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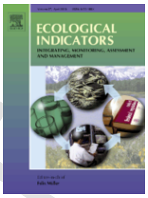

Review

Sustainable intensification – “oxymoron” or “third-way”? A systematic review

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ABSTRACT

Sustainable Intensification (SI) is a term that has been advanced to capture a concept that some consider as the ‘third paradigm’ for global agricultural development. However, the term has become subject to intense debates as well as scepticism and confusion regarding its meaning and the characteristics of production systems that could indicate SI (defined as “indicators”). This has resulted in a proliferation of literature. We have conducted a systematic review of a sample of this literature analysing the most commonly suggested indicators of SI in order to investigate the extent to which the critiques of SI are valid in their viewpoints that SI is an oxymoron, underpinned by a productivist agenda, and to identify the critical issues in the development of a comprehensive and unambiguous set of SI indicators. From 633 articles identified by a search of relevant databases, a sample of 75 articles were selected and analysed using the NVIVO™ software. The results were organised according to a Socio-Ecological Systems (SES) framework comprising seven sub-systems or components − resource system, resource units, governance system, resource users, interactions, outcomes, and environment. A total of 218 indicators (both positive and negative) were identified. Most of these indicators focused on the ‘outcomes’ of agricultural systems with the majority being related to agricultural production. Few indicators were identified as relating to the economic and societal dimensions of food systems. Whilst this potentially suggested a productivist bias in the current interpretation of SI it was difficult to draw a black and white conclusion, since for the other system components, the majority of the indicators suggested appeared to take a more holistic point-of-view and emphasised both productivity and sustainability of agricultural systems. Our analysis suggests that a key reason why SI may be viewed with scepticism is a lack of specificity and elucidation of the rationale, scale, and farm type for which SI is proposed. Moreover, a number of the indicators were so loosely defined that the interventions they imply could be enacted without due consideration of the social impacts of their adoption. We conclude that there is need to develop SI indicators according to specific farming types and scales and also with more consideration of the social and political dimensions of food systems in order to promote a constructive dialogue around the concept of SI to take place. Unless the concept of SI is described and measured in such a holistic and inclusive manner, it is unlikely to be accepted as a valid descriptor of sought-after agricultural practices by players in the Third Sector.

1. Introduction

Concepts designed to guide the trajectory of agricultural development have, over the decades, placed emphasis on different attributes of food production systems. Recently, the descriptor “Sustainable Intensification” (SI) has emerged. However, the concept has not been universally accepted, and both the term itself and the notions behind it have attracted debate, scepticism, and confusion with regard to its defining attributes and indicators as well as the means of measuring these. This has resulted in a proliferation of literature. The purpose of this paper is to provide a Systematic Review of a sample of the literature with the objective of exploring the extent to which critics of the concept are justified in their viewpoints that SI is an oxymoron and a concept underpinned by productivist agenda, and to identify the critical issues in the development of a comprehensive and unambiguous set of indicators for ecologically and socially sustainable intensification of agriculture.

The interest in SI derives from the adverse consequences of the “productivist paradigm” that has underpinned much policy for agricultural development over the last five decades. An example is the High External Input Agriculture (HEIA) employed during the “Green Revolution” (GR) of the 1960s and 70 s (Wallinga, 2009). The GR was founded on the use of technological innovations which ‘intensified’ agricultural production through monocultures of high-yielding crop varieties and increased use of nitrogen fertilizers. Other components included breeding livestock for increased feed-conversion efficiency and the widespread adoption of machinery, including mechanised irrigation (Douthwaite et al., 2003; International Food Policy Research Institute, 2002). The GR greatly increased agricultural yields (especially of major cereal crops) and pushed down food prices (Khush, 2001; Tilman et al., 2002; Evenson and Gollin, 2003), which made food accessible to poor consumers (Pinstrup-Andersen and Hazell, 1985). Nevertheless, this was accompanied by environmental

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and social costs. Adverse environmental impacts include: soil degradation due to mechanised ploughing, agrochemical residues and salinization; eutrophication and depletion of water resources; and loss of wildlife (Rodell et al., 2009; Zeigler and Mohanty, 2010; Pingali, 2012). Adverse social impacts include: effects of agrochemical use on the health of farm workers; increased farmer debt burdens and the marginalisation of smallholder farmers associated with higher input costs and lower food prices (Hewitt de Alcantara, 1976; Sangha, 2013). More recently, the contribution that agricultural systems make to global climate change through the emission of the greenhouse gases (GHG) nitrous oxide, methane and carbon dioxide has been emphasised (Smith et al., 2007; Bellarby et al., 2008; Foresight, 2011). It has been argued that HEIA, typified by the GR, is unsustainable due to its reliance on fossil fuels and declining freshwater resources (Harding and Peduzzi, 2012; Schwartz and Ibaraki, 2011).

As a response to the adverse impacts of HEIA a second paradigm emerged under the umbrella terminology of "Alternative Agriculture" (AA). AA accords high priority to the social and environmental impacts of agricultural systems. Practices are emphasised that seek to mimic processes occurring within natural ecosystems, including: the use of Integrated Pest Management (IPM); water and soil conservation practices; agro-forestry (Altieri, 2004; Pimentel et al., 2005; Pretty, 1995; Raynolds, 2000; Vandermeer, 1995); local production, trade and consumption; as well as enhancing social capital within farming communities. Farmers' markets, community-supported agriculture, and box schemes are examples of AA in practice (Renting et al., 2003). However, the prospect that such small, localised systems could generate enough food for a global population predicted to exceed nine billion by 2050 is unclear (Pimental et al., 2005). Moreover, such systems may be vulnerable to increasing weather extremes (e.g. droughts, floods) and uncertainties (e.g. irregular rainfall patterns) brought about by global climate change (Clark et al., 1998, 1999; de Ponti et al., 2012; Seufert et al., 2012; Loos et al., 2014).

More recently, the concept of "Sustainable Intensification" (SI) has been expounded and promoted. The term was first coined in the late 1990s in the context of smallholder, African agriculture (Pretty, 1997). Since then, the concept has gained traction and become pervasive through governments (Foresight, 2011; DEFRA SIP, 2016), research institutes (Royal Society, 2009; Barnes, 2012; Garnett and Godfray, 2011; Lampkin et al., 2015), International development institutions, (FAO, 2011; World Bank, 2012, 2013; Shepherd et al., 2013; USAID, 2015) and even transnational agribusinesses (Jöhr, 2010; SFSA, 2016; Monsanto, 2015). It may be that the concept of SI has become so appealing because it is perceived to represent a third way, between the contrasting paradigms of HEIA and AA (Islam et al., 2013).

Despite such diverse interest, the concepts underpinning of SI have neither been universally accepted, nor consistently interpreted. There are ongoing debates about: what SI really means (Buckwell et al., 2014; Garnett et al., 2013; Gliessman, 2014); how it might be measured and implemented (Tilman et al., 2011; Fish et al., 2014; Vanlauwe et al., 2014; Sutherland et al., 2015; Vosough Ahmadi et al., 2015); what indicators and methodologies can be used to monitor and assess whether SI has been achieved (Barnes and Thomson, 2014; Elliott et al., 2013; Firbank et al., 2013); if practices specified as SI can be applied to all types of agriculture (Garnett and Godfray, 2012; Loos et al., 2014; Petersen and Snapp, 2015); what the potential trade-offs associated with SI implementation might be and how these should be quantified (Crute, 2012; Ripoll-Bosch et al., 2012; Franks, 2014; Renwick et al., 2014; Struik et al., 2014).

The proliferation of such debates is not surprising given that both words describing the concept mean different things to different people. "Intensification" of cropping implies the efficient use of resources, however, in livestock production, "intensification" is used to describe stocking density, particularly in non-pastoral systems of production (Carswell, 1997). Likewise, since the publication of the Brundtland report (Our Common Future) in 1987 and the Rio Earth Summit in 1992, the meaning and means of achieving "sustainability" are not universally accepted (Piso et al., 2016). In combining these two words it is not surprising that energetic debate has been provoked. Indeed, one attribute of SI is that it has moved the debate about agricultural production beyond the well-rehearsed and polarised views typified by advocates of "industrial" versus "alternative" systems. Introduction of SI has stimulated discussions about priorities for agriculture, sought-after outcomes, ways of measuring system performance, and other intellectual strands of thinking that would not otherwise have occurred (Struik et al., 2014).

The confusions surrounding the interpretation of what SI is, and is not, have led to scepticism, especially within the Third Sector, comprising environmental NGOs and various other civil society organisations. Porritt , in a report produced for the Food Ethics Council (Food Ethics Council, 2012Please can you change this reference to read (Food Ethics Council, 2012 : 17)), described the concept as "… [a] deceit," an idea used to justify "business as usual" practices. Longfield, in the same report, suggests that SI will only serve to consolidate power in the hands of the rich and powerful. Cook et al. (2015) state that SI, as it is currently framed, is too narrowly defined, favouring an overly productivist, corporate agenda, lacking in social and political dimensions, and failing to address farming systems as a whole. Collins and Chandrasekaran (2012: 22), echo these opinions, stating that SI is a, "⋯Wolf in sheep's clothing." They state that SI is too tightly focused on highly technological solutions, many of which may not be acceptable to the public, and which have little in the way of participation from smallholder farmers. Finally, Lewis-Brown and Lymbery (2012: 1) state that SI "…produce[s] an oxymoron." They suggest that the metrics currently used to justify the concept are flawed, not taking into account the full impact of modern, intensive agriculture on natural resource use, or animal welfare.

While multiple perspectives are not undesirable, we believe that the conceptual difficulties inherent in the term, the lack of consensus and growing scepticism that currently surrounds the concept could eventually devalue its currency. Accordingly, we undertook a review of a sample of the current literature in order to address some of the concerns and confusions surrounding SI, and identify the critical issues in the development of a comprehensive and unambiguous set of indicators for ecologically and socially sustainable intensification of agriculture. We sought to achieve this by systematically analysing the most commonly suggested attributes of agricultural systems, referred to hereafter as "indicators of SI".

2. Methodology

2.1. Analytical framework – agriculture as a socio-ecological system

We conceptualise agriculture as a Socio-ecological System (SES). That is, a system comprising the interactions between humans (and their actions) and the biophysical variables which make up the natural world (Anderies et al., 2004; Halliday and Glasser, 2011). SES frameworks have been used to investigate agricultural systems, especially in the context of the sustainable use and management of multiple "ecosystem services" that these systems provide (see de Chazal et al., 2002; Kumaraswamy, 2012; Allen et al., 2014; Lescourret et al., 2015; McGuire et al., 2015). Thus, SESs frameworks provide a useful lens for this systematic review.

The SES framework used in this investigation is a version of one developed by Ostrom and others (Anderies et al., 2004; Ostrom, 2007, 2009; Ostrom and Cox, 2010; McGinnis and Ostrom, 2014). Within this framework SESs are conceptualised as comprising four interrelated sub-systems – the 'resource system', 'resource units', 'governance system' and 'resource users' – that 'interact' to produce system 'outcomes'. SESs operate within an 'environment' comprising social, economic and political settings with the focal SES influencing, and influenced by, other related systems.

The term 'resource system' refers to the biophysical parts of a SES (Ostrom, 2009). Within an agricultural system this may include a designated area of land being used for particular agricultural production, e.g. cereals, grazing livestock, or silage (Lescourret et al., 2015). 'Resource units' meanwhile includes the individual natural resources within the resource system and their properties (Ostrom, 2009). In an agricultural system 'resource units' can be: crops, livestock, agro-biodiversity, and soil properties (Waltner-Toews, 1996).

The 'resource users' are human entities that use the resources for sustenance, recreation, or commercial purposes (Ostrom, 2009). Within an agricultural system, farmers are the primary users; however, users can also include input suppliers, corporate food buyers, and food retailers (Kremen and Miles, 2012) as well as tourists and inhabitants that use the countryside (Schouten et al., 2009). The 'governance system' includes government and non-government organisations that manage a resource system, the rights and rules relating to the use of the system, and how the rules are made (Ostrom, 2009). Examples from agriculture include subsidy regimes in EU agriculture (e.g. single farm payments), regulations regarding migrant agricultural workers, and policies concerning price controls and trade liberalisation (Kremen and Miles, 2012; Reganold et al., 2011).

According to Ostrom and colleagues, 'interactions' within a SES may occur in complex and multiple directions among the four sub-systems (Ostrom, 2009). Examples of interactions within an agricultural system may be: farm management processes, knowledge sharing between farmers, the relationships between farmers, input suppliers and corporate food buyers, and the interactions between various ecological components, such as livestock and the grasslands they graze on (Moraine et al., 2016).

The 'outcomes' of a SES can be varied, including social as well as ecological dimensions. These outcomes create feedback loops and thereby affect the various system components (Ostrom, 2009). In an agricultural system examples of outcomes can be the efficiency of the use of resources (e.g. water, agro-chemicals and labour), and farm yields and incomes. However, the growing importance of multifunctionality of agriculture suggests that the analysis needs to move beyond these conventional outcomes. In this regard, the concept of 'ecosystem services' – including provisioning, regulatory, cultural, and supporting services – (Millennium Ecosystem Assessment, 2005) provides a useful tool.

The term 'environment' encompasses the variables not within the SES of interest, but nevertheless, may affect the SES. This may include the social, political and environmental settings of the SES of interest as well as related SESs. Examples in agriculture can be fluctuations within global markets and related price shocks (Walker et al., 2002) as well as the direction and funding for agricultural research (Reganold et al., 2011).

'Scale' is an important aspect of SESs, since the various components may operate and interact at multiple temporal and spatial scales (Ostrom, 2009). For example, within the governance sub-system the rule-making organisations may operate at different scales – from local, regional and national to global (McGinnis and Ostrom, 2014). In agriculture, diffuse pollution from agrochemicals applied on a farm could have impacts on large water bodies spread over large geographical areas. According to Ostrom (2009) it is important to identify and analyse such multi-scale relationships in order to understand why some SESs become sustainable whilst others collapse.

Although the SES framework proposed by Ostrom and colleagues is useful, the framework has predominantly been used to investigate the use and governance of single, common resources, such as communal fisheries and forests (Basurto et al., 2013; Hinkel et al., 2014; Vogt et al., 2015). An agricultural system, however, is not a single 'common' resource. Instead, it is a mosaic of multiple, interacting resources, operating under a range of management regimes and types of ownership, and producing numerous ecosystem goods and services. In order to reflect this diversity, we have used a modified version of Ostrom's SES framework (Fig. 1).

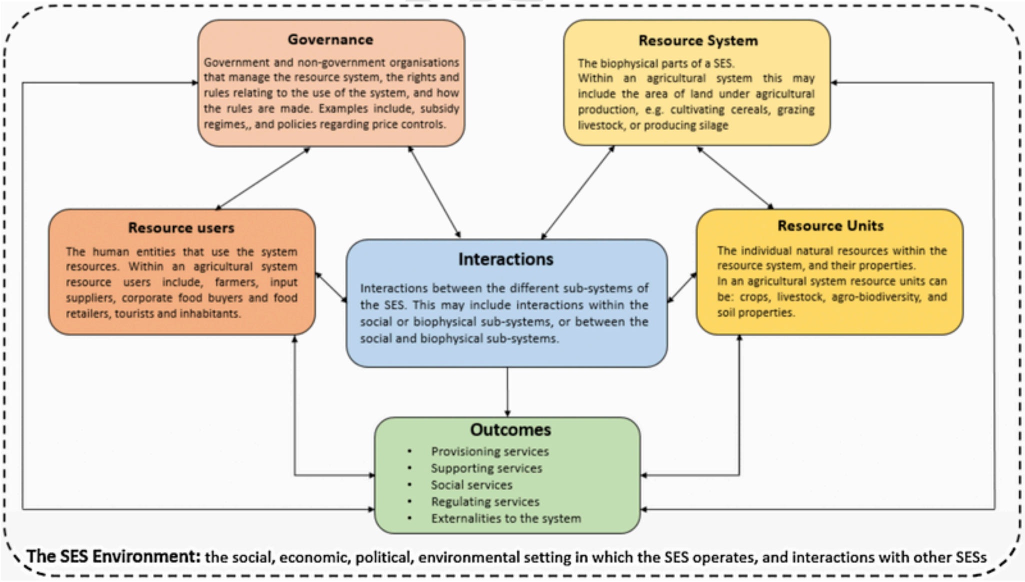

Fig. 1. The SES framework used in this investigation to structure data analysis.

Vogt et al. (2015) suggested that the framework developed by Ostrom and others focused more on social variables than ecological variables. We have addressed this criticism by acknowledging that interactions may occur within the social sub-systems, within the biophysical sub-systems, or between the social and biophysical sub-systems. The SES outcomes have also been further divided into lower level categories, including the four main types of ecosystem services, as described in the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment, 2005), and a fifth category called the 'externalities to the system', as suggested in Ostrom's original framework.

With regard to the scale issue, we considered six different scales, the smallest being the 'farm level' and the largest the 'global level' (Figs. 1 and 2). We consider each scale to be nested within each subsequent, larger scale (Fig. 2).

2.2. Data acquisition

Articles were selected according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analysis) flowchart, as shown in Fig. 3 (Liberati et al., 2009). Data were gathered via title, abstract and keywords searches of two scientific databases – Web of Science and Scopus – using relevant keywords, combinations of keywords, and synonyms of the keywords (see Table 1).

Fig. 2. scales at which SI can potentially be conceptualised and measured.

A total of 590 records were identified via database searches (Web of Science – 212 records, Scopus – 378 records). These records were supplemented by others from "grey" literature, websites, and blogs. The latter were obtained from Google and Google Scholar searches and collected in order to gain a fuller understanding of how the concept of SI, and its indicators and measurement methods are understood by a range of different stakeholder groups.

The initial 633 records identified were screened by reading the titles and abstracts of the peer-reviewed articles; the titles and the executive summaries, or a commensurate portion of the texts, of reports; and the entirety of websites and blogs. An article was excluded if it was a duplicate, was not related specifically to the measurement of SI, or the literature did not provide any specific examples of the indicators of SI. Primary research articles, reviews and meta-analyses, reports, conference proceedings and other grey literature, websites and blogs were included if the document discussed, or used, indicators and/or metrics of SI. After screening, 513 items were excluded from the review.

Eligibility for inclusion was determined by reading the full text of an item. A total of 120 records were assessed for eligibility, and after reading the full texts, 45 articles were excluded from analysis. Articles were excluded at this stage if the literature did not specifically relate to measurement/quantification of SI, or did not specifically discuss indicators of SI. After the eligibility assessment was conducted, 75 documents were considered suitable for inclusion in the analysis. These articles are listed according to serial numbers 1 to 75 in Appendix A. The year-wise distribution of the articles is shown in Fig. 4. It appears that, since the term SI was first proposed in the late 1990s (Pretty, 1997), the interest in the concept has grown steadily in

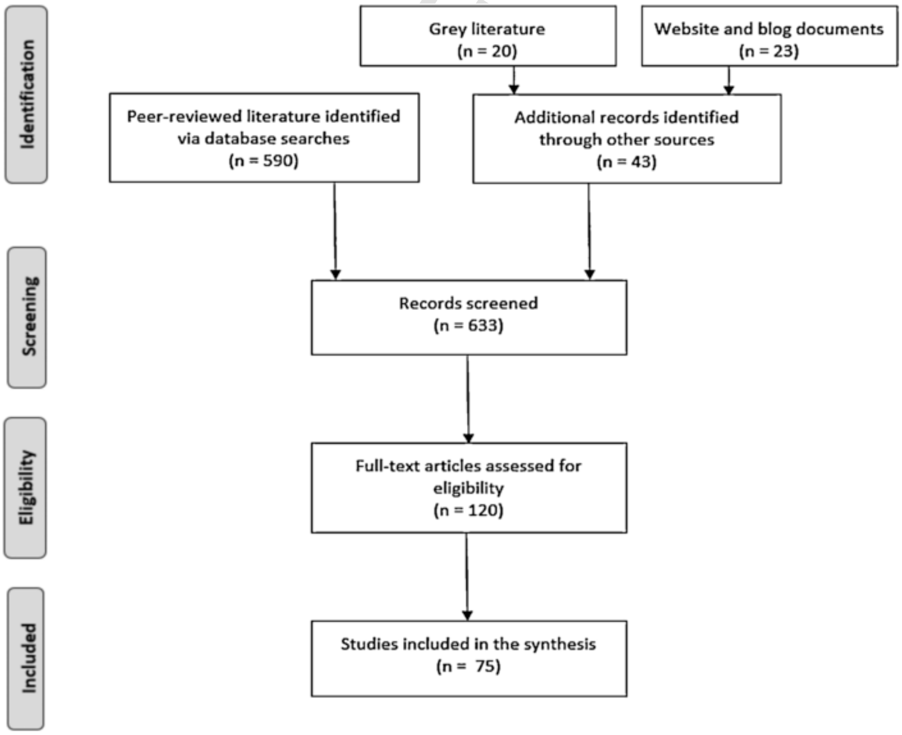

Fig. 3. Preferred reporting items for systematic reviews and meta-analysis flowchart (Liberati et al., 2009).

Table 1
Keyword combinations used for database searches.

Search no.	Search Term				
1	Sustainable Intensification	AND	Indicators		
2	Sustainable Intensification	AND	indicators	AND	agriculture
3	Sustainable Intensification	AND	measurement		
4	Sustainable Intensification	AND	measurement	AND	agriculture

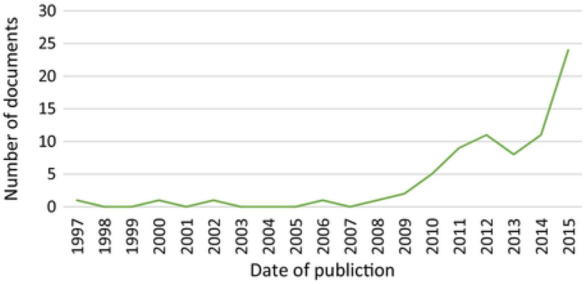

Fig. 4. Total number of documents discussing the measurement of Sustainable Intensification over time.

terms of the number of articles published per year, with peaks coinciding with the publication of two influential reports – the Royal Society report (2009) and the Foresight report (2011).

2.3. Data analysis

The sample was analysed using NVIVO™ 10 software (QSR International, 2012). The articles were coded into specific cross-cutting themes: the definition of SI used by the authors, potential indicators of SI suggested, scales at which the indicators were considered, the suggested quantitative measures of these indicators, and whether the indicators were considered to be positive (needs to increase or improve) or negative (needs to decrease), or 'unassigned'. The themes were categorised using the SES framework (Fig. 1). These findings, as well as the percentages of the total number of articles in which the indicators were mentioned, were then tabulated (Appendix B). For disaggregated analyses, classification sheets were constructed with seven different aspects of bibliographic information. These were: year of publication, 'actor group' to which the authors belonged (academia, research institutes, government organisations, NGO, industry, UN, or 'unclassifiable'), location of the source document, location of the study site, type of document (refereed journal article, report, web-site, blog post, conference preceding, or transcript), and type of farming discussed (mixed, arable, livestock, or 'unassigned'). Using the bibliographic information and the data on the indicators identified, tables were produced detailing the percentage of articles originating from each actor group for each of the main themes of the SES framework.

3. Results and discussion

A total of 218 indicators of SI were identified, covering all seven sub-systems of the SES framework. There were considerable variations in emphasis between each of the sub-systems. The highest proportion of these 218 indicators (36.24%) related to the 'outcomes' of agricultural systems, followed by the 'resource units' (18.81%), the 'resource users' (17.89%), and the 'interactions' (11.00%). The lowest proportion of indicators belonged to the 'governance' (5.50%), the 'environment' (5.50%), and the 'resource system' (5.05%) sub-systems. Full details of all of the indicators are provided in Appendix B. In the following sections only the most frequently suggested indicators – those that were suggested by more than four articles in the sample – are discussed.

3.1. Resource system indicators

A total of 11 indicators were identified under the 'resource system' sub-system. The majority of indicators were not assigned according to a specific farming type, and most were suggested at the landscape scale. Nine indicators were mentioned in only two or fewer articles (see Appendix B), suggesting a lack of commonality on those dimensions. Only two indicators – 'area under irrigation' (e.g. articles 27, 68, and 75) and 'habitat fragmentation' (e.g. articles 16, 24, and 60) – were mentioned by four or more of the sampled articles (Table 2).

The suggestion that 'area under irrigation' can be an indicator of SI may appear counterintuitive. The use of irrigation is a key attribute of HEIA (International Food Policy Research Institute, 2002) and can cause environmental degradation, such as, desertification (Danfeng et al., 2006; Singh, 2009; Romm, 2011), salinization (George et al., 1997; Kotb et al., 2000; Rozema and Flowers, 2008), and groundwater depletion (Rodell et al., 2009; Zeigler and Mohanty, 2010; Pingali, 2012). This indicator could be considered as highly productivist in nature and counter to the sustainability of the system. However, in arid regions Africa and Asia irrigation is an essential component of productive and viable agricultural production (Anbumozhi et al., 2001; Zhang et al., 2006). Irrigation helps overcome climate extremes and variability by providing greater control over soil water management, ensuring a predictable harvest. The key question here is the methods used for irrigation, some of which are demonstrably unsustainable. For instance, extraction of underground (fossil) water has been one the main causes of environmental problems associated with HEIAPlease can you insert the following reference: (Chartres, 2014). In contrast, some technically advanced irrigation methods, for example, drip irrigation, have been found to improve crop yields whilst increasing water-use efficiency (Ayars et al., 1999). The indicator therefore could be renamed as 'area under sustainable irrigation'. The articles that refer to 'area under irrigation' do not specify this and are unclear as to whether this refers to the irrigation typical of HEIA or approaches to irrigation that can embody features of sustainability.

In contrast, 'habitat fragmentation' was identified as a negative indicator of SI, and was described by article 24 (Ghersa et al., 2002) as a facet of the sustainability component of SI. 'Habitat fragmentation' can be considered as a negative indicator because it can have adverse consequences for sustainability, e.g. negative effects on wildlife and

Table 2
The most commonly suggested indicators identified as part of the 'resource system' sub-system.

Resource System					
Indicator	Positive, negative, unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Area under irrigation	Positive	Field, farm, landscape, continental, global	Arable, mixed	academia, NGO, research institute	9
Habitat fragmentation	Negative	Farm, landscape, continental, global	Unassigned	academia, NGO	7

biodiversity (Haddad et al., 2015). However, the negative impacts of habitat fragmentation can be mitigated if the fragmented habitats are connected through corridors, patches, mosaics, etc. (Ghersa et al., 2002; Prober and Smith, 2009). The precise wording for this indicator should, therefore, be 'habitat fragmentation without connectivity among fragments'.

3.2. Resource units indicators

Under the 'resource units' sub-system (Appendix B) there were 41 indicators, the majority suggested at the field, farm, or landscape scales (and few unassigned with regard to scale). Most were unassigned according to farming type, and were considered as positive for SI (Appendix B). Of the total 41 indicators, 23 were cited by four or more of the articles (Table 3).

'Soil organic matter' was identified as a positive, farm-scale indicator. This was not only the most frequently suggested 'resource units' indicator, but also the most frequently suggested of all the indicators identified in this investigation (e.g. articles 14, 22, 28, 45, 75). It is a highly pertinent indicator, as it has an impact on both 'sustainability' and 'intensification' (Matson et al., 1997; Bot and Benites, 2005; Johnston et al., 2009). Other frequently suggested indicators relating to soil quality were: 'water holding capacity of the soil', 'soil texture', 'soil pH' 'mineralisable nitrogen in the soil', and 'plant available phosphorous'. That so many indicators relating to soil resources were frequently suggested indicates that the scientific community is reacting to concerns surrounding the massive degradation of soils around the world as a result of HEIA (Labriere et al., 2015). For example, annual soil loss in the EU has been estimated at around 970 million tonnes a year, exceeding average soil formation rates by a factor of 1.6 (Panagos et al., 2015). Similarly, the costs to the British economy due to soil erosion is estimated at 205 million pounds a year (Verheijen et al., 2009).

The 'diversity of crops' and the 'diversity of livestock' were the second and fourth most frequently suggested indicators, respectively, within the 'resource units' sub-system. Both were identified as positive for SI. Article 43, describes the 'diversity of crops' as,

> "… measured in terms of species richness or genotype richness. Crop species richness is the number of species planted within a given cropping system at a given time. Genotype richness, on the other hand, is the number of distinct crop genotypes or varieties simultaneously planted in a given cropping system." (Smith et al., 2015: 18)

Table 3
The most commonly suggested indicators identified as part of the 'resource units' sub-system.

Resource Units					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Soil organic matter	Positive	Field	Arable, Mixed	GO, academia, NGO, research institute, UN	20
Diversity of crops	Positive	Farm, landscape	Arable, Mixed	academia, NGO, research institute, UN, industry	14
Fertilizer use (kg per ha)	Positive, Negative	Field	Arable, Mixed	academia, NGO, research institute	12
Diversity of Livestock	Positive	Farm, landscape	Livestock, Mixed	academia, NGO, research institute, UN	11
Use of improved crop varieties	Positive	Farm	Unassigned	academia, NGO, research institute	11
Number of crop protection chemical treatments	Negative	Field, farm	Unassigned	academia, research institute, UN, NGO	10
Water holding capacity	Positive	Field	Arable, Mixed	academia, research institute	9
Numbers of indicator species	Positive	Farm, landscape, national, global	Unassigned	academia, NGO, research institute, UN, industry	8
Diversity of soil biota	Positive	Field	Arable	academia, research institute, UN, industry, NGO	8
Soil texture	Positive	Field	Mixed	academia, research institute, UN, NGO	8
Wild biodiversity	Positive	Farm, landscape, continental	Unassigned	academia, research institute	6
Farm-land bird numbers	Positive	National, continental	Unassigned	academia, NGO	6
Soil pH	unassigned	Field	Mixed	academia, research institute	6
Depth of water table	Positive	Landscape	Arable	academia, NGO. Research institute	6

Agrobiodiversity, including crop and genetic diversities, is considered by some as fundamental to the sustainability of agricultural systems (Hoisington et al., 1999; Veteto, 2008) due to its value for crop improvement (Grando and McGee, 1990; Pasam et al., 2014). Concerns about the loss of agrobiodiversity during the twentieth century are widespread. For example, it has been estimated that in Bangladesh alone nearly 7000 varieties of rice have been lost since the widespread adoption of high-yielding varieties (Thrupp, 2000), and every week a traditional livestock breed becomes extinct (Thrupp, 2000). There is need to reconcile agrobiodiversity indicators with other frequently mentioned indicators, namely the 'use of improved crop varieties', and 'use of improved livestock varieties', which were the 5th and 20th most frequently suggested indicators, respectively (see Table 3). Both were identified as positive for SI, which might be construed as contradictory to indicators emphasising agrobiodiversity. For example, article 45 stresses the importance of crop diversity, but goes on to mention that agriculture must deploy high yielding crops. Similarly, Article 5 emphasises the role of tradi-

Table 3 (*Continued*)

Resource Units					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Crop pollinator numbers	Positive	Field, farm, landscape, national	Arable	academia, NGO, research institute, industry, GO	6
Species extirpation	Negative	Landscape	Unassigned	academia, NGO, research institute, UN	5
Use of organically derived fertilizers	Positive	Farm	Mixed	academia, research institute	4
Use of chemical fertilizers	Negative	Farm	Mixed	academia, research institute, industry	4
Calories produced/ha	Positive	Field	Unassigned	academia	4
Use of improved livestock varieties	Positive	Farm	Unassigned	academia, research institute	4
Diversity of wild bird species	Positive	Farm, landscape	Unassigned	academia, research institute	4
Mineralisable nitrogen in the soil	Positive	Field	Arable	academia, research institute	4
Plant available phosphorous	Positive	Field	Arable	academia, research institute	4

tional crop varieties while also suggesting that agriculture requires "…better seed varieties" (Food Ethics Council, 2012: 18). A number of the articles did not specify what exactly was meant by "better", or "improved", however, Pretty et al. (2011, p 8) suggested the use of crops and livestock breeds with a "… high ratio of productivity to use of externally and internally derived inputs". Meanwhile Robinson et al. (2015) suggest the use of drought resistant crop varieties, when discussing SI in dryland regions. Although agrobiodiversity is important in the breeding programmes of these "better" and "improved" varieties, there are concerns that under HEIA agrobiodiversity is rapidly being lost *in situ* (Maxted et al., 1997; Wilcox, 1990).

The indicator 'fertilizer use' was identified as both a positive and a negative indicator. This difference in interpretation depended on the context in which SI was discussed. In general, fertilizer use was seen as a negative indicator in more economically developed contexts, with article 48, for example, suggesting that agricultural yields must be increased without a corresponding increase in synthetic fertilizer use. In contrast, synthetic fertilizer use was seen as positive indicator in less economically developed contexts (e.g. article 45).

Two other related indicators are: 'use of organically derived fertilizers' and 'use of chemical fertilizers'. Both were identified as positive indicators, and frequently suggested in the articles discussing SI in Africa. However, the literature reviewed is not specific about what exactly is meant by 'use of chemical fertilizers'. If the indicator "chemical fertilizers", is interpreted to mean the use of the manufactured NPK fertilizers then there are risks of negative environmental consequences e.g. the leaching of fertilizers, causing eutrophication of waterways (Sangha, 2013); and the increased incidents and severity of pest outbreaks (Bottrell and Schoenly, 2012; Carey, 2009). However, if "chemical fertilizers" is interpreted to mean the adoption of emerging technologies, such as Nano-fertilizers, then impacts may be judged differently, since Nano-fertilizers could enable more targeted application of agricultural inputs and consequently limit both environmental and human health impacts (Naderi and Danesh-Shahraki, 2013; Kah, 2015). If "chemical fertilizers" is to be used as an indicator of SI, then greater specificity is required.

Indicators relating to biodiversity made up one third of the most commonly mentioned 'resource unit' indicators. Of these, all but one ('species extirpation') were considered as positive indicators, and only two ('diversity of soil biota' and 'crop pollinator numbers') were discussed in relation to a specific farming type (arable farming). Biodiversity indicators were suggested at all scales of measurement; however, the landscape was most frequently suggested. Although there is an agreement regarding biodiversity maintenance, the literature is not very specific as to what kind of biodiversity should be preserved, and where. The number of 'farmland birds' was frequently suggested in European literature (e.g. articles 7, 12, 48), but specific indicators were not suggested for other regions.

3.3. Governance indicators

A total of 12 indicators were grouped under the 'governance' sub-system (Appendix B). However, eight of these were suggested in two or fewer articles, and none were cited in more than five articles (Table 4). The majority were identified at the national scale, with few identified at any other scales, suggesting some convergence in opinion. The majority of the indicators did not refer to any specific farming type, a quarter referred to arable farms, and a smaller percentage to mixed farms. It is notable that governance was not something that stakeholders from industry discussed. Instead, the majority of these indicators came from academia and research institutes, with contributions from NGOs, the UN, and government organisations.

The most commonly suggested indicator was 'security of land tenure', commonly mentioned in the context of less economically developed regions (e.g. articles 36, 45), but a few articles (e.g. article 44) also mentioned this in the context of more economically developed regions. A closely related indicator – 'strength of land rights' –

Table 4
The most commonly suggested indicators identified as part of the 'governance' sub-system.

Governance					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Security of land tenure	Positive	Farm	Arable, Mixed	academia, research institute	5
Subsidies to encourage SI practices	Positive	National, continental	Unassigned	academia, research institute, UN	4
Payment for environmental services	Positive	National, continental	Arable	academia, NGO, UN	4
Strength of land rights	unassigned	National	Unassigned	GO, academia, NGO, research institute	4

was the (joint) second most frequently suggested indicator. The latter was suggested at the national scale but was unassigned with regard to farming type or whether it was positive or negative for SI. The rationale (e.g. as articulated in Article 44) was that governance structures, such as secure land tenure, could encourage agriculture to develop more sustainably, and was especially important when considering the economic sustainability of agriculture. Similarly, the importance of land rights has been discussed frequently by international organisations, such as the World Bank (Byamugisha, 2013), the U.N. (Economic Commission for Africa, 2004) and the IIED (Cotula, 2007). It has been suggested that a lack of land rights contributes to the continuation of poverty by discouraging investment in agriculture and encouraging discrimination based on ethnicity and gender (ECA, 2004; Lawry et al., 2014). Further evidence for the importance of land rights comes from the disassembling of collective farms and the implementation of long-term leases on agricultural land in China, which has been called "…the driving force behind the single greatest poverty-reduction achievement worldwide" (USAID, 2009: 1). Therefore, these two indicators, owing to their focus on the social and economic sustainability of smallholder farmers in less economically developed contexts, do not substantiate the criticism that SI is underpinned by productivist, and corporate-led agenda (Collins and Chandrasekaran, 2012; Lewis-Brown and Lymbery, 2012; Cook et al., 2015; Food Ethics Council, 2012).

Indicators relating to subsidies made up the rest of the most frequently suggested 'governance' indicators. These indicators were suggested at the national and continental scales and identified as positive for SI. However, the rationale behind subsidies were different. Whilst, some articles (e.g. articles 4, 18, 52) suggested subsidising farmers and landowners to provide environmental goods and services, some others (e.g. article 34), focused mainly on African agriculture, suggested the same to enable the purchase of expensive inputs, such as chemical fertilizers, which indicated a productivist concern.

There are many debates about agricultural subsidies. On the positive side, subsidies are seen as tools to stimulate agriculture to produce environmental goods and services in developed countries (Mattison and Norris, 2005), as well as to increase production and address multiple market failures in developing countries (Wiggins and Brooks, 2010; Gautam, 2015). On the negative side, subsidies are seen as: undermining the competitiveness of farmers from developing regions (by subsidising farmers in developed countries) (Wise, 2004), reasons for the consolidation of power in the hands of landowners, thereby weakening the position of tenant farmers (Wiggins and Brooks, 2010; Goodwin et al., 2011), and an incentive that can lead to wasteful use of resources and unsustainable agricultural practices (FAO, 2011; Gautam, 2015). Given these, it is unsurprising that the use of subsidies as an indicator of SI can be viewed by some with scepticism. To avert such criticisms those advocating subsidies need to be specific with regard to the exact nature of the problem that the subsidy is trying to address, and the context in which this incentive should be used.

3.4. Resource users indicators

A total of 39 indicators relating to the 'resource users' were identified. The majority were considered at the farm scale and none at the continental or global scale, suggesting that most of the articles were concerned with farmers and agricultural workers, rather than society at large. A large proportion were not associated specifically with farming type and most were considered as positive for SI (Appendix B). Of the total number of indicators identified, only 9 were mentioned by more than 4 articles (Table 5).

Within this sub-system, 'access to appropriate technologies' was the most frequently suggested indicator. For example, article 3 states that,

> "A new approach is needed to meet the world's food needs – sustainable intensification – that harnesses advanced technologies…" (USDA, 2015: 1)

It is interesting to note that this indicator is not suggested in the literature emerging from corporate players, perhaps because it could adversely impact on the sale of products founded in patented technologies. In terms of the precise nature of the technologies, few articles provide specific examples. Friends of the Earth International (2012) and the Food Ethics Council (2012) mention the use of genomics in crop breeding, whereas The Montpellier Panel (2013) mentions the use of precision technologies such as satellite imagery and geospatial tools. However, the other articles reviewed do not indicate such specific applications. More importantly, the vast majority of the articles suggesting this indicator do not provide the specific details necessary to judge impacts of technology on the social sustainability of agriculture, which is a key concern for many technology sceptics.

Table 5
The most commonly suggested indicators identified as part of the 'resource users' sub-system.

Resource Users					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Access to appropriate technologies	Positive	Farm	Unassigned	GO, academia, NGO, research institute, UN	16
Farmer income	Positive	Farm	Unassigned	GO, NGO, academia, research institute, UN	13
Education and knowledge	Positive	Farm	Arable, Mixed	academia, NGO, research institute	11
Non-agricultural employment	Positive	Farm	Mixed	academia, research institute	8
Off-farm employment	Positive	Farm	Livestock, Mixed	academia, research institute	8
Dependence on subsides	Negative	Farm	Unassigned	academia, GO, research institute	5
Land ownership	Positive	Farm	Arable	academia, research institute	5
Nutritional status	Positive	Farm	Unassigned	GO, academia, research institute	5
Labour reduction (time taken to perform a task)	Positive	Farm	Unassigned	NGO, research institute, GO	4

For example, the adoption of certain GR technologies have been identified as a factor widening rich-poor gaps since they have particularly benefitted the farmers in favourable regions at the expense of those in resource-scarce regions, such as Sub-Saharan Africa and Eastern India (Zeigler and Mohanty, 2010; Pingali, 2012). Evidence from India suggests that small-holder farmers could not adopt those technologies for a diversity of reasons, including: the inequitable distribution of land, poorly developed land rights, and a lack of output markets for their products (Pingali, 2012). The technologies also resulted in higher input prices, lower prices for products, and reduction in both wages and agricultural employment due to increased mechanisation (IFPRI, 2002). These factors have been suggested as the causes of increase in farmer debts and suicides (Sangha, 2013). Another negative consequence was the migration from agricultural to urban areas that were unable to absorb large numbers of unemployed workers leading to a transfer of poverty rather than poverty reduction (Pingali, 2012). Given such impacts, it is understandable why technological propositions relating to SI may be viewed with scepticism. If 'access to appropriate technologies' is to be used as an indicator of SI there is need for specific reference to the type of technology as well as consideration of the potential social consequences that may result from its uptake.

Other frequently identified indicators related to farmer income and employment (Table 5). 'Non-agricultural employment' referred to the income generating activities that take place on-farm, but did not involve farming. Examples include: eco-tourism, and the processing of agricultural outputs to produce speciality products, e.g. cheeses and wines (see articles, 8, 36, 51). 'Off-farm employment' was described as any income generating activities that did not take place on the home farm. Such activities could be both agricultural in nature (e.g. contract farming), or non-agricultural in nature (see articles, 25, 32, 36). All but one ('dependence on subsidies') of these indicators were considered to be positive for SI, with article 46 stating that,

> "…increasing income for farmers is also essential to purchase food, education, medicine and other goods and services essential for their livelihoods and development." (The Montpellier Panel, 2013: 11)

Dillon et al. (2015) have proposed that a household may be considered vulnerable if the farm business is not viable, and none of the occupants are engaged in off-farm employment. Chikowo et al. (2014) state that sufficient income is imperative for farmers to access new technologies, undertake better management of the farm, and become more productive and economically, and potentially, environmentally, sustainable. This means that farmer income is essential both for agricultural sustainability and productivity. However, farm income in many countries, such as the UK (DEFRA, 2016), has been declining. This suggests that farmer incomes and employment are particularly pertinent indicators to SI.

'Education and knowledge' was the third most frequently suggested indicator relating to resource users (Table 5), mentioned in articles discussing agriculture in both more and less economically developed contexts. The RISE foundation (2014): 28), for example, mentions of the "knowledge intensity" of agricultural systems. Similarly, the Food Ethics Council (2012: 16) states that SI will be "skills intensive", and Allan Buckwell mentions measuring "knowledge per hectare" (CAP2020, 2014: 1). The articles reviewed suggested that increasing farmers' knowledge and educational level has a number of positive impacts of relevance to SI in terms of increased productivity and capacity to adapt and innovate.

'Nutritional status' referred to both farmers and farm families, was identified as a positive indicator of SI, and was considered most frequently at the farm scale, particularly in the articles originating from less economically developed contexts (e.g. articles 43, 45, 56). Smith et al. (2015) state that,

> "…nutrition is frequently cited as an indicator of human wellbeing in SI systems…" (Smith et al., 2015: 28)

This suggests that the indicator 'nutritional status' reflects the social sustainability of an agricultural system (particularly in less economically developed regions) and runs counter to the criticism that the concept of SI is purely founded in the corporate-driven agenda for greater production.

'Labour reduction' was the sixth most frequently suggested indicator relating to resource users (Table 5). The literature was focused on more economically developed contexts and considered the reduction of labour as a positive indicator of SI (DEFRA SIP, 2015; Smith et al., 2012), with article 58 stating,

> "…. try and produce lamb with less labour required at lambing time…" (DEFRA SIP, 2015: 12)

In contrast however, articles originating from NGOs that focused on less economically developed contexts and considered 'increasing use of labour' as a positive indicator of SI (Chikowo et al., 2014; Food Ethics Council, 2012). These diametrically opposed indicators illustrate the highly context-specific way in which the concept of SI has to be interpreted.

3.5. Interactions indicators

A total of 24 Indicators were identified relating to 'interactions' (Appendix B). Field, farm and landscape were the most frequently suggested scales, and most were suggested in the context of arable farms; however, a large proportion were unassigned. A little over half of the indicators were identified as being positive for SI, a smaller proportion as negative, few were unassigned in this regard.

The most commonly suggested indicator relating to 'interactions' was the use of 'integrated pest and disease management (IPM)'. This was considered as positive and farm-scale in nature. IPM was mentioned by a wide range of actor groups including those from academia (e.g. articles 13, 27), industry (e.g. articles 54, 57), and the UN (article 52). Such a convergence of views is unsurprising given the purported negative consequences on ecosystem and human health attributed to chemical methods of pest control (Pingali, 2012). Examples include: the killing of non-target and beneficial organisms (IFPRI, 2002; Zeigler and Mohanty, 2010), the build-up of pesticide residues (Sangha, 2013), illness and even death of farm workers (Zeigler and Mohanty, 2010), pesticides in food chains having carcinogenic impacts (Sangha, 2013), and indebtedness of farmers to transnational agribusinesses selling pesticides (IFPRI, 2002;). IPM, popularised mainly through the works of the UN-FAO, is a technological response to these adverse consequences and employs a range of techniques including: genetic (host-plant resistance), biological, mechanical/physical and regulatory, while not denying the usefulness of chemical control in certain situations (Morallo-Rejesus and Rejesus, 1992).

The indicator 'market access' was the second most frequently cited indicator. In referring to this, Sir Gordon Conway states,

> "… farmers must have access to fair and efficient markets and be part of remunerative value chains." (Conway, 2013: 1)

Market access was considered as a significant component of SI, (e.g. articles 36, 43). It was most frequently discussed in the sampled articles in terms of small-holder farmers in developing countries, and their access to local markets (articles 3, 8, 43, 45). These articles discussed ‘market access’ as a “local challenge” (USDA, 2015: 2), and have suggested measuring physical access as “the distance to the nearest market” (Smith et al., 2015: 27). ‘Market access’ was identified a few times in articles discussing more economically developed regions (Muller, 2015; Syngenta, 2015) but was not well defined.

It is a no brainer to say that farmers’ access to markets is vital for an economically viable farming. Apart from the transaction of farm inputs and produce, markets create jobs for farming populations. This indicator, therefore, can be said to addresses both social and economic dimensions of agricultural sustainability. This indicator, however, does not take into account the globalised nature of modern agrifood markets that are increasingly being controlled by Transnational Corporations (TNCs) (Renwick et al., 2012). Such dominance of TNCs is not always viewed positively in terms of the sustainability of local agrifood systems (Fuchs and Clapps, 2009). Questions, therefore, arise as to who has the power and who controls the markets in which farmers need access to. Of the 11 articles citing market access as an indicator, only one article (article 5) discusses these points. However, it is not to suggest that the presence of TNCs is always an undesirable aspect of a market. If market access is to be an indicator of SI the key attributes of such market should be, as has been pointed out by Conway (2013), ‘fair’ and ‘efficient’. However, except Conway (2013) the rest of the articles do not emphasise these points.

Within this sub-system there is a strong emphasis on farmers’ knowledge and skills and the processes that could promote this. Three indicators were identified: ‘farmer advice and information infrastructure’, ‘farmer participation in research’, and ‘farmer to farmer knowledge exchange’. All were identified as positive for SI. The reasons for promoting knowledge and skills included: as a method of increasing the intensity of agriculture (Smith et al., 2015); as a tool to increase agricultural production (Royal Society, 2009); as a way to increasing the adoption of new technologies in agriculture (Royal Society, 2009; UN FAO, 2011; Pretty and Bharucha, 2014); and enabling the implementation of “context-specific, knowledge-intensive and regenerative practices of sustainable intensification” (Pretty and Bharucha, 2014: 8). As well as these productivity-related drivers, both the RISE Foundation (2014) and the Foresight report (2011) suggest that increasing the level of knowledge and skills among farmers could aid environmental sustainability.

Another key aspect was the need to build social (institutional) capital within farming communities. The indicator ‘Membership of a farmer in organisations’ related to this. This is typified by article 58, which states that a sustainably intensified system must,

> “… build and maintain collaborative networks and working relationships in order to improve the economic, social and environmental performance of agricultural land.” (DEFRA SIP, 2015: 8)

A little less than one third of the ‘interactions’ indicators related to soil conservation practices. These were; ‘maintenance of continuous soil cover’ (identified as a positive indicator), ‘number of tillage operations’ (identified as a negative indicator), and ‘management for soil conservation’ (unidentified with regards to whether it was a positive or negative indicator). Each was considered at either the farm or the field scale (Table 6), suggesting that they are highly context dependent. The indicator ‘management for soil conservation’ was not well defined in the articles reviewed; however, it was suggested that this would entail any processes that: increased the soil organic matter content, reduced soil erosion, and involved the use of nitrogen fixing plants, cover-crops and green manures (Petersen and Snapp, 2015). The focus on indicators relating to soil properties reflects concerns about global degradation of agricultural soils experienced during the 20th century – discussed in Section 3.2. However, unlike Section 3.2, the ‘interactions’ indicators relate to processes undertaken on-farm that influence the loss, degradation or conservation of soil resources. For example, evidence indicates that reducing the number of tillage operations reduces the rate at which soil is lost from agricultural lands (Montgomery, 2007; Derpsch et al., 2010; Prasuhn, 2012).

Table 6
The most commonly suggested indicators identified as part of the ‘interactions’ sub-system.

Interactions					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Integrated pest and disease management	Positive	Farm	Arable	academia, NGO, UN, research institute, industry	13
Market access	unassigned	Farm, landscape	Unassigned	GO, academia, NGO, research institute, UN, industry	11
Farmer advice and information infrastructure	Positive	National	Unassigned	GO, academia, research institute, UN	8
Membership of a farmer in organisations	Positive	Farm, landscape, national	Arable	academia, research institute, UN, GO	7
Maintenance of continuous soil cover	Positive	Field	Arable	academia, NGO, reseach institute, UN	7
Management for soil conservation	unassigned	Farm	Arable	academia, research institute	6
Farmer participation in research	Positive	Landscape	Unassigned	GO, academia, UN, industry	6
Farmer to farmer knowledge exchange	Positive	Landscape	Unassigned	academia, research institute, GO	5
Number of tillage operations	Negative	Field	Arable	academia, industry	4

3.6. System outcomes indicators

It would appear as if the majority of authors consider SI in terms of ‘ends’ rather than ‘means towards certain ends’ (Garnett and Godfray, 2012; Loos et al., 2014; Pretty and Bharucha, 2014), as the largest number (79) of indicators identified belonged to this category (Appendix B). However, only 24 indicators could be considered as frequently mentioned (Table 7).

The majority were identified at the farm scale, with smaller numbers at the field and the landscape scale. Few indicators were identified as unassigned, or at other scales. This is not unexpected, since the farm has traditionally been the unit of investigation within the

Table 7
The most commonly suggested indicators identified as part of the ‘outcomes’ sub-system.

Outcomes					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
GHG emissions	Negative	Farm, landscape, continental, global	Unassigned	GO, academia, NGO, research institute, UN	18
Soil erosion	Negative	Field	Unassigned	academia, NGO, research institute, UN	18
Yield of each agricultural product	Positive	Field, farm, landscape, national, global	Arable, Livestock	academia, research institute, GO	13
Yield (tonnes per hectare)	Positive	Field	Arable	academia, NGO, research institute, GO, industry	13
Nitrate run-off	Negative	Landscape	Arable, Livestock	GO, NGO, academia, research institute, UN	10
Water footprint (total water use/given area)	Negative	Farm	Arable, Livestock	GO, academia, NGO, research institute, UN	9
Water quality	Positive	Landscape	Unassigned	GO, academia, NGO, research institute	8
Increase in yields	Positive	Field, farm, global	Unassigned	GO, NGO, academia, research institute	8
Resource use efficiency	Positive	Farm,	Unassigned	academia, NGO, research institute, GO	8
Yield (kg)/input used	Positive	Field	Arable	academia, research institute, NGO, UN, industry	7
Livestock welfare	Positive	Farm	Livestock	academia, NGO, research institute, industry	7
Gender equity	Positive	Landscape	Unassigned	GO, academia, NGO, research institute	7
Cropping intensity	Positive	Field	Arable	academia, research institute	6
Land use intensity	Positive	Field	Arable	academia, research institute, UN	6
Energy efficiency	Positive	Farm	Unassigned	academia, research institute	5
Livestock stocking density	Negative	Field, landscape, national	Livestock	academia, research institute	5
Yield gap	Negative	Field, global	Arable	academia, research institute, UN	5
Variability in yield	Negative	Farm	Unassigned	academia, research institute, NGO, UN, industry	5
Salinization	Negative	Landscape	Arable	academia	5
Carbon dioxide emissions (CO2 t/ha)	Negative	Field	Unassigned	academia, NGO, research institute, UN	5
Soil compaction	Negative	Field	Arable	academia, research institute	4
Carbon sequestration	Positive	Farm, landscape, national	Unassigned	academia, research institute	4
Below ground carbon (mg of carbon/g of soil)	Positive	Field	Unassigned	academia, research institute	4
Farmer exposure to agro-chemicals	Negative	Farm, continental	Arable	academia, research institute, industry	4 5

agricultural literature (Firbank et al., 2013). However, recently, there has been a move towards considering larger scales, for example, DEFRA’s Sustainable Intensification Platform (DERFA SIP, 2016) have suggested considering SI at the landscape scale.

In terms of farming type, a little over half of the indicators were unassigned and less than one third were identified for arable farms. Far fewer indicators were identified in relation to livestock and mixed farms. Finally, the majority of the indicators were identified as being either positive or negative for SI, with very few identified as unassigned.

‘GHG emissions’ was found in articles originating from all of the actor groups except for industry. It was the joint-first (with ‘soil erosion’) most frequently suggested indicator related to ‘outcomes’, and the joint-second most frequently suggested of all the indicators identified (e.g. articles 1, 4, 6, 11, 55). In addition, ‘carbon dioxide emissions (tonnes/ha)’, was frequently suggested. Both were identified as negative and referred to the environmental sustainability facets of SI (Royal Society, 2009; UN FAO, 2011; DEFRA, 2015; Smith et al., 2015). Although the two indicators can be considered to be very similar, ‘GHG emissions’ was suggested at a variety of different scales (farm, landscape, continental and global), whereas, ‘carbon dioxide emissions (tonnes/ha)’ was only suggested at the farm scale. This difference may be due to the rise in popularity of online farmer decision support tools, such as “Farmscoper”,[1] “Carbon Accounting for Land Manager (CALM)”,[2] and the “Cool Farm Tool”.[3] Firbank et al. (2013), for example, used both the CALM tool and Farmscoper when calculating GHG emission in their investigation into SI in UK farms.

Indicators relating to soil resources were frequently identified, including: ‘soil erosion’, ‘salinization’, ‘soil compaction’, ‘carbon sequestration’, and ‘below ground carbon’ (Table 7). These indicators are directly related to some of the most pressing issues facing the productivity and sustainability of modern agriculture. For example, the loss of topsoil and the degradation of agricultural soils due to unsustainable agricultural practices (Horrigan et al., 2002; Montgomery, 2007) as well as the need to mitigate the effects of climate change brought about by GHG emissions addressed by the indicators ‘carbon sequestration’ and ‘below ground carbon’ (Lal, 2004; Johnson et al., 2007; Lal et al., 2007). As such, these indicators can be seen as focusing on both the environmental sustainability and the intensification facets of SI.

Six indicators relating to yield were commonly suggested by the articles reviewed (Table 7), accounting for 25% of the most frequently suggested ‘outcomes’ indicators. These were suggested by all six of the actor groups analysed, indicating a convergence of views. All of the indicators had the same basic premise, that yields should increase in a sustainably intensified agricultural system. It is of interest to note that in Pretty’s original article describing SI the focus was on increasing productivity rather than production (Pretty 1995; Pretty, 1997). Pretty stated that SI “…substantially improved agricultural yields” only when combined with “…regenerative and resource conserving technologies” (Pretty, 1997: 249). However, with the exception of the indicator ‘yield (kg)/input used’, the majority of indicators of yield measure the output component against the area of production, with less consideration of the other inputs required.

Two indicators related to the quality of water resources were commonly suggested (Table 7), with both suggested at the landscape scale. The indicator ‘water quality’ was described (e.g. by article 4) as a component of the environmental sustainability of SI, having repercussions for the continued ability of agricultural lands to be productive in the future; meanwhile, article 43, discussing SI in the context of African agriculture, suggested that ‘water quality’ was an indicator of human wellbeing. These findings suggest that ‘water quality’ is a highly appropriate indicator of SI, as it influences both the human and environmental facets of agriculture, as well as the ability to continue to produce.

Indicators relating to the intensity and efficiency of resource use (e.g. ‘resource use efficiency’, ‘land use intensity’ and ‘energy efficiency’) were commonly mentioned, suggesting the importance of debates surrounding the use of non-renewable resources in agriculture (Dalgaard et al., 2001; Hoeppner et al., 2006; Woods et al., 2010). Smith et al. (2015) and the RISE Foundation (2014), state that improving resource use efficiency is one of the key goals of SI.

Livestock welfare, another very general indicator, was mentioned in a number of articles. It is worth noting, however, that the majority of welfare indicators suggested in the sampled articles were those that would affect the productivity of agricultural systems (e.g. ‘rates of livestock mortality’, ‘disease’, and ‘stocking density’), rather than those that would indicate that the animal had led a “good life” (e.g. ‘incidents of un-natural behaviour’) (RSPCA, 2016). Article 4, for instance, states that,

> “Productivity is considered an indicator of good welfare because disease processes or stressors often have negative impacts upon it.” (Food Ethics Council, 2012: 24.)

Therefore, it can be said that the articles discussing livestock ‘welfare’ are interpreting the term from production-based point of view. However, in contrast, the indicator ‘stocking density’ was suggested as a negative indicator. For example, Smith et al. (2015) suggest limiting the stocking density in relation to the carrying capacity of the land; i.e. an indicator of sustainability, rather than intensification.

Social outcomes considered in the sampled articles included the recreational value of the SES, farmer safety, and number of resource users. The indicator ‘recreational value’ (e.g. articles 18, 35, 45) points to the importance of debates that argue agriculture to be multifunctional, providing goods and services beyond just the production of food, fuel and fibre (Millennium Ecosystem Assessment, 2005). Indeed, article 35 discusses SI as,

> “…. contributing to a range of valued public goods, such as clean water, wildlife and habitats, carbon sequestration, flood protection, groundwater recharge, landscape amenity value, and leisure and tourism opportunities.” (Pretty and Bharucha, 2014: 7)

Considerations of equity were infrequently mentioned and those related to justice and sovereignty were not mentioned at all in the articles reviewed. The indicator ‘gender equity’ was the only recognition of these considerations mentioned by more than four of the articles reviewed. That this indicator has been mentioned so few times is a concern. The requirement for gender equity is well understood and accepted in the contexts of sustainable agricultural and rural development. For example, gender equity has become central to the UN-FAO’s agricultural and rural development strategy, and is the third UN Millennium Development Goal (FAO, 2009; UN, 2016). Rural women play key roles in maintaining households, raising children, and undertaking agricultural activities (UN, 2014). Nevertheless, the roles these women play are often not accurately valued (World Bank, 2009). Rural women make up a disproportionately large number of the world’s poor, and a lack of education and the availability of capital for rural women has been implicated in stalling rural development, increasing environmental degradation and reducing food security (FAO, 2009; World Bank, 2009; Stevens, 2010). Thus the indicator ‘gender equity’ should be a key consideration when assessing the social, economic and environmental sustainability of agriculture.

This raises the question, if SI is being discussed in this way by ignoring key social dimensions, then can it be considered as truly sustainable? Sustainability has been described by the UN (United Nations General Assembly, 2005), government bodies (Foresight, 2011; Forestry Commission, 2015), academics (Kates and Parris, 2005; Colantonio, 2009) and NGOs (Adams, 2006) as comprising of three equally important ‘pillars’ (environmental, economic, and social). Debates around SI need to place more emphasis on the social facets of agriculture given it is of equal importance to economic and environmental considerations. This is particularly pertinent when considering the debates surrounding ‘food sovereignty’ and ‘food justice’. The former asserts peoples’ right to demand sustainably produced food, and define their local food-systems (Declaration of Nyéléni, 2007). The latter emphasises ‘fairness’ in regards to the distribution, production of food, and the participation in food-system (LaVaque-Manty, 2001; Alteri and Toledo, 2011; Patel, 2012; Hospes, 2014). Indeed, food justice is inherent in the definition of food security, as stated by the UN Food and Agriculture Organisation

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[1] Please see: http://www.adas.uk/Service/farmscoper.

[2] Please see: http://www.calm.cla.org.uk/.

[3] Please see: https://www.coolfarmtool.org/.

(Food Ethics Council, 2010). If food justice and food sovereignty are key to food security, then without a stronger emphasis on indicators of social sustainability any measure of SI is bound to be incomplete.

3.7. System environment indicators

The final sub-system relates to the wider environment in which the SES functions, with 12 indicators identified (Appendix B). The majority were identified at the national scale, with fewer at the global and farm scale, and none at any other scales. In terms of farm type, the vast majority of indicators were identified as unassigned, probably because these indicators affect all types of farm systems. Most of the 'environment' indicators were identified as positive, with far fewer identified as negative, and a smaller proportion unassigned. All but two of these indicators were suggested by less than 4 of the articles reviewed (Table 8).

The most commonly suggested indicator was 'access to credit', and was described by article 34 as,

> "···Ensuring that microfinance and rural banking are available to farmers' groups (for both consumption and production purposes)" (Pretty et al., 2011: 20)

This was emphasised most strongly in the literature originating from, or discussing, less economically developed contexts (e.g. articles 34 and 45). However, it was also mentioned by a small number of articles discussing more economically developed contexts (e.g. article 44). Efficient access to credit has been suggested as a powerful tool to combat rural poverty (Golait, 2007), and, limited access to credit has been suggested as hindering agricultural productivity and growth (Badini, 2010; Fletschner and Kenney, 2011;). Article 44 discusses this indicator as specifically related to social and financial considerations (Royal Society, 2009), and, article 45 emphasises the importance of better access to credit specifically to African smallholder farmers (The Montpellier Panel, 2013). Thus, this indicator does not accord with the criticism that the concept of SI is driven by corporate interests and focuses exclusively on a productivist point of view.

'Funding for agricultural research' was described by article 45 as important for the following reasons,

> "Increasing productivity on current land will require significant investments in agricultural research and extension…" (The Montpellier Panel, 2013: 26)

Evidence from the U.S.A and China has attributed agricultural productivity gains to the outputs of agricultural research (Fuglie and Heisey, 2007; Echeverria and Beintema, 2009; Foresight, 2011). This suggests that this indicator is being discussed within the sampled articles from a production-related perspective as distinct from one that fully embraces the social and environmental dimensions.

Table 8
The most commonly suggested indicators identified as part of the 'environment' sub-system.

7 Environment					
Indicator	positive, negative, Unassigned	Scale(s) of measurement	Farming type	Actor groups mentioning the indicator	Number of articles which mentioned indicator
Access to credit	Positive	Farm	Unassigned	academia, research institute	8
Funding for agricultural research	Positive	National, global	Unassigned	academia, NGO, research institute	5

It was noteworthy that there were no indicators mentioned in the sampled articles relating to the social setting, and only one indicator was suggested in relation to both the political setting ('direction of government policy'), and the environmental setting, ('climate shocks and anomalies'). This suggests that the extant literature is taking a more reductionist viewpoint when considering the wider environment in which SI operates.

Finally, within the articles reviewed there are conflicting views regarding the value of the indicators suggested for the system environment. For example, Friends of the Earth International (2012) criticises SI as

> "… promote[ing] liberalised trade, opening up markets of smallholder farmers and export agriculture."

Whereas the same article goes on to suggest that smallholder farmers need to be protected from unfair competition from imported agricultural goods. In contrast to this, the document published by the Montpellier Panel suggests that market systems in rural areas require further development in order to support the spread of SI (The Montpellier Panel, 2013). This indicates that even when SI is discussed in similar contexts, stakeholders cannot agree as to what it should look like in practice.

4. Conclusions and implications

Against the backdrop of differential interpretation, confusion, and scepticism regarding the concept of SI we conducted a Systematic Review of the existing literature using a SES framework in order to explore the extent to which the criticism of SI, and its indicators, are valid.

Our analysis revealed a large number of indicators, covering all of the SES sub-systems. However, there were considerable variations regarding the emphasis placed on the indicators, with the greatest proportion focused on system 'outcomes'. This seems to substantiate that SI is being discussed primarily as ends, rather than a means towards certain ends. The majority of these 'outcomes' indicators related to agricultural production. Whilst this potentially suggested a productivist bias in the current interpretation of SI it was difficult to draw a black and white conclusion, since for the other six system components, the majority of the indicators suggested appeared to take a more holistic point-of-view and emphasised both the productivity and the sustainability of agricultural systems. Our analysis suggests that a key reason why SI may be viewed with scepticism is because of a lack of specificity and elucidation of the rationale, scale, and farm type for which the indicators of SI are being proposed. A number of the indicators identified were so loosely defined that the interventions they imply could be enacted without due consideration of the social impacts of their adoption. Moreover, some indicators appeared to have trade-offs between them, e.g. the potential trade-offs between the use of improved crop or livestock varieties and the *in situ* conservation of agrobiodiversity. In Table 9 we list the indicators that we found most ambiguous in our review along with the reasons for their ambiguities.

As part of this investigation we used a modified version of Ostrom's SESs framework in order to structure our analysis of the most commonly suggested indicators of SI. For the sake of analysis each of the seven sub-systems within the framework was conceptualised as a discrete unit. In reality, however, this is an over-simplification. In-

Table 9
Ambiguous SI indicators identified in this investigation.

No.	Indicator name	Reasons for ambiguities
1	Area under irrigation	Lack of detail regarding the types of irrigation technologies which could be considered appropriate for SI; the impacts of those technologies on agricultural sustainability; and the context in which irrigation needs to be used
2	Use of improved crop varieties	Lack of clarity of the term 'improved'; lack of detail as to how this indicator could be combined with the *in situ* conservation of agrobiodiversity
3	Use of improved livestock varieties	Lack of clarity of the term 'improved'; lack of detail as to how this indicator could be combined with the *in situ* conservation of agrobiodiversity
4	Numbers of indicator species	Lack of detail as to which species should be preserved and under what contexts
5	Wild biodiversity	Lack of detail as to what biodiversity should be preserved and under what contexts
6	Use of chemical fertilizers	Lack of detail as to what types of chemical fertilizer would be appropriate for SI, the impacts of those technologies, and the contexts in which they should be used
7	Subsidies to encourage SI practices	Lack of detail regarding the exact nature of the problem(s) for which subsidies are needed; lack of consideration of the potential negative impacts of subsidies, especially on developing country farmers
8	Access to appropriate technologies	Unassigned in terms of farming type; lack of elucidation as to which technologies are deemed 'appropriate' and the impacts of those technologies
9	Market access	Globalised nature of modern agrifood markets is not taken into account by the majority of articles; lack of clarity as to who controls the market in which farmers need access to
10	Livestock welfare	Very poorly defined in the sampled articles; lack of clarity as to what this means and how this could be implemented in practice

stead of being static units there are feedbacks between all of the sub-systems. Take for example soil organic matter, an indicator highly emphasised within the sample of articles analysed in this review. This indicator can be seen as both an output and an input of an agricultural system. Therefore, that there is a need to develop SI indicators that are able to capture the dynamic interactions between different components of agricultural systems.

We conclude by arguing that there is need to address the aforementioned deficiencies in order for the concept of SI to become meaningful in practice and accepted by diverse stakeholders. Moreover, unless the actors from industry and the private sector engage with the concept of SI in a more holistic, socially-inclusive, and responsible manner, the concept may continue to attract criticisms from the Third Sector, thereby reducing its appeal.

Uncited references

Brundtland et al. (1987), Bunch (2003), Chartres (2014), Committee on World Food Security (2011), DEFRA (2013), Dore et al. (2011), FAO (2015), Godfray (2011), Ison et al. (1997), Johr (2012), Kirchner et al. (2015), McGinnis (2010), Pretty et al. (2000), Pretty et al. (2008a) and Pretty et al. (2008b).

Appendix A. The list of the sampled articles analysed in this systemic review

Article serial no.	Bibliographic information
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Appendix B. full list of the SI indicators identified in this review

Indicator	**positive, negative, Unassigned**	**Scale(s) of measurement**	**Farming type**	**Actor groups mentioning the indicator**	**Number of articles which mentioned indicator**
1. Resource System					
1.1 Size of the system					
Size of patches of uncropped land	Positive	Landscape	Arable	academia	1 (1.33%)
Area of High Nature Value farmland	Positive	Landscape	Unassigned	academia	1 (1.33%)
Physical proximity to markets	Positive	Landscape	Mixed	research institute	1 (1.33%)
Area under irrigation	Positive	Field, farm, landscape, continental, global	Arable, mixed	academia, NGO, research institute	9 (12%)
Percentage of land under production	Negative	Global	Arable, Livestock	academia, NGO	2 (2.67%)
Percentage area of land under different production systems	Negative	Global	Arable, Livestock	academia	1 (1.33%)
1.2 Predictability and variability of the system					
Altered fire regime	Negative	Landscape	Arable	academia	1 (1.33%)
Rainfall variability	Negative	Landscape	Mixed	academia	1 (1.33%)
1.3 Other features of the system					
% of land in productive use throughout the year	Positive	Landscape, global	Unassigned	academia	2 (2.67%)
Habitat fragmentation	Negative	Farm, landscape, continental, global	Unassigned	academia, NGO	7 (9.33%)
Slope of the land above 25%	Negative	National	Arable	academia	1 (1.33%)
2 Resource Units					
2.1 Number of units					
2.1.1 Wild units					
Wild biodiversity	Positive	Farm, landscape, continental	Unassigned	academia, research institute	6 (8%)
Numbers of indicator species	Positive	Farm, landscape, national, global	Unassigned	academia, NGO, research institute, UN, industry	8 (10.67%)
Farm-land bird numbers	Positive	National, continental	Unassigned	academia, NGO	6 (8%)
Diversity of wild bird species	Positive	Farm, landscape	Unassigned	academia, research institute	4 (5.33%)
Butterfly diversity	Positive	Farm	Unassigned	academia, research institute	3 (4%)
Earthworm population/m2 of topsoil	Positive	Field	Mixed	research institute	2 (2.67%)
Mammal diversity	Positive	Landscape	Unassigned	academia, research institute	2 (2.67%)
Crop pollinator numbers	Positive	Field, farm, landscape, national	Arable	academia, NGO, research institute, industry, GO	6 (8%)
Diversity of soil biota	Positive	Field	Arable	academia, research institute, UN, industry, NGO	8 (10.67%)
Number of beneficial insects	Positive	Farm	Mixed	research institute	1 (1.33%)
Species extirpation	Negative	Landscape	Unassigned	academia, NGO, research institute, UN	5 (6.67%)
2.2 Value of the units					
2.2.1 Monetary value					
Value of units/ha	Positive	Field	Unassigned	academia, research institute	2 (2.67%)
2.2.2 Nutritional value					
Calorific value/ha	Positive	Field	Unassigned	academia, research institute	1 (1.33%)
Calories produced/ha	Positive	Field	Unassigned	academia	4 (5.33%)
Protein produced/ha	Positive	Field	Unassigned	academia, research institute	2 (2.67%)
Fodder quality − nutritional content of fodder	Positive	Farm	Livestock	academia	1 (1.33%)
2.3 Types of units					
2.3.1 Domesticated units					
Diversity of crops	Positive	Farm, landscape	Arable, Mixed	academia, NGO, research institute, UN, industry	14 (18.67%)
Diversity of Livestock	Positive	Farm, landscape	Livestock, Mixed	academia, NGO, research institute, UN	11 (14.67%)
Use of improved crop varieties	Positive	Farm	Unassigned	academia, NGO, research institute	11 (14.67%)
Use of improved livestock varieties	Positive	Farm	Unassigned	academia, research institute	4 (5.33%)
2.3.2 Wild units					
Floristic diversity	Positive	Landscape	Arable	academia	2 (2.67%)
Structural diversity	Positive	Landscape	Arable	academia	1 (1.33%)
2.3.3 Soil resource units					
Soil organic matter	Positive	Field	Arable, Mixed	GO, academia, NGO, research institute, UN	20 (26.67%)

Soil texture	Positive	Field	Mixed	academia, research institute, UN, NGO	8 (10.67%)
Soil infiltration rate	Positive	Field	Mixed	research institute	1 (1.33%)
Soil porosity	Positive	Field	Mixed	research institute	1 (1.33%)
Water logging of soils	Negative	Farm	Unassigned	research institute	1 (1.33%)
Water holding capacity	Positive	Field	Arable, Mixed	academia, research institute	9 (12%)
Plant available phosphorous	Positive	Field	Arable	academia, research institute	4 (5.33%)
Mineralisable nitrogen in the soil	Positive	Field	Arable	academia, research institute	4 (5.33%)
Depth of soil	Positive	Field	Unassigned	academia, research institute	2 (2.67%)
Soil pH	unassigned	Field	Mixed	academia, research institute	6 (8%)
Low soil pH	Negative	Field	Mixed	academia, research institute	3 (4%)
2.3.4 Water resource units					
Bacterial count of water	Negative	Landscape	Livestock	research institute	1 (1.33%)
Depth of water table	Positive	Landscape	Arable	academia, NGO. Research institute	6 (8%)
2.3.5 Fertilizer units					
Fertilizer use (kg per ha)	Positive, Negative	Field	Arable, Mixed	academia, NGO, research institute	12 (16%)
Use of organically derived fertilizers	Positive	Farm	Mixed	academia, research institute	4 (5.33%)
Use of chemical fertilizers	Negative	Farm	Mixed	academia, research institute, industry	4 (5.33%)
2.3.6 Crop protection chemical units					
Number of treatments	Negative	Field, farm	Unassigned	academia, research institute, UN, NGO	10 (13.33%)
Quantity of crop protection chemicals used	Negative	Farm	Mixed	UN, research institute	2 (2.67%)
Timing of application of crop protection chemicals	unassigned	Farm	Unassigned	UN, research institute	2 (2.67%)
3 Governance					
3.1 Subsidisation					
Subsidies to encourage SI practices	Positive	National, continental	Unassigned	academia, research institute, UN	4 (5.33%)
Removal of subsidies to encourage SI practices	Positive	National	Unassigned	UN	1 (1.33%)
Payment for environmental services	Positive	National, continental	Arable	academia, NGO, UN	4 (5.33%)
3.2 Taxation					
Taxes to encourage SI practices	unassigned	National	Unassigned	academia, GO	2 (2.67%)
3.3 Property rights					
Security of land tenure	Positive	Farm	Arable, Mixed	academia, research institute	5 (6.67%)
Strength of land rights	unassigned	National	Unassigned	GO, academia, NGO, research institute	4 (5.33%)
Percentage of land owned by the farmer	Positive	Farm	Unassigned	academia	1 (1.33%)
3.4 Regulations					
Regulation of air quality	Positive	National	Unassigned	academia	1 (1.33%)
Regulation surrounding seed quality	Positive	National	Arable	UN	1 (1.33%)
Regulation of farming practices	Positive	National	Unassigned	UN	1 (1.33%)
Regulation of water quality	Positive	National	Unassigned	academia, research institute	2 (2.67%)
Regulation of crop protection chemicals	Positive	National	Unassigned	academia, UN	2 (2.67%)
4 Resource Users					
4.1 Number of users					
Availability of labour	Positive	Farm	Unassigned	academia	1 (1.33%)
Labour reduction (time taken to perform task)	Positive	Farm	Unassigned	NGO, research institute, GO	4 (5.33%)
Hired versus family labour	Positive, Negative	Farm	Arable	academia, research institute	3 (4%)
Locally sourced labour	Positive	Farm	Unassigned	research institute	1 (1.33%)
4.2 Socioeconomic characteristics					
4.2.1 Economic characteristics of the users					
Household purchases (% change in consumption/time)	Positive	Farm	Unassigned	research institute	1 (1.33%)
Financial savings	Positive	Farm	Unassigned	academia	2 (2.67%)
farmer income	Positive	Farm	Unassigned	GO, NGO, academia, research institute, UN	13 (17.33%)
Income/ha	Positive	Field	Unassigned	research institute	3 (4%)
Regional mean income from agriculture	Positive	Landscape	Unassigned	GO, academia	2 (2.67%)
National mean income from agriculture	Positive	National	Unassigned	academia, NGO	2 (2.67%)
Famer debt	Negative	Farm	Unassigned	industry	1 (1.33%)
Household dependency ratio	Negative	Farm	Unassigned	academia	1 (1.33%)
Dependence on subsides	Negative	Farm	Unassigned	academia, GO, research institute	5 (6.67%)
4.2.2 Proxies of user wealth					
Food stores	Positive	Farm	Arable, Mixed	research institute, academia	3 (4%)
Land holdings	Positive	Farm	Arable	academia, research institute	5 (6.67%)
Infrastructure age	Negative	Farm	Unassigned	research institute	1 (1.33%)
Total value of infrastructure	Positive	Farm	Unassigned	academia	1 (1.33%)
4.2.3 User welfare					
Farmer health	Positive	Farm	Unassigned	academia, NGO	2 (2.67%)
Nutritional status	Positive	Farm	Unassigned	GO, academia, research institute	5 (6.67%)

Farmer work/life balance	Positive	Farm	Unassigned	academia	1 (1.33%)
Farmer isolation	Negative	Farm	Unassigned	academia	1 (1.33%)
Number of farmers in poverty	Negative	Landscape	Unassigned	NGO, industry	2 (2.67%)
Farmer age	Negative	Farm	Arable	academia, research institute	3 (4%)
4.3 Dependence on the Resource system					
Non-agricultural employment	Positive	Farm	Mixed	academia, research institute	8 (10.67%)
Off-farm employment	Positive	Farm	Livestock, Mixed	academia, research institute	8 (10.67%)
4.4 Knowledge and skills					
Education and knowledge	Positive	Farm	Arable, Mixed	academia, NGO, research institute	11 (14.67%)
Knowledge/ha	Positive	Field	Unassigned	NGO	1 (1.33%)
Educational level of the farmer	Positive	Farm	Arable	academia, research institute	3 (4%)
Number of trainings received/a certain period of time	Positive	Farm	Unassigned	academia, research institute	2 (2.67%)
4.5 Perceptions of the SES					
Attitudes towards climate change	Positive	Farm	Unassigned	academia	1 (1.33%)
Attitudes towards quality of life	Positive	Farm	Unassigned	research institute	1 (1.33%)
Attitudes towards risk	Positive	Farm	Unassigned	research institute	1 (1.33%)
Attitudes towards wealth	Positive	Farm	Unassigned	academia	1 (1.33%)
Attitudes towards empowerment	Positive	Farm	Unassigned	research institute	1 (1.33%)
Attitudes towards technology	Positive	Farm	Unassigned	research institute	1 (1.33%)
4.6 Technologies available					
Access to appropriate technologies	Positive	Farm	Unassigned	GO, academia, NGO, research institute, UN	16 (21.33%)
Number of technologies adopted over time	Positive	Farm	Unassigned	academia, research institute	2 (2.67%)
% of land on which a technology has been adopted	Positive	Farm	Unassigned	research institute	1 (1.33%)
Percentage of famers adopting a technology	Positive	Farm	Unassigned	research institute	1 (1.33%)
5 Interactions					
5.1 Interactions within the social sub-system					
5.1.1 Informal networks					
Farmer to farmer knowledge exchange	Positive	Landscape	Unassigned	academia, research institute, GO	5 (6.67%)
Informal seed systems	Positive	Landscape	Arable	research institute, UN	2 (2.67%)
5.1.2 Formal networks					
Farmer membership of an agricultural organisations	Positive	Farm, landscape, national	Arable	academia, research institute, UN, GO	7 (9.33%)
Farmer participation in research	Positive	Landscape	Unassigned	GO, academia, UN, industry	6 (8%)
Farmer advice and information infrastructure	Positive	National	Unassigned	GO, academia, research institute, UN	8 (10.67%)
5.1.3 Market access					
Market access	unassigned	Farm, landscape	Unassigned	GO, academia, NGO, research institute, UN, industry	11 (14.67%)
Participation in direct sales markets	Positive	Farm	Unassigned	academia	1 (1.33%)
Access to market information via SMS	Positive	Farm	Unassigned	research institute	1 (1.33%)
5.2 Interactions within the ecological sub-system					
5.2.1 Internal nutrient cycling					
Rate of nitrogen mineralisation	Positive	Field	Arable	research institute	1 (1.33%)
Soil capacity for denitrification	Positive	Field	Unassigned	academia	1 (1.33%)
Biological nitrogen fixation	Positive	Field	Arable	academia, research institute	3 (4%)
Soil capacity for remediating excess phosphorous	Positive	Field	Livestock	academia	1 (1.33%)
5.2.2 Ecological networks					
Complexity of ecological networks	Positive	Landscape	Arable	academia, research institute	3 (4%)
5.3 Interactions between the social and ecological sub-systems					
5.3.1 Cropping systems					
Integrated pest and disease management	Positive	Farm	Arable	academia, NGO, UN, research institute, industry	13 (17.33%)
Use of terraces	Positive	Landscape	Arable	academia	1 (1.33%)
Integrated livestock and crop systems	Positive	Farm, landscape	Mixed	academia, NGO, research institute	3 (4%)
Crop rotations	Positive	Farm	Arable	academia	3 (4%)
Maintenance of continuous soil cover	Positive	Field	Arable	academia, NGO, research institute, UN	7 (9.33%)
Planting cover strips and field buffers	Positive	Field	Arable	academia	2 (2.67%)
Number of tillage operations	Negative	Field	Arable	academia, industry	4 (5.33%)
Field margins	Positive	Field	Arable	NGO	1 (1.33%)
5.3.3 Soil resources					
Management for soil conservation	unassigned	Farm	Arable	academia, research institute	6 (8%)
5.3.4 Water resources					
Management for waterway conservation	Positive	Field	Unassigned	academia, research institute	3 (4%)
5.3.5 Management of uncropped areas					
Management of uncropped areas within the landscape	Positive	Landscape	Unassigned	NGO	1 (1.33%)
6 Outcomes					
6.1 Provisioning outcomes					
6.1.1 Productivity of the SES					
Total factor productivity	Positive	Farm	Unassigned	UN	1 (1.33%)
Capital productivity	Positive	Farm	Unassigned	research institute	1 (1.33%)
6.1.1.1 Animal welfare					
Livestock welfare	Positive	Farm	Livestock	academia, NGO, research institute, industry	7 (9.33%)
Incidents of disease and disorders in livestock	Negative	Farm	Livestock	NGO, research institute	2 (2.67%)

Incidents of lameness in livestock	Negative	Farm	Livestock	NGO, research institute	2 (2.67%)
Incidents of unnatural behaviours in livestock	Negative	Farm	Livestock	NGO, research institute	3 (4%)
Mortality rate in livestock	Negative	Farm	Livestock	research institute	1 (1.33%)
6.1.2 Efficiency of the SES					
Resource use efficiency	Positive	Farm,	Unassigned	academia, NGO, research institute, GO	8 (10.67%)
Carbon footprint	Negative	Farm	Unassigned	NGO	1 (1.33%)
Energy efficiency	Positive	Farm	Unassigned	academia, research institute	5 (6.67%)
Water use efficiency	Positive	Farm	Unassigned	NGO	1 (1.33%)
Water footprint (total water use/given area)	Negative	Farm	Arable, Livestock	GO, academia, NGO, research institute, UN	9 (12%)
Water exploitation index	Negative	Farm	Unassigned	NGO, research institute	2 (2.67%)
Eco-efficiency score	Positive	Farm	Unassigned	academia, research institute	2 (2.67%)
6.1.3 Intensity of SES					
Capital intensity	Positive	Field	Unassigned	academia, research institute	2 (2.67%)
Energy intensity	Positive	Field	Unassigned	research institute	1 (1.33%)
Input intensity	Positive	Field	Unassigned	research institute	2 (2.67%)
Labour intensity	Positive	Field	Unassigned	research institute	1 (1.33%)
Cropping intensity	Positive	Field	Arable	academia, research institute	6 (8%)
Livestock stocking density	Negative	Field, landscape, national	Livestock	academia, research institute	5 (6.67%)
Land use intensity	Positive	Field	Arable	academia, research institute, UN	6 (8%)
6.1.4 Yield outcomes					
Increase in yields	Positive	Field, farm, global	Unassigned	GO, NGO, academia, research institute	8 (10.67%)
Profit/unit area/unit of labour used	Positive	Field	Unassigned	academia	1 (1.33%)
kg of crop/person day of labour	Positive	Field	Arable	academia, research institute	1 (1.33%)
Profit/person day of labour	Positive	Not mentioned	Unassigned	academia	3 (4%)
Yield (kg)/input used	Positive	Field	Arable	academia, research institute, NGO, UN, industry	7 (9.33%)
Yield gap	Negative	Field, global	Arable	academia, research institute, UN	5 (6.67%)
Yield of each agricultural product	Positive	Field, farm, landscape, national, global	Arable, Livestock	academia, research institute, GO	13 (17.33%)
Average yield of agricultural product	Positive	Farm	Unassigned	academia	1 (1.33%)
Yield (tonnes per hectare)	Positive	Field	Arable	academia, NGO, research institute, GO, industry	13 (17.33%)
Value of the yield of agricultural product	Positive	Farm	Unassigned	academia, NGO, research institute, GO	7 (9.33%)
Gross domestic product in agriculture	Positive	Not mentioned	Unassigned	academia	1 (1.33%)
Variability in yield	Negative	Farm	Unassigned	academia, research institute, NGO, UN, industry	5 (6.67%)
6.1.5 Food Safety					
Farmer exposure to agro-chemicals	Negative	Farm, continental	Arable	academia, research institute, industry	4 (5.33%)
Food safety	Positive	Farm	Unassigned	academia, research institute	2 (2.67%)
Incidents of pesticides in food	Negative	Farm	Arable	research institute, industry	2 (2.67%)
Incidents of mycotoxins in food	Negative	National	Arable	research institute, industry	2 (2.67%)
Incidents of food-borne diseases	Negative	National	Livestock	research institute	1 (1.33%)
6.1.6 Cost of food					
Cost of production	Negative	Farm	Unassigned	NGO, research institute	2 (2.67%)
Cost of food to the consumer	Negative	National	Unassigned	GO, NGO, research institute	3 (4%)
6.2 Supporting outcomes					
6.2.1 Soil characteristics					
Soil erosion	Negative	Field	Unassigned	academia, NGO, research institute, UN	18 (24%)
Farmer's perceptions of on farm soil loss	unassigned	Farm	Unassigned	research institute	1 (1.33%)
Rate of soil loss/ha/year	Negative	Field	Unassigned	research institute	2 (2.67%)
Desertification	Negative	Landscape	Unassigned	research institute, NGO	2 (2.67%)
Salinization	Negative	Landscape	Arable	academia	5 (6.67%)
Soil compaction	Negative	Field	Arable	academia, research institute	4 (5.33%)
6.2.2 Nutrient recycling					
Nutrient balance	Negative	Farm	Arable, mixed	Academia, UN, industry, NGO	6 (8%)
6.3 Social Outcomes					
6.3.1 Recreational value of the SES					
Recreational value of the SES	Positive	Landscape	Unassigned	Research institute, academia	3 (4%)
Public perceptions	Positive	national	Unassigned	Research institute	1 (1.33%)
Value of tourism to the economy	Positive	National	Unassigned	GO	1 (1.33%)
Number of leisure/tourism opportunities	Positive	Landscape	Unassigned	academia	1 (1.33%)
6.3.2 User equity					
Community equity	Positive	Landscape	Unassigned	research institute	2 (2.67%)

Gender equity	Positive	Landscape	Unassigned	GO, academia, NGO, research institute	7 (9.33%)
Cultural autonomy	Positive	Landscape	Unassigned	NGO, research institute	3 (4%)
Conflict amongst users	Negative	Landscape	Unassigned	research institute	1 (1.33%)
6.3.3 Number of users					
Population density/ha	Positive	Field	Unassigned	academia, research institute	2 (2.67%)
6.4 Regulating outcomes					
6.4.1 Carbon sequestration					
Carbon sequestration	Positive	Farm, landscape, national	Unassigned	academia, research institute	4 (5.33%)
Above ground carbon (tree biomass)	Positive	National	Unassigned	academia, research institute	3 (4%)
Below ground carbon (mg of carbon/g of soil)	Positive	Field	Unassigned	academia, research institute	4 (5.33%)
Total carbon (above + below ground carbon)	Positive	Not mentioned	Unassigned	GO	1 (1.33%)
6.4.2 Water quality					
Diffuse pollution	Negative	Landscape	Unassigned	NGO	2 (2.67%)
Nitrate run-off	Negative	Landscape	Arable, Livestock	GO, NGO, academia, research institute, UN	10 (13.33%)
Phosphate run-off	Negative	Landscape	Arable	NGO, research institute	3 (4%)
Crop protection chemical run-off	Negative	Landscape	Arable	NGO, research institute	3 (4%)
Water quality	Positive	Landscape	Unassigned	GO, academia, NGO, research institute	8 (10.67%)
6.4.3 Pests and diseases					
Incidences of crop diseases	Negative	Farm, landscape	Arable	academia, research institute	2 (2.67%)
Incidences of livestock diseases	Negative	Farm, landscape	Livestock	academia	1 (1.33%)
Incidences of insect pests	Negative	Farm, landscape	Arable	academia, research institute	2 (2.67%)
Incidences of weed species	Negative	Farm, landscape	Arable	academia, research institute	3 (4%)
Incidence of invasive species	Negative	Farm, landscape	Arable	academia	1 (1.33%)
6.4.4 Greenhouse gas emissions					
GHG emissions	Negative	Farm, landscape, continental, global	Unassigned	GO, academia, NGO, research institute, UN	18 (24%)
Carbon dioxide emissions (CO2 t/ha)	Negative	Field	Unassigned	academia, NGO, research institute, UN	5 (6.67%)
GHG/crop grown	Negative	Farm	Arable	research institute	1 (1.33%)
GHG/farm	Negative	Farm	Arable, Livestock	academia	2 (2.67%)
GHG/unit area	Negative	Field	Arable	research institute	1 (1.33%)
GHG/unit of input	Negative	Farm	Unassigned	academia, research institute	2 (2.67%)
GHG/unit of product	Negative	Farm	Unassigned	academia, NGO, research institute	3 (4%)
6.5 Externalities to the system					
6.5.1 Waste					
Waste production	Negative	National	Unassigned	NGO, research institute	2 (2.67%)
Recycling of waste products	Positive	Farm, landscape, national, global	Unassigned	NGO	1 (1.33%)
7 Environment					
7.1 Social setting					
	N/A	N/A	N/A	N/A	0 (0%)
7.2 Economic setting					
Funding for agricultural research	Positive	National, global	Unassigned	academia, NGO, research institute	5 (6.67%)
Access to credit	Positive	Farm	Unassigned	academia, research institute	8 (10.67%)
Access to insurance	Positive	Farm	Unassigned	academia	1 (1.33%)
Investment in agriculture	unassigned	National	Unassigned	NGO	2 (2.67%)
Investment in market development	Positive	National	Unassigned	NGO, research institute	2 (2.67%)
Renewable energy focus	Positive	National	Unassigned	academia	1 (1.33%)
Price shocks	Negative	Global	Unassigned	academia	2 (2.67%)
7.3 Political setting					
Direction of government policy	unassigned	National, Continental	Unassigned	NGO, research institute	2 (2.67%)
7.4 Environmental setting					
Climate shocks and anomalies	Negative	Global	Unassigned	academia	2 (2.67%)
7.5 Interactions with other systems					
Imports of fodder	Negative	National	Livestock	NGO	2 (2.67%)
Limiting imports of agricultural products	Positive	National	Unassigned	NGO	1 (1.33%)
Liberalised trade	Positive	Global	Unassigned	NGO	1 (1.33%)

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