Nature-based solutions for climate-resilient and circular food systems

A first step towards an economic evaluation

Vincent Linderhof, Annemarie Groot and Daan Verstand

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This study was carried out by Wageningen University & Research and was commissioned and financed by the Dutch Ministry of Agriculture, Nature and Food Quality within the context of the Knowledge Base programmes 'Food Security and Water Valuation' (KB35) and 'Circular and Climate Neutral Society'. The study received inputs from the project 'Nature-based solutions for climate-resilient and circular food systems' (KB-35-007-002) and 'Circular and Climate Neutral Society' (KB-34-007-010) and the project 'Transition Pathways' (KB-35-006-001).

Wageningen Economic Research
Wageningen, May 2023

REPORT
2023-021
ISBN 978-94-6447-679-8

WAGENINGEN
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Vincent Linderhof, Annemarie Groot and Daan Verstand, 2023. *Nature-based solutions for climate-resilient and circular food systems; A first step towards an economic evaluation.* Wageningen, Wageningen Economic Research, Report 2023-021. 34 pp.; 10 fig.; 2 tab.; 31 ref.

Nature-based solutions (NbS) are promising in contributing to societal goals such as food security and combatting and adapting to climate change. However, existing assessment approaches of nature and biodiversity lack a clear connection to food systems and food system outcomes such as food security and food system resilience. We propose a new methodology to assess benefits and costs of NbS in food systems from a social and an economic perspective that can be used by researchers, NGOs and governments. The approach includes 3 steps: 1. Theory of Change, 2. Food system framework and 3. Extended stakeholders analysis including distribution of benefits and costs. The approach is tested in two case studies from Ghana using information on workshops, focus group discussions and interviews with stakeholders. The case study results indicate that rainwater harvesting for irrigation (RWHI) and the Modified Taungya System (MTS) positively affect food security because of increased production, but both examples have negative impacts as well.

Key words: Theory of Change, Nature-based Solutions, Food Systems Approach, Extended stakeholder analysis

This report can be downloaded for free at https://doi.org/10.18174/629688 or at www.wur.eu/economic-research (under Wageningen Economic Research publications).

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Wageningen Economic Research Report 2023-021 | Project code 5200046891

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Contents

Glossary

Acronym	Description
GUFE	Ghanaian Urban Food Environments
NFP	Netherlands Food Partnership
SOP	Standard Operating Procedures
FNS	food and nutrition security
CSIR	Council for Scientific and Industrial Research in Ghana
MoH	Ministry of Health in Ghana
MoE	Ministry of Education in Ghana
MoFA	Ministry of Food and Agriculture in Ghana
TSS	Transition Support System
FDA	Food and Drugs Authority in Ghana
CSR	Corporate Social Responsibility
NGO	non-governmental organisation
RTE	ready-to-eat
WHO	World Health Organization
NNP	National Nutrition Policy
PFJ	Planting for Food and Jobs
GNSDF	Ghana National Spatial Development Framework

Summary

Nature-based solutions (NbS) are promising in contributing to societal goals, such as food security and combatting and adapting to climate change. However, the existing assessment approaches to assess the use of NbS to improve nature and biodiversity lack a clear connection to food systems and food system outcomes such as food security and food system resilience. We propose a new methodology to assess benefits and costs of NbS in food systems from a social and an economic perspective. These effects facilitate the identification of winners and losers of the NbS application. It can be used by researchers, NGOs and governments to advice and to shape the optimal governance structure to maximise the impact of the NbS from a food security, climate adaptation and circularity perspective. The new methodology is applied on two case studies in Ghana, showing its suitability and potential for other cases and analyses. With the application of the combination of the Theory of Change (ToC) approach and the food systems framework as ex-ante evaluation tools (see Figure S1), the insight into effects and impacts of NbS on climate-resilient and circular food systems is enlarged. Both existing frameworks present the effects of an intervention in detail with an own focus. By identifying the stakeholders related to the NbS and their effects based on the ToC and FS framework as an additional follow up-step, it can be assessed whether there are trade-offs, and indicated which stakeholder group(s) benefit from the NbS and which might be burdened with additional costs or negative effects. To mitigate the trade-offs, policy makers or private actors can come up with solutions for compensations or redistribution of benefits.

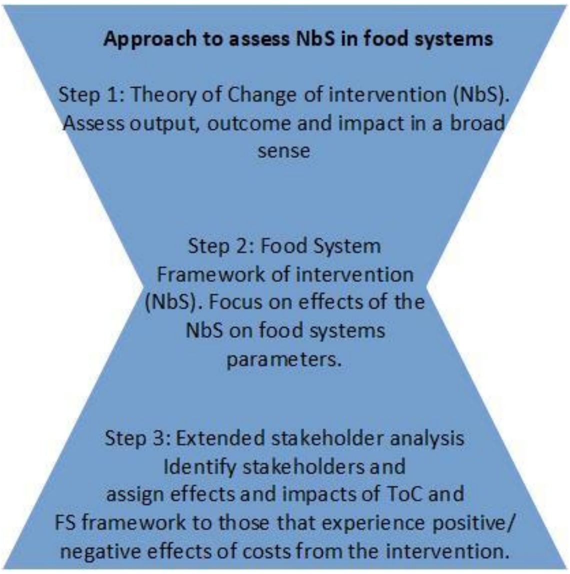

Figure S1 *The new 3-step approach to assess the contribution of NbS towards climate-resilient and circular food systems*

Our 3-step step approach (1. Theory of Change, 2. food system framework and 3. Extended stakeholders analysis including distribution of benefits and costs) is tested in two case studies from Ghana in which NbS are considered to enhance food security in a climate-resilient and circular food system. The case study results indicate that rainwater harvesting for irrigation (RWHI) and the Modified Taungya System (MTS) positively affect food security because of increased production, but both examples have negative impacts as well. Circularity in both cases is not guaranteed because of intensified production, meaning that additional policy actions are required. RWHI contributes to climate adaptation as it makes farmers less reliant on the water system. MTS mainly contributes to climate mitigation, by storing carbon emission in trees. Neither of these ecosystem services provided by either RWHI or MTS are rewarded yet. The application of the 3-step approach to the NbS can be helpful to convince other stakeholders to become involved in the implementation, although they might consider negative effects in the initial ideas.

1 Introduction

Background

The definition of Nature-based Solutions (NbS) is contested and there is no single and clear definition in the literature or practice. Regardless of the exact definition, there is a claim that NbS can contribute to societal challenges such as climate-resilient and circular food systems. The United Nations Environmental Programme (UNEP) introduced the concept of 'Nature-based Solutions' specifically to promote nature as a means for providing solutions to climate mitigation and adaptation challenges in different domains (IUCN 2012; 2016). Nature-based Solutions are considered to offer multiple ecological, economic and social benefits simultaneously including synergies and dealing with trade-offs. A list of Nature-based Solutions approaches and examples, as indicated by the International Union for Conservation of Nature (IUCN) is presented in the annex. One of three programs areas of the IUCN is 'Deploying Nature-based Solutions to global challenges in climate, food and development' particularly targeted at food (IUCN 2012). The European Commission (EC), however, has adapted a broader definition than the IUCN definition and places more emphasis on applying cost-effective interventions that are 'inspired by, supported by, or copied from nature' and 'simultaneously provide environmental, social, and economic benefits and help build resilience' by bringing 'more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes' (EC 2015). The EC considers Nature-based Solutions as interventions that aim to help societies to address a variety of environmental, social and economic challenges in sustainable ways, e.g. Keesstra et al. (2023).

Objective

This report proposes a new approach to assess the contribution of NbS to food security, climate resilience and circularity, as well as to improve understanding about the distribution of costs and benefits amongst stakeholders involved. It can be used by researchers, NGOs and governments to advice and to shape the optimal governance structure to maximise the impact of the NbS from a food security, climate adaptation and circularity perspective, see Keesstra et al. (2023). We suggest an 3-steps approach to ex-ante assessment of the potential benefits of NbS in food systems, namely; 1) Theory of Change of NbS; 2) Application of the NbS in the food systems framework; and 3) extended stakeholder analysis to identify and describe the stakeholders affected in a positive or negative way including the distribution of NbS impacts amongst stakeholders.

The design and implementation of NbS need to consider how the contribution of biodiversity and ecosystem services to human welfare can be valued and incorporated. Moreover, markets can be organised in such a way that NbS become more attractive to investors, producers and consumers, like payments for ecosystem services (IUCN 2012). The organisation of these markets depends on the interplay i.e. the roles and agreements between different aspects such as governance, social responsibility and distribution of economic benefits. Although it is important to understand the real costs and benefits of NbS, both immediate and over the longer term (IUCN 2012), advantages of NbS are often not immediately apparent, but instead accumulate over a longer period. Furthermore, those benefits are often not directly quantitatively measurable or valuable (Naumann et al. 2014). The IUCN has been working on the transformation of the private sector impacts with tools, standards and mechanisms (IUCN 2012). Moreover, in the case of public investments or involvement of private sector, the distribution of costs and benefits over the different stakeholders needs to be addressed as well, because those paying for NbS might not be the only ones benefitting. In addition, the distributions of the costs and benefits largely depend on the governance of the implemented Nature based Solution. State of the art knowledge about stakeholders in relation to NbS mainly focuses on their role in implementation (Ferreira et al. 2020). There is still limited insight into the distribution of costs and benefits over different stakeholders. Two essential aspects in NbS for climate-resilient and circular food systems are 1) the role of stakeholders throughout the process of implementation and 2) the identification of which stakeholder(s) invests in NbS and which stakeholder(s) receive benefits from the NbS.

The implementation of NbS with contributions to climate resilience circularity and food security is still limited to small-scale and pilot projects. To achieve impact with those NbS, its implementation needs acceleration and scaling (Budding Polo-Ballinas et al. 2022). With a better understanding of how NbS contribute to food security, climate resilience and circularity, and an increased understanding of the distribution of costs and benefits amongst stakeholders, the societal impact of NbS can be better assessed and as such increased.

Since we are focusing on the food system, the emphasis of NbS is not only on land use or agriculture but also on other segments of the food system, such as transport, wholesale, retail and consumers. In this study the nature-based solutions emphasised are the ones that mitigate greenhouse gas emissions, support carbon sequestration, adapt to climate change and strive for circularity.

Approach

First, we present the results of the explored literature on the current ways of assessing the impacts of NbS in general (Chapter 2). Next, we introduce our three step approach of assessing the effects of NbS and the distribution among stakeholders of these effects (Chapter 3). The first two steps consist of using two methods for evaluation Nature-based Solutions: Theory of Change and Food Systems framework. We use these existing approaches to summarise and visualise the impacts of NbS. We explore the Theory of Change (ToC) approach to define and visualise the outputs, outcomes and impacts of NbS in a systematic way. Then, we use the results to identify the effects of the NbS on the food systems using the Food Systems framework (van Berkum et al. 2018). Both frameworks are already used in food system analysis and are therefore also promising for the evaluation of NbS in food systems. The effects and impacts of Nature-based Solutions on food systems are the starting point for the third step that we present in this study; identify and labelling the stakeholders that invest and those who receive benefits from NbS prior to the implementation (ex-ante assessment). The effects and impacts from ToC and Food System framework are a prerequisite to identify the different stakeholders that invest and/or benefit from NbS. Therefore, ex-post assessments from earlier studies are required to be able to identify ex-ante assessments of the effects of NbS as intervention in the food system on circularity, climate resilience and insight into the distribution of costs and benefits amongst stakeholders. An ex-ante assessment can help to determine to what extend it is beneficial to invest in NbS in food systems. The three-step approach is further elaborated in Chapter 3.

This approach can be used to assess whether the implementation of a NbS in food systems can be seen as a just adaptation to climate change, because it identifies who experiences positive effects (benefits) and who carries the costs or experience negative effects. Just adaptation means that when adapting to climate change in one place, risks do not shift toward other places or further in the food chain. It tries to provide a more connected approach on adaptation risks (Lager et al. 2021). Knowing how costs and benefits are distributed among stakeholders is essential to address just adaptation (Brisley et al. 2012). By identifying who experiences benefits and who has to carry the costs or negative effects, winners and losers of adaptation by implementing NbS can be identified ex-ante, giving input for discussion on the realisation of NbS and possible re-distribution of benefits among stakeholders.

The approach we propose is applied on two NbS case studies, of which the results are presented in Chapter 4: small-scale rainwater harvesting for irrigation and the Modified Taungya System (MTS) as a type of agroforestry. The case studies are ex-ante evaluations. For both cases we consider that the NbS are applied in the context of the Bono East Region in Ghana, which will be affected by climate change in the future which will cause a reduction in water availability. Chapter 5 discusses the suitability of the approach and concludes.

2 Methodology

In the literature, there are several examples available for the assessments of NbS. However, these assessments are often explored from an ecological perspective. In the case of NbS in urban areas, there is also emphasis on the economic aspects of NbS, including valuation of non-marketed benefits. This chapter provides an overview of a selection of existing assessment approaches applied on NbS, including business models used for NbS. The existing assessment approaches will be judged how they link to food security, climate-resilience and circularity of the food system.

2.1 Assessment of NbS

NbS have the ability to adapt to and mitigate the impacts from climate change, conserve biodiversity and improve human health and well-being (Cohen-Shacham et al. 2016). Based upon experiences in urban areas, a framework for the assessment and implementation of the co-benefits of nature-based solutions was developed (Raymond et al. 2017; Raymond et al. 2017), see Figure 2.1. It covers a wide range of aspects, such as the climate and physical environment, ecosystems, biodiversity and socio-economic and socio-cultural systems. It tries to combine and link these aspects in the view of NbS. This framework includes relevant elements such as biodiversity, climate adaptation and mitigation and circularity in terms of urban regeneration. However, the framework of Raymond et al. (2017) lacks an explicit link to food security or the food system.

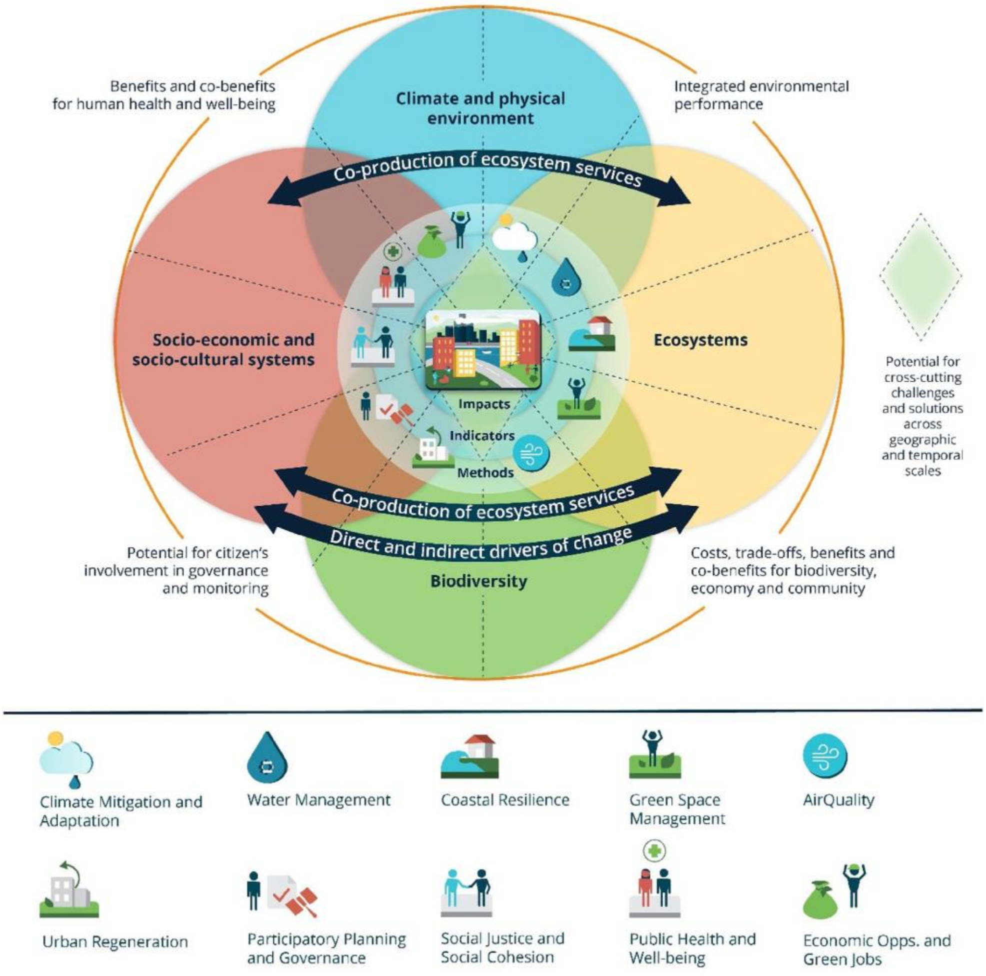

Figure 2.1 *The NbS assessment framework and ten challenge areas according to Raymond et al. (2017)*

Other examples of the assessment of NbS in several disciplines such as water management in urban environments (Oral et al. 2020) and climate change (Seddon et al. 2020) are discussed below.

Oral et al. (2020) assessed three NbS for urban water management in circular cities: (i) flood and drought protection; (ii) the water-food-energy nexus to switch from waste water treatment to commodity production including fertiliser, urban green, cooling and enhancing biodiversity; and (iii) water purification. Based on a literature review, they concluded that NbS provide additional benefits, such as improving water quality and increasing biodiversity. For the assessment criteria, several frameworks and indicators from the literature were used (Oral et al. 2020). The approach of Oral et al. (2020) does not have a clear link to food security, although there is a link with the Water-Energy-Food nexus and circularity from a water management perspective.

Seddon et al. (2020) introduced the socio-ecological framework for an integrated assessment of NbS to climate change (Seddon et al. 2020). Exposure, sensitivity and adaptive capacity form both the ecological and the socioeconomic system are included, see Figure 2. Concerns raised by Seddon et al. (2020) were the reliability and cost-effectiveness of NbS compared to engineered and more technical alternatives. However, they argued that the impact of NbS could outweigh the impact of engineered alternatives when other perspectives of vulnerability were considered. For example, the impact of NbS on climate change has three dimensions: reducing exposure (protection from erosion, inland flooding, coastal hazards and sea-level rise, moderate urban heat waves, managing storm waters in urban areas and sustaining natural resources in drier areas), reducing sensitivity to climate shocks, and support adaptive capacity.

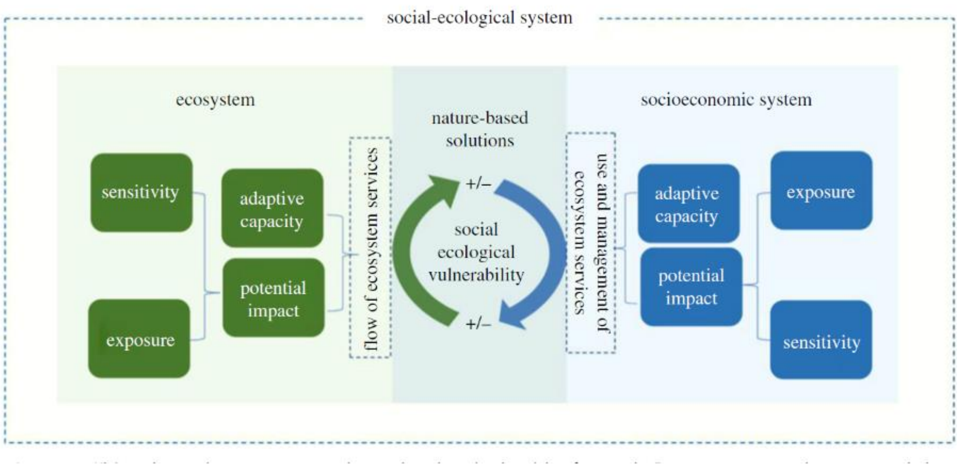

Figure 2.2 *Socio-ecological framework for an Integrated assessment of NbS to climate change (Seddon et al. (2020)*

The framework of Seddon et al. (2020) primarily focuses on climate change impacts, and does not explicitly link to food security. Moreover, stakeholders as such are not identified.

In response to remaining knowledge gaps and a lack of comprehensive evidence on the reversibility, flexibility, cost-effectiveness and feasibility and/or long-term sustainability of NbS, an EU study has recently been carried out (EC 2021). This study provides guidelines for urban practitioners to support the adoption of common indicators and methods for assessing the performance and impact of diverse types of NbS in urban areas (EC 2021). The suggested frameworks, indicators and evaluation methods are derived from the lessons learned of diverse EU-funded projects on NbS carried out. These lessons show the usefulness of linking the evaluation of NbS to the theory of change of the intervention. The authors stress, amongst others, the need for impact evaluations being scientifically sound making use of criteria including legitimacy, salience, credibility and feasibility for the identification of indicators, and the use of a transdisciplinary approach. In line with its urban focus, recommended indicators in the climate resilience challenge area primarily address direct impacts of NbS on greenhouse gas emissions via carbon storage and sequestration in vegetation and soil, indirect impacts of NbS on avoided greenhouse gas emissions from various activities, through the provision of passive cooling, insulating and/or water treatment; and impacts of NbS on temperature and human comfort. A large set of indicators with respect to the impact on resilience to natural and climate hazards are also provided. Moreover, the study provides a large set of indicators to capture the diversity of potential benefits, co-benefits, and trade-offs related to NbS use for urban water management. However, although the study recommends to consider the effect of NbS on knowledge and social capacity building, participatory planning and governance, social justice and social cohesion, and new economic opportunities, the report does not consider the distribution of costs and benefits amongst stakeholders (EC 2021). The handbook does not consider an assessment of the effects of NbS in relation to climate resilient and circular food systems.

Calliari et al. (2022) highlight the need for an integrated valuation of economic, social and environmental benefits and costs associated with NbS to ensure they are considered alongside conventional grey solutions. The authors discuss the benefits and climate impacts areas that could be addressed for several NbS options in different domains. For agriculture, retention of water and soil, mitigation of heat stress, control of disease and pests, carbon sequestration, soil fertility and biodiversity are possible criteria to assess the value of NbS. Droughts, floods and heat stress are considered key climate impact areas to look into. The distribution of costs and benefits amongst stakeholders has not been addressed in the study.

2.2 Method

The framework developed for the assessment of benefits of Nature-based Solutions in urban areas provide guidelines for stakeholders (Raymond et al. 2017; Raymond et al. 2017). However, this framework and its application mainly focused on the ex-post assessments which means that the decisions to implement Nature-based Solutions has already taken place. Our objective is work towards ex-ante assessment. Ex-post studies can help us with that by providing effects and lessons learned.

The assessment of the impact of NbS is complex and requires the involvement of multiple scientific disciplines (Sonneveld et al. 2018). With the perspective of the food system, opportunities emerge for actors in the food system to collaborate along the value chain. An interesting example of this collaboration is the certification chocolate products in the cocoa value chain. Although it is not an example of a Nature-based Solution, it shows the collaboration in chocolate production of all actors in the cocoa value chain. In the case of agricultural water management in low- and middle income countries, existing NbS examples have been analysed in a more integrated framework (Sonneveld et al. 2018). With a qualitative assessment on a five point scale, the success or failure of the NbS was determined for a range of factors, such as the involvement of stakeholders, see Tabel 2.1. All factors were equally important (Sonneveld et al. 2018).

Table 2.1 *Factors of assessment for success or failure of Nature-based Solutions*

Type of factors	Underlying factors
Trans-disciplinarity	identification of stakeholders and beneficiaries
	prevailing degradation process
	assessment of stakeholder involvement
	the degree of trans-disciplinarity (multiple disciplines)
	typology of nature-based solutions (i. non/minimal intervention, ii. partial intervention, iii. inclusive interventions in ecosystems)
Rewarding custodians	rewarding schemes for custodians
Institutional collaboration	stability of institutional collaboration
	stability of financing
Success/failure	success or failure of the nature-based solutions

Source: Sonneveld et al. (2018).

On the one hand, costs and benefits of the NbS were not explicitly addressed in the study of Sonneveld et al. (2018). On the other hand, the role of stakeholders and governance were explicitly addressed in the assessment. A successful implementation of Nature-based Solutions requires the involvement of multiple actors with practical experiences (Sonneveld et al. 2018). Obviously, these actors will also have responsibilities for investment, land rights, beneficiaries and people suffering from negative externalities. In contrast to the study of Sonneveld et al. (2018), our framework will emphasise the ex-ante assessments of NbS, including the context and conditions required.

In a study reviewing 142 papers, the current state of the art regarding citizen and stakeholder participation in NbS in urban environments was analysed (Ferreira et al. 2020). This review paper did however not address food systems, food security or urban food issues.

The authors make a distinction between users (citizen) and stakeholders (e.g. city planners) (Ferreira et al. 2020). Based upon their observations and taking in mind the impact of food systems, we can state the following:

- Understanding stakeholders' perceptions of risks, and challenges and engaging them in the planning process can potentially bring benefits, like reduction of costs, increase of acceptance etc.
- Stakeholders' perception of challenges: majority of the reviewed papers address challenges in relation to governance, financial and societal support
- The 'biodiverse edible schools' link food production and consumption with local biodiversity (Fischer et al. 2019). This concept adopts a long-term engagement of stakeholders from various domains to improve healthy food and environmental education at the school
- Main barrier hindering public participation is related to the cultural domain: poor social mobilisation is reflected in the citizens' perception that solving societal problems is the responsibility of government, and not their own
- Learning labs and living labs are also frequently discussed in literature
- The majority of the literature addresses social benefits of Nature-based Solutions, and environmental benefits (air quality, climate) and only a few studies look at the economic benefits.

2.3 Business models used for NbS

For the successful implementation of NbS, it needs to be clear how they create value for the actor(s) that implemented the NbS and for society (reduction of negative environmental externalities such as greenhouse gas emission, water pollution etc.). This value creation is often captured with business models of NbS. However, business models are usually only set up for the actor(s) that implement the NbS and not for other affected stakeholders, while NbS often affect more than one single actor. Moreover, NbS can be implemented in several forms with different governance structures. These examples range from small-scale NbS implemented by one agent to the implementation of large-scale, public NbS with the involvement of many agents actively and passively such as NbS in redevelopments of urban centres or NbS in coastal areas for flood protection such as re-installing mangrove forests. In all cases of NbS implementation, the economic benefits and costs need to be addressed for all actors affected. However, there have been a few studies on the economic and financial framework of the nature-based solutions.

Toxopeus and Polzin (2017) identified in the Naturvation project four archetypes of business models and financial arrangements for NbS, see Table 2.2. This serves as a starting point to understanding the possibilities for building business models based on ecosystem services of NbS and for suitability of financing arrangements. In the following paragraphs we cover the business models and financing literature relevant to NbS coming from various disciplines, such as ecology, urban planning, business, economics and finance. For each archetype presented in Table 2.2, we added, based on expert judgement, to what extent a specific archetype is applicable for a type of NbS and what the role of governments should be in stimulating these NbS.

Table 2.2 *Archetypes of business models for NbS according to Toxopeus and Polzin (2017)*

Type of business model - archetype	Description	Applicable for which NbS-type	Role of governments
Sustainable business model	Helps to understand the different types of value propositions, delivery and capture approaches that could be provided.	Especially small-scale involving one agent	Limited
Substitute	The business model archetype *substitute* with renewables and natural processes is widespread in urban nature-based solutions, delivering value by replacing 'grey' infrastructure with 'green-blue' infrastructure (such as green roofing and sustainable drainage systems).	Urban NbS for public purposes	Large
Adopting a stewardship role	This archetype takes a more social/educational angle on the business model by creating other types of opportunities for value capture through willingness to pay of residents and tourists (through education, recreation and self-harvesting, for example).	Small-scale NbS for single of group of entrepreneurs	Limited
Develop scale-up solutions	The business model archetype *develop scale-up solutions* is important in the context of speeding up the uptake of nature-based solutions. Standardised urban farming concepts such as 'Selbsternte' improve scaleup, as does more structured access to subsidies to stimulate private investment (in the case of green roofs). Finally, setting up an earmarked CO_2 market for urban emission abatement could structurally increase the value of urban tree investment.	Small-scale NbS to become common practice. Individual entrepreneurs	Large, to shape the appropriate settings (law and regulation, and markets of tradeable CO_2 permits)

Successful Nature-based urban innovation faces key challenges to obtain long-term (private) financing due to inability to capture value from their delivery of ecosystem services, i.e. lack of a successful business model. Toxopeus and Polzin (2017) concluded that there are several ways to discuss financing arrangements and business models for NbS with a focus on urban areas. The following views were observed to speed up the uptake of NbS:

- Stakeholder involvement ranging from citizens to businesses to policy makers (Nesshöver et al. 2017; Ugolini et al. 2015).
- Significant role of the business community, because they have the access to the necessary resources for scaling-up (New Climate Economy 2014; 2016).
- The success of for-profit business models in the provision of basic needs such as fresh drinking water (Loftus and March 2016).
- New business models such as product-as-a-service versus sales (Sousa-Zomer and Cauchick Miguel 2018).

In a review study, business models of NbS in urban areas have been researched (Bockarjova and Botzen 2017), which are usually examples of NbS in public spaces. The study focused attention on financial and economic values of Nature-based Solutions in urban areas. With an econometric analysis, the economic values were explored to explain the differences of values across different NbS. In particular, the study distinguished indirect and non-use values of the Nature-based Solutions. The analysis, however, did not consider the distribution aspect of benefits and cost across stakeholders or the governance aspect of how benefits and costs of ecosystem services are distributed in business models.

Additionally, the World Business Council for Sustainable Development developed a scheme on how Nature-based Solutions relate to ecosystem services, including provisional services and natural capital (WBCSD 2020). Figure 2.3 presents the scheme in which natural capital produces ecosystem services that provide values to business and society. These values form the need for natural capital to meet the demand for ecosystem services and building resilience as a society. NbS can provide solutions to improve natural capital in order to fulfil current and future demands for ecosystem services. The main issue is that not all ecosystem services are priced or valued adequately.

To value (or price) ecosystem services more appropriately, the World Business Council for Sustainable Development developed a seven-stage process for situating co-benefit assessment within policy and project implementation. The seven stages include: 1) identify problem or opportunity; 2) select and assess NbS and related actions; 3) design NbS implementation processes; 4) implement NbS; 5) frequently engage stakeholders and communicate co-benefits; 6) transfer and upscale NbS; and 7) monitor and evaluate co-benefits across all stages.

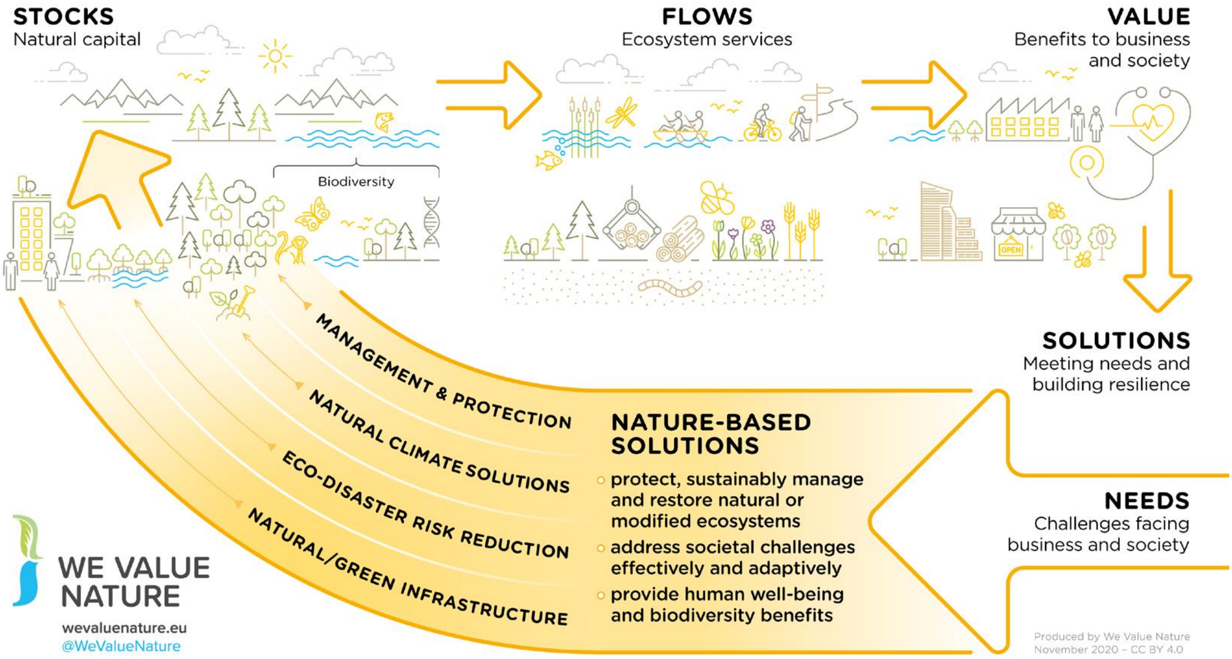

Figure 2.3 *Natural capital and NbS*
Source: Courtesy of We Value Nature (https://wevaluenature.eu/).

2.4 Conclusions on frameworks to assess NbS

There are no assessment frameworks and business models readily available for NbS targeted at the climate resilience and circularity of food systems. Moreover, the key focus of NbS assessment has been on the improvement of conservation of nature and its resources in urban context. The impacts of NbS are multi-faceted and their assessment requires the involvement of all relevant actors, including those who participated in the implementation as well as those who did not but might been affected by the NbS in the short and/or long term.

To increase the involvement of the private sector, the added value of the NbS and the distribution of cost and benefits have to become more clear in an early stage of the implementation process. However, most examples of business models for NbS are applied to implementations in urban areas, where the local or regional government played a central role.

Many examples of NbS are implemented at the community level with multiple stakeholders involved. This means that a business model regarding NbS, which could be regarded as projects, might discard the impacts of the multiple stakeholders or actors affected. In this case, business models for all actors should be considered and assessed.

Due to the lack of frameworks for assessing NbS and their contribution toward climate-resilient and circular food systems, we decided to explore current assessment frameworks that are being used in food systems research, and try to incorporate NbS and the distributions of costs and benefits among stakeholder into that. This is presented and discussed in Chapter 3.

3 Our approach to evaluate NbS for climate-resilient and circular food systems

First, it is important to select suitable NbS in the food system, see Keesstra et al. (2023). For NbS to contribute to climate-resilient and circular food systems, we consider five aspects – elements of the socioeconomic and environmental drivers and outcomes of the food system – that need to be addressed:

- Biodiversity
- Food security & healthy diet
- Climate-resilience of the food system
- Circularity of the food system
- Economic profitability of the system.

For successful contributions of NbS to climate-resilient and circular food systems, all aspects need to improve, or at least not deteriorate.

As concluded in Chapter 2, a proper ex-ante framework to assess NbS in food systems, including the distribution of costs and benefits for stakeholders, is not available. Therefore, we propose a three step approach. Building upon work from the European Commission (EC 2021), we combine two existing frameworks that are already used for in food systems: one relates to the expected impact of interventions, i.e. 'theory of change' (ToC) and one relates to expected impacts of changes in the food systems. i.e. the 'food systems framework' (FS Framework). Both frameworks start with the intervention of change, which are NbS in food systems in our case. The third step is the extended stakeholder analysis to gain insight in the distribution of the cost and benefits of anticipated NbS for specific stakeholders. Note that the first two steps of our approach can be conducted with (a selection of) stakeholders as well. This third step uses the outcomes of the first two steps to assign costs, benefits and investment options of NbS to stakeholders in practice.

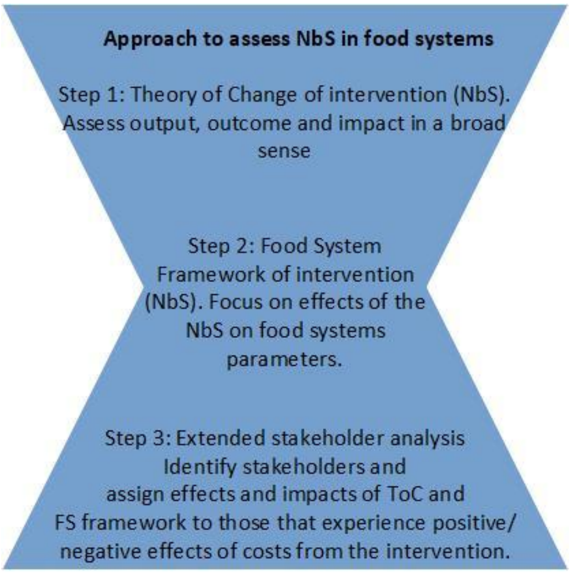

Figure 3.1 *Approach to assess the contribution of a NbS towards climate resilient and circular food systems*

We therefore propose the following approach to assess the winners and the losers of NbS selected in the food systems, also in the view of just adaptation, see Figure 3.1.

1. Identify the ToC for this NbS
2. Identify the effects of the NbS in the FS Framework
3. Identify stakeholders and their roles in the NbS intervention (during planning, implementation and beyond), in order to be able to link the investments in interventions (costs), impacts and outcomes (possible benefits), that came out of the from ToC and FS Framework, to stakeholder groups.

3.1 Step 1: Theory of change

The theory of change approach is a process used to support the planning and monitoring of any intervention such as a project, programme or in our case a NbS. This approach describes the overall goal for a NbS and the short, medium and long-term outcomes that are required to achieve the goal. The theory of change for NbS for climate vulnerability have been researched before (Conservation International 2013). Our goal is to achieve climate-resilient and circular food systems under the conditions that actors can make a living. Therefore, in this study a NbS has economic, social and environmental objectives.

The theory of change (ToC) approach distinguishes four levels:

1. Intervention, which is the planning, design, implementation and M&E of a NbS in this study
2. Output, which is typically the number of people willing to implement the intervention. In the case of the NbS, it would typically indicate the surface of the area involved in squared meters
3. Outcome, which is the effect of implementation of the intervention, which might be intended and unintended. All expected outcomes of NbS need to be included, whether or not it has positive or negative consequences on the impacts and achievable goals
4. Impact, which is the contribution to the goals and objectives. When multiple goals are considered, as is the case in this study, the impacts might be affected positively or negatively.

For the intervention, the scale of application NbS is essential. It can range from an individual investing in a NbS (rainwater harvesting with ponds at plot level) to a community investing in a NbS (a micro-dam for rainwater harvesting or restoring mangroves at the coast).

3.2 Step 2: Food Systems framework

The food system framework is created to oversee the complexity of the entire food system, and to consider the linkages to the socioeconomic and environmental drivers which influence the food supply chain (van Berkum et al. 2018), see Figure 3.2. The food system consists of the food system activities which are food production (agriculture, aquaculture, and fishing), storage and transportation, food processing, retail and distribution and food consumption. The main outcome of the food system framework is the food security, which consist of four pillars: food availability, food accessibility/affordability, food utilisation, and food stability. The element of food stability is missing in the framework, because it relates to the food security over time, which is not reflected in Figure 3.2. Furthermore, the framework also serves as a tool to oversee the other outcomes of the food system such as health, socioeconomic and environmental aspects.

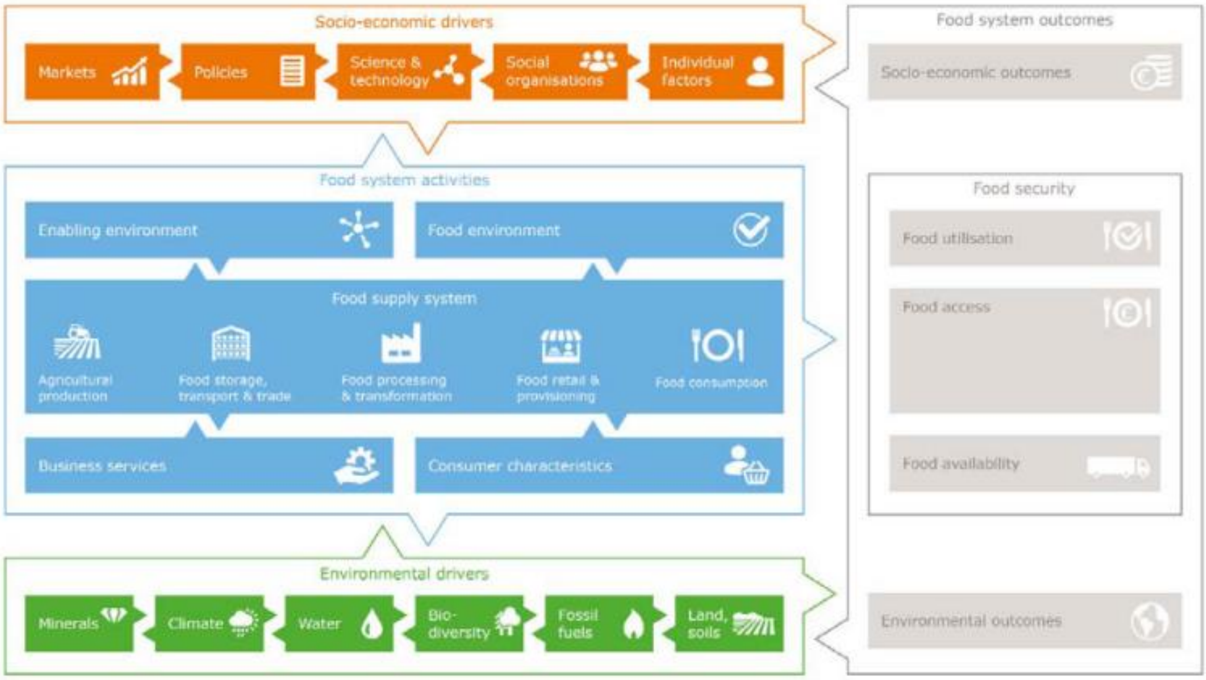

Figure 3.2 *Food system framework mapping the relationships of the food system to it drives and outcomes*
Source: van Berkum et al. (2018).

For each food system activity, there is a list of aspects to assess, which are:

- Food system outcomes (food availability, food access, food utilisation)
- Impact on economic drivers (employment, poverty, profits of food sectors)
- Impact on environment drivers (water, soil, air, ecosystems and biodiversity) with
  - climate – which we assess as the contribution to climate resilience or climate adaptation
  - circularity
- Stakeholders involved (beneficiaries, and unexpected negative impacts) (see Chapter 3.3)
- Governance including aspects such as:
  - Who invests
  - Who benefits
  - Who suffers from negative impacts

In addition, the economic and environmental drivers can be assessed according to the assessment frameworks of other studies (Sonneveld et al. 2018; Raymond et al. 2017).

3.3 Step 3: Extended stakeholders analysis

The two presented approaches are complementary in the case of NbS. The ToC helps to identify and evaluate impact, outcome and output of a specific intervention on all aspects related to the intervention. The FS framework creates overview in the complexity of the food system and related activities in a broad sense and identifies the effects of an intervention on each of the four pillars of food security. It also pays attention to health, socioeconomic and environmental aspects. Both approaches identify stakeholders affected, but in this step we describe the stakeholders and the way they are affected systematically. This is including indirect impacts and impacts from policy instruments envisaged.

Several aspects are relevant when including stakeholders in the ex-ante analysis: In the case of an ex-ante assessment, the governance aspect and the stakeholder participation are unobserved aspects yet, and they still can be shaped. Both aspects can affect the effectiveness and success of implementation of nature-based solutions for food systems purposes. Another thing that needs to be considered here is the scale level of implementation (individual vs. community nature-based solutions, local, regional, national or international nature-based solutions, administrative or agro-ecological zones, etc.). The scale determines how many and which stakeholders are, or should be, involved. This is also relevant to determine whether the NbS does lead to just adaptation. Furthermore, the role of stakeholders is not pre-determined, but might be negotiable or changeable.

In the following chapter we will apply this approach on two different case studies in which NbS are implemented in the food system.

4 Case studies

4.1 Introduction

As NbS were primarily introduced to restore ecosystems and improve biodiversity, there are not always positive impacts for food production and food security. In this study, we focus attention on the part of NbS that contribute to climate-resilient and circular food systems. Still, there are several forms how these NbS for climate-resilient and circular food systems can be implemented. Based on our work in Bono East region in Ghana, we select two examples for which we will elaborate on the approach introduced in Chapter 3 for introducing the NbS for climate-resilient and circular food systems.

The first example is rainwater harvesting for irrigation (RWHI), which reduces the burden of water abstractions from the existing water systems especially under changing climate conditions. In particular, we focus on the implementation of ponds, and wells by individual farmers. The second example is the Modified Taungya System (MTS) as an example of Forest and Landscape Restoration (FLR). This is a collaborative activity of farmers leasing degraded forest areas or fallow land that is converted into a combination of agricultural crop cultivation and tree planting.

Although both examples of NbS are rarely implemented in Bono East region in Ghana, these NbS are promising for adoption, especially in the perspective of climate change to reduce climate risks. Moreover, these NbS contribute to the food system as well. Larger adoption or implementation is still uncertain due to hindering factors such as high investments, lack of credit markets, lack of urgency because water resource scarcity is occurring infrequently still. With our approach for the process of adopting NbS such as RWHI and FLR MTS, the adoption of NbS can be easier because hindering factors might be overcome.

For each case study, we follow the presented approach in Chapter 3; First, we illustrate the theory of change of the nature-based solutions with the positive and negative impacts of achieving a climate-resilient and circular food system for the future. In particular, we sketch the preconditions of the success of the NbS. Then we depict how the food system would be affected when introducing the NbS using the food systems framework (van Berkum et al. 2018). Given both approaches, there will be a better insight in the intended changes and how stakeholders are affected. We discuss how the distribution of costs and benefits is among the involved stakeholders, in order to identify winners and losers of the NbS.

4.2 Rainwater harvesting for irrigation (RWHI) in Ghana

4.2.1 Description of RWHI

Rainwater harvesting for irrigation (RWHI) lessens the burden of water abstractions from the existing water systems especially under changing climate conditions. In particular, we focus on the implementation of ponds, and wells by individual farmers. Similar RWHI applications can be implemented at the community level. However, this requires other strategies of governance of the RWHI application, additional infrastructure to transport water from the community pond or well to the fields of individual farmers. With the emphasis on the RWHI decision by individual farmers, the responsibility of implementation and management is with the individual farmers. Alternatively, we can consider community initiatives for RHWI, where the community is responsible and decisions on cost distribution and sharing benefits are taken by the community. Moreover, community RWHI requires additional irrigation equipment as well.

4.2.2 Theory of change

Based on the descriptions of Rainwater Harvesting for Irrigation (RWHI) in Bono East Region (Linderhof et al. 2022), we summarised the expected outputs, outcome and impact of the measure RWHI according to the Theory of Change concept, see Figure 4.1. This graph visualises the anticipated effects of RHWI and how it contributes to a climate-resilient and circular food system in Bono East Region in Ghana. The ToC was derived from several consultations with stakeholders in Ghana working on rainwater harvesting and forest and landscape restoration.

When implementing rainwater harvesting for irrigation in terms of constructing a rain-fed pond or well, farmers have a choice to either change their cropping patterns (left side of the graph in Figure 4.1) or remain the existing cropping pattern (left-hand side of the graph in Figure 4.1). For convenience, we assume that farmers rely on existing water resources and have irrigation equipment available. The *output* of the measure RWHI is the number of farmers that is willing to participate in the RWHI.

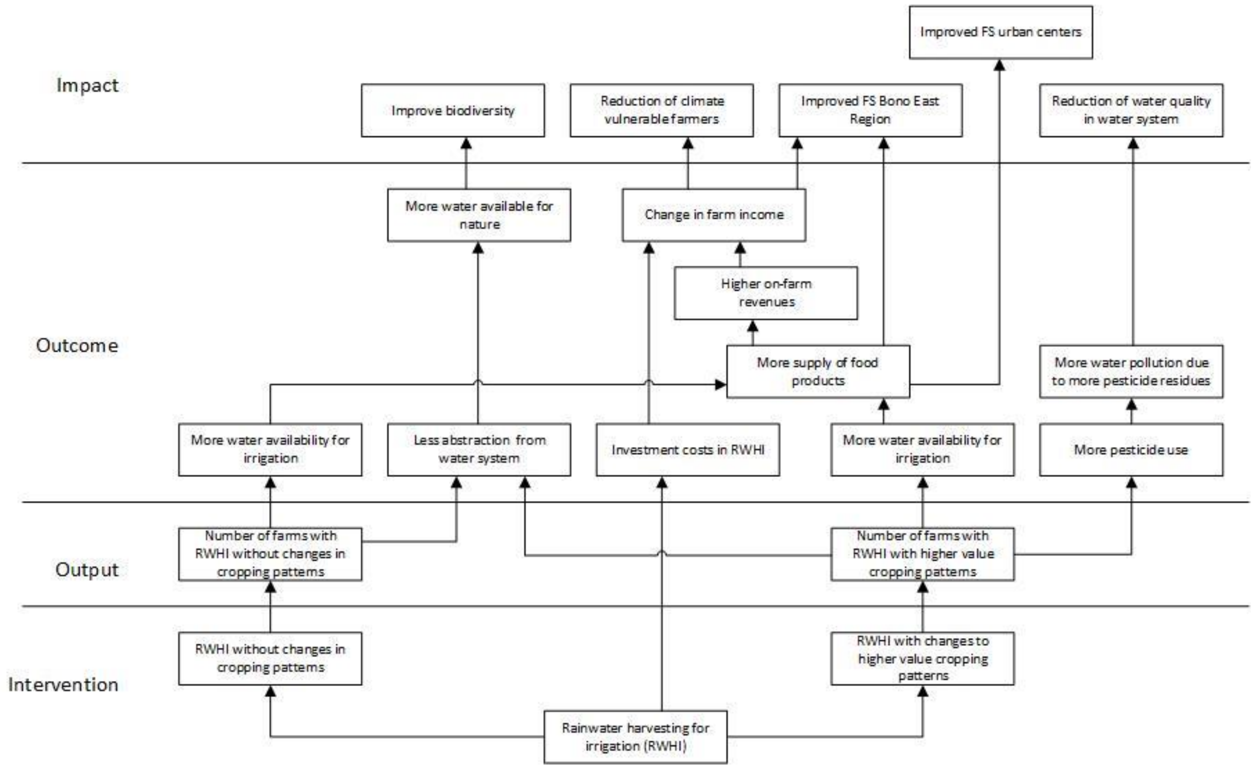

Figure 4.1 *Theory of change of rainwater for harvesting for irrigation (RWHI) in Bono East region, Ghana*

The implementation of RWHI has several *outcomes*. In both alternatives of the intervention, more irrigation water is available for crop production. Higher availability of irrigation water increases on-farm revenues. Farmers not changing their cropping pattern will have higher average yields (left-hand side of Figure 4.1) assuming that the prices of cultivated crops will remain the same or decline slightly. Farmers that will change to the cultivation of high-value crops will increase the on-farm revenues (right-hand side of Figure 4.1). Higher on-farm revenues will have a positive impact on income. Thus, farmers investing in RWHI will benefit if the increase in on-farm revenues increase is higher than the investment costs. Farmers have to invest in RHWI, which means that they have to consider investment costs for RWHI as part of their production costs, which affects their farm income, see Figure 4.1. Evidently, the investment in RWHI will only be beneficial for farmers when their farm income increase is higher than the increase in production costs mainly due to investment costs.

Farmers changing their cropping pattern (right-hand side of Figure 4.1) are likely to grow more high-value and more water-intensive crops. The production of these crops are likely to call for more fertiliser and pesticides usage, which might lead to higher concentrations of nitrogen, phosphorus and pesticide residues in the soil and water systems. There is a need for more sustainable agricultural practices when farmers invest in RWHI and switch to high-value crops.

At the level of *impact*, the contribution of the implementation of RWHI to climate-resilient and circular food systems is evaluated. The increase in availability of irrigation water during the growing season will increase the supply and diversity of food crop production in the region. Therefore, the food availability in the region will increase. As Bono East Region is a food supplying region for urban centres in Ghana, the increased food supply will also have a positive effect on food supply in the urban centres. As a results, the higher availability of food supply is likely to contribute to an improvement of food security in the region and urban centres, although the actual impact also relies on other drivers like food access, affordability etc.

From an environmental perspective, there are multiple impacts. The reduction of the irrigation water abstraction from the water system (either surface water or ground water) will have a positive or non-negative impact on water availability. In particular, the reduction of water availability due to climate change for other ecosystems and the natural environment in the river basins can be stopped or slowed down. As a consequence, there will be a positive impact on biodiversity as well. Moreover, the farmers become more climate-resilient (or in other words less climate vulnerable).

4.2.3 Food systems framework

Based on the expected impacts as indicated in Figure 4.1, we have indicated the impacts of RWHI within the food systems framework, see Figure 4.2. Elements in green indicated positive impacts of RWHI, while grey elements (activities, drivers and outcomes) indicate potential negative or ambiguous impacts of RWHI. White boxes mean that there is no effect of the intervention on this factor. Figure 4.2 shows that RWHI will several positive impacts on elements in the food system. It contributes to food security in two ways, see the food system outcomes at the right-hand side of Figure 4.2. First of all, it increases food availability in the area Bono East Region and in urban centres where food products are transported to. Secondly, when farmers change their cropping pattern, the diversity of food availability is likely to increase, which has a potential positive impact on the diversity of the diets as well as on the system' resilience to climatic hazards.

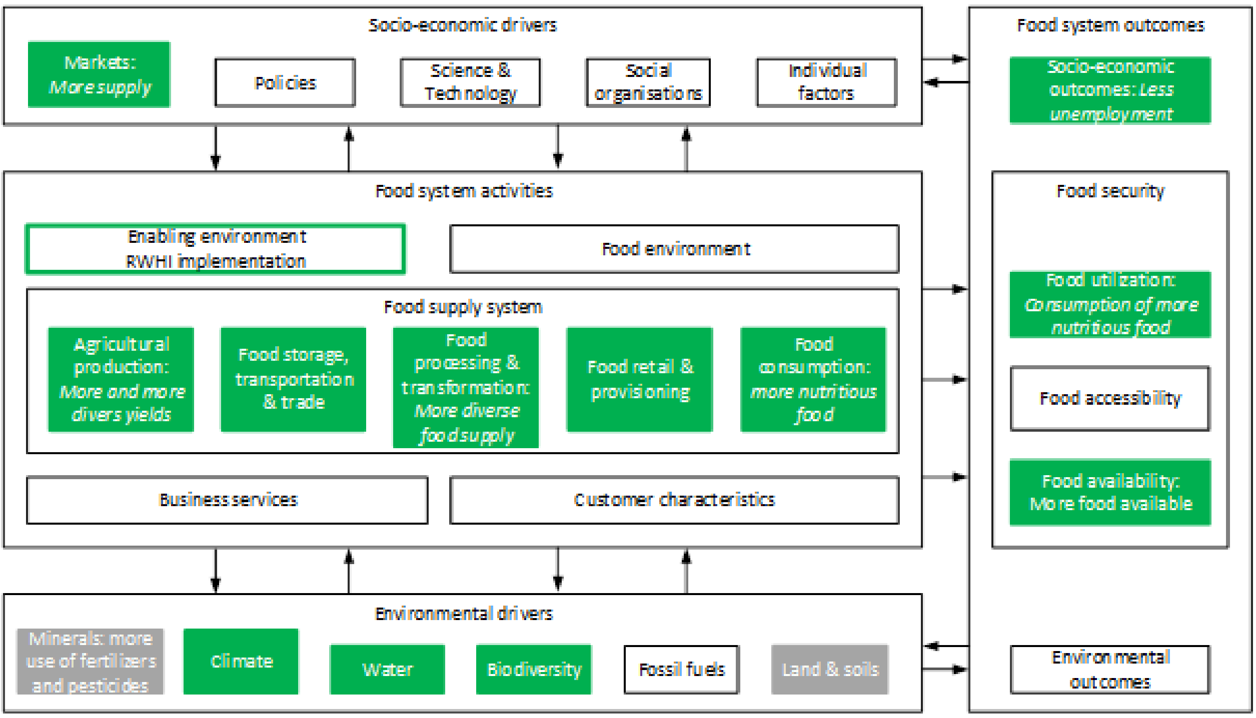

Figure 4.2 *Impact of RWHI within the food systems framework*

Although the availability of fresh water in the growing season is not yet a major problem in Bono East region, the impacts of climate change are noticeable by reducing amounts of precipitation in the last decade (Läderach et al. 2011; Ministry of Foreign Affairs 2018). In the future the supply of fresh water through the water system is likely to decline. As the agricultural sector in Bono East region provides food products for the region as well as other regions in Ghana, the continuation or improvement of the food production is of crucial importance for the region as well as Ghana.

4.2.4 Requirements and challenges of the intervention

As we consider RWHI to be farmers' decisions, farmers are the most important stakeholders. For the implementation of the RWHI, farmers need to invest in the construction of wells or ponds which costs them space – usually used for agricultural crops. This means that less area can be used for agricultural production, which might be a limiting factor since the farm sizes are usually rather small in Bono East region, i.e. 1-5 acres (Linderhof et al. 2022). In addition, farmers needs to invest in the construction of the pond or well, and farmers need to consider annual costs for maintenance of the ponds, or well as well.

Thus, the productivity of the remaining land needs to be improved in order to avoid any loss in farm revenues. This can be realised by more intensive cultivation of the existing crops which is likely to increase the use of fertiliser and pesticides. Alternatively, the farmer can switch to cash crops which are usually more water-intensive, and most likely also associated with farming practices with more fertiliser and pesticide use.

To stimulate the implementation of RWHI implementation and sustainable agricultural practices, a system of payment for ecosystem services (PES) to market the co-benefits could be considered. The ecosystem services to be paid for could be 1) more efficient use of water in order to reduce the abstraction from the water system 2) a more efficient use of inputs such as chemical fertiliser and pesticides when farmers switch to high-value crops to avoid the possible increase of both inputs as indicated by the grey box in Figure 4.2. Currently, there is no PES system in place.

4.2.5 Stakeholders

This section emphasises the perspectives of stakeholders as they can be identified from the Theory of Change and the Food Systems Framework exercise in the previous sections. Per stakeholder, we identify the effects of the NbS and the costs and benefits present.

Farmers
Farmers are key stakeholders in implementing RWHI, because they have to implement the measure. It requires an investment in RWHI and the production costs will increase due to investment costs. We assume that the irrigation equipment is present at farms because many farms already use irrigation for agricultural production. If a farmer does not have irrigation equipment, the investments and the costs of maintenance will increase even more substantially than for a farmer that already has irrigation equipment. Farmers will also benefit from the investments, by increasing productivity and switch to high-value crops. Farmers downstream, outside Bono East region, will also benefit from RWHI in the region, because the farmers in Bono East region rely less on water abstractions from the water system. Obviously, farmers downstream could also consider the implementation of RWHI themselves. Farmers growing high value crops in the current situation might be less off due to increased competition and consequently lower market prices.

Landowners
If the farmer is not the owner of the land, it is likely that the farmer is less likely to invest in rainwater harvesting or any other form of soil and water conservation. In Kenya, research showed that farmers are willing to invest as long as they have secured, long-term user rights of the land. If farmers are not land owners themselves, then land owners become a stakeholder as well. The landowner will benefit from RWHI on its lands, because productivity and thus value of the land can increase. The land owner does have to invest in the RWHI, unless (s)he is also the farmer.

Suppliers
Suppliers of fertilisers, seeds, pesticides and materials for RWHI might benefit from the NbS because demand for their products increases.

Food processing companies
From the perspective of the food systems framework, there are other stakeholders as well. Although they do not benefit directly, food processing companies located in Bono East region also benefit from the maintained or increased supply of food products. If rainwater harvesting can contribute to a more climate-resilient and secured way of food supply, the food processing companies also benefit from rainwater harvesting implementation because supply is more stable and predictable. However, these companies do not need to invest in RWHI themselves.

Consumers
A less obvious stakeholder are consumers in the urban areas of Ghana who rely on the food supply from Bono East Region and similar areas. The most common crops grown in Bono East Region and supplied to urban areas in Ghana are maize, mango, and yams. Cashew is also widely grown in Bono East Region, although it is primarily cultivated for exports. These consumers benefit from a reliable supply of food, and they do not need to invest in RWHI themselves.

Water managing authorities
Furthermore, the local or regional water managing authority responsible for the water system is a stakeholder as well. The water managing authority is not involved in the implementation of the pond or well as such but it can create a stimulus for investing in RWHI by discouraging the abstraction of fresh water from the water system. To do so, there would be a need for a system of water abstraction permits which has to be managed. To preserve fresh water in the water system for other functionalities like ecosystems and biodiversity, the water manager should discourage the abstraction of fresh water from the water system. In addition, the water managing authority might need to increase the monitoring of water quality due to more intensive farming practices associated with more intensive use of fertilisers and pesticides from which residues might end up in the soil and the water system.

4.3 Modified Taungya System (MTS) farmers in Ghana

4.3.1 Description of MTS

The Modified Taungya System (MTS) is a form of Forest and Landscape Restoration (FLR), which has been implemented since 2002. It succeeded the Taungya system, which is an agroforestry system in which farmers combine woody species with crops in the early years of a forestry plantation formation (Acheampong et al. 2020). It was introduced in the 1930s, as a response to the increased shortage of farmlands around communities, and high deforestation rates. It is a collaborative activity of farmers leasing state-owned degraded forest areas which they can partly use for agricultural crops and partly for tree planting. In the original Taungya system, farmers could participate for a maximum of three years. In the MTS farmers are allowed to continue cultivating until the trees reach full maturity. Participating farmers manage the areas and share in the yields of crops and trees. The crop production is produced for the market and not for farmers' own consumption. Once the trees are harvested, the farmers can keep 40% of the value of the harvested trees. In this system, farmers do not own the forest land, but can equally share in the benefits derived from forest land, both in the form of crop land, and in the revenues derived from the harvested trees.'
(van Oosten et al. 2022)

Note that MTS farmers can choose from a list of crops to grow in combination with the tree crops; not all crops are allowed. Land owners and farmers share the revenues of the trees and forest products, while farmers receive all revenues from agricultural production. MTS farmers have temporarily the right to use additional agricultural land to improve their agricultural produce, and the leased land can only be used for producing for the market (not own production). In this way, the community benefits from higher food availability which is likely to increase food security.

4.3.2 Theory of change

MTS is implemented as a intervention, and the *output* is mainly the number of farmers willing to participate and the suitable and available land to implement MTS, see Figure 4.3. For participating farmers, the activities of the MTS are additional to their common agricultural activities. As a result, the task of their own farm need to be taken over and we assume that this labour is partly taken over by other farm household members and partly by hired labourers.

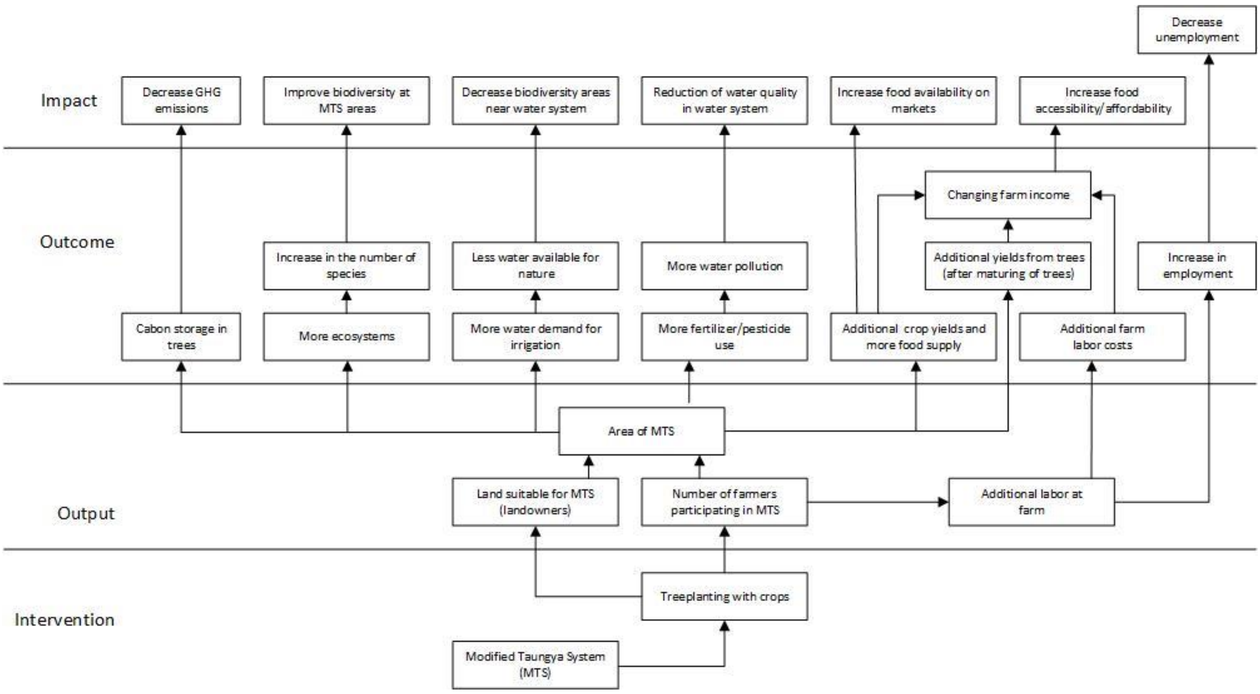

Figure 4.3 *Theory of change of the Modified Taungya System (MTS) in Bono East region, Ghana*

There are several *outcomes* identified. Obviously, participating farmers will increase their crop yields and also the yields for trees. This will increase the income of farmers, although they also face higher production costs due to hiring labour. Due to the increase of land used for vegetation, there are more ecosystems created, and it is likely that the number and diversity of species will increase. However, the cultivation of more land might also increase the demand for fresh water. Furthermore, the cultivation of crops and trees will increase the demand for chemical fertiliser and pesticides as well unless there is active stimulation of sustainable agricultural practices.

Finally, positive *impacts* of MTS are an increase of food security (food availability as well as food accessibility due to higher incomes), a reduction of GHG emissions, an increase in biodiversity and an increase in employment in the region. The trade-offs arise from an increase of water demand and a potential decrease of water quality as a result of increased fertiliser and pesticide use in the case that agricultural practices are unsustainable.

4.3.3 Food systems framework

Based on the expected impacts as depicted in Figure 4.3, MTS will have positive impacts on many elements in the food system, see Figure 4.4. Elements in green indicated positive impacts, while grey elements (activities, drivers and outcomes) indicate potential negative or ambiguous impacts. White boxes mean that there is no effect of the intervention on this factor. MTS contribute to food security in two ways. First, it increases food availability in the area Bono East Region and in urban centres as the produced food crops are produced for the markets. Second, the agroforestry of the MTS are additional activities for the participating farmers, so that farm income for farmers in Bono East Region is likely to increase, which increases the food accessibility or food affordability.

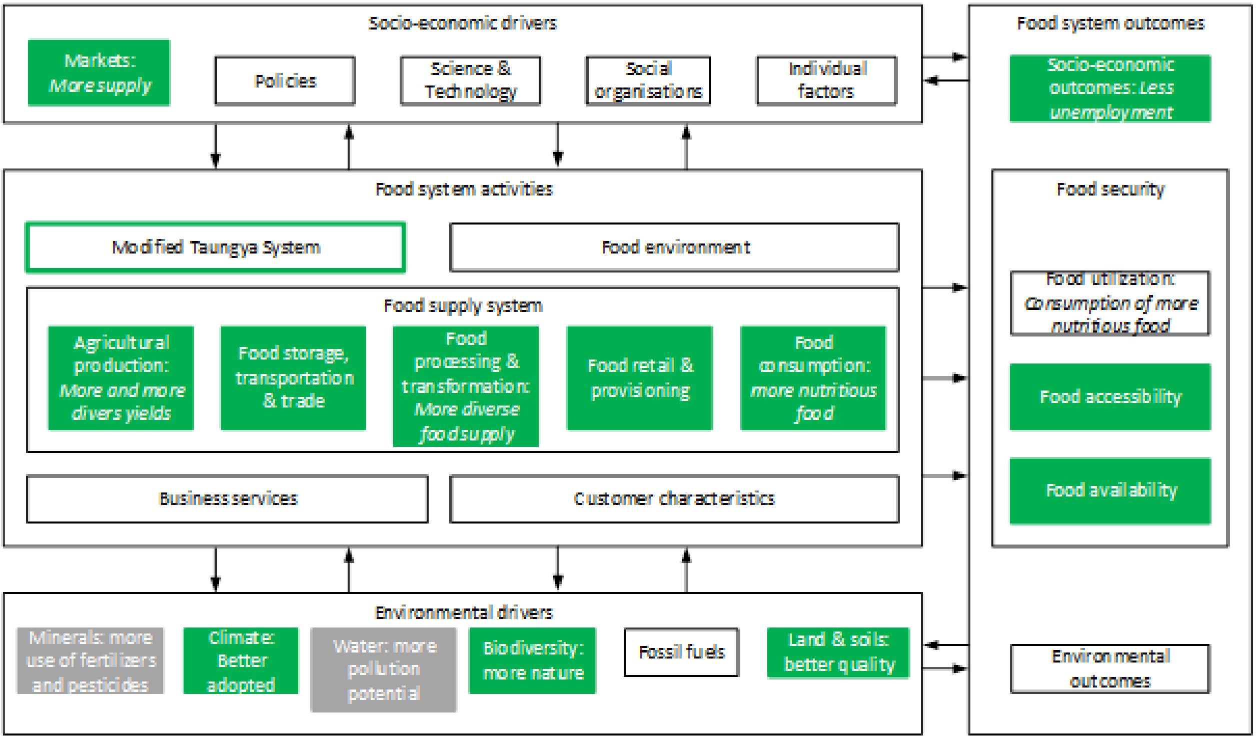

Figure 4.4 *Impact of the Modified Taungya System (MTS) within the Food Systems Framework*

As the MTS increases agricultural activities of participating farmers in terms of more production, the other elements of the food supply chain such as food storage and transportation, food processing and food consumption, will increase as well. At the end, employment in the agricultural sector and other activities in the food system will increase, and unemployment is likely to decrease.

4.3.4 4 Requirements and challenges

For climate resilient food systems, there are opposite effects. On the one hand, MTS increases the climate resilience of the food system as it stores more carbon for a longer period of time in the tree growing activities, which reduces greenhouse gas emissions. On the other hand, it decreases climate resilience, because the demand for fresh water for MTS activities will increase, which makes MTS more vulnerable in the case of periods of water scarcity.

With MTS, more carbon is stored in the growing of the trees within the MTS. Moreover, the soil of the land used for MTS is likely to become more fertile as it managed in a sustainable way. Obviously, sustainable agricultural practices (discouraging chemical pesticide and fertiliser use, and stimulating organic fertiliser use) need to be advocated otherwise MTS has negative consequences with respect to environmental pollution, and thus a negative effect on achieving a circular food system.

As in the case of RWHI implementation, a system of payment for ecosystem services (PES) could be considered for MTS as well, although the ecosystem services involved would be different. The ecosystem services would be the storage of carbon in trees, the increase of biodiversity and the improvement of the soil quality. A PES system could also be used to mitigate the increased demand for fresh water from the MTS. Alternatively, MTS could be combined with RWHI to avoid an increase of the demand for fresh water.

4.3.5 Stakeholders

This section emphasises the perspectives of stakeholders as they can be identified from the Theory of Change and the Food Systems Framework exercise in the previous sections.

In contrast to the RWHI case, there are two key stakeholders in the case of MTS: farmers and landowners, which is most likely the state.

Farmers
Farmers could be interested in MTS because it is a way to expand their land, at least temporarily, and increase their farm income. The yields of crops (and trees) are supply to local or regional markets, and farmers share in the earnings. Before earning, the farmer has to invest in inputs. And farmers might need to hire labour for their usual agricultural activities, or rely on more labour activities by other member of the households. For farmers to participate, the revenues should outweigh the additional production costs.

Land owner
The land owner, which usually is the state in the case of MTS, benefits from MTS because it receives payments for the agroforestry activities on their land. The state might also benefit because of the carbon sequestration that is realised in the MTS system, helping them in reaching their climate mitigation targets. Furthermore, biodiversity can increase, which is beneficial for the entire population and can help the state in reaching biodiversity conservation objectives.

Consumers
Another stakeholder are consumers in the urban areas of Ghana who rely on the food supply from Bono East Region. These consumers can benefit from the increased food and wood-production. These consumers benefit from a reliable supply of food, and they do not need to invest in RWHI themselves.

Suppliers
Because of increased agricultural activities in the MTS system, more demand will be arise for agricultural and forestry inputs. Suppliers will benefits from this, while they do not need to invest in the system themselves.

Food supply stakeholders
From the perspective of the food systems framework, there are other stakeholders as well. The yields either crops or trees are produced for the local and regional food markets. Therefore all actors in the food supply change (transporters, food processing companies, retailers) can benefit from MTS. As Bono East Region is also supply food like maize, mango, and yams to urban centres of Kumasi and Accra, for instance, the stakeholders might be located inside and outside the region. In addition to the food crops, there is also produced charcoal which is transported to urban areas where it is mainly used as a cooking fuel, as alternative cooking fuels are much more expensive.

Water authorities
The local or regional water managing authority in the area is an important stakeholder because the demand for fresh water will increase in the case of the implementation of MTS. To preserve fresh water in the water system for other functionalities like ecosystems and biodiversity, the water manager should discourage the abstraction of fresh water from the water system. To do so, there would be a need for a system of water abstraction permits which has to be managed. In addition, the water managing authority might need to increase the monitoring of water quality aspects due to the increase of farming area associated with more increased use of fertilisers and pesticides from which residues might end up in the soil and the water system.

5 Discussion and Conclusions

5.1 Discussion

Our proposed approach, which identifies first the effects of NbS via the ToC of the intervention and the food systems framework, and second analyse how these effects (positive and negative) are distributed among stakeholders, worked out well in the case studies. It helped to identify trade-offs, i.e., some stakeholder groups benefit from NbS, and some experience negative effects or costs. On the one hand, for example, farmers can benefit from rain water harvesting and irrigation because they can cultivate high value crops and increase productivity. On the other hand, the water authorities might experience negative effects for water quality, due to intensified farming activities.

The applied approach is an ex-ante evaluation, which means that the actual planning, design and implementation of for example the NbS might need to be reshaped. Note that changes of the technique of for instance RWHI as well as the governance structure of RWHI might affect the effects (e.g., the ToC) and food security (e.g. food systems framework). In extreme cases, new stakeholders need to be invited or even existing stakeholders can be excluded (Dijkshoorn-Dekker et al. 2020). Given the insight in the effects, there is a foundation to discuss governance aspects of the distribution of positive and negative impacts of NbS such as payment for environmental/ecosystem services and environmental taxes.

Although our approach is applied to specific cases, the same three steps could by followed by researchers, NGOs and governments to select and ex-ante assess other types of NbS or even other types of interventions related to the food system. Both examples were derived from one study in the Bono East region in Ghana, but there is no geographical limitation for application of our approach. It could be interesting to apply the approach to interventions with cross-border effects in which stakeholders in more than one country need to be considered.

Our suggested three-step approach can be time consuming; both the ToC and FS framework require a lot of information about the intervention and its effects. In parallel, relevant stakeholders should be determined and the identified effect should be assigned to the stakeholder-groups. However, the approach also provides more insight in who to involve in the planning and implementation process, so that these process will smoothen the adoption of RHWI and MTS as NbS.

The used approach is helpful to make a preliminary assessment of the justness of a nature-based adoption. From our analysis, it can become clear whether just adaptation is likely to take place after the NbS is implemented, or that risks shift toward other stakeholders or thematic areas. In the case of the RWHI, the farmers benefit from a higher probability of water availability for irrigation, while the risk for water pollution due to intensified use of fertilisers and irrigation will increase. Moreover, the approach provides a systematic overview of effects in the food system and beyond, although it does not quantify any effects. However, this approach can be used as a starting point to quantify the effects identified and in a next step to value them.

A follow-up step after quantifying the effects could be to try to monetarise the costs and benefits that occur after implementation of the NbS and see how large the costs and benefits for each stakeholder are. With that information, redistribution of benefits, like compensation or subsidies, can be developed and arranged. This can provide input for new business models related to NbS in food systems, which consider all actors or stakeholders throughout the food system.

Another option of using our approach is to search for adjustment or refinement of the governance structures to improve the impact of the intervention. An example mentioned in the case of RWHI was the implementation of a payment for ecosystem services scheme (PES). Obviously, the change of the governance structure will also affect the initial ToC and food system framework in our approach. In order to do this properly, it must be investigated when costs and benefits arise in time. Costs often occur before the stream of benefits starts, because investments in for instance rainwater harvesting techniques. Moreover, benefits is the future are usually discounted to the present in order to make a proper analysis. Our analysis can be used for that as a first attempt that identifies effects and the distribution among stakeholders.

5.2 Conclusions

Our new approach can be applied to various case studies as an ex-ante assessment of NbS to identify effects in food systems from a social and economic perspective. The existing assessment frameworks to assess NbS lack a clear connection to food systems and food system outcomes like food security, and food system resilience. With the application of the combination of the ToC approach and the food systems framework as ex-ante evaluation tools, the insight in the effects and impacts of NbS on climate-resilient and circular food systems is enlarged. Both existing frameworks present the effects of an intervention in detail with an own focus. By identifying the stakeholders related to the NbS and its effects based on the ToC and FS framework as an additional follow up-step, it can be assessed whether or not there are trade-offs, i.e. some stakeholder group(s) benefit from the NbS and some might be burdened with additional costs or negative effects. To mitigate the trade-offs, policy makers or private actors can come up solutions for compensations or redistribution of benefits.

Our three step approach (1. Theory of Change, 2. food system framework and 3. stakeholders including distribution of benefits and costs) is tested in two case studies from Ghana in which Nature-based Solutions are implemented in food systems. The case study results indicate that rainwater harvesting for irrigation and the agroforestry according to the MTS positively affect food security because of increased production, but both examples have negative impacts as well. Circularity in both cases is not guaranteed because of intensified production, meaning that additional policy actions are required. RWHI contributes to climate adaptation as it makes farmers less reliant on the water system. MTS mainly contributes to climate mitigation, by storing carbon emission in trees. Neither of these ecosystem services provided by either RWHI or MTS are rewarded yet.

Our new approach and examples can be used in a wide variety of case studies as an ex-ante assessment to identify effects and the distribution of effects among stakeholders, and trade-offs. It can be seen as a first attempt to assess NbS in food systems from a social and economic perspective. Our three step approach is very relevant in the aim at of just adaptation and possible redistribution of benefits towards stakeholders that are negatively affected by the NbS. A follow-up action of our framework could be the composition of business models for all stakeholder groups involved.

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Appendix 1

Table A1 *Five main categories of approaches, including examples of nature-based solutions*

Category	Examples
Ecosystem restoration approaches	Ecological restoration
	Ecological Engineering
	Forest landscape restoration
Issue-specific ecosystem-related approaches	Ecosystem-based adaptation
	Ecosystem-based mitigation
	Climate adaptation services
	Ecosystem-based disaster risk reduction
Infrastructure-related approaches	Natural infrastructure
	Green infrastructure
Ecosystem-based management approaches	Integrated coastal zone management
	Integrated water resources management
Ecosystem protection approaches	Area-based conservation approaches, including protected area management

Source: (CEM of IUCN 2020).

Appendix 2

Table A2.1 *People interviewed*

Name	Organisation
Dorcas Ansah	WIEGO
Franka van Marrewijk	African Architecture Matters
Herbert Smorenburg	Choices International Foundation
Julia Anyanewaa Appiah	MDF Ghana
Sodey Akoto	University of Ghana
Valerie Gueye	Ghana Food Movement

Table A2.2 *Participants in the workshops on 2 November 2021 and 2 December 2021*

Name	Organisation	Participated in	
		workshop 1	workshop 2
Abraham Oduro	Research and Development Division, Ghana Health Service	V	X
Ato Kwamina	Agriculture and Climate Empowerment Centre Ghana	V	X
Bezalel Adainoo	Stay Well Now	V	X
Cecilia Akuley Gyimah	MDF Ghana	V	V
Cecilia Kwateng Yeboah	CERATH Development Organization	V	X
Daniel Amanquah	Sight & Life	V	V
Debbie Ajei-Godson	Farminista Africa Limited	V	V
Elijah Amoo Addo	Food for All Africa	V	V
Ellen Mangnus	WUR	X	V
Franka van Marrewijk	African Architecture Matters	V	X
Freda Asem	University of Ghana	V	X
Geoffrey A. Asalu	University of Health and Allied Sciences	X	V
Herbert Smorenburg	Choices International Foundation	V	V
Julia Anyanewaa Appiah	MDF Ghana	V	X
Nelson Owusu Ntiamoah	African Youth League (AYoL)	V	V
Nicole Metz	Netherlands Food Partnership	X	V
Ore Fika	Erasmus University Rotterdam	X	V
Paa Kofi Osei-Owusu	CERATH Development Organization	V	V
Pearl E. Selormey	HortiFresh	X	V
Philip Emefe	DSM	V	V
Rene van Veenhuizen	Hivos	X	V
Representative	Dutch Embassy	X	V
Richard Yeboah	MDF Ghana	V	V
Stella Obanyi-Brobbey	CERATH Development Organization	V	X
Theodore Makafui Adovor	Farmhub Ltd	V	V
Tracy Mensah	Ghana Netherlands Business & Culture Council (GNBCC)	V	V
Wristberg Ebenezer Ofei	CERATH Development Organization	V	X

V=Participated.

X=Not participated.

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REPORT 2023-021

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Report 2023-021
ISBN 978-94-6447-679-8

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