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Research Paper

Translating theory into practice: A flexible decision-making tool to support the design and implementation of climate-smart agriculture projects

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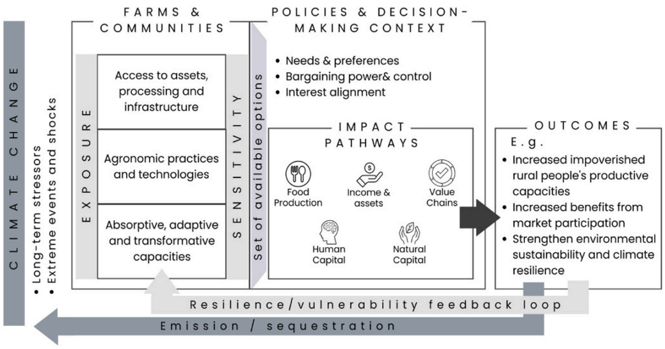
HIGHLIGHTS

- Satisfying the requirements of all climate smart agriculture (CSA) pillars is challenging at the level of an individual project or agent.
- Development of a CSA decision aid tool by a process of co-creation to operationalise CSA pillars across outcome areas.
- Tools to identify specific trade-offs in the performance of climate smart agriculture at project level, should be relevant to portfolio design.
- The ability to map both performance and knowledge gaps across diverse CSA parameters is a valuable means of comparing initiatives.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Climate-smart agriculture (CSA) is a conceptual framework for responding climate-related risk in agriculture across the three pillars of Mitigation, Resilience, and Production. Existing tools have been developed which seek to operationalise the CSA concept to evaluate and benchmark progress; each of which have their own relative strengths and weaknesses.

OBJECTIVE: The translation of this concept into actionable projects/portfolios hence requires the careful evaluation of potential trade-offs and synergies between these three pillars. The hereby presented decision-making tool aims to offer a basis for a structured evaluation of such trade-offs and synergies.

METHODS: It does so by assessing five different outcome pathways on how they contribute to a project's performance across the three pillars of CSA. We aspire that the use of this tool will allow for more deliberate design and implementation of projects in agricultural development, increasing the resilience and productivity of farming systems whilst ensuring the sustainable use of the environmental resource-based agriculture depends on.

RESULTS AND CONCLUSIONS: This tool was applied in a workshop setting to evaluate the relative strengths and weaknesses of two distinct projects; demonstrating the utility in visualising the same performance in different

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ways. Of particular importance was ability to demonstrate how focusing on productivity and adaptation may trade-off mitigation activities.

SIGNIFICANCE: The results of the case study application demonstrated the challenge in meeting all the CSA requirements; particularly where the main objective of a project is to enhance and increase productivity. This reinforces how supporting all three pillars is challenging for a single project and therefore CSA is arguably more achievable when viewed in terms of a portfolio of activities which can collectively compensate for the limitations of a single project.

1. Introduction

Climate-Smart Agriculture (CSA) is a concept to support decisions addressing climate-related risks to agricultural production systems and societal wellbeing by considering three foundational outcome pillars and accounting for the trade-offs and synergies among them (Rosenstock et al., 2016). The three pillars of CSA are outcomes in agricultural systems that contribute to, or at least consider; i) sustainable and equitable increases in agricultural productivity and incomes, ii) greater resilience of food systems and farming livelihoods, and, where possible iii) reduction and/or removal of greenhouse gas emissions associated with agriculture (FAO, 2017).

Although synergies among objectives appear possible, they are not automatic (Smith and Olesen, 2010) and conditions for adoption are highly context- and location-specific, requiring farmers to ultimately identify what is climate-smart for the biophysical, agricultural, and socio-economic context of a given place and time. Consequently, translating the concept of CSA into practice is knowledge-intensive and can require significant institutional support (McCarthy et al., 2011); (Neufeldt et al., 2013). Although CSA has gained popularity as a scholarly solution, difficulties arise when attempting to translate it into farmer and civil society actions, as well as new policy directions (Chandra et al., 2018). Furthermore, the failure to incorporate issues related to social justice further complicates the acceptance and implementation of CSA (Taylor, 2018). This approach can favour simple guidance to follow, obfuscating how system-level or indirect processes can positively or negatively modulate the perceived outcomes of CSA at a local scale. Therefore, determining the likely outcomes of a CSA intervention becomes complex due to the need to consider trade-offs that are beyond the direct control of CSA implementers (Pfeifer et al., 2020). In that regard, the barriers to meaningful intervention can be both conceptual (in terms of framing) and practical (due to resource and other limitations).

1.1. Lessons from CSA implementation and framing

Reviews of CSA conceptualisation and implementation present some recurring challenges which identify potential barriers as well as avenues for progressing the CSA concept. For example, a review of identified CSA programmes by the UK Foreign, Commonwealth, & Development Office, (UKFCDO) found that although all programmes aimed to alleviate poverty by increasing productivity and/or resilience of farmers to climate change impacts (UKFCDO, 2021), evidencing 'resilience' remains a challenge. CSA approaches have a greater likelihood of being adopted when seen as profitable to farmers, but ideally, increased productivity is supplemented by additional resources and services to enable adoption (Smith and Olesen, 2010). The above review presented the caveat that what is meant by 'adoption' is not always commonly understood. Cognizance of context is highly important, as 'natural resource-dependent' and sensitive subsistence practices are specifically at risk from both gradual and sudden climate-related stressors (Azadi et al., 2021). Furthermore, Azadi et al. (2021) reframe CSA as 'Vulnerable-Smart Agriculture' (VMA) with a conceptual framework that emphasizes different types of capital of greatest immediate value to smallholder farmers. Similarly, when focusing on the most climate-vulnerable populations, the role of CSA and productivity gains are considered in terms of household food security (Antwi-Agyei et al., 2021). Communities which supplement their own food sources directly arguably present a more acute level of vulnerability and achieving security within such a system can be at the cost of sacrificing yields, specialization or cash crops (Adger et al., 2009).

Outside of this very fundamental issue of meeting these basic needs, there are many different definitions of resilience both within the portfolio reviewed in (UKFCDO, 2021) and more broadly. Moreover, reliance itself is difficult to quantify in a comparable way, as it is relational, relative (in comparison with other instances and settings) and is likely to differ based on the nature of the climate stressors (i.e. gradual vs sudden changes) (Fanzo et al., 2018). One of the challenges remains the ambitious 3 pillar framing of CSA. UKFCDO (2021) found that CSA programmes focused on achieving potential synergies between at least 2 of the pillars of CSA (normally productivity and adaptation), itself by no means a trivial undertaking. The actions of vulnerable actors such as small-scale farmers when making adaptation decisions suggest that adaptation is motivated by several stressors (Azadi et al., 2021) but adaptive capacity is often the deciding factor (Burnham and Ma, 2017). This may be taken to suggest that mitigation is considered of less immediate importance when it is not directly linked to some tangible benefits. In practical terms, studies such as Kichamu-Wachira et al. (2021) who synthesise the results of numerous assessments of the effectiveness of activities within the African context highlighting the efficacy of green manure in increasing yields (+63%) whilst crop rotation and conservation tillage had a lesser but positive effect on soil organic carbon (SOC) which was not significantly improved under green manure alone. Crucially the integration of different practices (e.g. green manure and conservation tillage, conservation tillage and crop rotation) produced a more pronounced effect on both yields and SOC under lower fertilizer application rates (which itself can assist mitigation efforts).

1.1.1. Temporal and spatial concerns

CSA takes place within a dynamic system, with potentially mismatched temporal boundaries between CSA goal and implementation (Dossou-Yovo et al., 2022). Related to the previous point, longer-term strategies may mean benefits are only realised by farmers in the future whilst costs may incur in the near term (Béné et al., 2016). Indeed, the farmer may be guided to take up a practice which required an "eternal" increase in input or sacrifice of profit, whilst the benefit only becomes apparent at an undetermined point when a climate event is taking place. Indeed, the farmer may be guided to take up a practice which required an "eternal" increase in input or sacrifice of profit, whilst the benefit only becomes apparent at an undetermined point when a climate event is taking place. This lack of profitability increases reliance on (input, equipment etc) subsidies which increase the risk of programmes failing once these supports come to an end, or where programmes lack an exit/legacy strategy. A common challenge across multiple similar frameworks (e.g. nature-based solutions) is difficulty in defining the future timeframe and scale of impact against which adaptation capacity is measured. In its review, UKFDCO (2021) found that few programmes explicitly planned against future impacts framed around specific climate modules.

> "Programmes referred to adaptation to drought but were not explicit about the severity of drought being planned for." UKFDCO (2021) p24

Time-limited funding is often at odds with the time necessary to embed meaningful and (stable) changes in resilience. Therefore, longer-term approaches need also to identify means of reducing this 'incentive gap' between adoption and the benefit that reaches farmers (including instances where CSA initiatives where farmers are the intended beneficiaries but not the adopters). Several studies (e.g. Contasti et al., 2023; Branca et al., 2021) have suggested that measures such as carbon credits or payment for ecosystem service could act as an appropriate exit strategy to link longer terms efforts associated with mitigation with more immediate concerns around livelihoods and resilience. However, UKFDCO (2021) presents a caveat in that within the developing world context, measures such as carbon credits offer low dividends to farmers and high transaction costs, reinforcing the 'incentive gap' they are purported to alleviate.

As a possible evidence base for establishing carbon credits (Kearney et al., 2017) presents the use of satellite imagery to estimate above-ground biomass levels. The authors suggest that -due to smallholder size- the payment of direct carbon credits may not be sufficient to drive CSA adoption; rather advocating the use of such methods at landscape scale in the first instance, to reduce monitoring costs and increase accuracy. In spatial terms, the implementation of CSA at scale remains a significant challenge due to agroecological and socioeconomic mutuality which can manifest as trade-offs across the 3 CSA pillars, studies such as Lewis and Rudnick (2019) demonstrate how this is equally a concern within a single 'productive and well resourced' region (in this case California) and reinforce how the 'triple win' CSA paradigm is not always achievable. The authors identify trends such as declining shares of agriculture in GDP and levels of mechanization which vary with geography but are manifesting in both the global North and the global South. Giller et al. (2009) questioned whether there was widespread adoption of conservation agriculture in sub-Saharan Africa with lack of consideration of the trade-offs for farmers being one of the main limitations.

On a more fundamental level, regional variability has implications for making realistic and realisable CSA objectives and this is arguably most pronounced with greater spatial granularity. Prestele and Verburg (2020) suggest that there have been limited attempts to identify and quantify co-benefits and trade-offs at the local level. The authors distinguish variability in initial conditions, variability in maximum potentials for adaptation, mitigation and productivity, and variability in socioeconomic limitations. The authors argue that failure (particularly within large projects) to consider these variances at the local level, risks unrealistic appraisal of cross-pillar co-benefits (and trade-offs) when discussing CSA performance at wider geographic scales (Taylor, 2018).

1.2. Project aims

In 2021, the Syngenta Foundation for Sustainable Agriculture (SFSA) refocused its global strategy towards Climate-Smart Agriculture to better align its interventions with the realities of targeted farming systems and to maximize impact across environmental, social, and economic dimensions (Jayne et al., 2018). This refocused strategy emphasizes the importance of a holistic approach to CSA and commits to having all projects deliver positive outcomes or, at the very least, avoid negative consequences – for all three pillars of CSA (SFSA, 2021). This will likely require a shift to multi-sector, long-term and outcome-based projects and partnerships built on a blend of on-farm, value chain, finance, and policy interventions (Wigboldus et al., 2016; Schut et al., 2020; Klauser and Negra, 2020). However, this broader scope of intervention design can introduce complexities in project planning. Therefore, tools are crucial in facilitating the design and evaluation of interventions, assessing their potential to create climate-smart outcomes.

To support the implementation of its strategy and translate it into farm-facing interventions, SFSA collaborated with the Natural Resources Institute of the University of Greenwich (NRI). This led to the development of the hereby presented decision-making tool that enables the analysis of potential interventions across the three pillars of climate-smart agriculture. This tool was specifically built to avoid over-simplification of protocols and to focus on the local context, and farmer decision-making processes and motivations. Further, it was designed to be explicit about potential trade-offs between CSA pillars, such as between Production and Mitigation (Tittonell and Giller, 2013). Production and Resilience (Vanlauwe et al., 2014) and the tool offers decision-making guidance on how such trade-offs manifest within the local context and priorities.

The hereby presented tool possesses several key attributes to ensure its effectiveness. These attributes aim to produce standardized, coherent, cost-effective, and decision-relevant information across several key steps of project planning and execution (Van Wijk et al., 2014), such as:

1. To support the design of interventions to the context and the climate challenges of the targeted farming systems (van Wijk et al., 2020);
2. To improve existing projects to more deliberately deliver and report against a standardized set of outcomes across the three pillars of CSA
3. To have a simple structure, allowing for qualitative input by non-subject matter experts in CSA

To achieve this, the tool was designed based on a minimum-viable product (MVP) that refers to the essential intrinsic functionality to inform project design and execution in a meaningful way (Fig. 1).

2. Development methodology

Key steps in the development process, as well as tool structure and functionality, are described below.

2.1. Overview of existing tools

To guide the development of our solution, we conducted a review of existing tools that assist agencies and practitioners in implementing projects that either directly aim at delivering across the three CSA pillars or are at least compatible with CSA objectives. The tools we identified are: Smarter Metrics for climate change agriculture (Stephenson et al., 2020); Climate-Smart Agriculture Rapid Appraisal (Mwongera et al., 2017); Climate-Smart Agriculture Programming and Indicator Tool (Quinney et al., 2016); Consensus-driven decision support framework "Target CSA" (Brandt et al., 2017).

The tool described here is primarily intended to support Syngenta Foundation implementation teams in Africa and South Asia, as well as local stakeholders, to assess existing project portfolios on climate-smart outcomes. In light of this objective, we defined the following evaluation criteria:

1. Usability for projects not intentionally designed for CSA outcomes
2. Usability by individuals without subject matter expertise in CSA
3. Flexibility and manageability of input data requirements
4. Ability to capture and highlight trade-offs between CSA outcomes
5. Actionability of outputs and analysis
6. Overall ease of use

An assessment of the tools against the selected review criteria is listed in Table 1. The evaluation served as a foundation for the development of a conceptual framework. This framework aims to create a holistic decision-making tool that considers all three outcome pillars, is user-friendly, and generates actionable insights to enhance project design and implementation (Rose et al., 2016).

Based on the above, there appears to be a specific utility in a simple, easy-to-use, decision support tool that can visualise CSA trade-offs at different scales, without being overly time consuming, and includes consideration beyond the farm level. In addition, there is a need to help identify specific gaps in knowledge on the performance of CSA

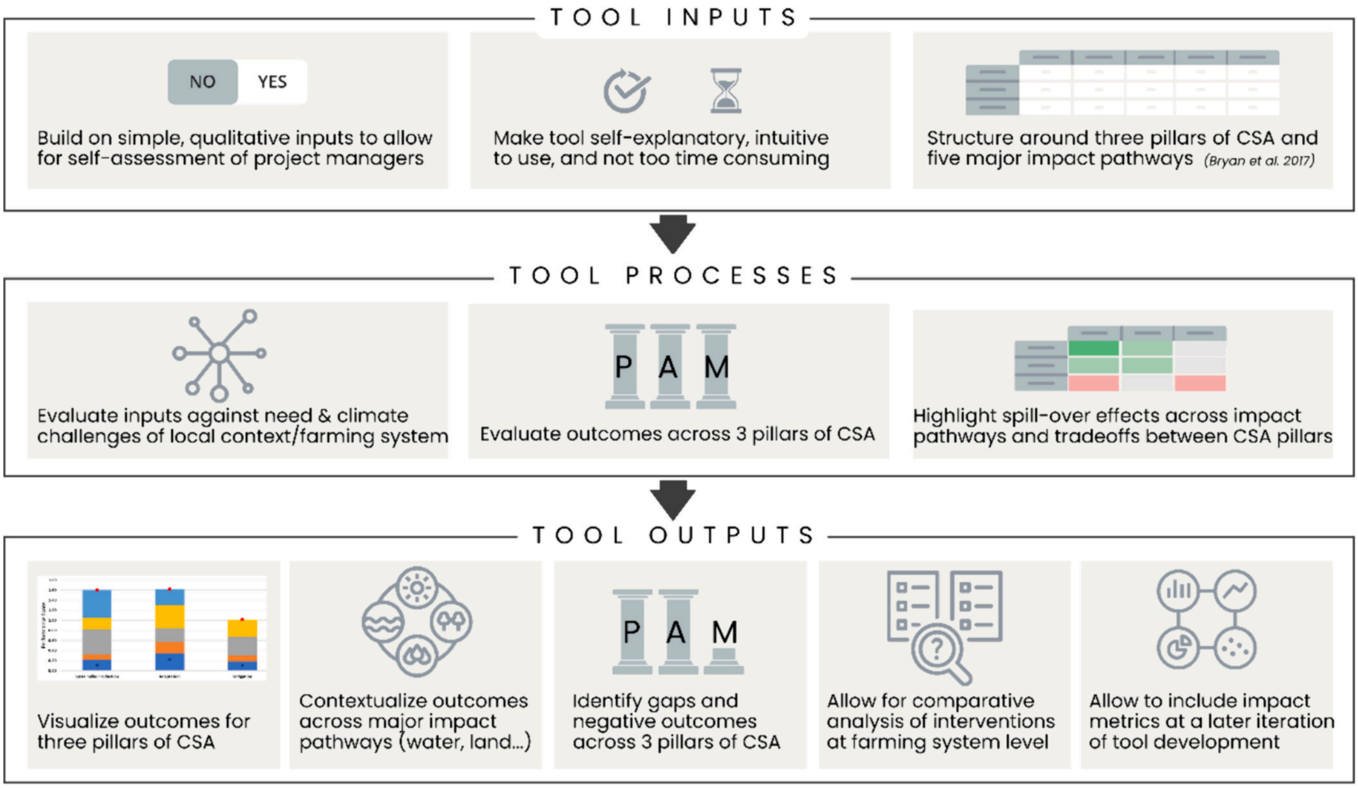


Fig. 1. MVP of the CSA design and decision-making tool. The tool process seeks to balance the need to reflect diverse pathways to multiple benefits and challenges, whilst having limited barriers to use.

Table 1

Reviewed CSA tools and frameworks used to guide the design of the assessment tool. Desirable features and challenges were identified based on the criteria described above.

Tool	Smarter Metrics for climate change agriculture (Stephenson et al., 2020)	Climate-Smart Agriculture Rapid Appraisal (Mwongera et al., 2017)	Climate-Smart Agriculture Programming and Indicator Tool (Quinney et al., 2016)	Consensus-driven decision support framework "Target CSA" (Brandt et al., 2017)
Usability for projects not intentionally designed for CSA outcomes	Best suited for ex-ante evaluation of interventions	- Offers approach for ex-post analysis by assessing interventions against needs and priorities - Identifies intervention opportunities and potential barriers to adoption	Allows for ex-post analysis of projects	- Intervention focus is limited on social dimensions of CSA - Requires ex-ante data analysis and stakeholder consultation
Usability by individuals without subject matter expertise in CSA	Practical approach based on decision trees with yes/no questions. Easy to implement	- Includes questions that require basic knowledge of crop cycles, production constraints, and preferred practices - Requires input from multiple stakeholder groups	Extremely practical approach, supported by Excel-based assessment tool. Easy to use	Requires expert opinion and in-depth analysis of various climate and environmental data sets for decision-making
Flexibility and manageability of input data requirements	Little information requirement for answering input questions	Requires gender-disaggregated interviews with various stakeholder groups	Applicable at multiple scales and with no specific input data requirements	Requires data across several environmental and socio-economic domains, mostly from globally available data sets
Ability to capture and highlight trade-offs between CSA outcomes	No consideration of potential trade-offs between CSA pillars	Highlights potential trade-offs of interventions and connects them to adoption challenges	Does not capture trade-offs and synergies	Highlights potential trade-offs for decisions, albeit focusing on national level
Actionability of outputs and analysis	- Mostly focused at stock stacking at organizational level. Not directly usable for individual projects or farms. - Little contextualization of evaluation. Mostly generic questions at global level	Offers actionable advice on best-suited interventions based on stakeholder preferences, perceived challenges and farmer priorities	- No recommendations for actions - Categories of interventions are generalized and at the level of CSA pillars - Useful to choose indicators	Focuses on interventions at national scale and policy level
Overall ease of use	Individual steps are simple to perform, however entire process can be time consuming	- Requires interviews with various stakeholders - No support tool to structure data collection and analysis	Excel-based assessment solution with results visualization and straightforward assessment process	Time consuming process that requires expert opinion and stakeholder interviews at multiple steps

initiatives.

2.2. Conceptual framework

Based on the tools that were reviewed in step one, we developed a conceptual framework. This also draws on the concept of resilience for development, together with existing climate change and resilience frameworks (i.e., Bryan et al., 2017; de Brauw et al., 2019; Njuki et al., 2021). The framework (Fig. 2, adapted from Bryan et al., 2017) incorporates elements from various other frameworks, including those focused on gender and climate change (Behrman et al., 2014); climate change and nutrition (Fanzo et al., 2017); and agriculture and nutrition (Herforth and Harris, 2014); into the widely used resilience framework by Frankenberger et al. (2014).

The framework emphasizes the interconnected nature of interventions that can act on farms, communities, policies, and decision-making, while also distinguishing between different pathways to achieve desired impacts or outcomes. It illustrates how outcomes are influenced by a range of factors and how multiple pathways can lead to desired outcomes. The choice of pathways is similar to those raised in other studies, Azadi et al. (2021) whose conceptual framework for VSA distinguishes different sources of 'livelihood capital': human, physical, social, financial and natural capital. Whist these are framed around the centrality of small-scale farmers, our study includes consideration of market connectivity.

This understanding also helps to avoid setting ineffective CSA targets and identifying which individuals or groups are likely to benefit or not from the interventions. For instance, Hellin and Fisher (2018) argue that it is crucial to differentiate between groups for whom agriculture is a feasible pathway out of poverty and those for whom it is not, particularly in relation to CSA and livelihoods. The pathways outlined in the framework include agricultural production, income and assets, value chains, and human and natural capital, all of which contribute to achieving the desired outcomes of CSA interventions. Moreover, elucidating the impact pathways aids in recognizing the direct and indirect outcomes that may either strengthen or impede cross-pillar CSA benefits (Andrieu et al., 2019).

Trade-offs and synergies are critical to understanding farmer adoption of CSA interventions:: Adolph et al. (2020) discuss how trade-offs between multiple objectives of food security, sustainability and meeting immediate livelihood objectives (in line with the 3 CSA pillars) are more likely when agricultural policies encourage short-term productivity and do not recognize the diversity of African smallholder farms. Under conservation, agriculture is often cited as an example of CSA claims to have multiple advantages such as saving labour, reducing erosion, and increasing soil fertility and thus yields (Giller et al., 2009). A frequent temporal trade-off identified is that yield improvements generally come after several years, and there may even be yield reductions in the short term (Giller et al., 2009). A review use of conservation agriculture in Sub-Saharan Africa by Rodenburg et al. (2020), while confirming evidence of improved soil characteristics, including soil carbon levels, and often yields, also identified trade-offs with increased labour demands, especially for weed control. A further major trade-off is as regards the use of crop residues, leaving these residues in the field is critical to improving soil fertility and carbon stocks, but for many farmers they are a critical source of fodder for livestock during the dry season (Giller et al., 2009; Rodenburg et al., 2020). In other cases, crop residues are simply burnt in the field to facilitate tillage at tremendous environmental cost in terms of air pollution and at a cost to soil carbon content and fertility.

Under shaded coffee systems in Central America Haggar et al. (2021) found no difference in the response of coffee to fertilizer applications at low or medium shade levels from agroforestry trees, and only at high shade levels was productivity reduced. Furthermore, the most profitable farmers were those who combined moderate levels of shade with higher use of inputs (Lalani et al., 2023). Furthermore, among low-input farms, those with high shade maintained a low but positive net income while those with low shade had negative net incomes. Thus, while there was a trade-off between productivity/income and use of high levels of shade, this was not true for moderate shade conditions and high shade was synergistic with productivity and income under low input conditions. Thus, the interactions between the economic and environmental performance of these systems were not a simple linear relationship.

Table 2 gives a practical example of how an intervention in one domain can be influenced by indirect and feedback mechanisms. In this case, co-benefits from gender empowerment can be seen in the development of a female (dairy farmer) led tree nursery in Kamotony, Kenya (World Bank, 2015) prompted by concerns due to school fees. This project, through sales of indigenous tree seedlings, supported investment in education and expansion of dairy production; improving milk

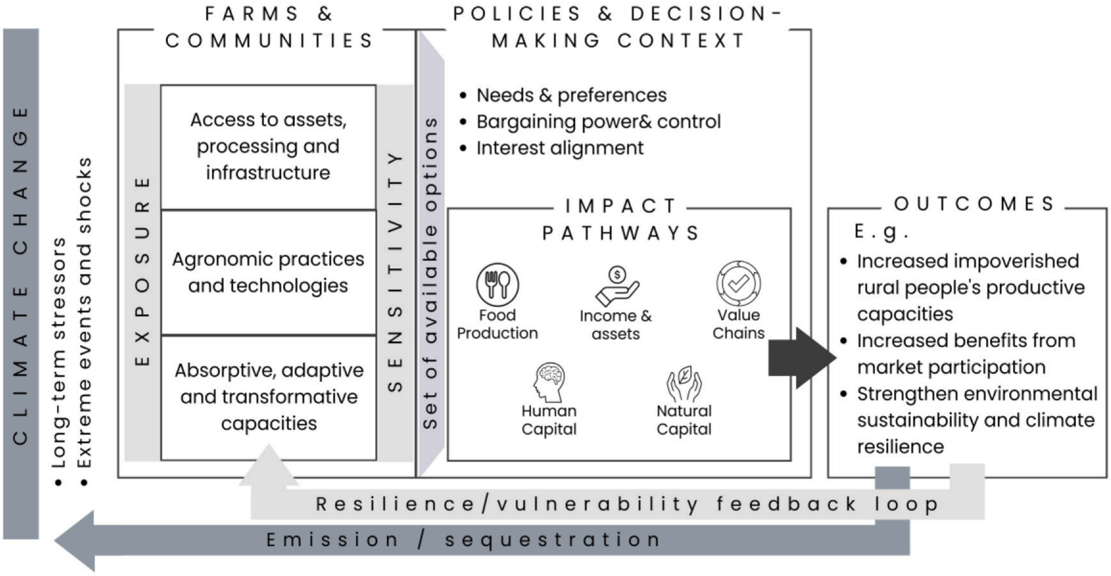


Fig. 2. Conceptual Framework of the CSA design and decision-making tool. This framework is based on the positive feedback loops between climate impacts and vulnerability to future impacts, emphasizing the need for multi-dimensional outcomes across different pathways to embed meaningful resilience. Mitigation activities contribute to reducing global risk, whereas adaptation is needed to respond to localised impacts.

Table 2
Pathways and trade-offs in CSA outcomes based on the establishment and expansion of a female-led tree nursery and associated development of dairy and home garden systems. The potential trade-offs within CSA pillars, which are expressed in terms of potential pathways to increased capital through CSA, adapted from Azadi et al. (2021). The '+' and '-'symbols reflect positive or negative outcomes across the three CSA Pillars.

Pathway	Sustainable Agricultural Productivity	Resilience and Adaptation	Mitigation
Agricultural Production	increases in dairy productivity (+)	Increased availability of indigenous seedlings (+) Expansion of agroforestry initiatives (+)	Healthier soils and increased soil organic carbon (+)
Incomes and Assets	Increased income allows for more access to farm inputs (+)	Increased incomes give access to climate-resilient varieties (+) Increased opportunities for women increase their control over income (+) Increased access to credit (+) Expanded access to nutritious food (+)	Additional manure storage needed (−)
Value Chains	Access to new markets (+)	Increased opportunities to market new crops (+)	
Human Capital	Youth participation in agricultural activities (+)	Increased opportunities for young's education (+) Agroforestry systems provide fuel wood reducing time demands for wood gathering (+) Dependent on presence of FAO funds for training in CSA (−)	
Natural Capital	Increased production output from the farm level (+)		Increased methane emissions due to livestock expansion (−)

yields, fodder production, feed storage etc. This secured funds for education as well as access to capital. The resultant manure derived compost availability helped develop home gardens for nutrient supplementation but ran the risk of additional emissions if not managed properly. It demonstrates the complex interactions and interdependencies within the framework, shedding light on the potential ripple effects that can arise from CSA interventions.

2.3. *Tool structure*

Our tool is designed to assess the impact of CSA interventions on five specific outcome pathways: agricultural production, income and assets, value chains, human capital, and natural capital (Quandt, 2018; Bryan et al., 2017). To ensure that our tool captures both the biophysical and socioeconomic parameters of CSA outcomes, we considered the insights presented by van Wijk et al. (2020). They highlighted that some existing CSA tools focus heavily on the physical science aspects of CSA, which may not be sufficient for assessing outcomes (Constas et al., 2014). Given that CSA settings may not necessarily be information intensive (Eichler Inwood and Dale, 2019), we designed our tool to be flexible and agile. Additionally, since it may be challenging to establish explicit performance criteria that can be integrated across all five outcome pathway areas, we opted to express the impact of CSA interventions in relative terms. Specifically, we benchmarked the performance in the absence of CSA against the performance of the portfolio with CSA interventions.

Our tool focuses on outcomes and does not categorize CSA interventions as technical, behavioural or practice based. We believe that this approach provides a simple and effective means of identifying trade-offs and highlighting the multi-objective nature of CSA interventions. Additionally, our tool considers the spill-over and indirect effects of interventions, feedback loops, and differentiated pathways to impact/outcome, which are crucial for understanding the dynamic nature of resilience or vulnerability to climate shocks and stressors. Finally, we emphasise the importance of taking a portfolio view of CSA interventions, as this enables us to aggregate information at the project level and provide insights into the performance of the entire portfolio. This approach allows us to identify areas where investments are necessary to improve performance and to exchange both information and good practices across projects.

The tool is structured to support prioritisation and allow for contextualisation of different user settings (de Olde et al., 2017) (Fig. 3). In terms of prioritisation, the user has the capacity to determine the relevance of specific outcome areas to their operations. If a particular outcome area is deemed less relevant, a reduced number of criteria questions are presented for that area. The choice of which questions are retained was based on a co-design process within the project team and prospective users. This collaborative approach aimed to identify criteria questions that have cross-sectional relevance, addressing basic issues, which are relevant to different contexts such as considerations of well-being and productivity. Co-design in this instance is considered important to ensure the inclusion of relevant and context-specific indicators that can reflect a potentially diverse portfolio of projects.

2.3.1. *Situational analysis*

In the situational analysis phase, the tool presents contextualising questions across 8 thematic areas based on the presence of, or perceived sensitivity to, water stress, soil loss, biodiversity, income equality, carbon stocks, farm support, gender roles and climate impacts (Fig. 4). These elements are chosen to reflect regional characteristics that inform the underlying challenges for effective CSA implementation or contribute to the vulnerability of both ecosystem services and functional social systems (Below et al., 2012). The answers to these questions are used to generate optional weightings for assessing performance across each outcome. At the same time, the user can select which of the 8 situational questions are relevant to each outcome area. These two processes are intended to foster meaningful participation in the indicator selection and framing process, blurring the line between user and co-designer (Bell and Morse, 2012). Furthermore, the specific choices made by the user moderate the results in some cases. E.g. 'Increased irrigation' is not considered a CSA benefit in instances that experience 'Significant Water stress'.

2.3.2. *Evaluation of project performance*

The scoring of CSA interventions is expressed in terms of the five outcome areas mentioned in Table 2. These outcome areas are chosen to reflect both socio-economic and bio-physical processes, as mentioned adapted from existing frameworks (Quandt, 2018; Bryan et al., 2017; de Brauw et al., 2019; Njuki et al., 2021), which seek to illustrate environmental, economic, and social trade-offs within the CSA implementation. Each outcome area has relevance to all CSA pillars, whilst some may be argued to be more associated with a particular pillar.

Agricultural Production

'Agricultural Production' reflects the fundamental importance of agriculture as underpinning food security and income, as well as

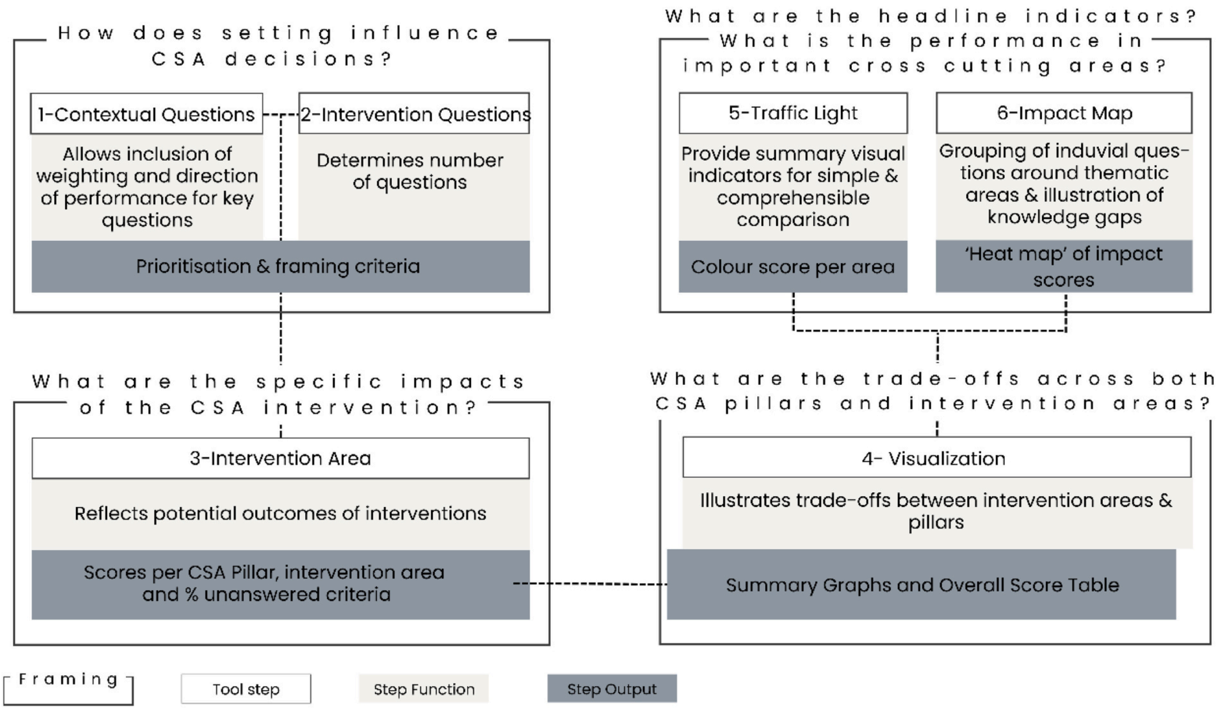
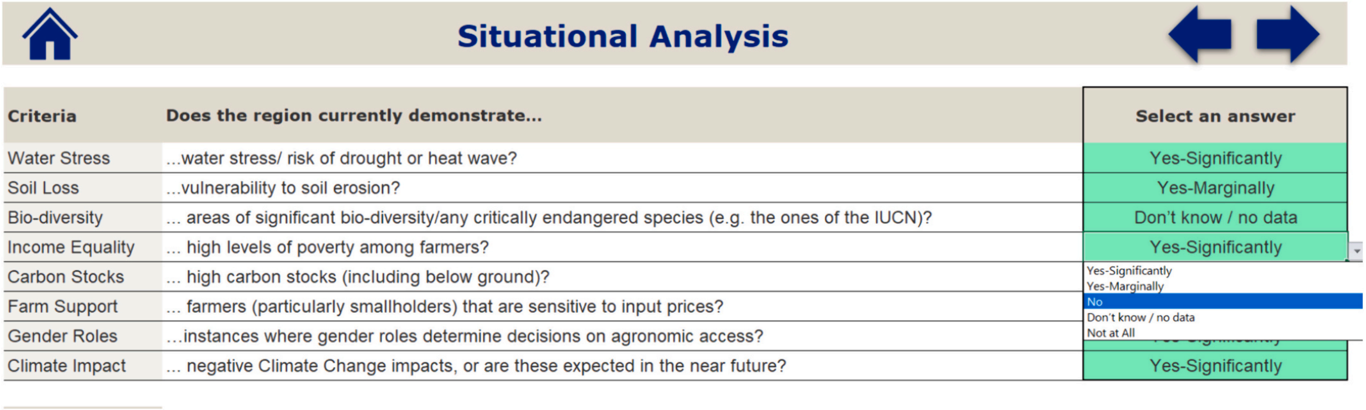


Fig. 3. Overall tool structure with a description of four major steps, distinguishing framing options, title, function and output of each step.



Criteria	Does the region currently demonstrate...	Select an answer
Water Stress	...water stress/ risk of drought or heat wave?	Yes-Significantly
Soil Loss	...vulnerability to soil erosion?	Yes-Marginally
Bio-diversity	... areas of significant bio-diversity/any critically endangered species (e.g. the ones of the IUCN)?	Don't know / no data
Income Equality	... high levels of poverty among farmers?	Yes-Significantly
Carbon Stocks	... high carbon stocks (including below ground)?	
Farm Support	... farmers (particularly smallholders) that are sensitive to input prices?	
Gender Roles	...instances where gender roles determine decisions on agronomic access?	
Climate Impact	... negative Climate Change impacts, or are these expected in the near future?	Yes-Significantly

Fig. 4. Screenshot of the 'Situational Analysis' Excel sheet of the CSA design and decision-making tool. This step serves a dual purpose; firstly, as an opportunity to reflect on the regional specificities that may influence CSA outcomes. Secondly, by answering the questions, the user defines context parameters that the tool will translate into additional weighting if needed.

necessitating resources which may embody climate impacts or other local environmental impacts.

Labour and Assets

The inclusion of 'Labour and Assets' recognises that agriculture is an essential component of income for many communities, particularly in the developing world context. It highlights the importance of safeguarding the wellbeing and practical needs of the CSA implementors themselves. More important, CSA requires that agricultural economic activity also must not disadvantage or marginalise others through, for example, exploitative wages, reduced access to assets, etc.

Value Chains and Processing

The section on 'Value Chains and Processing' understands that the positive and negative effects of agricultural activities extend beyond the field, particularly where additional resources may be needed, or when CSA enables access to new markets.

Natural Capital

The inclusion of 'Natural Capital' performance criteria is based on the need to protect fundamental ecosystem services which are essential for both mitigation and adaptation, as well as maintaining sustainable agricultural systems.

Human Capital

Seeking to enhance 'Human Capital' considers agricultural activities as part of a community of actors that are potential stakeholders in the success of CSA, regardless of their direct involvement in agriculture. Access to, and the ability to share knowledge is crucial. This includes the need to involve the whole community in planning for mitigation and adaptation strategies, especially where there exist groups which may have previously been excluded on gender, ethnic or other grounds.

For each of the five outcome areas, users are required to determine whether defined criteria are expected to change in the presence of a CSA intervention. User responses are chosen from a predefined set of answers, ranging from 'significant increase' to 'significant decrease', with scores ranging from −2 to 2. These scores are based on a positive or negative contribution to CSA when relative to a situation in which the project/intervention was not implemented. For each outcome area, the scores are averaged based on the number of active (i.e., prioritised and compulsory) questions. The scoring mechanism is intended to be flexible to support wide participation (Morse, 2015). It allows participants to assess and understand the likely holistic performance of CSA interventions.

A higher score indicates a change that is consistent with the broader CSA objectives outlined earlier. The scores generated by the tool are qualitative and do not require prior quantification of CSA benefits. Equally, the user has the capacity to determine if a question is not applicable or they do not know the answer, which returns a neutral score for that criterion. This feature is intended to ensure that the tool can be used in situations where limited information is available. However, each active area contains questions that are considered fundamental to CSA and therefore require an answer even if that is 'don't know'. The full list of questions is available within supplementary material.

2.3.3. *Visualization of performance*

Once scores are completed, they are mapped to the three CSA pillars based on their relevance. This mapping allows the calculation of a single overall score for performance, as well as visualization in three different ways: i) net performance at the level of the outcome area, disaggregated by positive or negative scores by CSA pillar; ii) net performance at the level of the CSA pillar, disaggregated by positive or negative scores at the outcome area; and iii) a radar chart of overlapping performance compared with a neutral score (Fig. 5). This approach is based on the value of presenting the same information from different perspectives (Mikalef et al., 2019). It assists in identifying potential trade-offs at both the conceptual level (i.e. CSA pillars) and less abstract scales (i.e. outcome areas). These varied visualization formats are intended to support the tool's utility at both project and portfolio-level CSA interventions.

To facilitate an actionable conception of performance using a traffic light system was established based on whether the responses at the level

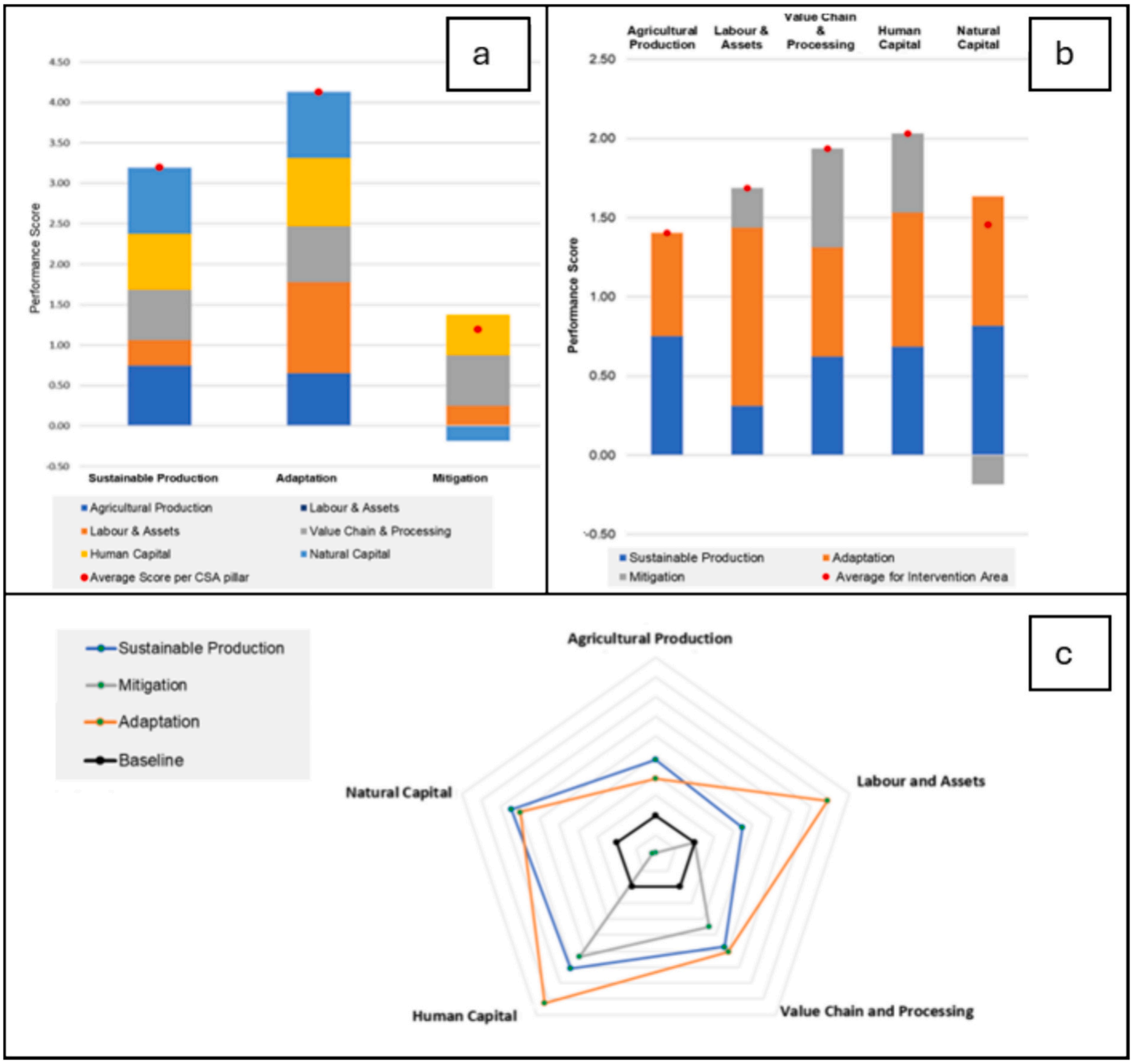


Fig. 5. Visualization of performance across the three CSA pillars and five outcome areas. The scores shown here are derived from internal testing reflecting a cropping system for drought-tolerant crops which benefits from linkages with wider value chains to add value but requires additional on-farm inputs. Graphs a and b reflect the same score of overall performance disaggregated by outcome area and pillar respectively. The radar chart (c) displays the scoring of each Outcome Area as quantitative variables represented on axes starting from the same point. The baseline refers to a neutral score between a positive and negative impact. In this case, the beneficial outcomes in Human capital and Labour and Assets associated with the Adaptation pillar are traded off against negative impacts in Natural Capital through activities that limit Mitigation.

of the outcome area (prior to any weighting) present an overall positive or negative appraisal of CSA performance. To further enhance the assessment, scores are accompanied by an 'impact heat map' whereby the (unweighted) scores for each individual criterion question are distinguished and mapped across each relevant CSA pillar. This mapping allows individual criteria to be visualized across cross-cutting thematic areas such as 'nutrition' and 'diversity and inclusion'. These topics were identified as consequential by early testers during the co-creation process, suggesting that consideration of performance across thematic (rather than output) areas is necessary for insights that support decisions at a portfolio level. An important aspect of designing indicators within the broad area of sustainable agriculture is the ability to identify data or knowledge gaps (Aznar-Sanchez et al., 2019). This tool facilitates the identification of knowledge gaps at different levels of aggregation.

Firstly, the tool presents the percentage of active questions unanswered. This information is accompanied by a visualization of performance at the level of the outcome area, which is also reflected in an accompanying traffic light score. At the individual criterion level, the spread of unanswered questions is visualized in the impact map and does not generate a score in any of the pillars. The rationale behind this is the need to identify not just gaps but be cognisant of where they are located thematically. This approach also seeks to distinguish where an aggregated score is due to poor performance or a lack of knowledge.

3. Perspectives of users

As part of the iterative improvement of the tool, several **initial** project evaluations were undertaken to gauge its ability to provide meaningful insights. Whilst the perceptions of users should not be taken as an absolute account of tool useability, they do provide an indication of tool strengths, limitations, and areas that may require more targeted user support.

The visualization of results was perceived as actionable and enlightening at the level of overall CSA pillars. The ability to present differing scenarios of performance across a portfolio was considered useful in designing and prioritising projects. Users also found the segmentation of different themes useful, particularly in identifying gaps in CSA performance or focusing on specific priorities. However, users encountered difficulties in linking specific interventions to outcomes or linking interventions and outcomes to the context-specific requirements of a given farming system. Despite the heat map providing a high level of granularity in illustrating the contribution of individual criteria to results (e.g., Fig. 6b), users expressed challenges in establishing these connections. The visual mapping of data gaps is arguably a more useful and intuitive way to demonstrate both the extent and location of knowledge gaps. This output may point to potential inconsistencies and avenues for knowledge exchange if there appear to be inconsistencies when the ability to answer some questions would imply sufficient knowledge to answer other related questions (Fig. 6).

Whilst the visualization was considered well aligned with existing objectives and presented in a familiar format, additional support may be needed to facilitate the actionability of results in terms of (re-) designing interventions. Without additional verification, there remains the concern that the tool may not fully inform donors of a project's CSA performance, particularly in instances where a project has a limited duration. The usefulness of the tool is also a function of the baseline knowledge of its users. When asked about the capacity of such a tool to identify important gaps or significant opportunities to implement changes, testers with diverse experiences stated that whilst they were prior awareness of the beneficial CSA activities (and deficiencies) within their programmes/portfolio, the tool could provide a simple way to track progress based on their existing knowledge. Although this came with the caveat that it can be challenging to respond accurately to the questions without additional effort, such as data gathering or consulting other team members.

After the initial process of tool development, to gain meaningful perspective from potential users, a workshop was conducted on August 21st, 2023, in Dhaka, Bangladesh. The objective of the workshop was to identify more effective ways to support smallholder farmers in becoming climate-smart and resilient, whilst also contributing to the common goal of emission mitigation. The participants included academics whose expertise is relevant to CSA, along with experts from the SFSA Bangladeshi team (List of attendees available within supplementary material). Two CSA bundled interventions in the region were evaluated using the tool, based on the ultra-high-density planting (UHDP) regime of mango cultivation and alternative wetting and drying (AWD) of rice. The evaluation was based on the Use Cases information generated for the scalability of these interventions. The CSA impact of these interventions was compared to a baseline of the *status quo* without the intervention (traditional mango and rice cultivation practices; Fig. 7).

The workshop utilised a 'Collaborative decision-making process' (Larson Jr, 2013), known for its efficiency in reducing time consumption, and considering all stakeholder proposals (Konaté et al., 2023) to assess the criteria for each Outcome Area. The process involved a

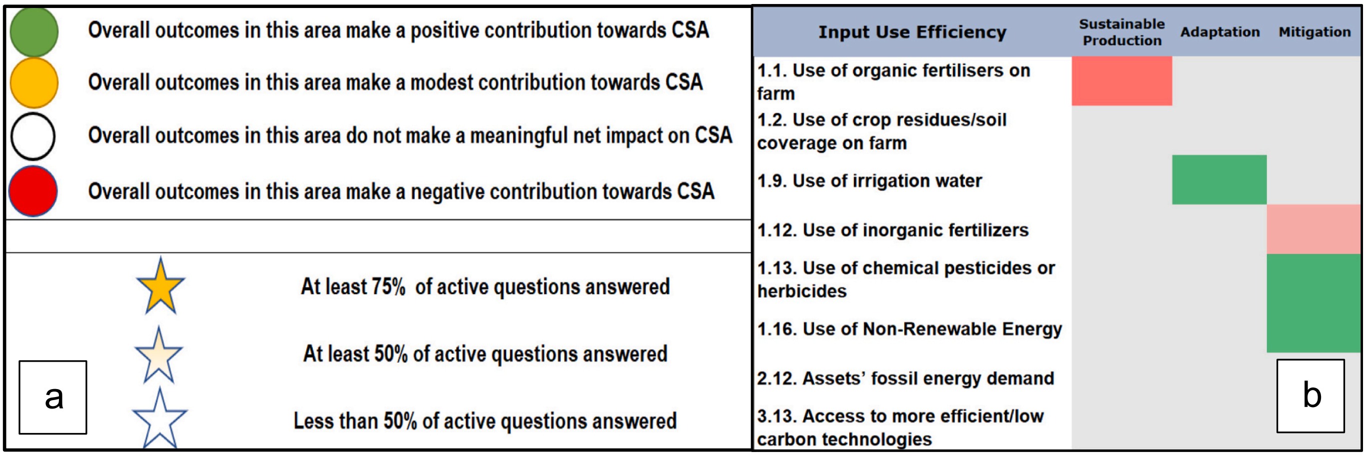


Fig. 6. a: Traffic light designations used to denote performance based on overall responses per outcome area; 6b: example of traffic light scores across the cross-cutting thematic area of 'input use efficiency'. In this example, negative impacts are observed due to increased chemical fertilizer use and a significant reduction in organic fertilizer amendments. Conversely, reductions in chemical pesticide use and fossil energy are seen as positive for mitigation, as they reduce both direct and indirect emissions. Contrastingly, there appears to be a knowledge gap regarding the energy demands of on -farm assets and the use of crop residues. As these aspects are closely related, these cross-cutting themes allow for better cross-referencing of what is known and unknown in relation to performance and can point to areas in need of clarification.

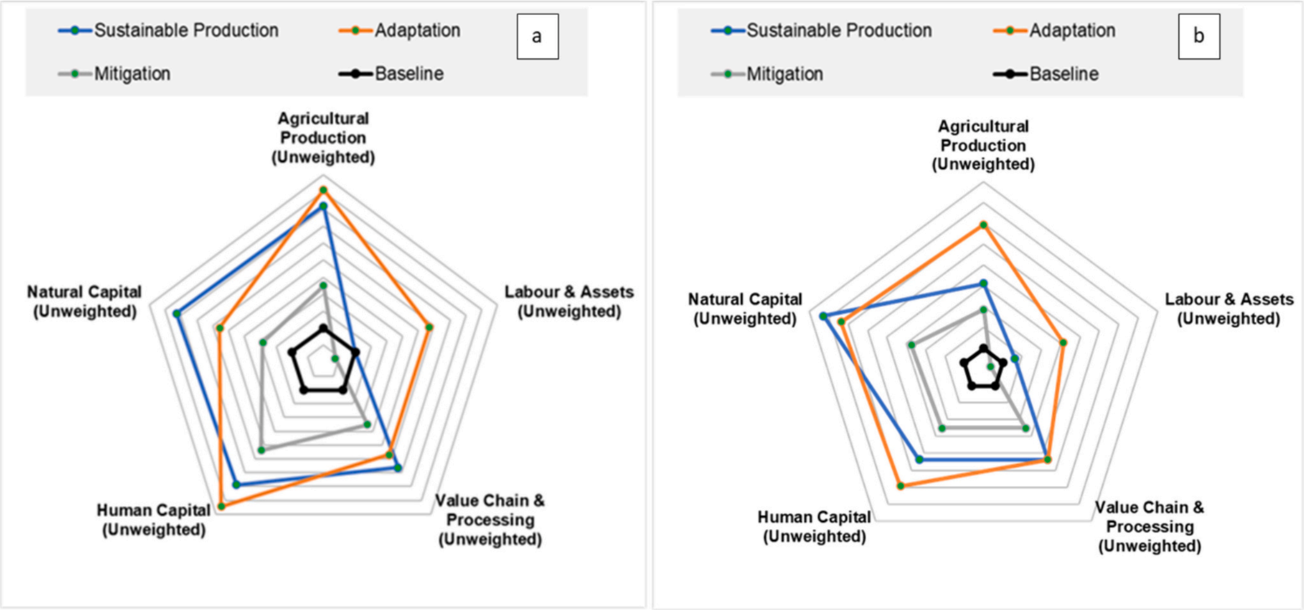


Fig. 7. Spider graph score for (a) UHDP, and (b) AWD bundled interventions. The baseline distinguishes positive and negative outcomes.

preparation phase, during which the methodology and CSA initiative were introduced, information on the case studies provided followed by a cycle of assessment for each of the 5 Outcome Areas. This cycle included sharing a common definition of the assessment criteria, engaging in group discussions to generate alternative assessment perspectives, and holding a plenary discussion to reconcile these differing viewpoints. This cycle included establishing a common definition of the assessment criteria, engaging in group discussions to generate alternative assessment perspectives, and holding a plenary discussion to reconcile these differing viewpoints. Workshop attendees were organised into interdisciplinary groups; ensuring both subject and project expertise in each group. Within each group, members initially assessed the case studies individually before reaching a consensus on a group score. Members initially assessed the case studies individually before reaching a consensus on a group score. In some instances, these discussions resulted in a majority assessment being overturned based on individual expert advice. Final assessment values for each criterion were determined through inter-group discussions, reaching a consensus or majority decision (Fig. 8). This transition from individual and intragroup scoring to intergroup discussion and overall agreement (including the importance of minority and expert opinion) helped consolidate understanding of the strengths and weaknesses of each initiative. The collective sharing of individual and group responses to each question helped identify areas that were most contested. The application of this system reinforced how an interdisciplinary and iterative process can ameliorate data gaps, but nonetheless (subject or project) expert knowledge is needed to sense-check assumptions and (if necessary) overrule a minority decision.

The UHDP-based intervention was ranked as a positive contributor to productivity and adaptation goals. However, this increased agricultural productivity comes at the cost of increased on-farm inputs, such as mechanization and fertilizer application; as well as potentially damaging the soil structure, albeit with short-term fertility improvements. However, there was the view that over its lifetime, the intervention could enhance aboveground carbon stocks, reduce pressure to expand the cultivation area, and ultimately increase the nutrient use efficiency per unit of output. These potential long-term benefits suggest that the UHDP intervention could contribute positively to mitigation goals. On the other hand, there was a concern that the lower tree height would reduce the need for on-farm labor during the harvesting period, which could negatively impact local incomes.

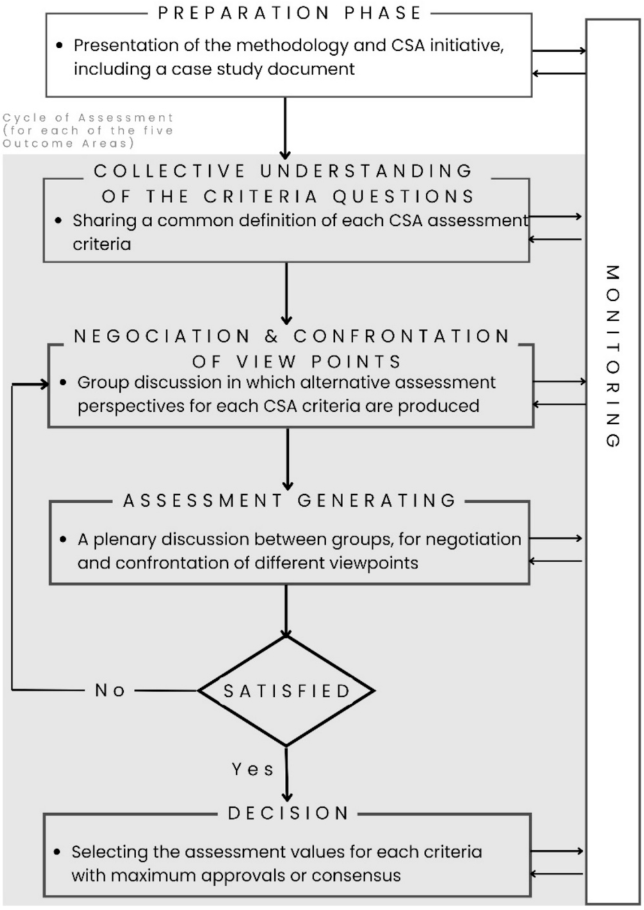


Fig. 8. Model of the collective decision-making process (adapted from Adla, 2010).

Interestingly, the AWD-based intervention performed less well than expected in mitigation as there was the perception that it would come at the cost of increased fertilizer use, losses in soil carbon, and potentially increased cattle husbandry. Under certain conditions (e.g., clay soils), AWD can increase N_2O emissions (even offsetting reduction in CH_4 emissions) due to the transition from anaerobic to aerobic soil conditions. The duration of flooding, transition to aerobic conditions, water level above the soil surface, and the relative timing between fertilization and flooding are the main drivers affecting GHG mitigation potential under AWD. Therefore, careful planning and site-specific management options are necessary (Lagomarsino et al., 2016). Additionally, the respondents evaluated the intervention as labor-intensive, as the number of weeds is greater in AWD during the growing phase, compared to continuously flooded systems (Enriquez et al., 2021).

When comparing results organised thematically within the CSA heatmap, some important spillover effects were discussed which were common to both case studies. The consensus scores for both cases studies suggested that the additional manpower associated with both these production systems could worsen local labor constraints and increase the need to source labor from other localities. Also, for both case studies, failure to manage on-farm labor has suggested increasing the burden of labor on vulnerable groups particularly migrant workers reliant on agriculture. However, the UHDP case study was seen as reducing risk faced by the farmer due to supply chain connectivity as more regionally concentrated production can assist in consolidating and scaling the transport and storage needs along the value chain. (Although regionalised concentration may also come at the cost of redundancy/resilience along the value chain as a whole, itself a spillover concern).

There was a view that a more specific emission reduction mechanism, such as in alternative wetting and drying (AWD) was challenging with the more generalized questions of the tool. This feedback has been taken into consideration for the next iteration of the tool, which includes Methane reduction as a specific criterion (question 5.9 in the supplementary material). Overall, the UHDP option returned a higher score, reflecting its focus on increasing productivity and improving livelihoods, however its lower score in the natural capital outcome area demonstrates important trade-offs in areas such as soil health and biodiversity (Table 3).

Considering the segmentation of performance is arguably the most important insight that can be offered by the tool. By presenting information in various ways, such as through pillar and outcome area scores, it helps to convey the concept of trade-offs. However, it is important that the users do not simply view trade-offs in abstract terms but engage with the individual activities that contribute to them. This is particularly the case when comparing scores due to consistent but underwhelming performance alongside scores that reflect more extreme drivers of positive and negative outcomes (Anderson, 2018). As mentioned, this can be facilitated by discussing the results as expressed as a heat map, but reviewing more granular performance can be assisted by including practitioners who are involved in delivering or facilitating specific activities on the ground. This analysis can serve as a sense-check to verify if the perceptions of CSA benefits are realistic and achievable. In cases with the absence of CSA performance verifiability, drawing on prior knowledge of what incentives have worked in similar settings can be applied (Piñeiro et al., 2020).

Table 3

Summary Scores for workshop case studies; note that each outcome score is disaggregated in terms of positive and negative pillar scores and vice versa.

	UHDP		AWD	
Outcome Area	Average score	% Questions answered	Average score	% Questions answered
Agricultural Production	1.78	100%	1.09	94%
Labour & Assets	0.34	100%	0.31	100%
Value Chain & Processing	1.28	100%	1.13	94%
Human Capital	1.97	100%	1.28	94%
Natural Capital	1.36	100%	1.64	94%
Overall score	**6.73**	**100%**	**5.45**	**95%**
Of which				
Sustainable Production	2.69		1.98	
Adaptation	3.05		2.57	
Mitigation	0.99		0.90	

4. Discussion

With our design and decision-making CSA tool, we seek to support actionable insights to design for and evaluate projects against CSA outcomes. This is an important precursor to identifying barriers to implementation (Zakari et al., 2019). The challenges involved in operationalizing CSA are highlighted with the co-development of this simple decision-support tool. Our aim with this tool is to organise criteria across diverse output areas, enabling practitioners to easily translate CSA objectives into an amalgamation of practices for which good performance should be readily conceivable. The successful operation of CSA can provide a forum for the dissemination of exemplary case studies and share good practices (Kakraliya et al., 2018). By recognizing that performance across pillars and outcome areas may both present trade-offs and how challenging 'win-win' (or indeed win-win-win) results are to achieve, a more explicit project design can be more achievable, maximizing co-benefits and avoiding unnecessary trade-offs.

4.1. CSA within a heuristic setting

Our tool appears to provide meaningful results in a limited number of real-world case studies. The tool results pointed to elements that contributed to positive and negative outcomes whilst also identifying knowledge and intervention gaps.

In terms of supporting peer learning, whilst the tool can be used readily by a single user, ideally it should be used in a group or more than one individual. This can facilitate multi-stakeholder engagement, which is considered essential in gaining an understanding/acceptance of common concerns and objectives (Osumba and Recha, 2022). At larger scales, CSA may be considered part of a collaborative agriculture policy design process, necessitating engagement from multiple stakeholder types (Faling and Biesbroek, 2019). In this case, a preparative discussion may be used to identify more easily rectified knowledge gaps and individuals that may need to be consulted to maximize coverage of portfolio activities. As the questions within the tool do not generally specify a time frame, the users will need to decide and be explicit about whether performance is assessed on a contemporary or prospective basis. The results should be reviewed with wider stakeholder groups to identify the drivers of both good and bad performance, mapping them with identifiable activities. The presence of subject and project specialist opinion was crucial to provide a more rounded context for the efficacy of particular projects, as seen in the case of potential trade-offs surrounding soil fertility (under high density mango plantations) and risk of additional GHG fluxes (alternative wetting and drying of rice cultivation). These discussions are valuable in identifying key areas of clarification and emphasise the importance of collaborative tool usage.

The application of case studies demonstrates its capacity to reflect different projects operating currently and following wider consultation within agricultural specialists, incorporates a sufficient range of criteria to have broad relevance whilst still maintaining a low barrier to uptake. This does not reduce the importance of an incomplete outcome, as identification of the areas that are unknown, or the gaps in the impact map, are themselves insightful (Brody et al., 2008). For example, the concentration of 'don't know' responses within the broader mosaic of topics in the impact map may point to areas where additional knowledge is needed. Achieving such an overview requires a good coverage of responses to individual criteria (de Olde et al., 2016). During our workshop, attendants felt that the graphic visualization of results, especially the heat map, was more informative and more readily communicative than a comparison of numerical scores, particularly in relation to an emphasis on trade-offs. This visualization is most valuable when there is an awareness of the aspects of CSA interventions that have a marginal to no impact and those that have a more substantial impact, particularly when there is a 'high knowledge density' (i.e., a large amount of information necessary to generate meaningful results) associated with the system under review (Barrios et al., 2020). Currently, the tool is being applied within SFSA to inform decision-making in relation to CSA portfolio development.

4.2. Limitations of the tool

The tool was developed to meet the minimal viable product (MVP) specification, which prioritizes simple functionality. However, meeting this requirement comes with its own trade-offs. The main limitation of the tool is that it is based on perception rather than verified metrics of performance. Whilst this tool does provide quantification of perceived performance, it serves as a proxy for actual indicators that measure performance across the three pillars of CSA. Rosenstock et al. (2019a, 2019b) bemoans the lack of evidence for CSA implementation and performance, highlighting insufficient measurement and co-location of studies. The outputs of this tool, being perception based can be readily mapped to appropriate quantitative indicators of performance, provided the boundaries between impact quantification and tool application are consistent.

Whilst this tool does respond to the need for inclusion of all three CSA pillars, the meaningfulness of the tool results depends on accurate user knowledge and understanding. As the defined outcome areas incorporate a range of activities that will interact with different CSA actors, this can lead to a lack of clarity when the boundaries between CSA and non-CSA activities and outcomes are not clear. Adequate context setting and local insights are essential in translating scores into actions and priorities (Zakari et al., 2019). Ideally, available data on CSA performance would be applied in using the tool, but at the very least this process may inform a template for future data gathering and validation by CSA practitioners (the supplementary material SM1 contains suggested indicators that may inform this process.) Therefore, additional user experience is needed to improve the tool as part of ongoing development and identify opportunities to ameliorate some of the limitations, whilst also maintaining the MVP objectives.

4.3. Scope of evaluation

As mentioned, the variety of different activities included in the tool reflects its intended application within the portfolio design, monitoring, review, evaluation, and revision process. A portfolio approach is more meaningful at the regional level, as it considers trade-offs across CSA parameters, ideally involving many different cropping systems (Shirsath et al., 2017). Furthermore, Kakraliya et al. (2018) caution against viewing any single intervention in isolation and demonstrate pathways for layering practices and technologies to enhance adapting to climate risks and 'build resilience…under diverse production systems'. This implies that a portfolio-level view, encompassing many potential outcome areas and intervention types, is likely to be more meaningful than focusing on single projects. Our tool can be used to reflect an entire portfolio, by providing individual scores per project, resulting in a mosaic of scores that can be compared temporarily or spatially. E.g., Scores for individual projects may be compared based on their age, size, location, type, etc. Additionally, project scores may be benchmarked over time to compare the improvement of degeneration across different outcome areas.

Alternatively, this tool can be used to provide a single score for a portfolio whereby the performance criteria are assessed in aggregate (i.e., the effects of multiple projects are considered holistically in each outcome area). However, a single portfolio score presents the additional challenge of identifying important interactions between projects that are co-located. This makes it more difficult to present benchmarks or targets, as improving the performance score at the aggregate level differs from improving scores at the project level, considering that they have levers and barriers that manifest at different scales (Paut et al., 2019). Whilst the comparison of individual qualitative project scores within the umbrella of a portfolio is arguably more meaningful, the experience of some workshop participants is that the visualization of performance is more impactful.

5. Conclusion

The Design and Decision-making CSA tool offers an approach to evaluate climate-smart outcomes from a given intervention (or set of interventions) in agricultural development. It can highlight spillover effects and trade-offs between the three pillars of CSA and across five outcome pathways. This tool was built to be flexible in terms of input data requirements and to provide an actionable analysis to guide intervention design and implementation. Initial use cases with SFSA project managers have indicated its usefulness in making project and portfolio-level decisions, and evaluating and designing interventions for CSA outcomes. In the development of a practice of application, both project and subject specialists reviewed a number of case studies, emphasizing that whilst positive outcomes across all three pillars of CSA were considered credible, important trade-offs remain, such as balancing adequate productivity, necessary input, indirect emissions and direct localised environmental burdens. Identification of individual trade-offs at the project level can assist in the design of a portfolio in which the strengths and weaknesses of individual projects can complement each other. This seeks to identify pathways for the actualisation of all 3 pillars of CSA, which may be beyond the gift of a single project.

The ability to identify and present performance in different levels of disaggregation-including the trade-off between broad CSA pillar aspirations and specific outcomes- is helpful in communicating with different stakeholders and portfolio managers. We therefore see this as an opportune moment to release the tool into the public domain, inviting partners and organizations in agricultural development to test it and collaborate for further tool improvement, to develop a standardized solution to evaluate the CSA outcomes of interventions in agricultural development. However, we emphasise that this (and other such tools) are best served accompanied by efforts to gather sufficient data and information to be able to reliably utilise tools such as these to make informed decisions.

CRediT authorship contribution statement

Conor Walsh: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Mara Renn:** Conceptualization, Data curation, Funding acquisition, Investigation, Project administration, Resources, Visualization, Writing – original draft, Writing – review & editing. **Dominik Klauser:** Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources, Validation, Writing – original draft, Writing – review & editing. **Alessandro de Pinto:** Conceptualization, Funding acquisition, Investigation, Methodology, Writing – original draft. **Jeremy Haggar:** Writing – review & editing. **Rouf Abdur:** Funding acquisition, Resources, Validation. **Richard J. Hopkins:** Writing – review & editing. **Farhad Zamil:** Funding acquisition, Project administration, Validation.

Declaration of competing interest

Conor Walsh, Alessando de Pinto and Jeremy Haggar reports financial support was provided by Syngenta Foundation for Sustainable Agriculture in terms of funding for research time and associated costs. Beyond the funding of research time, the authors declare that they have no known competing financial interests or personal relationships that

could have appeared to influence the work reported in this paper. The other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The Syngenta foundation is committed to transparency, ethical conduct, and our mission. We define conflicts of interest as situations where personal or business interests diverge from our objectives. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this study. Furthermore, whilst the research presented here is intended for use by Syngenta foundation, it was developed in conjunction with independent academic researchers and revised based on advice and input from external experts and practitioners.

Data availability

Data will be made available on request.

Acknowledgments

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Appendix A

Table A1
List of participants in the workshop in Dhaka, Bangladesh.

Organization	Sector	Area of expertise	N° of participants
FAO	International Cooperation	Food Systems	1
Soil Resource Development Institute	Governmental	Soil	2
BRAC	International Cooperation	Climate Change	1
Syngenta Bangladesh	Private	Sustainability	1
Sher-e-Bangla Agricultural University	Academia	Entomology	1
Bangladesh Agricultural University (BAU)	Academia	Entomology	1
Sher-e-Bangla Agricultural University	Academia	Plant pathology	1
Department of Agricultural Extension	Governmental	Agriculture	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Nutrition	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Agriculture services	1
Christian Commission for Development in Bangladesh (CCDB)	Non-governmental	Climate Change	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Agricultural Insurance	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Program development	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Country director	1
Helvetas	International Cooperation	Gender and social parity	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Communications	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Program administration	1
Natural Resources Institute, University of Greenwich	Academia	Climate Change	1
Syngenta Foundation for Sustainable Agriculture	International Cooperation	Climate Smart Agriculture	1
Total Participants			**20**

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2024.104060.

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