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# Sustainability Spaces for Complex Agri-Food Systems

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## Abstract

As a result of the complexity of agri-food systems, popularly-supported 'win-win' solutions rarely result in wholly satisfactory outcomes. We draw on documented cases of the introduction of agricultural input subsidies; the intensification of livestock production; and the development of genetically modified crop varieties as examples of agri-food systems in which there are multiple interconnected sustainability priorities and inevitable conflicts. Generic or narrowly conceived goals may not fully reflect the multiple and conflicting dimensions of sustainability that are relevant to such cases. There is a need to advance established multiple-win agendas, such as sustainable intensification and climate smart agriculture, to more fully reflect this complexity. We propose the use of the sustainability space concept for defining and monitoring sustainability priorities that might become the basis for effective management of complex systems. We further outline the challenge of defining and monitoring these priorities, which will require carefully designed, interdisciplinary and participatory research agendas.

While profit and productivity remain key motivations for agricultural development, donors and policy makers are increasingly seeking to improve the sustainability of food production, access to and the availability of food, and the resilience of supply chains, by promoting win-win solutions. Popular concepts, such as sustainable intensification (SI) and climate smart agriculture (CSA), are oriented around simultaneously achieving multiple targets, inclusive of increased food production, improved food security, adaptation to and mitigation of climate change, the conservation of ecosystems, and improved livelihoods (Pretty, 2008, Godfray et al., 2010). The no-compromise motivations of CSA and SI are attractive in a context of constrained donor budgets and multiple policy goals.

However, the much acknowledged reality that agri-food systems operate at a range of temporal and spatial scales and are comprised of complex interconnections (Darnhofer et al., 2012, Folke, 2006), complicates the task of achieving synergistically positive developments across multiple priorities.

SI describes, and is predominantly used in advocacy of, increasing the productivity of agricultural land in ways that do not result in a long term compromise of the social and ecological function of land and landscapes. However, there is a tendency for SI to be conceived along the lines of limited sustainability considerations and its application has sometimes been criticised for prioritising productivity over other goals (such as food security, biodiversity, social equity) (Petersen and Snapp, 2015, Godfray, 2015). CSA agendas encapsulate a somewhat broader set of priorities – e.g. food security and responses to climate change – but are sometimes vaguely defined allowing for generic prescriptions of CSA practice (Whitfield, 2016, Neufeldt et al., 2013). In cases of both narrowly and vaguely conceived sustainability goals particularly in agri-food systems of complex interconnections, there is a danger of constrained research agendas, missed opportunities for improving system sustainability, or outcomes with unintended negative consequences. It is argued here that a conceptual framework that accounts for multiple facets of sustainability and is oriented around limits rather than achieving synergistic benefits can contribute towards addressing some of these limitations of the SI and CSA approaches.

Box 1 describes examples of interconnections and relationships between multiple, and sometimes contested social and ecological priorities across the multiple scales of agri-food systems, based on syntheses of documented case studies. Across these complicated situations, which are broadly reflective of agri-food system complexity, several key themes challenge the appropriateness of targeting multiple-wins interventions:

- In contrast to the generic goals of CSA, the relevant dimensions of sustainability in a given case are highly context specific and, for many system stakeholders, they are much broader than the production-focus of SI.
- These multiple dimensions of sustainability often interact through both positive and negative feedbacks and in non-linear ways and need to be considered collectively.
- These interrelationships transcend spatial, temporal and sectoral boundaries, including across food supply chains, future generations, and from local to global. As such, they also involve multiple ecological and social stakes and varied priorities and values. Given these varied, and at times conflicting, agendas (e.g. animal welfare vs food prices vs smallholding farmer livelihoods vs fresh water), there is a real potential for even desirable outcomes to have losers as well as winners.
- Achieving positive impacts across these varied aspects of sustainability simultaneously may well not be possible. It is likely that desirable outcomes will require compromises in one or more aspects.

### Box 1: Complex Agri-Food System Cases

**Case 1:** In 2005, the government of Malawi introduced a redesigned national agricultural input subsidy programme (Dorward and Chirwa, 2011). Associated with the programme, improved access to fertiliser and seeds has resulted in significant increases in national maize production (Denning et al., 2009). Increased productivity provides a means for smallholder farmers to break out of a low production poverty trap (Dorward and Chirwa, 2011). Furthermore, as a result of reduced dependence on maize imports, the carbon footprint associated with the country’s food miles are also reduced and the food system is thought to be more resilient (Chinsinga, 2011). However, there has been some evidence from neighbouring Zambia of similar input subsidy programmes resulting in reductions in area allocated to non-cereal crop production and negative impacts on production diversity (Zulu et al., 2014, Chinsinga, 2011). Concerns have also been raised in relation to subsidy programmes about the sustainability of agricultural inputs (e.g. finite phosphorus and the high energy process of fertiliser production) (Childers et al., 2011), the crowding out of the private sector from the inputs market and affordability of subsidies (Jayne et al., 2002), and the prospect of producers becoming dependent on uncertain subsidies. In addition to these varied impacts at a national level, subsidies and changes in national production profiles have the potential to affect international import and export markets, with both positive and negative economic implications elsewhere (e.g. amongst Malawi’s traditional maize suppliers).

**Case 2:** Increases in food poverty rates and associated dietary deficiencies amongst those with low socioeconomic status in the UK, have been argued by some to be due to the lack of affordability of high quality food, such as red meat (Ashton et al., 2014). Mega farms for livestock rearing have been proposed as a way of keeping food prices down and improving access to red meat, without becoming dependent on cheap imports (Harvey, 2013). Such systems, in which animals are zero-grazed, can achieve a higher production per unit area of farm land than pasture grazed cattle and further allows for the tight control of manure and the avoidance of its discharge into water courses. However, mega farms are strongly opposed by animal welfare activists who promote a narrative that confounds scale and outcomes by associating "factory farming" with poor animal welfare conditions. Others are concerned. about the impacts of mega-farms on the livelihoods of small-to-medium scale beef farmers, and on the cultural landscapes of cattle grazing areas (Harvey, 2013, Saul, 2013). Other environmental campaigners argue that, given the ecological footprint (e.g. water use and carbon emissions) of livestock rearing, non-meat alternative sources of protein and iron should be invested in.

**Case 3:** International donors have invested in the development of improved crop varieties using genetic modification, leading to advances in important traits such as drought resistance and enhanced nutritional quality for staple crops in countries with high incidence of malnutrition and crop failure (e.g. the Gates Foundation funded Water Efficient Maize for Africa programme). The technology holds promise for improving the speed and effectiveness of breeding processes, something which is becoming increasingly important in the context of adapting to changing climates and the development of crop traits that will require fewer agricultural inputs (e.g. fertilisers and pesticides). Investment in the technology today is seen as being of value to future generations. However, GM opponents have expressed concerns about the long term uncertainties associated with the environmental release of genetically modified organisms (GMOs), such as the spread of transgenes into wild relatives and producing new super weeds (Conway, 2000) and the expression of new allergens within food crops (Goodman et al., 2008). As reflected in recent debates in Kenya about the labelling and traceability of genetically modified organisms, there are concerns that tracing genetically modified material through production systems in less economically developed countries will be difficult and presents a potential choice between increasing production costs (in an already resource constrained system) or compromising the ability and rights of consumers and growers (particularly in future generations) to choose to be GM-free (Whitfield et al., 2015).

These cases present a dilemma. Where certain context-specific aspects of sustainability are overlooked, i.e. where there are narrowly or generically defined system goals, there is the potential for unjust outcomes, yet, in a system of negative feedbacks and non-linear associations, achieving positive impacts across all facets of sustainability seems unlikely. The question then is can we conceive of a sustainable space for complex systems which defines the boundaries of acceptable compromise.

Rockström et al. (2009) introduced the planetary boundaries concept as a framework for thinking about ecological tipping points and a basis for defining the boundaries of planetary-scale system sustainability. Raworth (2012) further points out that in staying within global ecological thresholds, we cannot afford to compromise socio-economic conditions to the extent that people are forced to live below acceptable levels of well-being or without basic human rights. A sustainability space for any given system has n-dimensions defined by the multitude of social and ecological boundaries that represent the limits of acceptable compromises for a system (Figure 1).

[FIGURE 1 HERE]

In complex systems, changes across these multiple dimensions are interconnected. Systemic changes have the potential to move multiple components in positive and/or negative directions relative to the boundaries of the sustainable space. The boundaries of the sustainable space are also likely to change over time, as non-renewable resources are depleted or as climates change, for example. Within this conceptualisation, sustainability is a measure of the extent to which systemic changes, over time, move components of the system within or beyond limits of a non-static sustainability space (Figure 2).

[FIGURE 2 HERE]

This presents several challenges for research. The first is to define and describe a multi-scale and multi-faceted system, a challenge for which there is a precedent within socio-ecological systems and farming systems research and a variety of sophisticated approaches and techniques, in which participatory and deliberative techniques are often combined with a range of simple and complex modelling programmes and scenario outputs (Whitfield and Reed, 2011), will have relevant application here. The second challenge is to determine, and regularly recalculate, the boundaries of sustainability. In some cases this will involve downscaling absolute limits and rights (e.g. poverty lines, nutritional guidelines, climate change targets, non-renewable resource quantities) into context specific metrics and in other cases it will require the translation of abstract concepts into measurables, for which well-developed techniques from ecological economics may be applicable. It will necessarily be an interdisciplinary endeavour, but even more than this, it will involve engagement with potentially political issues, requiring the negotiation of the alternative needs, priorities, and values of system stakeholders (Reed, 2008). The third challenge is for research to inform management, both through the development of systems for early warning of sustainability thresholds being crossed and through the modelling, testing, and evaluation of system interventions.

A boundaries concept for socio-ecological interactions has been operationalised within research on relatively simple socio-ecological trade-offs. Mouysset et al. (2014) model the 'coviability' of financial incentives, land use, and bird species abundance in order to make a case for the ecological and social sustainability of a combination of cropland taxation, grassland incentives, and biodiversity. The study demonstrates that system models and boundary definitions can inform policy and hold promise for the effective management of complex agri-food systems. As demonstrated even in this relative simple system, such management is unlikely to manifest as a single change to production or cropping systems (such as the adoption of a new technology), but will rather be associated with a combination of changes in policy, land tenure, infrastructure, markets, relationships, and social and cultural norms; with the potential for multifaceted shifts in the state of a system.

Policy safeguards that respond to monitored system change and act to reinforce the boundaries of the sustainability space will be an important component of such interventions. In relation to the cases described, certain safeguards already exist and we might reasonably conceive of others: regulations that define animal welfare standards and biosafety, carefully targeted subsidies and production quotas that limit unequitable market forces, donor aid or investment for supporting minimum standards in health and safety and building biosafety capacity, and others. Without such safeguards, these scenarios might well represent systems that exist, in part, outside of the sustainability space. Mechanisms of compensation or a redirection of finance and resources to those that lose (e.g. supporting alternative economic development in locations of unsustainable natural resource extraction), may be part of a sustainable change. However, the boundaries concept particularly emphasizes a rights-based approach to justice; by outlining fundamental thresholds, or social and environmental lines, for which there is an obligation not to cross.

The concept of a multi-dimensional sustainability space for agri-food systems represents an unpacking of the persuasive objectives of multiple win concepts (SI, CSA) and encourages research that engages critically with questions about sustainability; what is to be sustained, where, at what scales, and for whom. It requires that the goals of agricultural change be specifically defined and contextually relevant, i.e. responding to the particular concerns, priorities and stakeholders of a given system, and that they are broad in scope , i.e. not necessarily prioritizing  production related goals and impacts but also emphasizing knock-on effects across a broadly conceived agri-food system. It presents challenges for research and policy alike, but by engaging with these challenges there is greater potential than exists under current win-win agendas to meet the multiple objectives of agri-food systems in ways that are effective and contextually appropriate.

## References

ASHTON, J. R., MIDDLETON, J. & LANG, T. 2014. Open letter to Prime Minister David Cameron on food poverty in the UK. *The Lancet,* 383**,** 1631.

CHILDERS, D. L., CORMAN, J., EDWARDS, M. & ELSER, J. J. 2011. Sustainability Challenges of Phosphorus and Food: Solutions from Closing the Human Phosphorus Cycle. *BioScience,* 61**,** 117-124.

CHINSINGA, B. 2011. Seeds and subsidies: The political economy of input programmes in Malawi. *IDS bulletin,* 42**,** 59-68.

CONWAY, G. 2000. Genetically modified crops: risks and promise. *Conservation Ecology,* 4**,** 2.

DARNHOFER, I., GIBBON, D. & DEDIEU, B. 2012. *Farming Systems Research: an Approach to Inquiry,* London, Springer.

DENNING, G., KABAMBE, P., SANCHEZ, P., MALIK, A., FLOR, R., HARAWA, R., NKHOMA, P., ZAMBA, C., BANDA, C., MAGOMBO, C., KEATING, M., WANGILA, J. & SACHS, J. 2009. Input Subsidies to Improve Smallholder Maize Productivity in Malawi: Toward an African Green Revolution. *PLoS Biology,* 7**,** e23.

DORWARD, A. & CHIRWA, E. 2011. The Malawi agricultural input subsidy programme: 2005/06 to 2008/09. *International journal of agricultural sustainability,* 9**,** 232-247.

FOLKE, C. 2006. Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change,* 16**,** 253-267.

GODFRAY, H. C. J. 2015. The debate over sustainable intensification. *Food Security***,** 1-10.

GODFRAY, H. C. J., BEDDINGTON, J. R., CRUTE, I. R., HADDAD, L., LAWRENCE, D., MUIR, J. F., PRETTY, J., ROBINSON, S., THOMAS, S. M. & TOULMIN, C. 2010. Food security: the challenge of feeding 9 billion people. *science,* 327**,** 812-818.

GOODMAN, R. E., VIETHS, S., SAMPSON, H. A., HILL, D., EBISAWA, M., TAYLOR, S. L. & VAN REE, R. 2008. Allergenicity assessment of genetically modified crops[mdash]what makes sense? *Nat Biotech,* 26**,** 73-81.

HARVEY, F. 2013. UK needs 'mega farms' to keep food prices down, say experts. *The Guardian*, 12th November 2013.

JAYNE, T. S., GOVEREH, J., MWANAUMO, A., NYORO, J. K. & CHAPOTO, A. 2002. False Promise or False Premise? The Experience of Food and Input Market Reform in Eastern and Southern Africa. *World Development,* 30**,** 1967-1985.

MOUYSSET, L., DOYEN, L. & JIGUET, F. 2014. From population viability analysis to coviability of farmland biodiversity and agriculture. *Conservation biology,* 28**,** 187-201.

NEUFELDT, H., JAHN, M., CAMPBELL, B. M., BEDDINGTON, J. R., DECLERCK, F., DE PINTO, A., GULLEDGE, J., HELLIN, J., HERRERO, M. & JARVIS, A. 2013. Beyond climate-smart agriculture: toward safe operating spaces for global food systems. *Agriculture & Food Security,* 2**,** 12.

PETERSEN, B. & SNAPP, S. 2015. What is sustainable intensification? Views from experts. *Land Use Policy,* 46**,** 1-10.

PRETTY, J. 2008. Agricultural sustainability: concepts, principles and evidence. *Philosophical Transactions of the Royal Society B: Biological Sciences,* 363**,** 447-465.

RAWORTH, K. 2012. A safe and just space for humanity: can we live within the doughnut. *Oxfam Policy and Practice: Climate Change and Resilience,* 8**,** 1-26.

REED, M. S. 2008. Stakeholder participation for environmental management: a literature review. *Biological conservation,* 141**,** 2417-2431.

ROCKSTRÖM, J., STEFFEN, W., NOONE, K., PERSSON, Å., CHAPIN, F. S., LAMBIN, E. F., LENTON, T. M., SCHEFFER, M., FOLKE, C. & SCHELLNHUBER, H. J. 2009. A safe operating space for humanity. *Nature,* 461**,** 472-475.

SAUL, H. 2013. Campaigners warn against rise of the 'mega-farms': Could massive pig, fish and dairy units harm the environment? *The Independent*.

WHITFIELD, S. 2016. *Adapting to Climate Uncertainty in African Agriculture: Narratives and Knowledge Politics,* London, Routledge.

WHITFIELD, S., DIXON, J. L., MULENGA, B. P. & NGOMA, H. 2015. Conceptualising farming systems for agricultural development research: Cases from Eastern and Southern Africa. *Agricultural Systems,* 133**,** 54-62.

WHITFIELD, S. & REED, M. 2011. Participatory environmental assessment in drylands: Introducing a new approach. *Journal of Arid Environments,* 77**,** 1-10.

ZULU, P., KALINDA, T. & TEMBO, G. 2014. Effects of the Maize Input Subsidy Program on Groundnuts Production in Zambia. *Journal of Agricultural Science,* 6**,** p253.

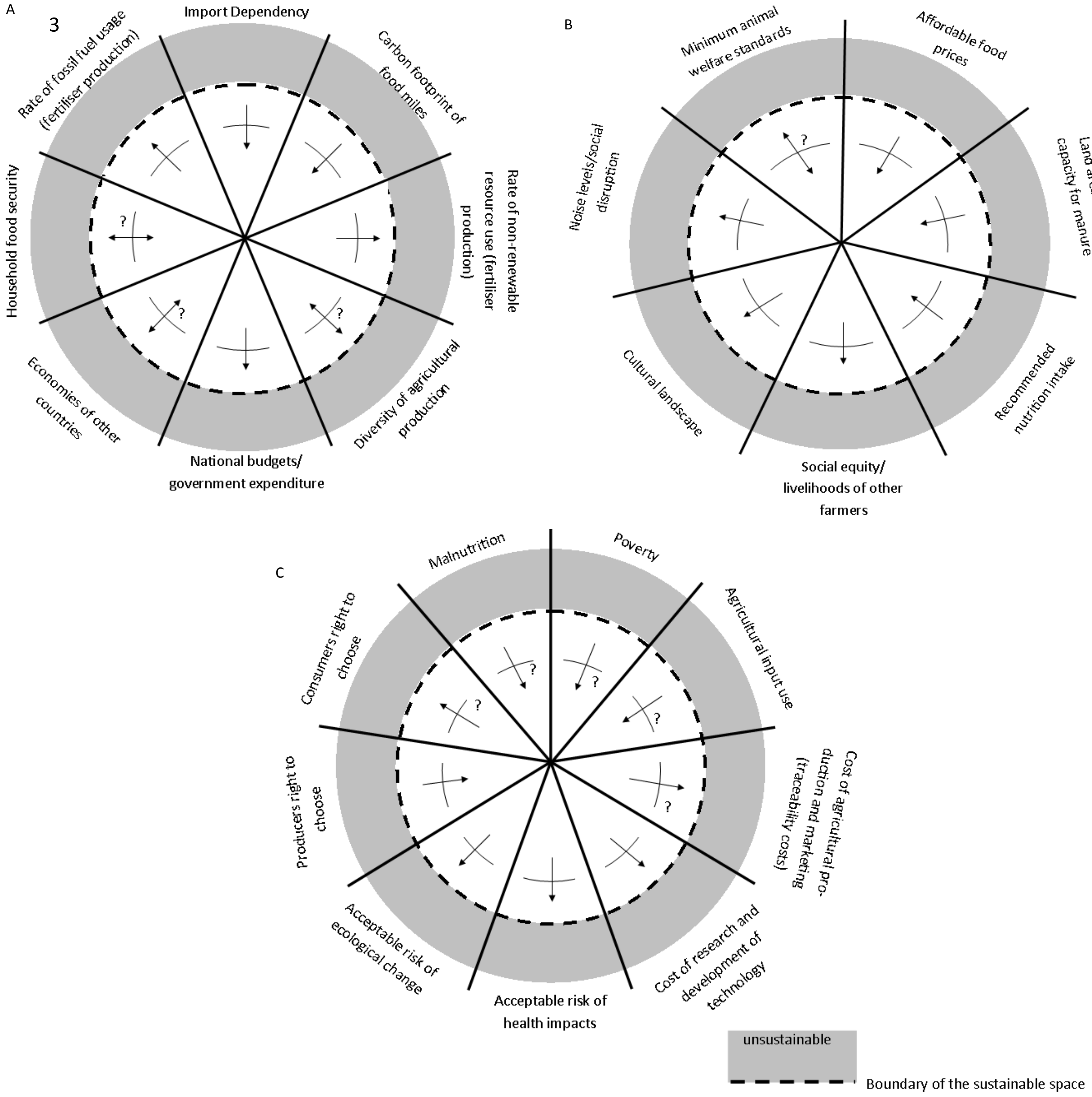
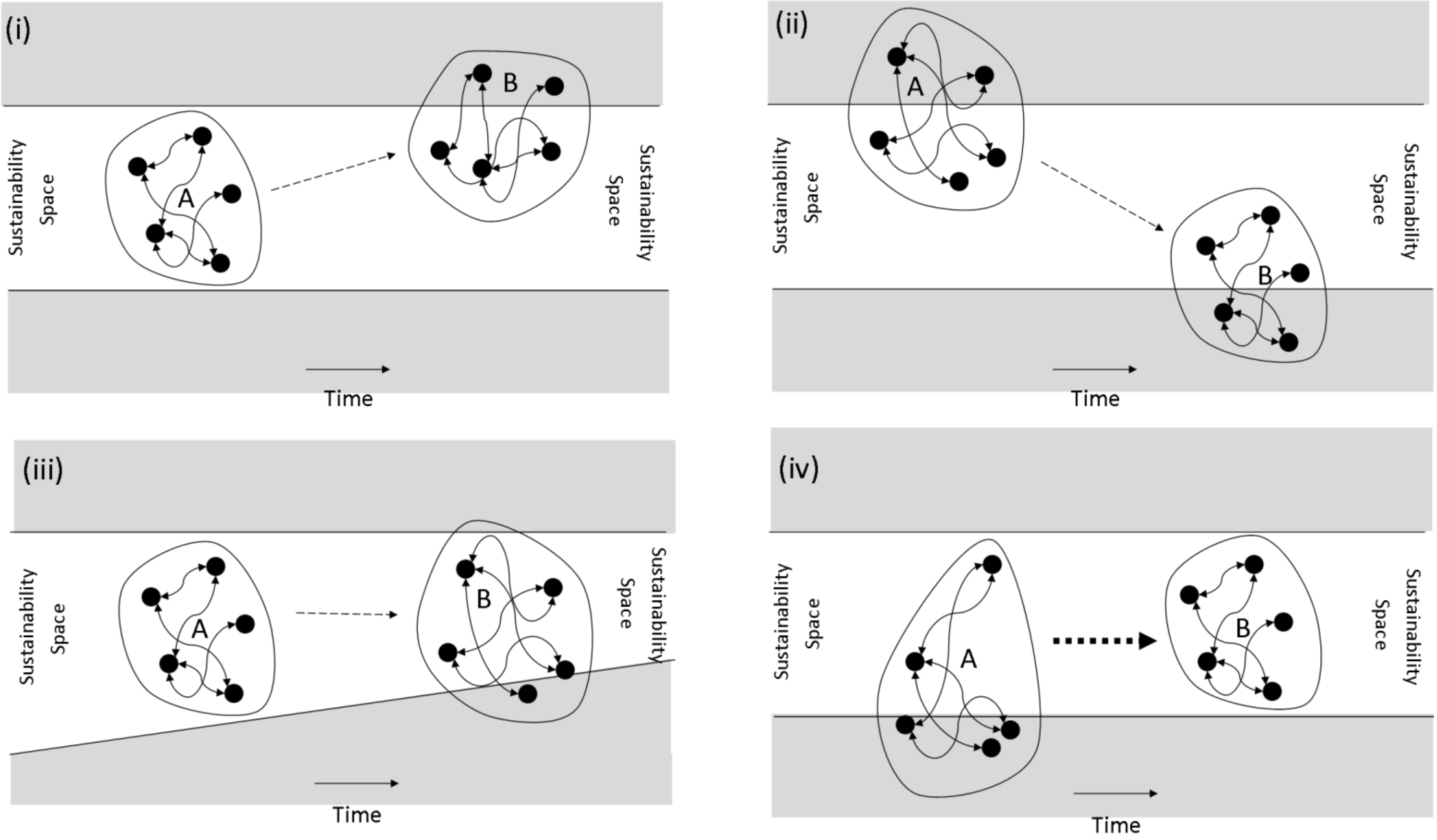


Figure 1: Schematic representation of the dimensions of the sustainability space and the direction of change relative to it in the three cases described: (a) agricultural input subsidies; (b) intensification of livestock production; and (c) the development of genetically modified crop varieties. Arrows indicate movement towards or away from unsustainable outcomes and question marks are used to indicate significant uncertainty about impacts of change within particular dimensions of sustainability.



▪▪▪▪▪▪▶ Sustainable

- - - - - - -→ Unsustainable

Figure 2: A representation of potential system changes from state A to state B. The sustainability of a system change depends on the position and shape of state B relative to the sustainability space. In representations i, ii, and iii, changes in the system result in unsustainable compromises for certain system components. In some cases this might occur as a result of other system components moving into the sustainable space (ii), or the boundaries of the space shifting (iii), but neither should be considered sustainable changes. A sustainable system change is represented by iv in which changes to system dynamics bring all components within the sustainable space.