Agricultural systems
by design

8th International Farming System Design Conference
Palaiseau – 25-29 August 2025

AgroParisTech

INRAE

ideas
INITIATIVE FOR DESIGN
IN AGRIFOOD SYSTEMS

Agricultural systems by design

Key-Note

From concept to practice: exploring the promise and pitfalls of resilience in farming systems design

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WAGENINGEN UNIVERSITY & RESEARCH

Alliance Bioversity & CIAT

CGIAR MULTIFUNCTIONAL LANDSCAPES

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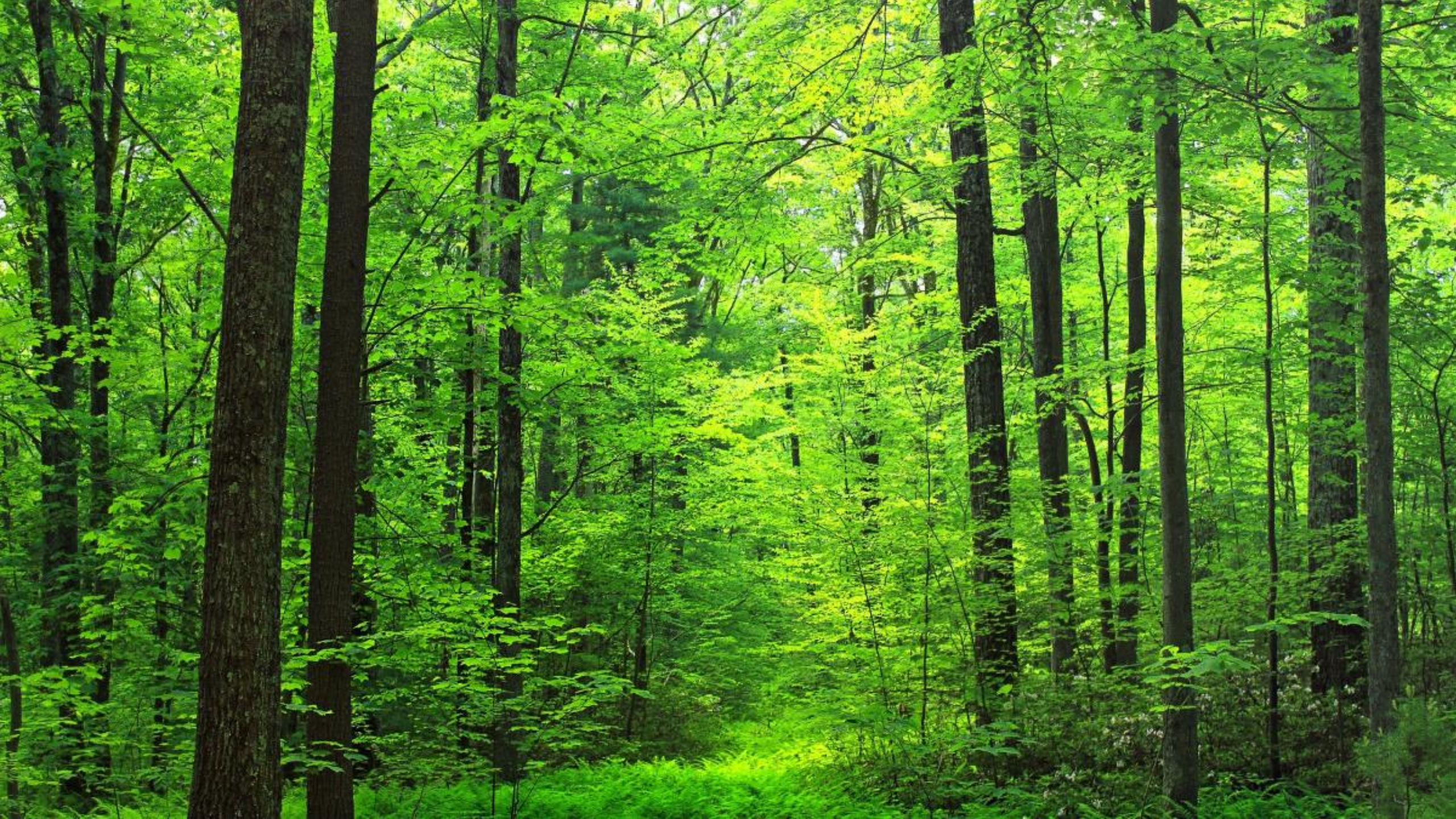
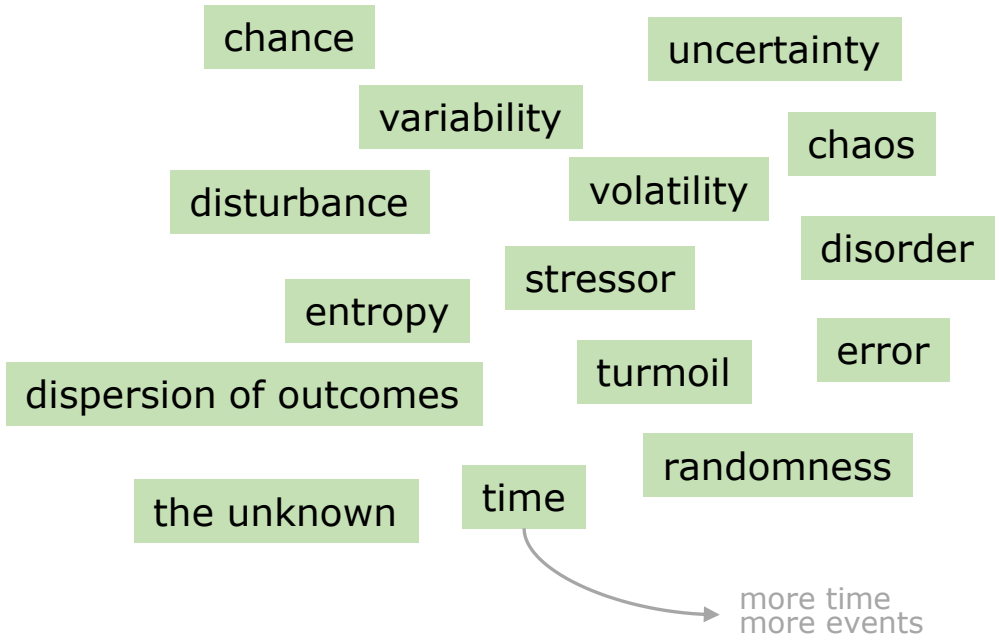


Disorder in natural systems

Disorder in a managed system

Disorder in natural systems

Disorder in a managed system



Disorder in natural systems

chance
uncertainty
variability
chaos
disturbance
volatility
disorder
stressor
entropy
error
turmoil
dispersion of outcomes
randomness
time
the unknown

more time
more events

Disorder in a managed system

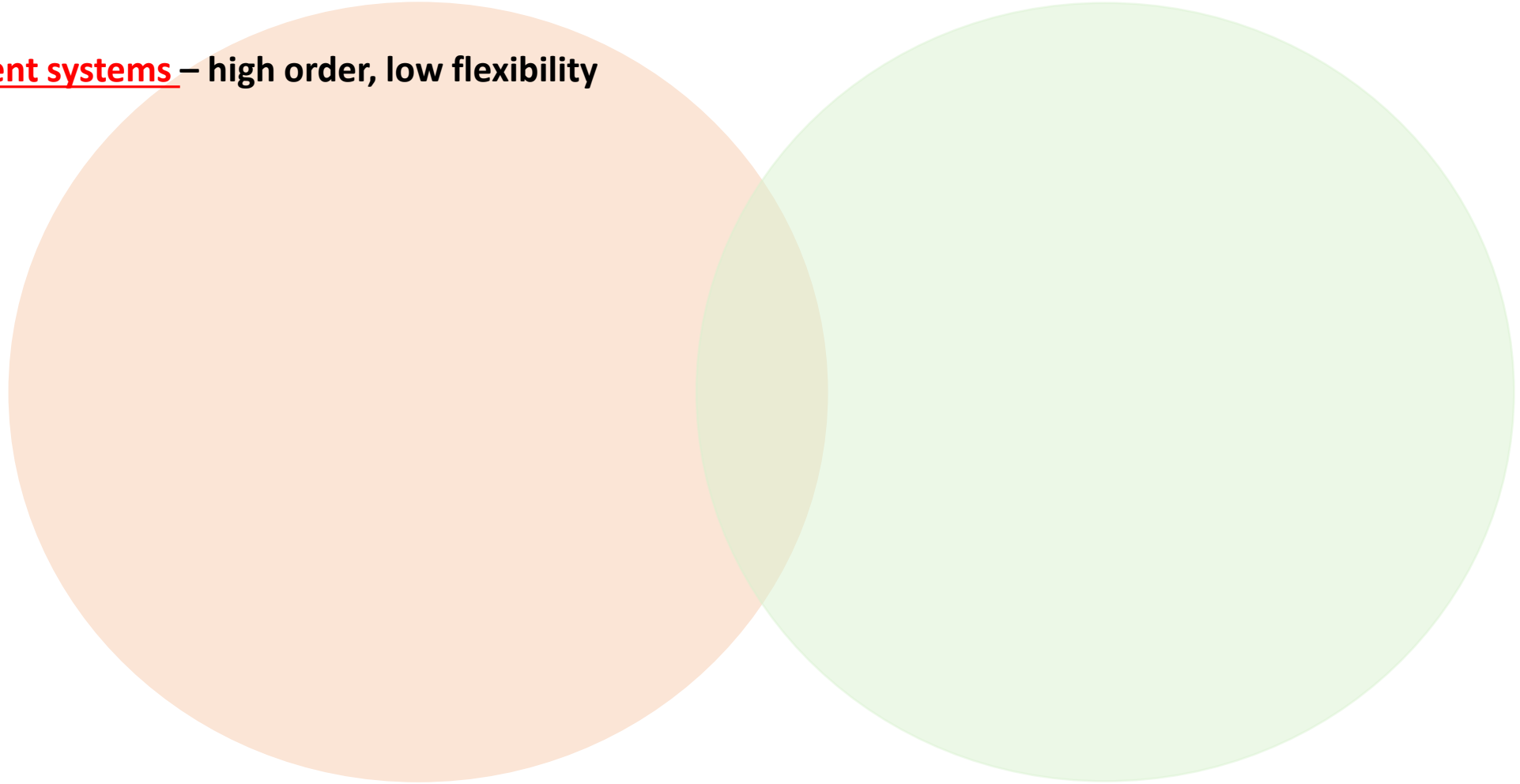
Structural properties

diversity
mutations
redundancies
variability
plasticity
creativity
crazy ideas
mistakes
experiments
imperfect, incomplete knowledge
uncertainty

Dynamic, human driven

Efficiency ≠ Resilience

Efficient systems – high order, low flexibility



Efficiency ≠ Resilience

Efficient systems – high order, low flexibility

- Just in time
- Specialization
- Outsourcing, dependencies
- Linear value chains
- Centralized control
- Standardization
- Scalability through uniformity

Maximize output, minimize costs

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Resilient systems – moderate order, high flexibility

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Resilient systems – moderate order, high flexibility

- Redundancies
- Diversification
- Sovereignty, agency
- Self-regulation & learning
- Interconnectedness & feedbacks
- Decentralization
- Slack and buffers
- Modularity

Having sufficient + flexibility to evolve

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- Scalability through uniformity

Maximize output, minimize costs

?

RUE

Labor

Time

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Having sufficient + flexibility to evolve

Resilience: from ecology to agricultural system

~ "***capacity*** *of a [socio-ecological / farming] system*"

"to experience disturbance and still maintain its ongoing functions and controls" (Holling, 1973)

"in the face of increasingly complex and accumulating economic, social, environmental and institutional shocks and stresses" (Meuwissen *et al.*, 2019)

"[*for]* *guaranteeing production over a wide range of conditions"* (Sundstrom *et al.*, 2023)

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Resilience:
= a system trait
= the process of change
= the outcome of this change

Moser *et al.*, 2019

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➔ *Dynamic system / time*
➔ *Facing Disturbance*
➔ *Towards a Target state / functions*

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} Desirability?

Resilience: is it (always) desirable ? For whom?

"Guaranteeing production over a wide range of conditions" Sundstrom *et al.*, 2023

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Other functions E.g., ecosystem services, livelihood Van der Lee *et al.*, 2022

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/ Absorption

a. Robustness

Meuwissen *et al.*, 2019

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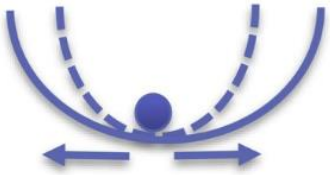
/ Absorption

a. Robustness

/ Flexibility



b. Adaptability

Meuwissen *et al.*, 2019

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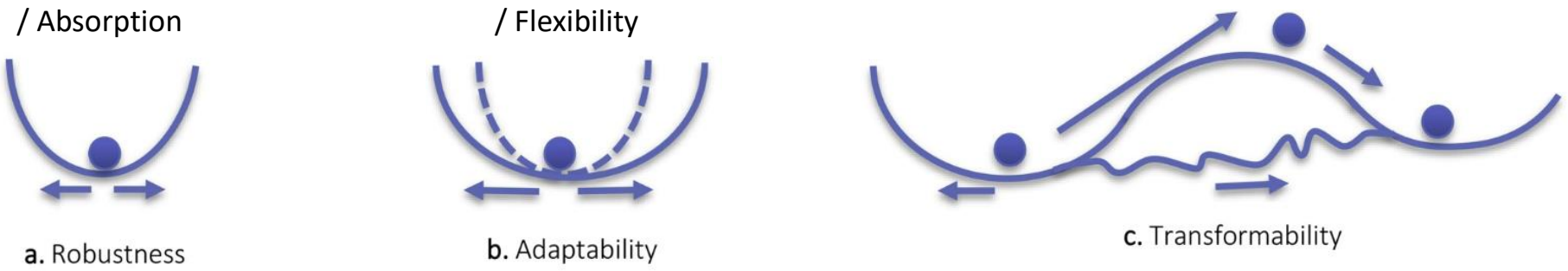


Meuwissen *et al.*, 2019

Recent frameworks

1. Resilience *of what*?

2. Resilience *to what*?

/disturbance(s)
Known or unknown

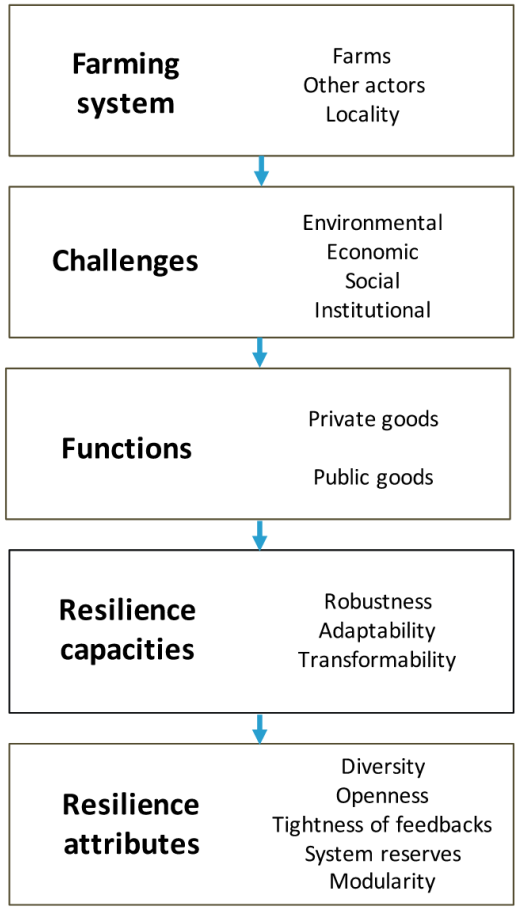
3. Resilience *for what purpose*?

4. What *resilience capacities?*

Resilience as an outcome

5. *What enhances* resilience?

Resilience as trait



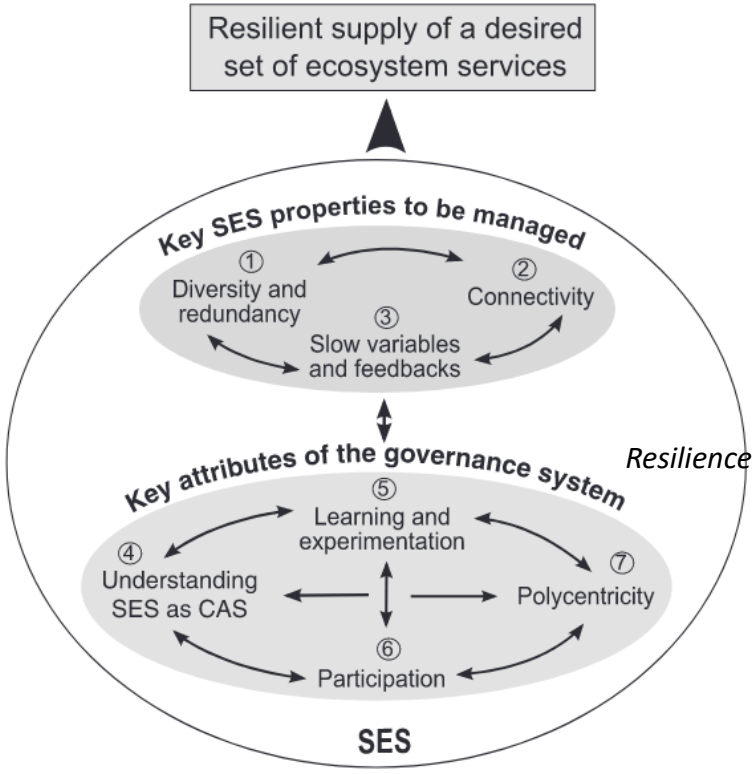
Meuwissen *et al.*, 2019

Recent frameworks

5. *What enhances* resilience?

Resilience attributes	Diversity Openness Tightness of feedbacks System reserves Modularity

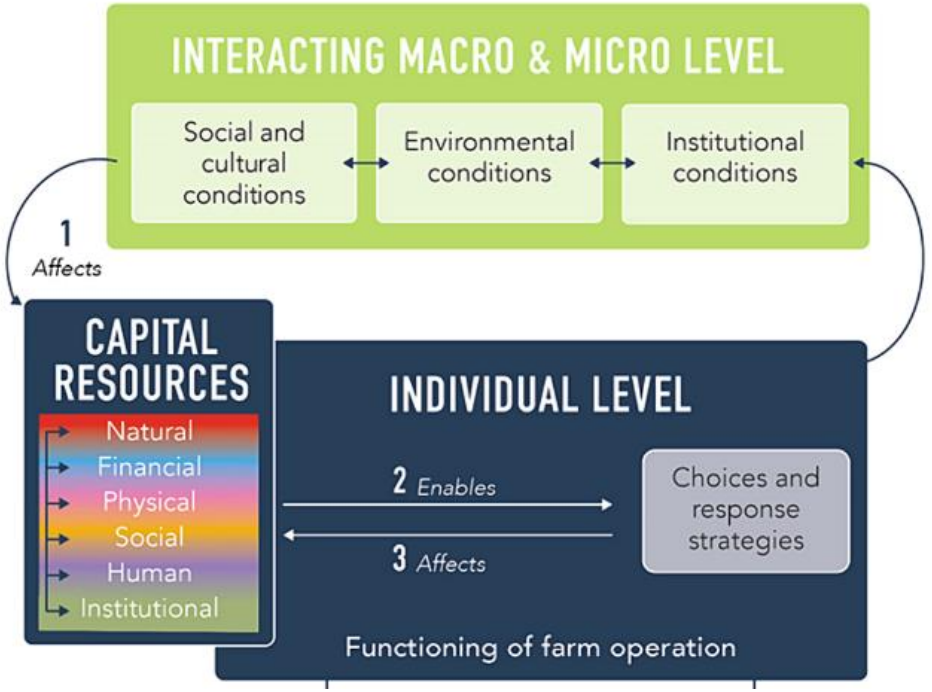
Meuwissen *et al.*, 2019



Biggs *et al.*, 2012

Interacting levels

Resilience as a process



Malherbe *et al.*, 2024

Recent frameworks

5. *What enhances* resilience?

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Meuwissen *et al.*, 2019

Behaviour-based resilience indicators

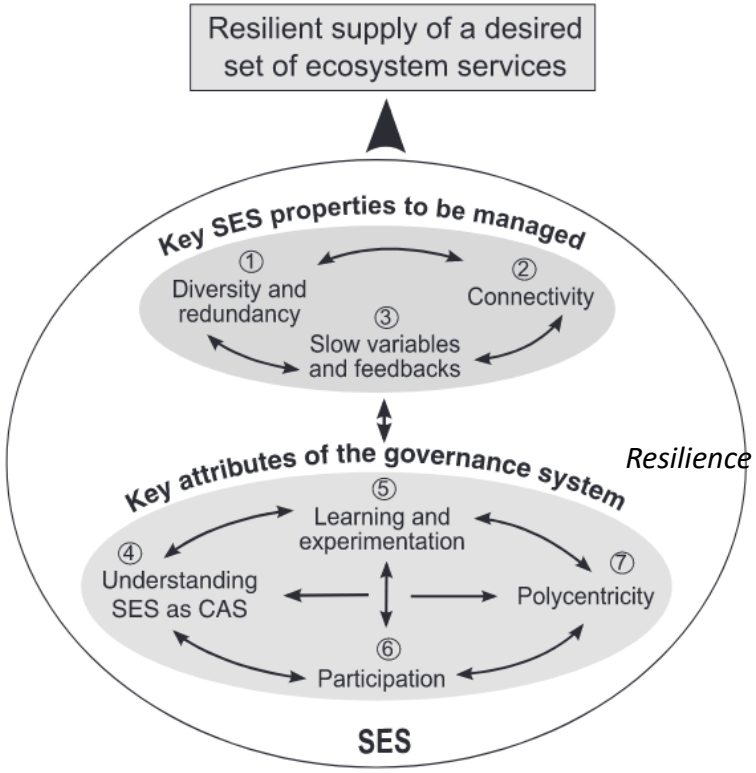
Socially self-organized

Ecologically self-regulated

Reasonably profitable

Globally autonomous and locally interdependent

Cabell and Oelofse, 2012



Interacting levels

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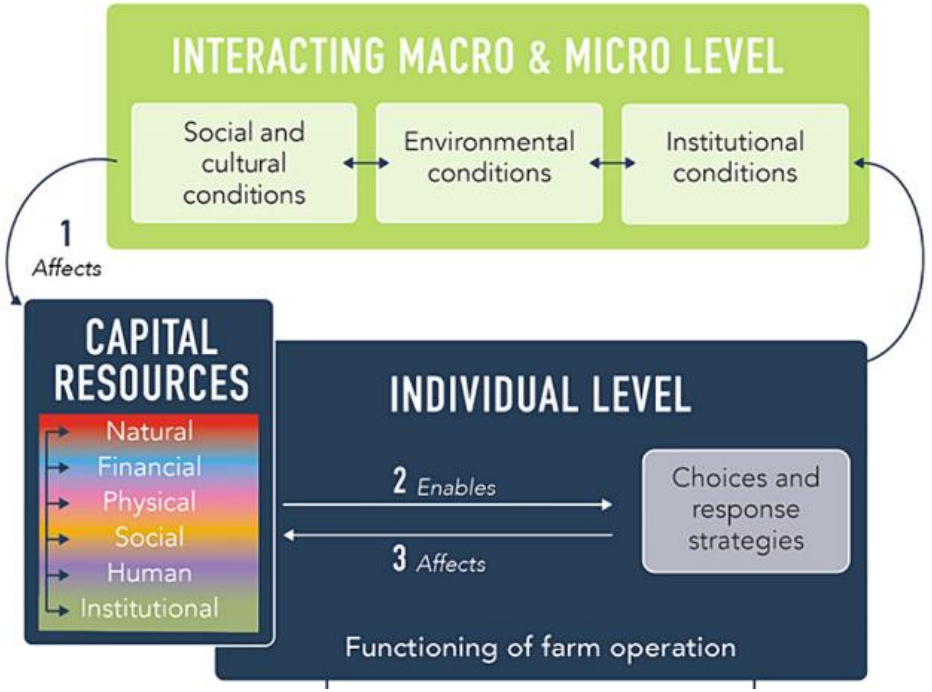


Malherbe *et al.*, 2024

3 main types of assessment (1)

Perception-based / subjective

Performance-based / objective

Attribute-based

Jones & Tanner, 2017
Pret *et al.*, 2024

3 main types of assessment (1)

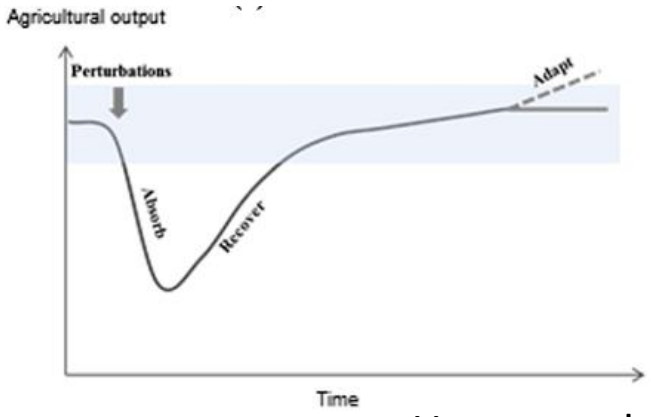
Perception-based / subjective | Performance-based / objective | Attribute-based

"The concept of subjective resilience stems from the premise that people have an **understanding of the factors that contribute to their ability** to anticipate, buffer and adapt to disturbance and change. Subjective household resilience therefore relates to an **individual's cognitive and affective self-evaluation** of their household's capabilities and capacities in responding to risk." Jones and Tanner, 2017

Vs. data-driven,
with indicators selected by experts
& dynamics "objectively" measured

3 main types of assessment (2)

Perception-based / subjective | Performance-based / objective | Attribute-based



Urruty et al., 2016

Vs. data-driven,
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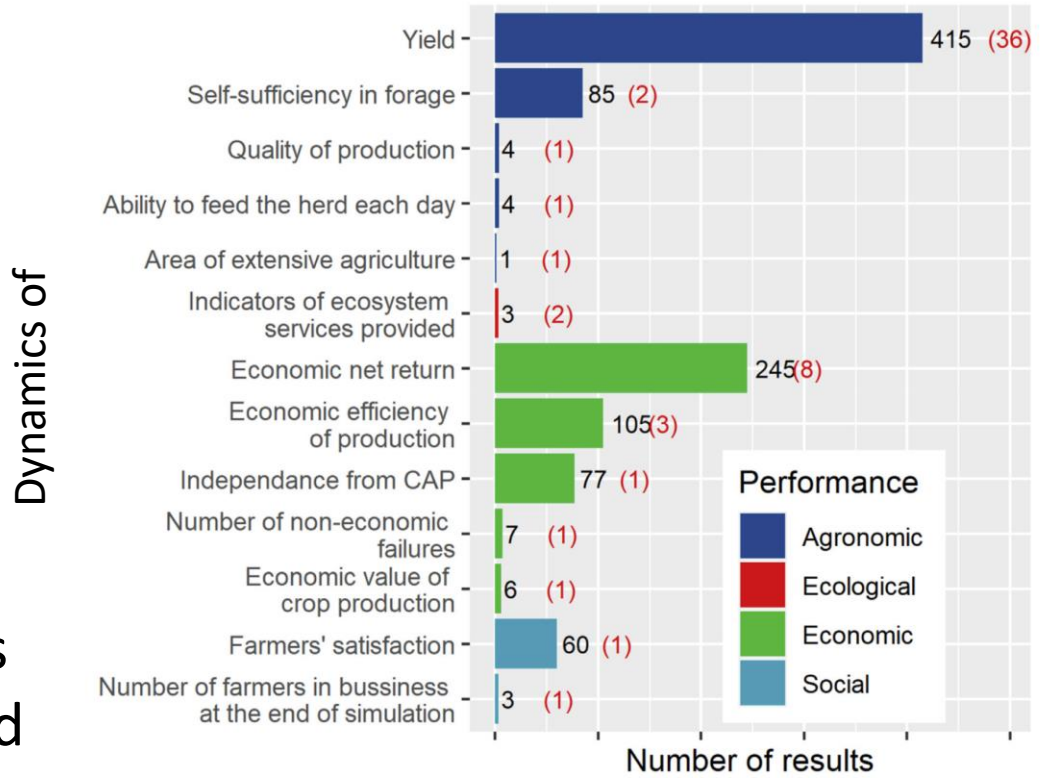
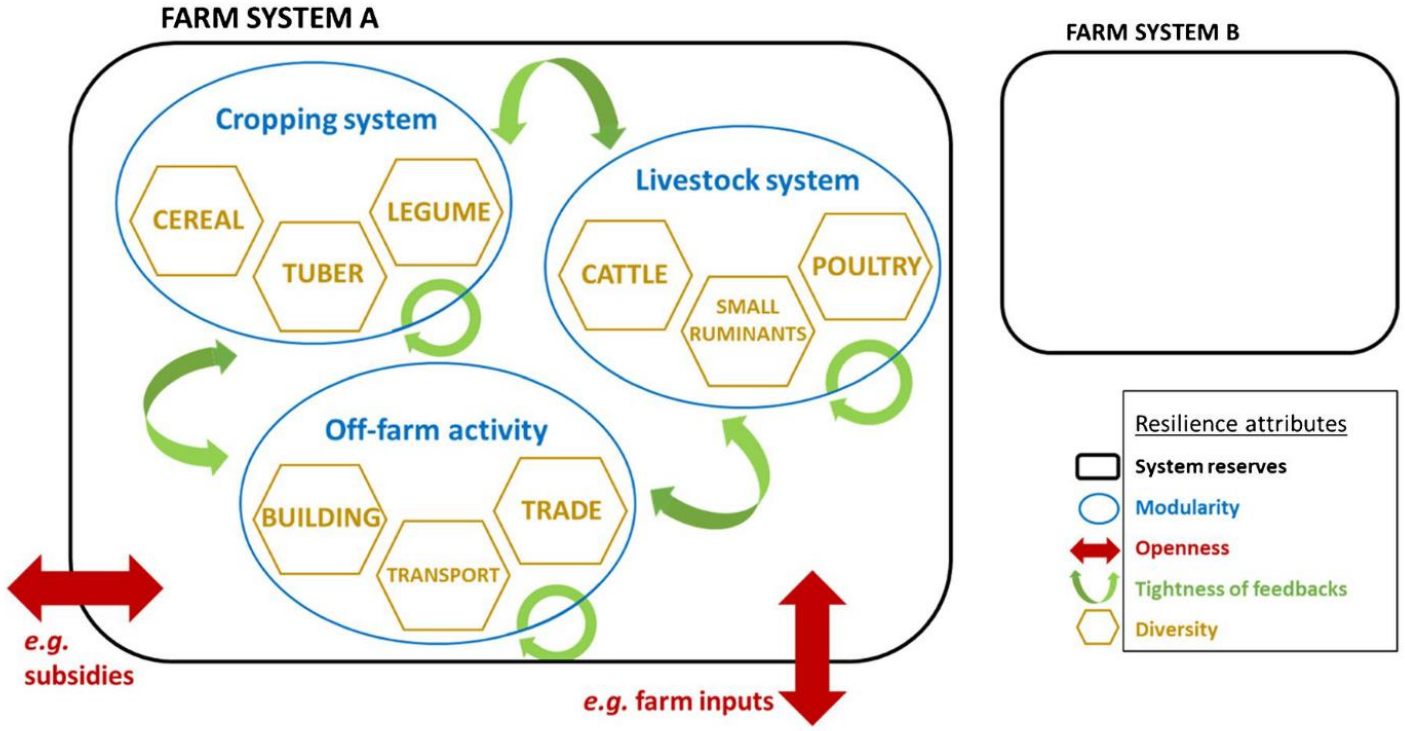


Dardonville et al., 2021

3 main types of assessment (3)

Perception-based / subjective | Performance-based / objective | Attribute-based



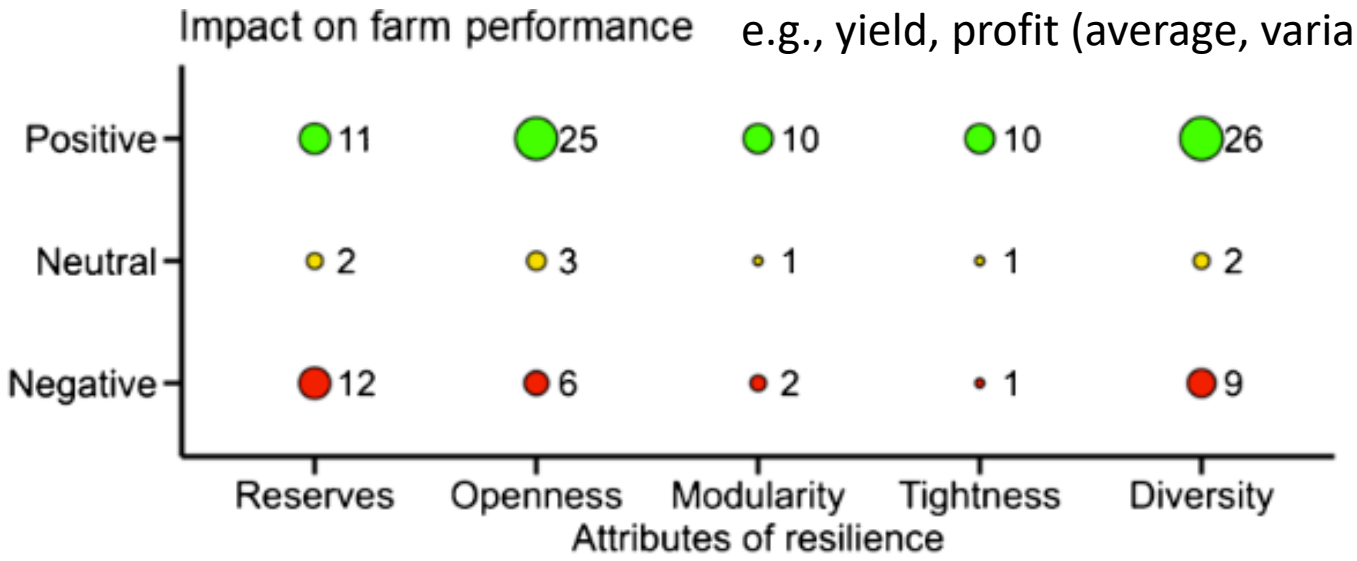
Resilience attributes	Diversity Openness Tightness of feedbacks System reserves Modularity

Meuwissen *et al.*, 2019

Fig. 3 Resilience attributes and their interconnections at farm level. Adapted from Meuwissen et al. (2019). Black squares represent system reserves for farm system **A** and **B** (farm reserves are larger for system A than B). Blue circles represent the different modules and/or activities for a given farm system, with green arrows representing the interconnections between and within them. Red arrows represent the interconnection between the farm system and the external environment. Yellow hexagons represent the diversity of sub-components for a given module

Pret *et al.*, 2025

Resilience attributes & farm performances



e.g., yield, profit (average, variability, etc.)

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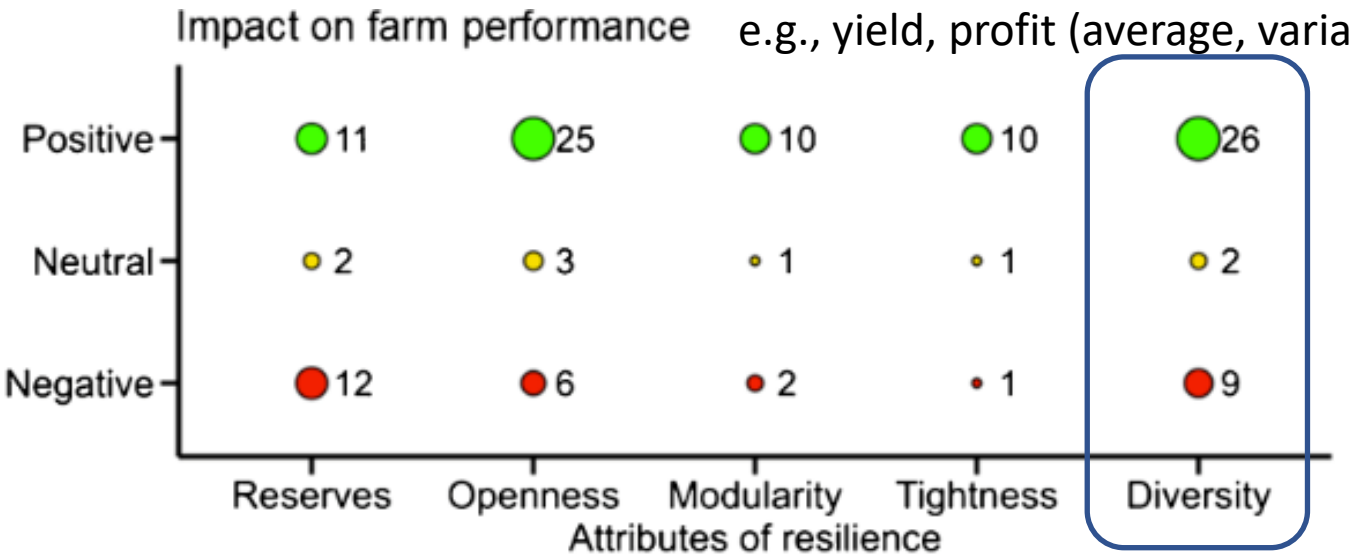
Resilience attributes & farm performances



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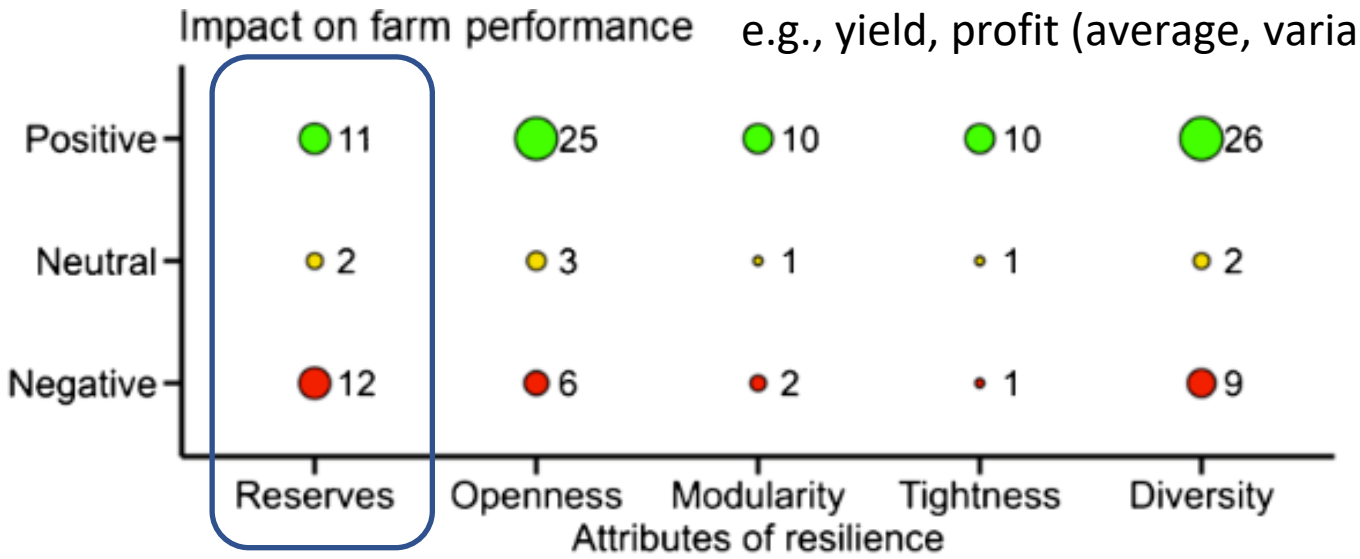
↗ Crop diversity ➔ stabilizing productivity
➔ lowering average profitability

Resilience attributes & farm performances



Pret *et al.*, 2025

↗ Cattle herds (reserves) ➔ farm profitability
➔ variability of farm income

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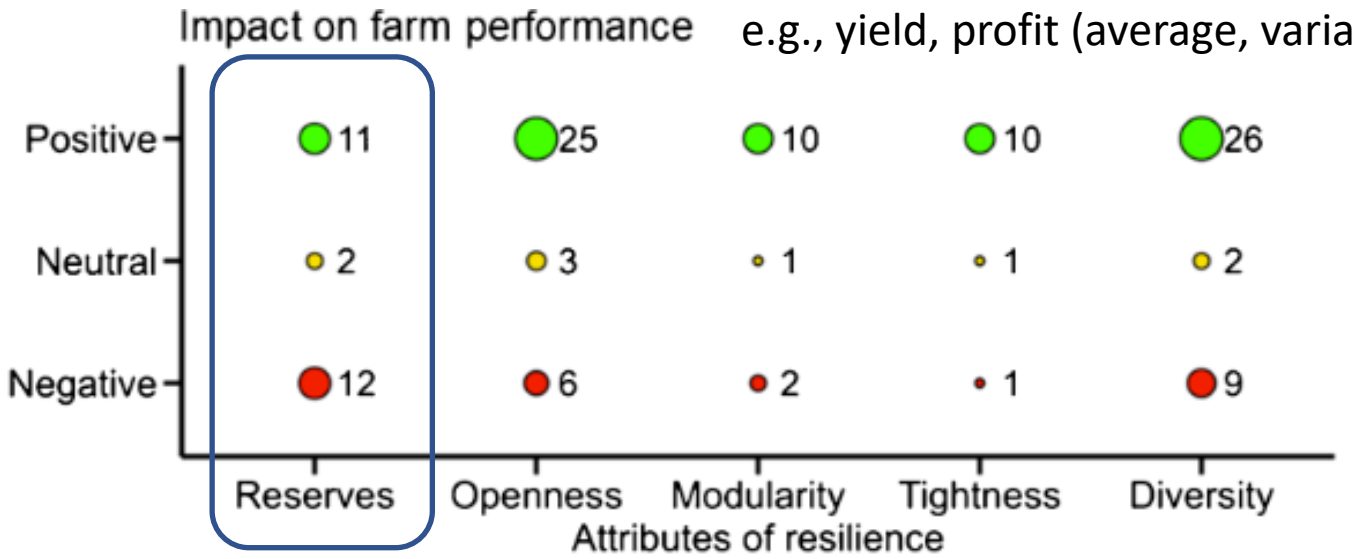
Resilience attributes & farm performances



Pret *et al.*, 2025

↗ Cattle herds (reserves) ➔ farm profitability
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↗ Crop diversity ➔ stabilizing productivity
➔ lowering average profitability

➔About trade offs

➔Increasing attributes is not always positive ➔ Implications for design?

Towards a paradigm shift for designing resilient systems?

From efficiency to redundancy & performance reduction in a more variable environment

Towards a paradigm shift for designing resilient systems?

From efficiency to redundancy & performance reduction in a more variable environment

~ From system control to management, as **uncertainty** becomes a key component

=> Switch from **farm to household, with a relational approach**:

"farm resilience depends on the ability of the farmer to make sense of available options, and to navigate uncertainty by experimenting, learning, engaging in ***networks and collaborating****"*

Darnhofer *et al.*, 2016

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~ From designing a system

To reach performances

To be able to absorb/react to disturbances

=> **Build robust strategies through a pro-active process, not only reactive**

Key challenges

1. Consider different scales

- Competitions/synergies for resources ➔ Function diversity and redundancy at different scales
- Design farming systems AND associated governance

Sundstrom *et al.*, 2023

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<u>2. Consider different time horizons and trajectories</u>

- Prepare for risks / keep open and elastic
- Long-term thinking; e.g., slow variables

Sabatier *et al.*, 2017

Sundstrom *et al.*, 2023

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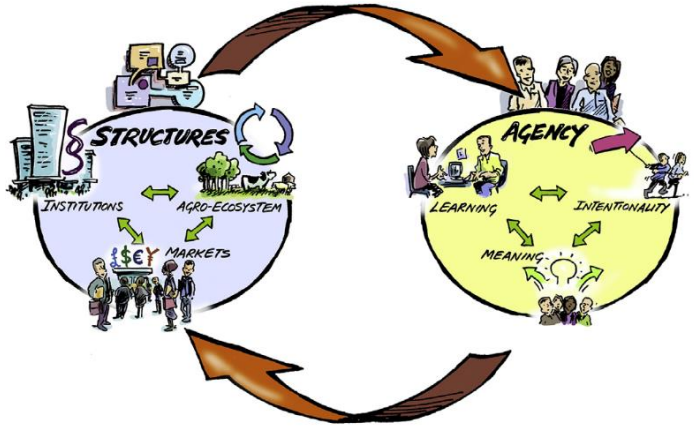
Sabatier *et al.*, 2017

3. Consider all dimensions

- E.g., social, working conditions, justice, agency
- Acknowledge trade-offs

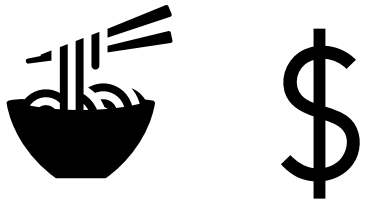
Perrin *et al.*, 2024

Sundstrom *et al.*, 2023

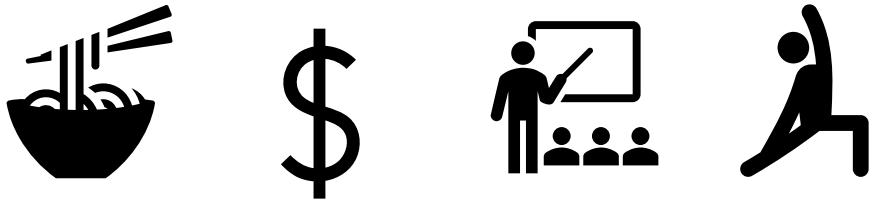


Darnhofer *et al.*, 2016

Farming households and livelihoods



Farming households and livelihoods



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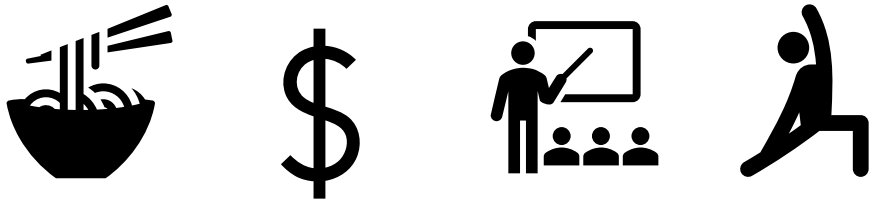
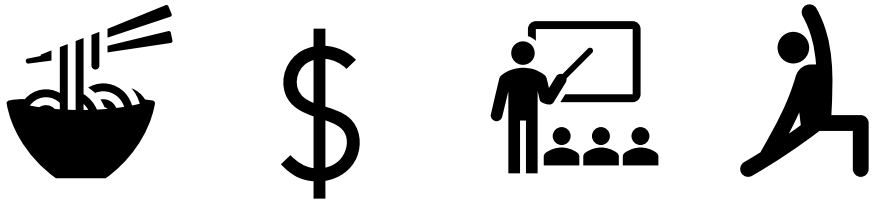


- Resilience for what?
  - Farm or household?

Farming households and livelihoods



- Resilience for what?
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- Making ends meet might imply

  limited resilience at farm level!

Agency

The ability to make decisions and act upon them (Kabeer, 1999)

Agency

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- Agency often not equally distributed within households
  - Gender and social norms
  - Cultural expectations
  - Access to education and knowledge
  - Laws, governance, policies

Agency

The ability to make decisions and act upon them (Kabeer, 1999)

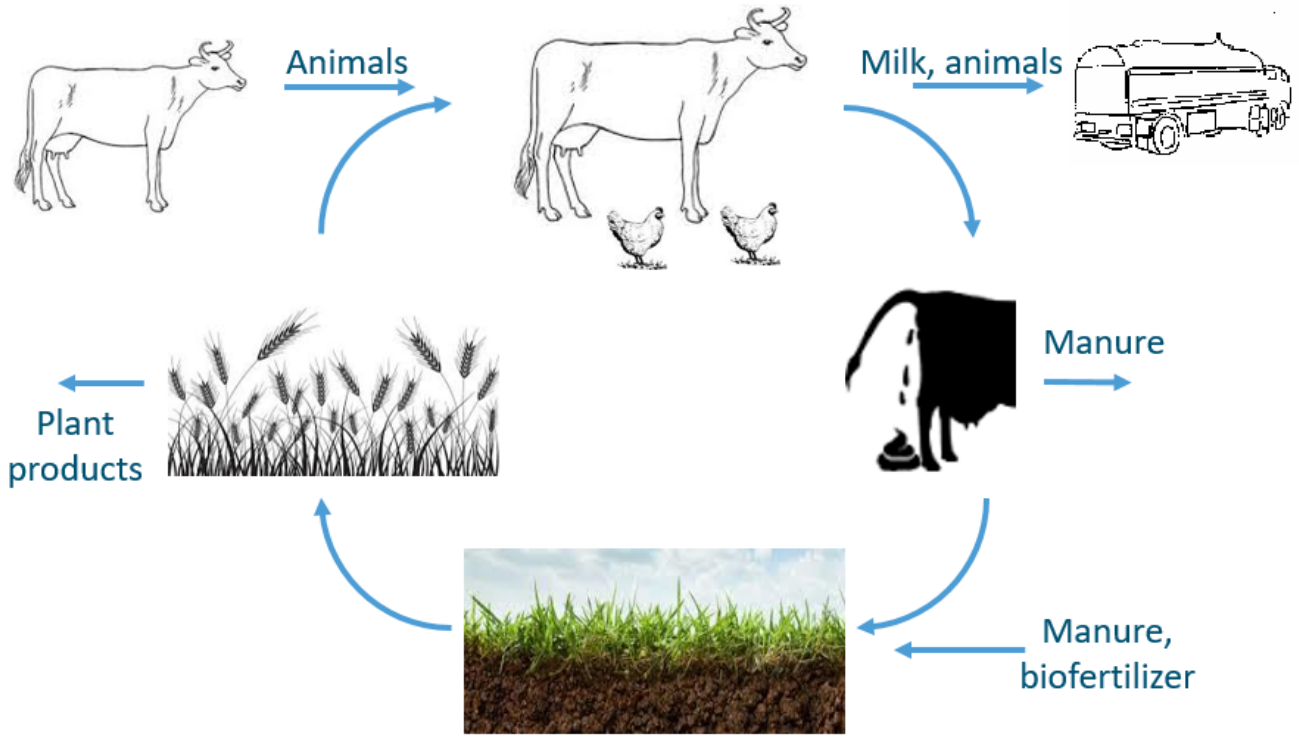
- Agency often not equally distributed within households
- Agency key characteristic for resilience at all scales
  - Buffers
  - Connectivity
  - Diversity

Windows of opportunities

- Farm components building blocks

→ Is this picture complete?

- Can all components change?
  - Gender, social, cultural norms
  - Personal wishes
  - …



Trade-offs across scales and dimensions

For what

To what

	Field	Farm	Landscape
	Individual	Household	Community
Economic			
Social			
Ecological			

Adelhart Toorop & Rietveld, in prep.

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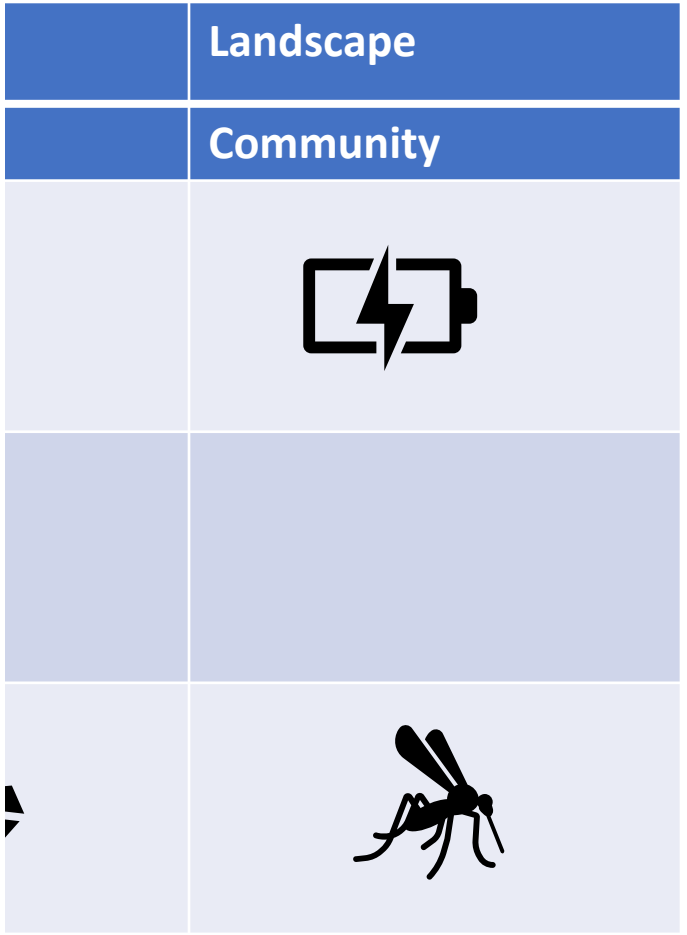
Table 1: Framework with checkpoints for increased resilience cross-scale

	Individuals	Farm /household	Community	Landscape
Economic Resilience: *Enhancing Stability and Livelihood Security*	Promote diverse income opportunities and financial literacy to reduce vulnerability to market fluctuations.	Diversify farm production (e.g., agroforestry, mixed cropping) and income streams to reduce reliance on single commodities.	Strengthen cooperative models, local markets, and shared financial resources (e.g., microfinance, community investment funds).	Ensure fair access to land and water resources while promoting sustainable market integration that benefits local economies.
Ecological Resilience: *Maintaining Functioning Ecosystems and Natural Cycles*	Encourage sustainable land management practices and knowledge transfer on regenerative agriculture.	Promote soil conservation, water retention strategies, and crop-livestock integration to sustain long-term productivity.	Develop collective natural resource management (e.g., shared grazing areas, watershed management) and strengthen local seed systems.	Maintain ecological diversity by preserving multifunctional landscapes (e.g., wetlands, forests, agroforestry systems) to buffer against climate shocks.
Social Resilience: *Strengthening Networks, Governance, and Equity*	Support education, training, and access to decision-making processes to enhance agency and adaptability. Participation in cooperative structures	Foster intergenerational knowledge transfer, equitable land tenure, and strong family-based support networks. Participation in cooperative structures	Strengthen social capital through cooperative structures, community-led governance, and inclusive decision-making.	Promote adaptive governance models that integrate local knowledge, empower communities, and ensure equitable distribution of resilience benefits.



Adelhart Toorop & Rietveld, in prep.

From concept to practice: exploring the promise and pitfalls of resilience in farming systems design

- Natural systems vs. managed systems, entropy, disorder
- Frameworks, assessment methods
  - Systems that thrive despite disturbances
- Challenges for (co-)design
  - Trade-offs across scales
  - Time horizons
  - Dimensions of performances
- Pitfalls
  - Resilience to what and for whom?
  - Agency, windows of opportunities
  - Winners and losers

Key messages

- Consider “resilience of what and for whom?”
  - Resilience is not just about systems adapting or transforming - it’s about people having the freedom and capacity to evolve.
- Efficiency ≠ resilience
- Incorporate resilience in design process
  - Foster agency
  - Supporting governance
  - Collaborate across scales

References

Biggs, R., Schlüter, M., Biggs, D., Bohensky, E. L., BurnSilver, S., Cundill, G., ... & West, P. C. (2012). Toward principles for enhancing the resilience of ecosystem services. *Annual review of environment and resources*, *37*(1), 421-448.

Cabell, J. F., & Oelofse, M. (2012). An indicator framework for assessing agroecosystem resilience. *Ecology and Society*, *17*(1).

Dardonville, M., Bockstaller, C., & Therond, O. (2021). Review of quantitative evaluations of the resilience, vulnerability, robustness and adaptive capacity of temperate agricultural systems. *Journal of Cleaner Production*, *286*, 125456.

Darnhofer, I., Lamine, C., Strauss, A., & Navarrete, M. (2016). The resilience of family farms: Towards a relational approach. *Journal of rural studies*, *44*, 111-122.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., & Holling, C. S. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst.*, *35*(1), 557-581.

Holling, C. S. (1973, November). *Resilience and stability of ecological systems*.

Jones, L., & Tanner, T. (2017). 'Subjective resilience': using perceptions to quantify household resilience to climate extremes and disasters. *Regional Environmental Change*, *17*(1), 229-243.

Kabeer, N. (1999). Resources, agency, achievements: Reflections on the measurement of women's empowerment. *Development and Change, 30*(3), 435–464.

Meuwissen, M. P., Feindt, P. H., Spiegel, A., Termeer, C. J., Mathijs, E., De Mey, Y., ... & Reidsma, P. (2019). A framework to assess the resilience of farming systems. *Agricultural Systems*, *176*, 102656.

Malherbe, W., Biggs, R., & Sitas, N. (2024). Comparing apples and pears: linking capitals and capacities to assess the resilience of commercial farming operations. *Agricultural Systems*, *217*, 103934.

Moser, S., Meerow, S., Arnott, J., & Jack-Scott, E. (2019). The turbulent world of resilience: interpretations and themes for transdisciplinary dialogue. *Climatic change*, *153*(1), 21-40.

Perrin, A., Cournut, S., & Martin, G. (2024). Further consideration of working conditions is needed in farm resilience assessment. *Agricultural Systems*, *214*, 103845.

Pret, V., Falconnier, G. N., Affholder, F., Corbeels, M., Chikowo, R., & Descheemaeker, K. (2025). Farm resilience to climatic risk. A review. *Agronomy for Sustainable Development*, *45*(1), 10.

Sabatier, R., Joly, F., & Hubert, B. (2017). Assessing both ecological and engineering resilience of a steppe agroecosystem using the viability theory. *Agricultural Systems*, *157*, 146-156.

Sundstrom, S. M., Angeler, D. G., & Allen, C. R. (2023). Resilience theory and coerced resilience in agriculture. *Agricultural systems*, *206*, 103612.

Urruty, N., Tailliez-Lefebvre, D., & Huyghe, C. (2016). Stability, robustness, vulnerability and resilience of agricultural systems. A review. *Agronomy for sustainable development*, *36*(1), 15.

van der Lee, J., Kangogo, D., Gülzari, Ş. Ö., Dentoni, D., Oosting, S., Bijman, J., & Klerkx, L. (2022). Theoretical positions and approaches to resilience assessment in farming systems. A review. *Agronomy for Sustainable Development*, *42*(2), 27.