United Nations University
Institute for Integrated Management of Material Fluxes and of Resources

POLICYBRIEF
No. 7, 2025
A training outcome of the Knowledge Academy for the Resource Nexus (KARE)

Transforming Agri-Food Systems: A Coupled Citizen Science and Nature-based Solutions (CS-NbS) Approach

Taha Loghmani-Khouzani, Yamikani Makwinja, Ally Mkumbukiy, and Aatralarasi Saravanan

Highlights

1. Global agri-food systems face threats from emerging external shocks, necessitating transformations toward increased sustainability and resilience.

2. The decentralized coupling of Citizen Science and Nature-based Solutions (CS-NbS) at the interface of agri-food and Water, Sanitation, and Hygiene (WASH) systems can cause systemic transformation.

3. CS-NbS can be driven through **capacity building** for the stakeholders to participate in CS-NbS co-development via the provision of **sustainable finance** and **reliable data infrastructure**.

Introduction

GAchieving Resource Nexus efficiency for sustainable food security amid global shocks like climate change, pandemics, and geopolitical tensions exacerbate socio-ecological crises (Makwinja, Piyo, and Nyirenda, 2023; Mkumbukiy et al., 2025) is a major challenge, particularly in the Global South. For example, climate change alters temperature and precipitation, affecting crop growth, planting seasons, and agricultural zones (Furtak & Wolińska, 2023), increasing complexity and uncertainty for current and future governance of agri-food systems.

On one hand, external shocks impact low-income populations along the global agri-food chain, including smallholder farmers, the hardest. On the other hand, managing the impacts of external shocks requires accurate projections, which depend on the availability of reliable data, specifically ground-level meteorological data that are FAIR; Findable, Accessible, Interoperable, and Reusable (Saravanan, 2025).

There is a need, therefore, to build localized and decentralized capacity in agri-food practices to tackle these challenges while contributing to a systemic transformation.

1) Extreme events affecting agri-food have increased by 50% in the last 10 years and are now occurring at a rate four times higher than in comparison 20 years back (Extreme weather events in Europe, 2018).

2) Climate change could cut maize, wheat, and rice yields by up to 45%, 50%, and 30%, while a 2050 population of 9.8 billion will drive food, water, and energy demand up by 50%, 55%, and 61% (Food and Agriculture Organization of the United Nations, 2021).

Moreover, effective implementation of transformative approaches requires reliable data, participatory initiatives, and decentralized natural resource governance (Loghmani-Khouzani et al., 2024). Not only must these approaches simultaneously enhance vulnerable communities' agri-food, scientists' access to reliable data and information, and decision-maker capacities to better govern agri-food systems, but it is also imperative that such transformative processes occur through (re)harmonization of Nature-Human systems, to avoid path-dependent problems in the future (Madani, 2022).

But how do we begin a transformative process?

The Challenge of Transforming Agri-Food Systems

Although the complexity, uncertainty, and diversity of the goals of various stakeholders around agri-food makes its transformation complex or potentially wicked, transforming it will significantly affect the entirety of the system and cause potential spillovers to other systems. This can be traced back to the central role of agri-food systems in connecting the Resource Nexus. For example, water is an essential link between all Nexus constellations. Water is the primary input and output of agri-food systems regarding drinking, irrigation, and WASH. Transforming agri-food systems toward sustainability would entail creating a circular connection between its output in the form of wastewater and its input in the form of irrigation water, nutrient soil, and fertilizers. In more developed regions, this mainly occurs via centralized grey infrastructure for wastewater treatment; however, this is not the case in less-developed regions. This is where participatory, cost-effective, small-scale, and decentralized approaches aligned with nature's intrinsic values to treat and reuse wastewater can reduce the global development deficit while transforming agri-food systems toward sustainability and resilience.

Examining the policy cycle, as well as what transformations are and how they can be governed, we argue that such processes are more likely to succeed in an overarching and enabling context of sustainable finance where stakeholders can locate shared challenges, develop a mutual understanding for them, and co-develop responses to tackle them based on existing and emerging local and global values (Figure 1). In short, a transformative process must include:

1. Challenge Co-Identification: Evidence-based scientific output on what was, what is, and what is to be under various scenarios. Findable, Accessible, Interoperable, and Reusable (FAIR) data are prerequisites for such output.

2. Co-Development: Inclusive and environmentally just participation of stakeholders in co-developing Nature-based approaches to shared challenges based on 1. This process should optimally include co-Design, co-Implementation, and co-Monitoring.

3. Feedback: Rigorous Co-Evaluation feeds into 1, where stakeholders could jointly analyze and provide evidence to all stakeholders regarding the approach's effectiveness.

The results of this process can inform evidence-based policies at the science-policy-society-practice interface.

But how do we bring a transformative process into action?

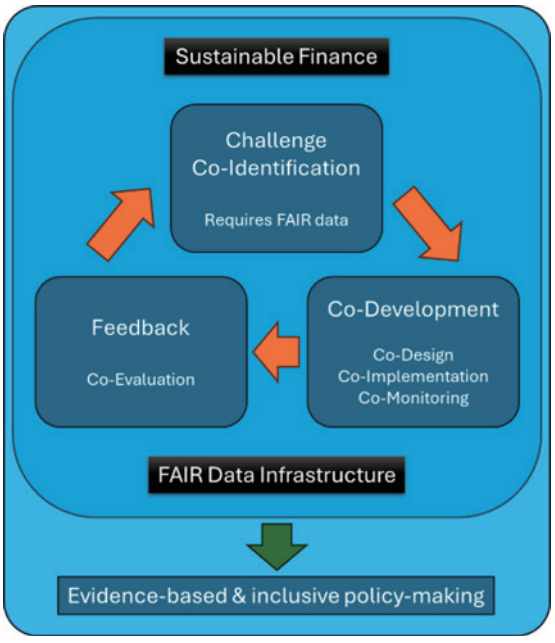

Figure 1: A transformative process (Source: Authors)

A Coupled Citizen Science and Nature-based Solutions Approach (CS-NbS)

As previously argued, an optimal thread that we can pull on transforming agri-food systems is to focus on water, as it connects the Resource Nexus and serves as the primary input and output of agri-food systems. Loghmani-Khouzani et al., (2024) suggest a coupled approach where Citizen Science is closely coupled with Nature-based Solutions (CS-NbS) at the interface of agri-food and Water, Sanitation, and Hygiene (WASH). The authors describe CS as "a participatory, collective scientific effort in which, according to their capabilities, citizens are encouraged and involved in the scientific process" (2024, p. 2) and NbS as "'approaches' that take fundamental inspiration from the evolutionary knowledge invested in nature to effectively and efficiently address societal challenges while providing various services, including those of the ecosystem." (2024, p. 5). The review takes inspiration from the Attitude-Behavior-Context (ABC) triangle. Based on ABC, engagement in sustainability-related CS can promote sustainable attitudes among the engaged stakeholders, while NbS provide sustainable contexts by design. Therefore, arguing a CS-NbS may result in a visible change of systemic behavior, i.e., transformation.

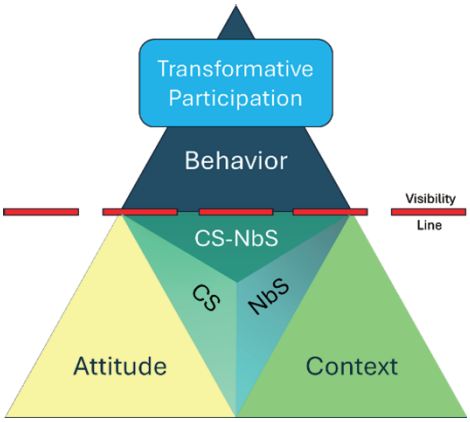

Figure 2: ABC triangle via coupled CS-NbS (Loghmani-Khouzani et al., (2024))

Nature-based Solutions (NbS)

Nature and the resources it provides sustain our environment, the societal interactions that form within, and the resulting economy. From the onset, NbS provides sustainable contexts, as, by definition, they (re)harmonize nature and humans. They are environmentally friendly, socially just, and economically cost-effective. NbS provides vast ecosystem services that benefit humans and significantly enhance degrading environmental conditions. However, there are barriers to their adoption

Resource Nexus persepctive

- Water, Biota, Soil, material Space, Climate (Key resources)
- Land, Waste, Energy, Food (Derived resources)
- NbS are created using Material, Soil, Land, Waste, and Space. Biodegradation, capillary rise, evapotranspiration, and photosynthesis convert fecal matter containing Water, Biota, and Energy to Biota, Energy, and Food, impacting the Climate.
- Resource Nexus perspective supports synergized utilization of resources in agri-food systems while reducing trade-offs in their use.

NbS Adoption Barriers

Although recent efforts show an increasing trend in NbS research, and examples of NbS treating wastewater and reusing it for irrigation purposes and aquifer recharge exist (Reis et al., 2023; Silva et al., 2022), the research atmosphere is biased in their application toward climate change extremes and less on agri-food, WASH, and biodiversity (Loghmani-Khouzani et al., 2024). This is mainly due to insufficient data on their adoption and the ecosystem services they provide for the diverse stakeholder groups. Although NbS are not new and have been adopted worldwide by local communities for generations, their effectiveness has not been scientifically reported.

To adopt water and agri-food-related NbS, Loghmani-Khouzani et al., (2024) reflect on the most critical barriers:

- Knowledge Gaps: Lack of data and information on NbS effectiveness.
- Limited financial resources for sustainable implementation.
- Insufficient stakeholder engagement and community support.

However, the question is:

Can Citizen Science (CS) Overcome the Barriers to NbS Adoption?

Although CS utilization in NbS adoption, specifically in agri-food and WASH systems, has yet to be adopted on a broader scale, an ever-growing body of literature suggests an untapped potential in CS. If CS is coupled with NbS, the required capacity and training are provided, and FAIR principles and ethical guidelines are properly considered,

Two critical aspects must be considered when adopting a CS-NbS approach. First, NbS are best opted for a hybrid coupling with grey infrastructure for maximum impact (Loghmani-Khouzani et al., 2025). The second is to move away from a "problem-solution" to a "challenge-response" mindset, emphasizing human responsibility in system transformation (Davies, Loghmani-Khouzani, and Fath, 2024).

These actions will enable a transition toward inclusive, sustainable, and resilient agri-food systems.

it can tackle all the major barriers to NbS adoption. CS actively engages stakeholders around a shared problem, tackling the lack of participation. Research suggests that engagement and inclusion in CS activities can create trust among the stakeholders, leading to increased ownership of challenges and acceptance of decisions. Moreover, as citizen scientists often engage with it due to self-interest in learning or contributing back to nature and society, or as it is directly related to a problem that affects them daily, it can be a meaningful and cost-effective mechanism for monitoring NbS effectiveness, tackling the barriers of funding and lack of an evidence base simultaneously.
Finally, how can policymakers enable a CS-NbS approach to transform agri-food systems?

Conclusion

In the face of external shocks like climate change, geopolitical tensions, and pandemics, integrating Citizen Science (CS) into Nature-based Solutions (NbS) is critical to enhancing the sustainability and resilience of agri-food systems. A CS-NbS approach generates empirical evidence, promotes inclusiveness, and strengthens collaboration across science, policy, society, and practice. Reliable CS data can also improve decision-making, particularly in regions with limited access to FAIR data.

Action Points

To drive this transformative change, the following actions are recommended:

1. Capacity Building for Stakeholders:

- Co-design and implement small-scale, decentralized CS-NbS projects (co-DIME) with frameworks for FAIR (Findable, Accessible, Interoperable, Reusable) data protocols and privacy safeguards.
- Raise awareness of NbS benefits for agri-food systems and WASH (Water, Sanitation, and Hygiene).

2. Incentivizing Participation in CS-NbS:

- Highlight CS-NbS's role in enhancing data quality, fostering environmental awareness, and advancing sustainability knowledge.
- Engage businesses, insurers, and public-private partnerships to secure funding.
- Allocate public budgets and provide financial incentives for NbS adoption.

3. Infrastructure for FAIR, Private, and Safe CS-NbS Ecosystems:

- Foster collaboration between policymakers, CSOs, local communities, and other stakeholders.
- Use CS for long-term data collection to demonstrate NbS effectiveness.
- Integrate digital tools (e.g., AI, modeling) to streamline

REFERENCES

Davies, T., Loghmani-Khouzani, T., & Fath, B. D. (2024). "Solutions" are not the answer. Frontiers in Sustainability, 5, 1509972. https://doi.org/10.3389/frsus.2024.1509972.

Extreme weather events in Europe. (2018, March 22). https://easac.eu/publications/details/extreme-weather-events-in-europe.

FAO (Food and Agriculture Organization of the United Nations). (2021). The state of the world's land and water resources for food and agriculture. Systems at breaking point. The synthesis report. https://www.fao.org/land-water/solaw2021/en/.

Furtak, K., & Wolińska, A. (2023). The impact of extreme weather events as a consequence of climate change on soil moisture and on the quality of the soil environment and agriculture – A review. CATENA, 231, 107378. https://doi.org/10.1016/j.catena.2023.107378.

Loghmani-Khouzani, T., Dany, V., Seifert, N., Madani, K., & Guenther, E. (2024). Can citizen science in water-related nature-based solutions deliver transformative participation in agri-food systems? A review. Agricultural Systems, 220, 104052. https://doi.org/10.1016/j.agsy.2024.104052.

Loghmani-Khouzani, T., Dubois, E., Ottaviani, S., Serrao, L., & Starkey, E. (2025, working paper). Are water-related Nature-based Solutions (NbS) assessed to their full multi-benefit potential? A Resource Nexus perspective review. Sustainability Nexus Forum.

Madani, K. (2022). Inclusive Green Recovery: An Essential Post-COVID-19 Paradigm Shift to Recover Better. https://doi.org/10.13140/RG.2.2.15244.69762.

Makwinja, H. Y., Piyo, G., & Nyirenda, V. (2023). Perception of smallholder farmers on the efficacy of ecological farming in Chiradzulu district, Southern Malawi. Conference on International Research on Food Security, Natural Resource Management and Rural Development, 235. https://www.tropentag.de/2023/abstracts/full/235.pdf.

Mkumbukiy, A., Loghmani-Khouzani, T., Madani, K., & Günther, E. (2025, under review). Agrifood systems' resilience for sustainable food security amid geopolitical tensions: A systematic literature review.

Reis, M. C. G., Borges, A. C., Cunha, F. F. D., & Silva, R. R. D. (2023). Evapotranspiration beds as a zero-discharge nature-based solution for wastewater disposal: A review. Ecological Engineering, 189, 106896. https://doi.org/10.1016/j.ecoleng.2023.106896.

Saravanan, A. (2025, working paper). High-resolution precipitation estimation in ungauged wheat/maize fields using satellite imagery and crop model inversion.

Silva, J., Celeri, M. de O., Borges, A., & Fernandes, R. (2022). Greywater as a water resource in agriculture: The acceptance and perception from Brazilian agricultural technicians. SSRN Scholarly Paper 4224290. https://doi.org/10.2139/ssrn.4224290.

Authors: Taha Loghmani-Khouzani, Yamikani Makwinja, Ally Mkumbukiy and Aatralarasi Saravanan

Contact: Taha Loghmani-Khouzani, loghmani@unu.edu.

Acknowledgements:
The authors would like to acknowledge the support and input of Prof. Dr. Edeltraud Günther (UNU-FLORES), Prof. Dr. Kaveh Madani (UNU-INWEH), and Prof. Dr. Serena Coetzee, as well as Victoria Dany, and Nadine Seifert (TU Dresden).
This policy brief is the output of training presented by Andrew Dunn (UNU-CRIS) and Thato Masire (UNU-FLORES) to NEXtra doctoral researchers at UNU-FLORES in 2024/25. The training was partially funded by DAAD (Deutscher Akademischer Austauschdienst).