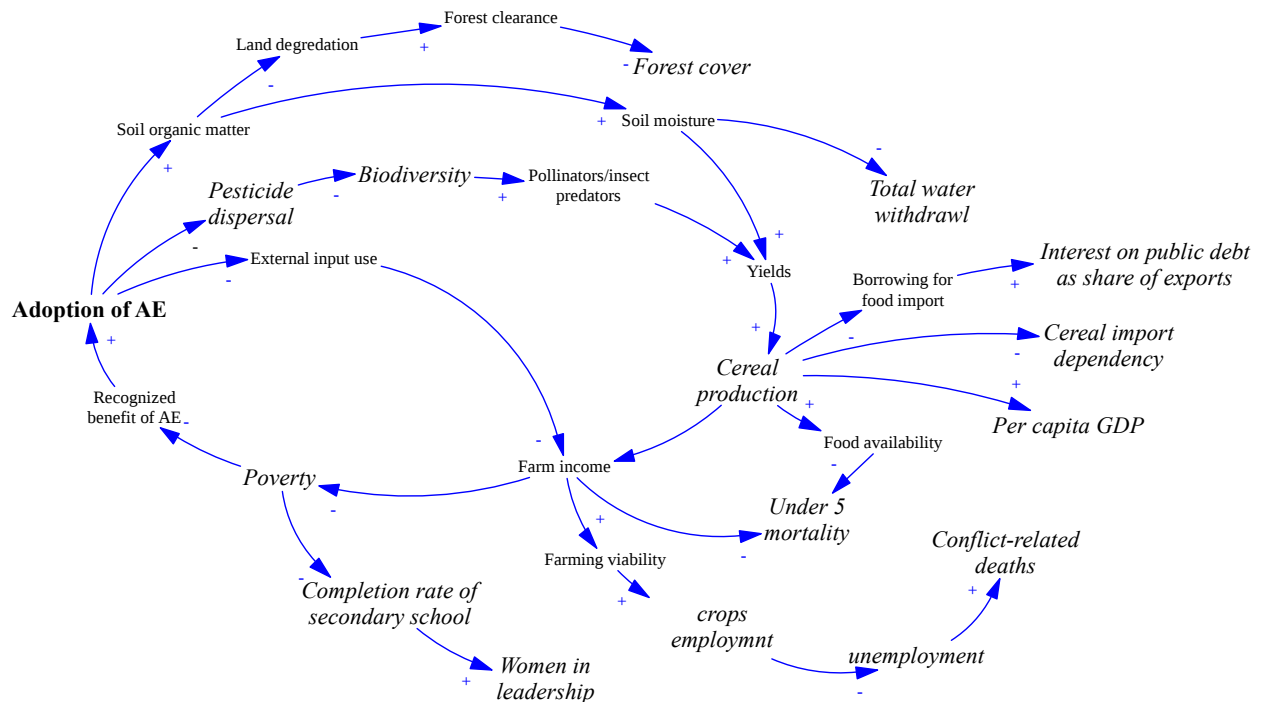


Figure 13. Causal loop diagram of adoption of agroecological approaches.

The arrows show causal linkages. The polarity of the arrows indicates the direction of causality. A positive polarity indicates that the connected variable tend to move in the same direction. For example, if cereal production increases then Food availability will increase. A negative polarity indicates that the connected variables will tend to move in opposite directions. For example, if Pesticide dispersal increases (decreases) then Biodiversity will decrease (increase).

A simplified narrative following this causal chain (as there are many potential pathways illustrated) is that with the adoption of AE pesticide dispersal decreases, encouraging biodiversity along with pollinators and insect predators to proliferate. Natural pest predators will boost cereal yields and production over the long term. Farm income is increased with improved production and reduced use of external inputs that is associated with AE. Also, AE farmers are less vulnerable to price surges of inputs. Poverty incidence is decreased and recognition of the benefits of AE puts into place a reinforcing feedback loops that increase the AE adoption rate. AE practices build soil organic matter that increases soil moisture and yields, adding another reinforcing feedback loop to the AE adoption process. The added soil moisture creates the potential to lessen total water withdrawals. Improved soil organic matter also mitigates land degradation and the need to clear forest for agriculture, thereby helping preserve forest cover. Other indicators are driven by AE adoption. Reduced poverty from AE encourages completion of secondary education and helps empower women. Improved farm incomes make farming a more viable employment opportunity, increasing agricultural employment and reducing the unemployment rate in aggregate. The lower unemployment rate can lessen the risk of conflict-related violence. Increased cereal production and farm incomes improve availability and access of food and help reduce under 5 mortality. GDP will grow with improved cereal production. Increased cereal production has the potential to reduce cereal import dependence and the government's need to borrow funds for imports, reducing interest payments on public debt, freeing fund to be invested in farmer trainer, small scale water management systems and small and medium sized rice processing facilities.

- 3) ***Spill-over effects are significant:*** The spill-over effect to other sectors, especially also to other production sectors is highly relevant since the simulation results reveal that the contribution of agriculture decreases over time, for example concerning GDP or employment. While agriculture used to be a key sector for employment (in 1990 contributing around 60% to total employment) and is still very important (in 2010 around 49% of total employment), the decreasing contribution is likely to continue. According to our simulation, total employment in 2050 is split into around 57% for services, 24% for industries, and 19% for agriculture. In other words, services and agriculture more or less exchange their role for total employment. Similarly, the importance of agriculture for GDP follows a decreasing trend (accounting for around 19% in 1990, 14% in 2014, and 4% in 2050), while the share contributed by industries (22% in 1990, 23% in 2014, and 36% in 2050) and services (59% in 1990, 63% in 2014, and 60% in 2050) increases over time so that even the rather indirectly generated changes are significant. This leads to the situation that for example the improvement in industry and service production contribute around two third to the

additional GDP produced in the AE scenario compared to the BAU scenario, although the changes between the two scenarios only concern the implementation of the agroecological principles in the agriculture sector. Hence, the diffusion of effects – triggered by changes in agriculture but initiating momentum also in other sectors – is substantial for the positive development of overall indicators in the long term. However, despite the decreasing importance of agriculture for employment and value added in the long-term, the enduring relevance of agriculture and which methods it applies is beyond controversy: for employment (as mentioned currently for 50% of employment), especially for the poor, and of course for food production and the impact on the environment emerging in this process.

- 4) ***Policy impacts are amplified over time: The improvement in the AE scenario regarding several indicators increases over time due to the reinforcing action of a set of positive feedback loops.*** The increasing improvement refers to both the results in the AE scenario comparing today with 2030 and 2050, and to the difference in performance between the two scenarios comparing 2030 and 2050. This can be explained by some positive feedback loops that were triggered by the implemented policies in agriculture and subsequently continuously reinforce the original improvement. For example, the increase of agriculture production leads to an increase of GDP that allows higher government revenue enabling higher government expenditure for more government services, for example in education, health, infrastructure, increasing productivity and consequently GDP. Similarly, the increase of GDP raises household revenue and facilitates higher investments also in other production sectors, reinforcing the original improvement. Hence, the AE scenario generates effects that diffuse to the whole system, improving even indicators that are rather indirectly linked to agriculture and this improvement grows over time due to the activated reinforcing feedback loops.
- 5) ***The outlook in the BAU scenario is alarming: The results indicate for the BAU scenario that after 2030 counteracting factors lead to a reduction of crops production*** (in tons and in monetary terms). After a decade of increase of crops production (for example for cereal production in tons of around 24% in 2030 compared to the level of 2017) the negative effects of climate change on agriculture, and a slight decreasing trend of harvested area starting around 2030 cause a decreasing tendency reaching in 2050 approximately the level of 2020 again. Since the reasons for the decrease are addressed in the AE scenario (for example by remarkable expenditure in climate change adaptation for agriculture), and consequently alleviate these impeding factors in the AE scenario, the resulting growth is more sustainable in the AE scenario than in the BAU scenario.

- 6) ***A set of counteracting factors offset benefits in the AE scenario:*** The analysis reveals some areas where unintended side-effects counteract positive developments also in the AE scenario. For example, agricultural water withdrawal in 2050 is very similar in the two scenarios, despite the remarkable increase of water efficiency reducing water withdrawal per hectare of irrigated harvested land by around 40%. This is due to the fact that the harvested area using the efficient irrigation methods is increased. Of course, this increase also contributes to the increase in crop production and the following positive effects, but at the same time it counteracts the improved water efficiency so that agricultural water withdrawal is not significantly reduced. Similarly, the results for cereal dependency ratio indicate that even significant improvements in growth (such as the increase of cereal production) may be inhibited by the strong growth of the population. While we observe a decrease of cereal import dependency from around 56% in 2012 to around 43% in 2030 in the AE scenario, the dependency starts to increase again after 2030 to more than 60% in 2050 due to the fact that population growth exceeds cereal production growth. Hence, the increase in production reduces the dependency in the AE scenario compared to the BAU scenario (where cereal import dependency increases to around 63% in 2030 and even around 80% in 2050), but this reduction is counteracted by the population growth (doubling population according to our simulations from currently around 16million to more than 32million people in 2050). The results suggest that population growth not only creates higher demand for cereals, but also for other services such as education and health at the micro and macro level, which is to be expected.
- 7) ***Synergies between many proposed policies positively contribute to development:*** The simulation results reveal that synergies strengthen the improvement in the AE scenario revealing that the proposed policies support rather than counteract each other. Synergies mean that the results of the joint implementation of all policies is higher than the sum of achievement of each single policy. Such synergies can be caused by various mechanisms through which a policy leads to better enabling conditions for another policy. For example for crop production, large synergies emerge from the interaction of productivity improvement (sustainable land management, natural fertilizer use, Integrated Pest Management – IPM – and knowledge dissemination by farmers), enlargement of cultivated area (through agro-livestock integration and reduction of land degradation), and the decrease of negative effects from climate change (adaptation). The synergies indicate that the AE scenario is composed of concerted interventions building a comprehensive scenario.
- 8) ***The inertia of the system slows down development:*** The analysis point to significant delays between policy and effect emphasizing the need for quick action. For example, while the strong increase of expenditure for reforestation starting in 2019 quite quickly facilitates a

break with the decreasing trend in forest cover, it takes more than 10 years to initiate a reversal of that trend that we observe only after 2030. Similarly, the improvement of completion rate (% of population in the age of 20-24 that completed secondary school) caused by the increase of female enrollment also starts to be visible only after 2030. Such results indicate the time needed for immediate changes in specific intervention areas, such as forest growth, regeneration of land and soil, but also education and training, stressing the urgency of action.

- 9) ***The proposed interventions are not sufficient: The generated improvements are significant but also indicate need for additional policies (in other sectors).*** For example, the implementation of the proposed policies can significantly reduce poverty by nearly 30% in 2050 in the AE scenario compared to the BAU scenario. However, according to the simulation, still 10% of the population in 2050 in the AE scenario lives below the poverty line, highlighting the need for additional policies addressing for example distribution and unemployment in other sectors, to eliminate poverty as it is for example the goal of the 2030 Agenda. Similarly, the observation concerning counteracting effects suggests that policies to slow population growth (e.g. female education, access to contraceptives) could be useful to avoid that improvements for the population (such as the increase of revenue, food production, education or health services provided by the government etc.) are impeded by growth in population.
- 10) ***A comprehensive long-term analysis is essential: The analysis affirms the imperative of a holistic impact assessment that reviews the interdependencies between different dimensions of capital, as it is requested by TEEB.*** The analysis shows that a systems modeling approach can support this initiative by contributing to such an investigation that take into account the interactions between various sectors and indicators of development, that integrates feedback loops, time delays, and enables the identification of synergies. Revealing the importance of these aspects, the analysis shows that neglecting them will limit the produced insights. Further, such integrated analysis demonstrating the widespread and long-term impact can be helpful for increasing acceptance for interventions that first need effort and generate positive effects only with a long delay. Such an example is the increase of expenditure for reforestation that initially mainly increases government expenditure without a visible effect on forest cover, while the results show that the positive impact in 2050 is remarkable (increasing forest land by around one million hectare in 20 years, approximately the amount that has been destroyed in the last two decades). Hence, indicating the long-term effects may help to implement policies that really increase sustainability.

Limitations:

Using a cost-benefit valuation approach to assessing true costs of rice production: Attributing costs and benefits to rice production systems is in itself extremely difficult, with many costs unaccounted for (such as costs to human health from pesticides, or fertilizer runoff in water) and many benefits unable to be monetized (such as biodiversity benefits from pesticide-free rice paddies or the cultural value of rice in Senegal).

We recognize that we could for example take the few monetary values that we have (revenue per tonne of rice under contrasting production systems avg water consumption cost under contrasting systems- cost of burning rice revenues versus not burning + benefit of rice straw incorporated versus exported) to compare between our two alternatives (as per data in the annexed spreadsheet). Doing so would result in the following calculation:

avg revenue for rice, Senegal, conventional system, monetary value, \$/ha, source E	\$ 2,302.00	avg revenue for rice, Senegal, water conserving system, AWD or SRI, monetary value, \$/ha, , source E	\$ 2,422.00
avg water consumption cost, Senegal, conventional system, monetary value, \$/ha	\$ 801.00	avg water consumption cost, Senegal, water conserving system, AWD or SRI, monetary value, \$/ha	\$ 626.00
Total Cost per Tonne Rice Husk or Straw Burned	\$ 217.00	Value of Nutrient Content per Tonne of Rice Straw (2015) in Senegal, USD;	\$ 8.60
value per ton, conventional production and water management, with rice straw burned	\$ 1,284.00	value per ton, AE production and AED or SRI water management, with rice straw incorporated in soils	\$ 1,804.60

but we are not convinced that this approach is insightful. So many more elements of the rice sector in Senegal that are centrally important may be well known, and may even be reasonably well documented, yet cannot enter into such a cost-benefit analysis. An example might be risks of pesticides to human health; as noted above, a comprehensive approach to pesticide risk assessment in West Africa was published in 2014, which found that in Senegal in 2007 and in 2010, no irrigated rice perimeters met acceptable levels of pesticide risk to both human and

wildlife health (Jepson et al. 2014). While the relative toxicity of the pesticides involved are well documented, this is not translated into the expected costs to human or environmental health. Equally the costs and benefits of government investing in small and medium sized mills and more localized distribution channels are not captured in this format- for example the differences for women and youth employment from community ownership. The application of the TEEBAgriFood Framework includes identifying, beyond costs and benefits, but also impacts and dependencies; an initial identification of these in rice production systems was completed in the first TEEBAgriFood Rice pilot study, provided here in Annex 3. We would suggest that such a table does not do full justice to the outcomes of different management systems and that the impacts and dependencies – throughout the food value chain – is well captured through the application of the T21 systems model and its outcomes. While a cost/benefit form of true cost assessment has value and should still be pursued, but it is not the only form of analysis, nor may it be the one of most direct interest to policy makers.

Applicability of results: The dynamics and relations captured in this model are largely generic interconnections, thus it can be assumed that they also generate similar dynamics in other countries (although of course the concrete scale of generated change will be dependent on the country-specific circumstances, the currently implemented policies and the proposed policy changes).

Spatial elements: The T21-iSDG Senegal model does not explicitly include spatial distribution of crops, and is calibrated by using national averages for key indicators. Therefore, the model cannot not represent the diversity of environmental and climatic conditions that characterize Senegal's different regions. That diversity should be considered in order to refine and adapt policy interventions to local conditions. Similarly, the model does not track seasonal dynamics but works with data yearly frequency, which might not highlight within-year variations of importance for crops production. Nevertheless, our approach is consistent with the frequency of data available for most indicators and with the long-term orientation of the analysis.

Incorporation of stakeholder perceptions, and risks of forecasting: The long-term nature of the projections that we analyse implies a series of limitations for the results that we produce. First, policy responses to the prevailing issues in rice have been articulated by diverse stakeholders, but each has contributed from their personal knowledge, not through an elaborate multistakeholder process that should precede the confirmation and adoption of policies. Second, all the simulation results should not be taken as precise forecasts, but rather as indications of trends and policy impacts obtained under a precise set of assumptions. Those projections are useful to learn about the general causal relations, the unintended and unexpected side-effects, the impeding and counteracting factors for improvement to support the development of

coherent and effective strategies for development. Third, the model is formulated at a high level of aggregation and focuses on the representation of the interlinkages between the different sectors. On the one hand that means that also in the agricultural sector, we analyse policies and effects from an aggregated perspective. On the other hand, this aggregation and macro perspective allows us to assess the intersectoral effects, dependencies and impacts. In a subsequent stage of the policy process these results should inform the use of sectorial models and other more detailed planning tools. Fourth, there are factors and causalities that are not integrated in the model. Mostly, that is the results of a balancing act, in which we aim at integrating the main relevant links without including too many factors that would impede adopting a macro-perspective. In addition, some interdependencies might not have been included in the model due to lack of data or other kind of evidence concerning that specific causal relationship. Finally, our model is implemented at the national level and does not account for diversity at the sub-national level, which should be considered for successful implementation.

Section 9: Reflections on results

This complex exercise, exploring options for the future of the rice sector in Senegal has had a number of key outcomes:

Reinforcing the value chain approach: Taking a view across rice value chains has highlighted the many interrelated issues that are not evident when looking only at the production side. The size, distribution and ownership of rice mills, for example, can have important impacts on all sides of the chain: the ability to separate and mill particular varieties of local importance and the capacity to recycle mill waste back into the field, for example, or the costs of transportation to markets.

Stakeholder input to build contrasting pathways: While a complete stakeholder consultation was beyond the resources of this study, great value was found in not simply reviewing the existing literature but in soliciting the perspective on possible pathways for a diverse set of stakeholders. It was striking that amongst the stakeholders consulted, a fair convergence of opinion on viable future pathways emerged.

Taking a systems approach to analysis: Through the intricacies of the stakeholder perspectives, the implications of future pathways within the rice sector in Senegal are manifold. The TEEB AgriFood Foundations study recommends taking a system approach. In this study, it was possible to take a broad systems form of analysis, through building on and modifying a highly detailed, documented and verified systems dynamics-based model to support national development planning in Senegal around the Sustainable Development Goals, structured to analyse medium-long term development issues at the national level; and integrating the economic, social, and environmental aspects of development into a single framework.

The recommendations of stakeholders on how issues in the rice sector in Senegal should be addressed were brought into a coherent assessment of aligned policy responses across the rice value chain. The assessment presents and compares the results for the selected indicators under two different scenarios: the Business As Usual (BAU) assumes that current policies are continued into the future, while the Agroecology (AE) scenario assumes the implementation of the policy responses proposed by stakeholders, grouped around agroecological principles proposed by FAO (2018a) that we translated in nineteen policy interventions. The analysis of the simulation lead to ten primary findings, and nineteen policy recommendations.

The results of the simulated agroecological scenarios indicate significant possible improvements by 2050 in all selected SDG indicators, linked to the four dimensions of capital, when compared by to “business as usual”. The results illustrate the interlinked nature of the system and reveal that the changes implemented in agriculture spread and diffuse through the whole system. While it can be expected that there will be improvements in produced and natural capital through a “greener” more sustainable system of rice cultivation, there are a number of unexpected impacts as well. For example, an important contribution to the improvement of completion rate in secondary school (human capital) is generated by the empowerment of women (supporting gender equality in land tenure rights, employment and education), whereas other policies are especially relevant for the reduction of poverty (social capital), such as the job creation through knowledge and labor intensive agroecological production and the formalization of the sector in combination with the diversification of production improving income and its distribution.

Policy options as per the outcomes from this assessment: The assessment points to many implications for policy options as outlined above in section 8. Most directly the assessment highlights that agroecological interventions are highly effective: The implementation of the proposed policies generate a significant improvement of all selected indicators for the four dimensions of capital. Interestingly for policy makers, there is a strong effect of spillover and feedback: improvements in the AE scenario with respect to several indicators increase over time due to the reinforcing action of a set of positive feedback loops. This can be explained by some positive feedback loops that were triggered by the policies implemented in the agriculture sector, and subsequently continuously reinforce the original improvement. For example, the increase of agriculture production leads to an increase of GDP that allows higher government revenue enabling higher government expenditure for more government services, for example in education, health, infrastructure, increasing productivity and consequently GDP.

The value of such a comprehensive, long-term analysis, and a holistic impact assessment that reviews the interdependencies between different dimensions of capital is highlighted, reinforcing the aims of the TEEB AgriFood initiative.

9: Recommendations

Based on the findings of our analysis, this section presents seventeen policy recommendations regarding the implementation of agroecology in Senegal. Many of these recommendations are also relevant to other countries facing similar challenges.

- 1) **Taking a holistic lens on prevailing issues in the rice food value chain in Senegal** and asking the perspective of a diverse group of stakeholders brings out the many complexities and interlinkages of the sector.
- 2) **Despite a diversity of perspectives, there is consensus on prevailing issues and policy responses**, which point to the compelling need for a paradigm shift in agricultural investment, to agroecological approaches that can substantively contribute to food security and nutrition while generating many positive externalities.
- 3) **The implementation and dissemination of agroecology should be strengthened and supported** since the potential for a remarkable positive impact on various dimensions of capitals has been demonstrated. More specifically, the following interventions concerning the implementation of agroecology can be recommended:
- 4) **It is necessary to significantly increase government expenditure for implementing and strengthening sustainable land management in a holistic way**, supporting specifically small-scale production, processing and storage. The support should be directed towards different activities:
 - a. A major part of this expenditure should facilitate **training and extension services** on integrated and agroecological crop management options (including for example systems of rice intensification) aiming at the increase of area that is sustainably managed.
 - b. The government should strengthen **participatory research** (for example in collaboration with research institutions concerning the development and official recognition of knowledge provided by the agroecological farms; research on scaling up agroecology and barriers to do so, capitalization and popularization of results).
 - c. The government should foster the **access to equipment** (for example facilitating availability of small tillers for use in traditional/small-scale production which are currently hard to source) and **access to credit** (for example by supporting financial organizations to extend credit and micro-credit to provide preferential terms to producers or traders of agroecological products only, and other producers or traders otherwise contributing to resilience).
 - d. The government should encourage **smaller and medium sized mills and community storage options** (since they provide benefits, such as capacity for the use of by-products decreasing the waste share, reduction of transportation costs, higher prices for producers,

lower prices for consumers, greater market efficiency and availability at the community markets).

- e. Government expenditure (derived from savings with the debt relief of the AE scenario) should allow for **marketing of AE products** (also by encouraging the procurement by public services of agroecological product for example in hospitals, schools, armed forces, prisons, etc.), for **awareness raising** (for example concerning the potential of agroecological practices to protect the environment), and for **promotional efforts towards greater diversity in cultivation and consumption** of crops (for example promoting diversity within crops but also within one crop).
- 5) **Training on sustainable land management should be combined with policies to improve knowledge dissemination among farmers, such as the increase of expenditure for farmers' organizations, the promotion of farmer to farmer propagation or the dissemination of best practices.** Together these interventions enlarge the area that is sustainably managed and lead to the enhancement of the provision of ecosystem services (including practices such as polycropping, intercropping, crop rotation, multi-layer farming etc. as well as the reduction of mineral fertilizer and pesticide use and the increase of natural fertilizer use and integrated pest management). While the positive impact of investment in training and knowledge might be realized only with a delay in time, these policies are key to improve production since they are more sustainable than for example subsidizing inputs. First, they generate fewer negative effects for environment, such as dispersion. Second, the investment in human capital builds up a stock of knowledge that remains – generating positive effects over decades – even when the investment fades out (Zuellich et al 2015).
- 6) **Existing subsidies for mineral fertilizer and chemical pesticide should be shifted towards subsidizing the use of natural fertilizer and strengthening integrated pest management**, for example by encouraging producers to produce, collect and market their own natural fertilizers (e.g., azolla or green manures), by supporting the implementation of alternative approaches such as the use of organic fertilizer derived from the Non-Sewerage Sanitation System along the fecal sludge management treatment facilities, and by providing training on the production and use of natural fertilizer as well as integrated pest management or biological pest control (see above: training on sustainable land management). This reduces the negative impacts on the environment (for example pesticide dispersion), and the costs of input while maintaining soil fertility and pest control (Settle & HamaGarba 2009; Jepson et al. 2014).
- 7) **Agro-livestock integration should be supported**, allowing animal and crop production on the same land and facilitating agroecological practice, for example by providing animal dung for natural fertilizer production, animal strength for crop production without increasing expenditure, and crop residues as animal feed. More specifically, integrated rice-fish systems contribute to crop diversity, farm productivity in biomass or in economics, the quality and

quantity of the food products, optimizes resource utilization through complementary use of scarce land and water resources, and realize synergies since fish provide organic manure enhancing soil fertility, and help control weeds by feeding on weed roots (Parvez et al 2016).

- 8) **Saving potentials should be identified and realized**, thus increasing efficiency in governmental interventions, for example concerning irrigation and subsidies for mineral fertilizer or pesticides. Focusing on efficiency (for example for water use), synergies (for example with agro-livestock integration) and the reduction of external input needs (for example pesticide use), the implementation of the proposed agroecological policies in this simulation analysis allows a decrease of government expenditure of around 0.6% of GDP each year (as opposed to investment in large scale schemes with high debt servicing) that leads to a decrease of the total debt-GDP-ratio of around 74% in 2050 in the AE scenario (where it is around 6%) compared to the BAU scenario (still at around 23%). Hence, the interventions facilitate a repayment of debts, lowering the interest payments and even allowing an increase of government expenditure in the future.
- 9) **Government expenditure for climate change adaptation should be significantly increased.** The adaptation in agriculture includes the investment and implementation of practices for production, inherent to agroecology, such as locally-adapted seed use, contour farming, cover cropping, training, moisture, fire and pest management, but also the investment in research and infrastructure development in agriculture and connected areas such as water supply (e.g. reservoir construction, efficient waste water reuse and treatment), natural ecosystems (e.g. restore watersheds and habitats, conserve crop-related biodiversity) and adaptation to extreme weather events (for further details, see UNFCCC 2007 and UNEP 2014a). It has been shown that this can lead to a remarkable reduction of negative impacts of climate change and the population affected by natural disasters, but the results also revealed the urgent need for investment in climate change adaptation in other sectors.
- 10) **Reforestation interventions should be strengthened in order to prevent the depletion of natural capital.** The analysis highlighted alarming trend of forest loss decreasing forest in only 15 years from 1990 until 2015 by around 1 million hectares accounting for more than 12% of the current stock. While the simulations indicate a continuation of such a trend if no measures are taken (BAU scenario), they also reveal that it is possible to revert the decreasing trend and even rehabilitate the lost forest (AE scenario), but only if determined action is taken. Similarly, according to our simulations, there is a potential to impede or even revert the dwindling of fish resources. This emphasized the importance of the agroecological principle “responsible [natural resource] governance”.
- 11) **Investment in human capital towards empowering people, especially women, should be increased.** One highly relevant factor of this empowerment is to foster gender equality. There, it is key to target the roots of inequality, specifically the gap in education by increasing female enrollment in all levels of education, empowering future generations of women in their self-

determination. Womens' education has been shown to be the second most important determinant toward reducing malnutrition, after access to clean and safe water (Smith and Haddad 2015). Changes in enrollment of girls and women not only increase completion rates (an important indicator for social capital and the SDGs) but also the percentage of women in leadership positions in the future. The empowerment of rural women (for example by promoting their participation in producer groups or recognizing their legal land ownership) can contribute to such an increase in female enrollment assuming that in households with empowered women, girls are sent to school. Further, additional policies in other sectors, such as education, health and employment regulations are necessary to strengthen gender equality. Higher gender equality is both a goal in itself and in addition, it improves voice and accountability in the country contributing to a higher level of good governance (Kaufmann et al 2017) with all the subsequent positive effects of an improvement of on governmental service provision and productivity in all sectors (Kaufmann et al 2005, Kaufmann et al 1999).

- 12) **Land tenure system should be improved** by developing and applying land management policies that recognize legal land ownership by women and youth, and explicitly allocate land for agroecological farming practices, including registration of land designated for agroecological practices with market values. Such a recognition empowers the targeted groups, and consequently also contributes to gender equality, for example by facilitating the land holders' access to credit.
- 13) **The social components of agroecology should be promoted**, such as the reconnection of food production and consumption to increase the access to agroecologically produced food by urban consumers, especially for poor people, the job creation by labor and knowledge intensive agroecological production, and the support of small and medium sized production, processing and storage activities. These are important aspects for the improvement of food security and the reduction of inequalities, both relevant indicators for social capital and the SDGs.
- 14) **Counteracting factors should be identified and eliminated if necessary**. For example, the analysis revealed for example that the simulated population growth (doubling population from now until 2050) can countervail even remarkable improvements generated by the proposed policies (or any other policies) as has been shown for cereal import dependency once growth in population exceeds the growth in cereal production (although it nearly doubles in the AE scenario compared to the BAU scenario in 2050). Hence, addressing population growth might be useful to ensure that growth in revenue, food production, or the provision of governmental services really contributes to an improvement of the well-being of the population. Similarly, when aiming at the absolute reduction of water withdrawal, it is important to consider the tradeoff of increasing the extent of agricultural land under less intensive practices. The introduction and dissemination of even very efficient methods can

lead to an increase of absolute water consumption if the increase of application area exceeds the savings gained through higher efficiency.

- 15) **Accompanying/enabling policies in other sectors should be considered**, not only concerning the counteracting factors (see above) but also to address negative side-effects and to further increase the improvement in development indicators. For example, to prevent the negative side-effects from positive GDP growth (caused by the agroecological interventions) further additional policies in other sectors might be appropriate such as further promoting material consumption efficiency and recycling in other (production) sectors to ensure sustainable consumption and production patterns and to address the increasing material footprint generated by the increase of GDP. In addition, of course further policies in other sectors than agriculture could significantly improve the analyzed indicators and dimensions of capital, for example interventions in areas, such as education, health, infrastructure, distribution policies (through targeting fiscal pressure and subsidies and transfers), renewable energy and governance.
- 16) **In order to obtain significant results by 2030, policies should be immediately implemented.** The significant delays between policy and effect, especially for some intervention areas, such as education, reforestation and land or soil recovery emphasize the importance of quick action. In addition, the inherent feedback loops reinforce positive developments over time, so that the improvement is higher the sooner these dynamics are activated.
- 17) **Political will for the implementation of the proposed policies should be strengthened.** While this report focuses on the question of what to do (analyzing the impact of proposed interventions) it does not address the question how to implement such interventions. However, of course it is key to identify and consider enabling and success factors and conditions for the implementation, such as charismatic leadership, horizontal pedagogical practices, favorable public policy, local and favorable markets, social organization, effective farming practices, cultural legitimacy (Khadse et al. 2018). In any case, a comprehensive impact assessment should also help to create such political will and contribute to a favorable environment.
- 18) **Consult and learn from experience when it comes to details of implementation.** As it has been noted, this analysis focusses on the comprehensive impact assessment from a rather macro perspective reducing the level of details within one sector but allowing the integration of several sectors and dimensions of development. Accordingly, our recommendations provide rather general guidelines. For concrete steps and detailed plans, sectoral planning tools and experts, but also experiences and showcases from other countries and regions should be consulted⁴⁴. In any case, it is of course key to take into account the country- and region-specific contexts and circumstances to identify concrete steps.

⁴⁴ Various showcases have been documented and analysed, see for example www.fao.org/agroecology/knowledge/practices/en/ or www.agroecology-pool.org/showcases/

- 19) **Promote the use of comprehensive long-term analysis** that reveals interactions, spill-over effects, reinforcing or counteracting feedback loops and impeding factors as well as delays. Conceivably, such an analysis could be an ongoing monitoring and evaluation exercise based on the TEEB AgriFood Framework. This analysis would highlight the interconnected nature of the system; assessments that neglect those interdependencies will not be able to provide the same insights and are very likely to underestimate some aspects of impact (for example by overlooking spill-overs, reinforcing feedback loops or synergies) or overestimating other aspects (ignoring counteracting effects or tendencies). Using a system model as a tool of analysis facilitates such a comprehensive impact assessment by taking into account the general interdependencies and aspects of complexity (delay, non-linearity, feedback) and at the same time being adaptable to country specific contexts and circumstances.

Overall observations

“The Economics of Ecosystems and Biodiversity” initiative of the UN Environment asks us to look at the many invisible flows between capital stocks, and to promote the use of comprehensive long term analysis that reveals interactions, spillover effects, and reinforcing or counteracting feedback loops. This analysis highlights the interconnected nature of the system; assessments that neglect those interdependencies will not provide the same insights. A key one here, unexpectedly, was how much a reorientation of the rice sector to respect forms of capital can ricochet through the national economy, even given the relatively small size of rice production in Senegalese agriculture.

The long-term nature of the projections that we analyse implies a series of limitations for the results that we produce. First, policy responses to the prevailing issues in rice have been articulated by diverse stakeholders, but each has contributed from their personal knowledge, not through an elaborate multistakeholder process that should precede the confirmation and adoption of policies. Second, all the simulation results should not be taken as precise forecasts, but rather as indications of trends and policy impacts obtained under a precise set of assumptions. Those projections are useful to learn about the general causal relations, the unintended and unexpected side-effects, the impeding and counteracting factors for improvement to support the development of coherent and effective strategies for development. Third, the model is formulated at a high level of aggregation and focuses on the representation of the interlinkages between the different sectors. On the one hand that means that also in the agricultural sector, we analyse policies and effects from an aggregated perspective. On the other hand, this aggregation and macro perspective allows us to assess the intersectoral effects, dependencies and impacts. In a subsequent stage of the policy process these results should inform the use of sectorial models and other more detailed planning tools. Fourth, there are factors and causalities

that are not integrated in the model. These are the results of a balancing act, in which we aim at integrating the main relevant links without including too many factors that would impede adopting a macro-perspective. In addition, some interdependencies might not have been included in the model due to lack of data or other kind of evidence concerning that specific causal relationship. Finally, our model is implemented at the national level and does not account for diversity at the sub-national level, which should be considered for successful implementation.

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Annex 1

Explanation of policy variables and assumptions used in Table 4:

Expenditure for agriculture water efficiency and irrigation equipment (% of GDP):
- Decrease of expenditure for (inefficient) irrigation equipment frees money for other purposes
- Increase of expenditure for efficient irrigation equipment
Natural fertilizer use per ha harvested area (ton/ha/year)
- Increase of natural fertilizer use (since in the AE scenario the production and use is trained)
Expenditure for fertilizer subsidies (% of GDP)
- Decrease of subsidies for mineral fertilizer decreases the use of mineral fertilizer
Average biological pest control use per ha harvested area
- Increase of biological pest control (since in the AE scenario the use is trained)
Pesticide use per ha harvested area (kg/ha/year)
- Decrease of pesticide use (assuming that it is replaced by biological pest control)
Share of arable land used for agro-livestock
- Assumption that 33% of arable land is converted to agro-livestock land
- assuming that the productivity on agro-livestock land is 90% compared to arable land (on the former arable land that is now agro-livestock land they produce 90% of what has been produced on the land when used as arable land only PLUS 17% of what is produced on land when it is used as pasture land only)
Share of pasture land used for agro-livestock
- Assumption that 7% of pasture is converted to agro-livestock land
- Assuming that the productivity on agro-livestock land is 17% compared to pasture land
Base salary for farmers ⁴⁵
- It is assumed that farmers (supported by the government through expenditure for sustainable land management, farmers organization) diversify their production and consequently can increase their income
Expenditure for climate change adaptation in agriculture (% of GDP)
- It is assumed that the government invest intensively in climate change adaptation in agriculture.
- We use investments in adaptation for agriculture in a rather broad sense that include covering of adaptation cost for agriculture, water supply and natural ecosystems (UNFCCC 2007), respectively agriculture, extreme weather events and water supply / flood protection (UNEP 2014a). Based on the mentioned adaptation cost literature these adaptation investment needs sum up to around 33-42% of total adaptation investment needs. These investments are able to reduce the negative effects of climate change on agriculture to a minimum and reduce the proportion of population affected by natural disasters
Expenditure for sustainable land management (% of GDP)

⁴⁵ The % indicates the minimum salary relative to average salary.

- The focus of the expenditure for SLM is the training of farmers, and consequently increases the area of harvested area sustainably managed. This includes the application (and production) of natural fertilizer, biological pest control, techniques of SLM (such as polycropping, intercropping, crop rotation, multi-layer farming etc.). - This increases employment in agriculture (since SLM is more labor intensive), and soil nutrient balance (more natural fertilizer), and decreases agriculture land decrease (less land degradation and abandonment) and dispersion (less use of mineral fertilizer)
Average knowledge dissemination about sustainable agriculture by organized farmers (person/farmer/year) - It is assumed that farmers (also pushed by 'movements' such as in ZBNF) and supported by organizations (that are supported by government (see below) increase their knowledge sharing in forms of farmer to farmer propagation, dissemination of best practices etc. - Concrete assumption: one farmer trains 0.4 other farmers per year (or in other words: one farmer trains one other farmer every 2.5 year)
Waste share reduction due to small scale mills - Due to the support of small scale farmers and mills (see for example farmers organization and SLM) the waste share is reduced (increasing the food available for the population and the agriculture production value per ton
Processing share increase due to small scale mills - Due to the support of small scale farmers and mills (see for example farmers organization and SLM) the processing share is increased (increasing the processed food available for the population and the agriculture production value per ton)
Expenditure for farmers organization (% of GDP) - Expenditure for farmers organization strengthens the exchange between the farmer (for example facilitates the training of farmers by farmers (see above), facilitates initiatives concerning small scale storage, processing etc.
Expenditure for additional reforestation (% of GDP) - The investment in reforestation increases forest land by reforesting other land (not land that is used for agriculture)
Proportion of population below food poverty line with access to non-marketed food - Due to the support of small scale farmers (through training in SLM, support of farmers organization) and due to the fact that employment in agriculture increases (due to the increase in labor-intensive agriculture) more people have access to non-marketed food, decreasing undernourishment and malnutrition in the population.
Proportion of adult population with partial employment - Due to the job creation through knowledge and labor intensive agroecological production the population that has a partial employment increases
Women's economic opportunity index

-	It is assumed that the support of government is especially directed towards small-scale farmers (e.g. training in SLM, support of farmers organization) and women increasing their participation and rights
	Report of the gender gap in employment in relation to gender gap in education ⁴⁶
-	It is assumed that the support of government is especially directed towards small-scale farmers (e.g. training in SLM, support of farmers organization) and women decreasing the gender gap (for example participation) in relation to the education gender gap
	Education gender bias (secondary, tertiary)
-	It is assumed that the empowered women in agriculture send more of their girls to school increasing the female enrolment in secondary and tertiary
	Voice and Accountability (scale -2.5 to 2.5)
-	It is assumed that the support and empowerment of farmers (especially through the training and farmers organization) increases the possibilities and the ability to participate in the civil society, controlling and holding government accountable (in other words increasing the dimension of good governance (as defined by the indicator of the World Bank): voice and accountability)

Annex 2.

Checklist to Assess Coverage of Application of TEEBAgriFood Framework to Rice Food Value Chains in Senegal.
(provided in a separate document, not possible to copy here).

⁴⁶ A value less than one means that the disparities in employment rates are lower than in completions of education; and a value greater than one vice versa.