

How scalable is sustainable intensification?

Sustainable intensification is a concept of growing importance, yet it is in danger of becoming scientifically obsolete because of the diversity of meanings it has acquired. To avoid this, it is important to consider the various scales on which it can aid progress towards feeding human populations while also protecting the environment.

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Put simply, sustainable intensification (SI) describes approaches to global agriculture that would increase yields without adverse environmental impact and without putting more land under cultivation. The term's origin dates back to the 1990s, when it was developed in an exclusively African context¹. It became prominent as a scientifically meaningful objective for global agricultural policies and development only in the late 2000s (Fig. 1). The concept was promoted by an influential report by the Royal Society², which contributed to the UK government embracing the term and establishing an SI research platform (SIP) in 2014. However, 'sustainable' remains a contested term. We recently reviewed the effects of specified changes to farming systems on agricultural productivity³, and found that in the past six years, few studies considered more than one or two different sustainability metrics. Less surprising but equally problematic was the shortage of long-term and broad-scale studies.

There are now signs that the SI bandwagon is faltering. Some activists have long considered SI an oxymoron⁴, but scientists have also begun to question its adequacy as a helpful concept for addressing food security⁵. It has been suggested that the way SI has been defined and developed "lacks engagement with established principles that are central to sustainability"⁶. Indeed, SI has acquired such a range of meanings in its 20-year history that use of the term itself may be unsustainable. Although there is agreement that SI should not prescribe particular techniques, its objective as presented in contemporary academic and policy documents can be anything from increased on-farm efficiency to the education of subsistence-farming communities. At the root of this divergence

are diverse views of how farming and conservation should relate to each other.

The need for a sustainable definition

Definitions can shape our thinking and ambiguity can hide a paradigm shift. The history of the term biodiversity illustrates how the application of different paradigms to the same word causes confusion. Widely adopted in the 1980s, 'biodiversity' was defined as including the diversity of all living things at the genetic, species and assemblage levels. In practice, genetic diversity was too hard to quantify and ecosystem diversity too vague, so attention focused on species diversity, usually species richness. This implied that all species were of equal value and encouraged the conservation of species-rich, climax or plagioclimax assemblages as being the least replaceable in a short timescale. Understandably, however, ecologists wanted more than a bean-counting role and so began to use the word biodiversity to refer to the variety of ecological roles in a community (functional diversity). This approach accepts that different species may occupy the same general niche, and that the roles of rare species might be very small, or even redundant. Now, increasingly, 'biodiversity' is used to mean assemblages of diverse living organisms *per se* rather than any measure of diversity, and the ecosystem services literature values those assemblages that benefit people, whether directly or indirectly⁷. The focus shifts towards common taxa with recognized functions (for example, insect pollinators) rather than rare and obscure ones, and the monetary valuation of ecosystem services allows biodiversity offsetting, whereby habitat loss can be justified by habitat restoration elsewhere, losses in species richness notwithstanding⁸. 'Sustainable intensification' now risks also

going through such a sequence of semantic shifts by which one meaning of a term becomes the enemy of another.

The words sustainable and intensification are also widely interpreted. 'Sustainable' can evoke such diverse concepts as financial profitability, management of environmental impact, maintenance of natural capital and building resilience against rapid change, as well as more elusive concepts such as naturalness. 'Intensification' often carries connotations of large-scale and industrial farming, of monoculture crops and caged or low-welfare livestock. But the combination of these two terms has an even wider semantic scope. Early definitions of SI emphasized the notion of agronomic efficiency — maximizing the output to input ratio so as not to waste resources. This focus can be criticized for paying insufficient attention to the temporal dimension of sustainability. Some advocates go further to argue that SI should account not just for how much food can be produced, both now and into the future, but also the types, variety and nutritional content of the food. This leads to definitions of SI as "the process of delivering more safe, nutritious food per unit of input resource, whilst allowing the current generation to meet its needs without compromising the ability of future generations to meet their own needs"⁹. Then, giving more cultural weight to the 'sustainability' element in a global context, some argue for inclusion of social and ethical considerations such as labour rights, animal welfare and social equality — hence claims that sustainable intensification "needs to be mindful of the social, economic and ethical context within which food production activities take place"¹⁰. This breadth of meaning calls into question the usefulness of SI as a concept: for example, interviews with 30 agricultural

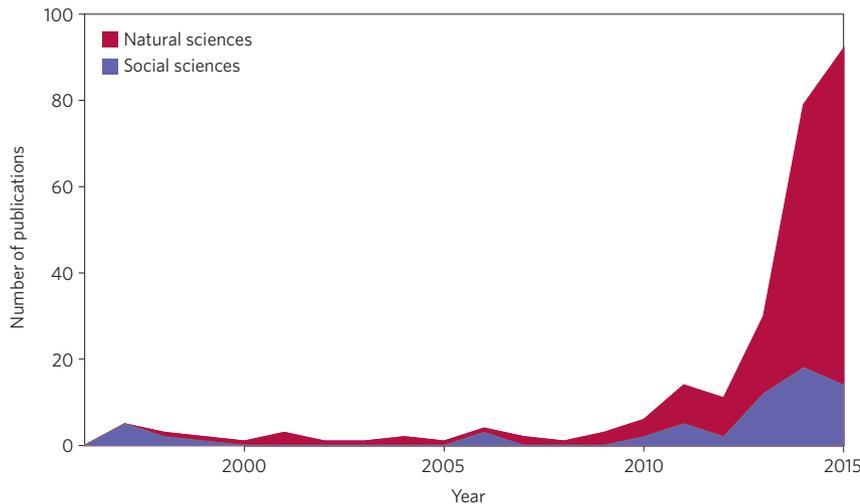


Figure 1 | The number of articles with titles or abstracts mentioning sustainable intensification published in social science journals and natural science journals up to the end of 2015. The data are from ISI Web of Science records.

experts¹¹ suggested that the term is not uniformly understood nor generally seen as a significant departure from current agricultural practices. Although calls for definitional clarity are being issued, proposed definitions, in our view, remain vague and difficult to operationalize. Here we attempt to rehabilitate the term and show the importance of its role in both theoretical and applied areas.

Integrating four visions of SI

Interpreting the ethics of sustainability in different ways and pursuing intensification at different scales allows us to classify the visions sketched above into four types.

1. Agronomic efficiency¹²: increasing the production efficiency of a parcel of land, that is, the agricultural output per unit resource input or per unit area¹³. Here sustainability arises because it is assumed that increased productivity from a given area can be achieved without significant detriment to other goods and services arising outside of that area. This vision is measurable and readily attracts agronomic policy-shapers from both government and industry. Considerable progress is documented in ref. 14.
2. Agronomic sustainability⁹: increasing or sustaining the productivity of a unit of land while ensuring its future viability (including resilience to external pressures). Here, maintaining natural capital may be taken as a surrogate objective. This vision is similar to ecological intensification¹⁵, invoking the basic sense of 'sustainable' as meeting present needs without compromising

future resilience, and has long been advocated by environmentalist groups. It may be exemplified by the addition of biochar or mycorrhizae to enhance soil function¹⁶, and charted in the long-term adoption of organic farming in parts of England¹⁷.

3. Global efficiency: maintaining or increasing some benefit from non-farmed land while generating a target level of agricultural production from the minimum possible area. This vision is exemplified by the land-sparing paradigm, where agricultural production is traded off against a single ecological benefit, such as species conservation¹⁸. Its spatial purview is always greater than the field scale, and is potentially global. An example concerning the Great Plains landscape of the USA is given in ref. 19.
4. Global sustainability¹⁰: increasing the quality and quantity of agricultural production along with a range of other benefits considered part of sustainable development. This vision is potentially global, both spatially and ethically; typical objectives include self-sufficiency, or staying within a safe (physico-biotic) and just (socially responsible) operating space²⁰. Such a vision is increasingly popular in the discourse around international development and is illustrated in many success stories from African communities²¹.

All four categories envisage changes that maintain or enhance agricultural production while obtaining various intrinsic or extrinsic benefits. At the same time, they may be characterized by attention

to different temporal, spatial and ethical scales — which we collectively call 'scope'. Compared with type 1, type 2 has an increased time-horizon and type 3 considers a greater spatial extent. But we may also characterize global sustainability (type 4) as a vision that extends further up a categorical scale of desired benefits. Acknowledging that different stakeholders have different expectations of what goods a farming system should deliver in order to be considered sustainable, we seek to make SI more broadly acceptable by recognizing an 'ethical scale'. Here a structured classification of ecosystem services will be helpful.

SI and ecosystem services

Ecosystem services may be defined as "the benefits people obtain from ecosystems"²² or "the outputs of ecosystems from which people derive benefits"²³. Provisioning of foodstuffs is thus the primary ecosystem service of most agroecosystems, and each of the above visions for SI entails certain additional ecosystem services sought from the landscape as a whole. Ordering these according to how closely they are linked to agricultural provisioning allows us to use the concept of scale once more for the ethical scope of SI. Thus we ask how much the ecosystem services typically sought from farmed landscapes may be either positively correlated or traded off with overall agricultural productivity, under all kinds of possible system changes that might constitute SI. Answers to this question must be context dependent in terms of both location and historical time, but our recent review³ suggests a typical ordering, from positive to negative correlations with agricultural provisioning, as follows: (i) soil maintenance; (ii) pollination (where relevant); (iii) biocontrol (where relevant); (iv) air and water quality; (v) greenhouse gas mitigation; (vi) animal welfare (where relevant); (vii) landscape aesthetics; (viii) recreation; and (ix) species richness.

Soil maintenance represents those 'supporting services' that contribute to natural capital at the field scale; without it, agriculture must decline or switch to intensive soilless systems. Pollination and biocontrol represent 'intermediate services' provided locally by animals (typically invertebrates) by way of ecological facilitation; their potential value is large but depends on crop types and cultivation systems. The so-called regulatory services of air and water quality protection and greenhouse gas mitigation are also linked to agricultural production systems, and there seem to be many strategies for avoiding trade-offs at both field and landscape scales. The remaining services

are more ambivalent. Enhancing animal welfare (beyond basic health) is sometimes shown to enhance and sometimes decrease livestock productivity, with much depending on the definitions and metrics used.

Aesthetic and recreational services relate to productivity in rather contingent ways that are nevertheless important for the social sustainability of farming, especially within farming communities. Species richness is here ranked last for a few reasons: relatively few taxa, globally, depend on farmland¹⁸; functional biodiversity of pollinators and biocontrol agents are considered separately in (i) and (ii) — and even farmland birds seem to decrease in diversity with increasing productivity³.

The ecosystem services higher up the above list are of greater private interest to farmers, whereas those lower down are typically of greater public interest. This axis thus has bearing on the type of policy incentives required for delivery of the services, and provides an additional rationale for our classification of visions. Of these four types of SI, type 1 is not explicitly concerned with these services unless any of them directly benefits productivity; type 2 is directly concerned with soil maintenance, as well as pollination and biocontrol insofar as these contribute to productivity; and type 3 concerns any services that are traded off against productivity and enjoyed at landscape to global scales (for example, (v) and (vii)–(ix)). Type 4 is then defined broadly as including any specified range of ecosystem services — including more socioeconomic ones. Thus the ethical scale of an SI vision may be framed in terms of the range of services that is sought from the landscape as a whole.

In adopting this approach, we must also consider how the side effects of agricultural activities need to be offset against the ecosystem services of the agroecosystem itself. Thus, for example, fertilization to improve pastures may provide an ecosystem service in mitigating greenhouse gases, but fertilizer manufacture may release CO₂ through fossil fuel combustion. Life-cycle assessments are necessary, including both ecological and non-ecological components, and recognizing that each of these components may be either positive or negative.

Defining SI by scope

We propose capturing the full range of visions of SI in the following definition: 'Sustainable intensification means changes to a farming system that will maintain or enhance specified kinds of agricultural provisioning while enhancing or maintaining the delivery of a specified range

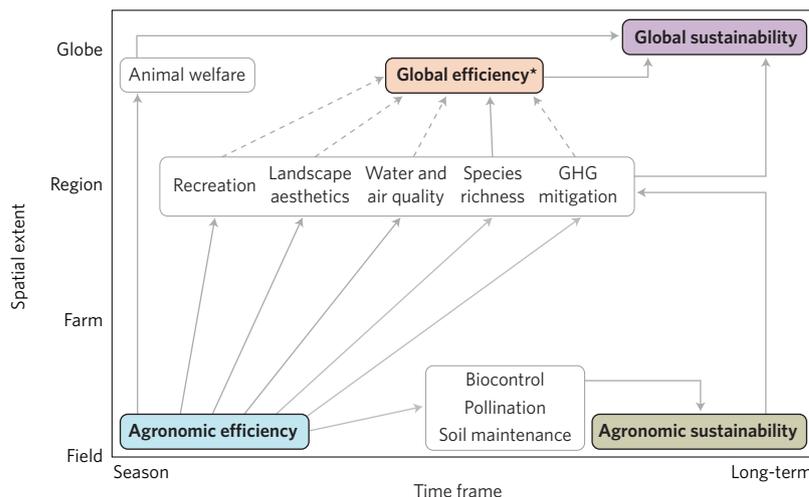


Figure 2 | Visions of SI plotted against the time frame and spatial extent (spatiotemporal scales) at which agricultural productivity and the delivery of other ecosystem services are assessed. A selection of ecosystem services is overlaid to indicate how the ethical scale of visions is typically augmented in moving (arrows) from one vision to another. Space, time and ethical scale together specify the scope of a vision of SI. *The global efficiency vision typically considers species richness and is ambiguous with regard to time frames: critics see a short-term focus on agricultural intensification, yet its environmental vision is typically long-term.

of other ecosystem services measured over a specified area and specified time frame.'

This definition comprises two main variables: agricultural production and ecosystem services. The former may be qualified by aspects of food quality as well as basic yield. The latter must be qualified by three components: the range of ecosystem services considered, and the spatial extent and time frame over which they are assessed. If agricultural production is assessed as simply calorific yield and only a single ecosystem service is required, the situation can be treated mathematically as an optimization problem, and indicators of SI can readily be derived to measure progress. In the realistic situation where multiple aspects of food quality and ecosystem services are considered, however, this is not possible without reducing them to a pair of common currencies, which in turn would violate the scope of the chosen definition of SI. This is why our definition emphasizes enhancing rather than increasing outputs. Assessing whether a particular change in a farming system qualifies as SI under a given definition will require some choice of metrics for each of the outputs deemed important, together with criteria for deciding whether any of them has suffered a significant decline. Devising and co-analysing such metrics is a significant challenge that may require political input.

At restricted scales, our canonical definition for SI yields each of the four types

as special cases. Type 1 limits the temporal, spatial and ethical scales, type 2 limits the spatial and ethical scales and type 3 tends to restrict temporal, spatial and ethical scales in particular ways. Type 4 potentially has no limits of scale (Fig. 2) and, as an aspiration, might be termed globally sustainable intensification (GSI).

Outlook for the future

In scientific and technological development, a clear definition cannot be more than a tool towards a desired end. A canonical definition such as we offer here cannot serve even that purpose merely by citation; the scope of SI needs to be clearly stated by specifying the spatial, temporal and ethical scales that are directly considered in any proposal or assessment. Workers in this field will no doubt intend their contributions to promote GSI, but it is important that we be realistic about the actual scope envisaged in any particular case. It can be challenging in scientific work to assess the long-term, global, public and cultural impacts of agricultural practices, yet quantitative attempts at these must be made in order to justify our visionary aspirations. A scheme for type 3 SI, for example, should be promoted with comments on how it is expected to contribute to true global sustainability. In policymaking, a failure to take responsibility for the widest possible scope of SI will increasingly jeopardize the well-being of people around the world and in future

generations, while poor framing of SI may well lead to unreasonable burdens being placed on farmers themselves.

SI is mentioned in the UN's Sustainable Development Goals²⁴ for 2030, and as such is likely to remain on political agendas for some time, whether or not its meaning be clarified. We hope, therefore, that our proposal for clear scoping of SI will assist policymakers in framing both challenges and solutions in accordance with the needs of food security, environmental protection and human flourishing in general. Our review³ exploring how far SI in the UK can be linked to delivery of ecosystem services was limited by the scope of much published work, but our framework helped to identify knowledge gaps more clearly by asking the question of scope. Routinely asking and answering this question should help scientists to provide better estimates where data are lacking, policymakers to avoid externalizing environmental costs, and farmers to appreciate the diversity of

ways in which their livelihoods can promote human flourishing. □

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