Sustainable intensification in agriculture

Navigating a course through competing food system priorities

A report on a workshop

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Foreword

This report is based on discussions held at a two day workshop held in January 2012, co-organised by the Food Climate Research Network and the Oxford Martin Programme on the Future of Food. The workshop was facilitated by Kath Dalmeny of Sustain and funded by the Foresight Programme and the Oxford Martin Programme on the Future of Food.

The purpose of the workshop was to bring together key thinkers from the academic and policy community, and from diverse disciplines, to consider the meanings, issues and challenges around sustainable intensification in general, and particularly in relation to three areas of concern: environmental sustainability; animal welfare and human wellbeing (specifically nutrition). A list of workshop participants is provided on the next page.

This report draws upon these discussions and upon further analysis and exploration subsequent to the workshop. It was written by Tara Garnett and Charles Godfray with valuable input from all the workshop participants, most of whom provided comments on a draft version. However, it is emphasised that this report is by no means a consensus document. It should not be seen as representing the unanimous views of everyone present or endorsed by the organisations to which they belong. The role of this document, rather, is to map out some of the conceptual territory that was explored, to stimulate discussion, and to identify areas where further work is needed.

The report is aimed at policy makers, both in the UK and elsewhere, working in areas relevant to food security. While clearly 'food security' is about far more than agricultural policy alone, our intention here is to take a small part of the food security puzzle – agricultural policy – and to consider how it intersects with environmental, animal welfare and health policies. Our argument is that agricultural policy, if it is to help rather than hinder the ultimate goal of food security, needs to operate in an integrated manner with these other policy areas.

Ultimately, this report argues the case for a more 'systems' oriented approach to decision making. While it does not go so far as to define a research agenda or make policy recommendations – this would require more work than has been possible in the time available – it urges the need for a substantial programme of future activity in order to:

(a) deepen and extend understanding of systems interactions;

(b) consider and define what specific goals societies wish agricultural production to achieve;

(c) develop metrics that will enable societies to measure progress in achieving them; and

(d) implement successful policies.

The workshop participants provided invaluable input to the report, both during the workshop and subsequently by commenting on a draft version. They are listed as follows:

Tara Garnett	Food Climate Research Network (organiser)
Charles Godfray	Oxford Martin Programme on the Future of Food (organiser)
Kath Dalmeny	Sustain (facilitator)
Hannah Rowlands	Oxford Martin Programme on the Future of Food (note taker)
Mike Appleby	World Society for the Protection of Animals
Andrew Balmford	University of Cambridge
John Barrett	Department for International Development
Ian Bateman	University of East Anglia
Tim Benton	University of Leeds
Phil Bloomer	Oxfam
Barbara Burlingame	Food and Agriculture Organisation
Denise Coitinho	World Health Organisation / Standing Committee on Nutrition
Marian Dawkins	University of Oxford
Liam Dolan	University of Oxford
David Fraser	University of British Columbia
Andy Haines	London School of Hygiene and Tropical Medicine
Brian Harris	Biotechnology and Biological Sciences Research Council
Mario Herrero	International Livestock Research Institute
Irene Hoffmann	Food and Agriculture Organisation
John Ingram	NERC and University of Oxford
Richard Perkins	WWF
Anna Saunders	Department for Environment, Food and Rural Affairs
Pete Smith	University of Aberdeen
Phil Thornton	International Livestock Research Institute / Climate Change Agriculture and Food Security Programme
Camilla Toulmin	International Institute for Environment and Development
Sonja Vermeulen	Climate Change, Agriculture and Food Security Programme
Jeff Waage	London International Development Centre
Andreas Wilkes	World Agroforestry Centre
Kathy Willis	University of Oxford

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1. The context for the discussion

Food production and consumption today take place in a world of abrupt contrasts and rapid change. The global population is growing, globalising and urbanising; people on average are becoming richer and their lifestyles and expectations are changing – and these changes all influence not just how much but what kind of food they will want and can afford to eat, as well as how this food is produced and distributed, and who benefits in the process.

At the same time, while the stability and security of the food system is underpinned by its environmental resource base, the evidence overwhelmingly suggests that these resources are being depleted and damaged in ways that threaten food production in the long term and also have broader implications for human wellbeing. Much of this damage is caused by the food system itself - food is both agent and victim of environmental harms.

There is therefore increasing concern about the prospects for food security over the next forty years. It is feared that as populations grow, recent progress to reduce hunger will not be sustained and more people will go hungry. Attempts to increase food production to meet demand will generate more environmental damage, and this in turn will undermine our future capacity to produce food.

Policy makers across the world now recognise that the way in which food is produced and distributed needs to change. The question is: what does it need to change into? What does a food system that feeds people adequately while minimising environmental harms (or even improving environmental outcomes) and adapting to those that have already been generated actually look like?

Different people have different answers. The differences are shaped by their views on a broad spectrum of issues: about the relationship between different types of economic development and human wellbeing, their relationship with the natural world and their beliefs about technology; on how far the future can be and should be ordered differently from how it is at present; about whether people can and should be persuaded to behave differently from how they do today; and ultimately by how they define 'a good life'.

These broad value-sets manifest themselves in more specific, concrete suggestions for the future of food in coming years. Some stakeholders suggest extensions and modifications of the status quo, others argue for more radical changes. Some focus specifically on food production while others address the food system as a whole.

This document looks at one particular suggested approach to food production: that we seek to 'sustainably intensify' production. The phrase has recently become controversial because both its critics and some of its advocates presuppose that it refers to particular systems of production. The purpose of this paper is to argue that it does not. On the contrary, since the goal of sustainable intensification is to achieve a union between sustainability on the one hand, and productivity on the other, it is unlikely to resemble anything we have today - although it will certainly adopt elements from the broad range of production systems that currently exist. Hence our purpose here is to explore what sustainable intensification might mean if both of the two words that make up the phrase - 'sustainable' and 'intensification' - are assigned equal weight.

This document begins by outlining the origin of, and controversy surrounding, sustainable intensification (2) before asking whether, in view of this controversy, it is worth retaining the idea as a useful guiding principle – and concluding that it is (3). It then (4) goes on to consider some of the main issues that need to be considered and addressed when thinking about sustainable intensification. It draws out a set of concepts (5) that emerge from a consideration of these issues and that require further exploration and clarification before offering a few conclusions (6).

2. Origin of, and controversy surrounding, sustainable intensification

Sustainable intensification is a term now much used in discussions around the future of agriculture and food security. It has only become common in the last few years, following the publication of the UK Royal Society's highly influential report, Reaping the Benefits, that explored the future of crop production, and a number of later major scientific and policy reports[1,2,3,4]. However the term actually dates back to the 1990s and was coined in the context of African agriculture, where yields are often very low, and environmental degradation a major concern[5,6,7]. This pro-poor, smallholder oriented origin of the phrase is worth noting in the context of the current controversy around sustainable intensification.

Sustainable intensification has been defined as a form of production wherein "yields are increased without adverse environmental impact and without the cultivation of more land"[8]. In this sense, the term denotes an aspiration of what needs to be achieved, rather than a description of existing production systems, whether this be conventional high-input farming, or smallholder agriculture, or approaches based on organic methods. While the intensification of agriculture has long been the subject of analysis[9], sustainable intensification is a more recent concern. It is still not clear what sustainable intensification might look like on the ground, how it might differ amongst production systems, in different places, and given different demand trajectories, and how the tradeoffs that inevitably arise, might be balanced. However it provides a framework for exploring what mix of approaches might work best based on the existing biophysical, social, cultural and economic context and a growing body of work is starting to emerge that explores what implementation might look like in practice[10].

It is important to emphasise this openness: as originally conceived, the definition does not articulate or privilege any particular vision of agricultural production. Unfortunately, this blank canvas approach, while in principle a strength, has recently proved to be a drawback:

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1 The Royal Society (2009). Reaping the benefits: science and the sustainable intensification of global agriculture, London.

2 Godfray H C J, Beddington J R, Crute I R, Haddad L, Lawrence L, Muir J F , Pretty J, Robinson S, Thomas S M and Toulmin C (2010). Food Security: The Challenge of Feeding 9 Billion People, *Science*, Vol 327.

3 Herrero M, Thornton P K, Notenbaert A M, Wood S, Msangi S, Freemand H A, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Parthasrathy Rao P, Macmillan S, Gerard B, McDermott J, Seré C, Rosegrant M. (2010). Smart Investments in Sustainable Food Production: Revisiting Mixed Crop-Livestock Systems, *Science* 327, 822

4 Foresight (2011). *The Future of Food and Farming. Final Project Report.* The Government Office for Science, London

5 Foresight (2011). *The Future of Food and Farming. Final Project Report.* The Government Office for Science, London

6 Reardon T, Crawford E, Kelly V and Diagana K (1996). Promoting Farm Investment for Sustainable Intensification of African Agriculture, Final Report, USAID.

7 Pretty J (1997). *The sustainable intensification of agriculture,* Natural Resources Forum, Blackwell Publishing Ltd.

8 The Royal Society (2009). Reaping the benefits: science and the sustainable intensification of global agriculture, London.

9 Boserup, E. 1965. The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. London: Allen & Unwin

10 McDermott JJ, Staal S J, Freeman HA, Herrero M and Van de Steeg J A (2010). Sustaining intensification of smallholder livestock systems in the tropics, *Livestock Science* 130 (2010) 95–109

the canvas has become covered with contradictory assumptions and counter-assumptions (see Box 1) about what sustainable intensification 'is' or 'should be'.

If sustainable intensification is to be a useful aid to thinking about how food production should develop in coming years, the assumptions that underpin these different interpretations of, and attitudes to, sustainable intensification need to be exposed and explored, so that analysis as to the way forward is founded on a shared understanding of what is actually being discussed. Put simply, differing interpretations of sustainable intensification hinge upon three linked assumptions. The first is that sustainable intensification denotes a particular type of agriculture; the second that it is inherently bound up with arguments about the 'need' to produce more food; and lastly, that the 'intensification' side of the term should be privileged over 'sustainable.' These three criticisms are addressed in turn.

2.1. Description or aspiration?

The first criticism is that sustainable intensification represents a particular type or system of agriculture. In particular, it has been interpreted by some as coterminous with current high-input, high-output Western modes of production. As such, the concept has been endorsed by some interest groups, particularly the farming industry, and criticised by others, particularly those from within the environmental community[11,12]. Under this interpretation, sustainable intensification is not, as was originally intended, an *aspiration* (how food production should change), but a *description* of agricultural practices already in place that can be adapted to meet future challenges. Agroecology, often interpreted as a competing paradigm, has by contrast become aligned with smallholder systems of production, even though, ironically, sustainable intensification itself was originally coined in the context of smallholder African agriculture[13,14,15]. Agroecology is, like sustainable intensification, not a clearly defined concept but it tends to connote a preference for organic practices (although chemical inputs are not excluded), for multiple, rather than single food and non food outputs from the farm system, and for smallholder as opposed to large scale commercial production[16].

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11 ADAS et al (2011) Meeting the Challenge: Agriculture Industry GHG Action Plan Delivery of Phase I: 2010 - 2012 04 April 2011, ADAS, AEA (Agricultural Engineering Association), AHDB (Agriculture and Horticulture Development Board), AIC (Agriculture Industries Confederation), CLA (Country Land and Business Association), Farming Futures, FWAG (Farm Wildlife Advisory Group), LEAF (Linking Environment And Farming), NFU (National Farmers Union), NIAB/TAG (National Institute of Agricultural Botany/The Arable Group), ORC (Elm Farm Organic Research Centre), RASE (Royal Agricultural Society of England)

12 Tudge C (2011). What does sustainability mean? And what on earth is sustainable intensification? The Campaign for Real Farming, http://www.campaignforrealfarming.org/2011/07/what-does-sustainability-mean-and-what-on-earth-is-sustainable-intensification/ accessed 10 December 2011

13 Reardon T, Crawford E, Kelly V and Diagana B (1995). Promoting farm investment for sustainable intensification of African agriculture. MSU International Development Paper No 18, Michigan State University, Michigan, United States

14 Reardon T, Crawford E, Kelly V and Diagana K (1996). Promoting Farm Investment for Sustainable Intensification of African Agriculture, Final Report, USAID.

15 Pretty J (1997). The sustainable intensification of agriculture, Natural Resources Forum, Blackwell Publishing Ltd.

16 UN (2010). Report submitted by the Special Rapporteur on the right to food, Olivier de Schutter 17 December 2010, United Nations Human Rights Council Sixteenth session, United Nations General Assembly

Box 1: Sustainable intensification: description, aspiration, or oxymoron? A selection of views

Trojan horse? "Sustainable intensification to me sounds weird ...is there not a danger that it will be used as a Trojan horse for those who want us to have lots more biotech and GM and so forth? ... is there a potential conflict between how this idea might be used and the future of small-scale farming?"

Caroline Lucas, MEP, HoC, Oral Evidence, Sustainable Food, 7 December 2011

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/c879-vii/c87901.htm

Production within an ecosystem services framework? "For us ...it means basically increasing production in a given area while reducing key environmental consequences and increasing what we call the flow to key environmental services. We are talking about key ecosystems and the services they provide."

Mark Driscoll, WWF, HoC, Oral Evidence, Sustainable Food, 7 December 2011

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/c879-vii/c87901.htm

Hi tech? "...sustainable intensification ...will take many forms. Biotechnology ....will undoubtedly be part of the picture ... housed livestock will also be part of the picture".

Peter Kendall, NFU, Letter to the Sunday Times, 9 January 2012

Or all about smallholders? Sustainable intensification of agriculture is the only way to avoid localized chronic food and nutrition insecurity ....Unleashing the full potential of smallholders, including that of women farmers, is ..key"

United Nations General Assembly. Agricultural Technology for Development Report of the Secretary General: A/66/100, August 2011

Science *as distinct from* politics? On sustainable intensification..."Why is it necessary to rule out any technology if there is a prospect that it can deliver higher levels of productivity with improved resource use efficiency ...? There are of course people that want the world to be organised differently to the way it is at present - but that's politics and has little to do with science."

Ian Crute, AHDB, Farmers Guardian Debate, 7 October 2011

http://www.farmersguardian.com/home/latest-news/watch-again-food-security-debate/42133.article

What's the intended output? "for me sustainable intensification means that we have to produce more from the land, but more of what? More food, yes, but also the other things that land produces."

Philip Lowe HoC, Oral Evidence, Sustainable Food, 7 December 2011

http://www.publications.parliament.uk/pa/cm201012/cmselect/cmenvaud/c879-vii/c87901.htm

Sustainable intensification *versus* agroecology? "The ..Foresight study … underlined the imperative of …'sustainable intensification' through industrial agriculture (see note)[17]. *In contrast*, this UN report on agro-ecology states that it is often labour demanding practices such as agro-forestry, leguminous cover crops and mixed cropping that have proven potential to reduce the use of inorganic fertilizers whilst substantially improving yields. "

Institute for European Environmental Policy

http://cap2020.ieep.eu/2011/3/23/un-report-on-agro-ecology

Sustainable intensification *and* agroecology? "Food outputs by sustainable intensification have been multiplicative – by which yields per hectare have increased by combining the use of new and improved varieties and new agronomic–agroecological management …and additive – by which diversification has resulted in the emergence of a range of new crops, livestock or fish

Pretty J, Toulmin C & Williams S (2011) Sustainable intensification in African agriculture, International Journal of Agricultural Sustainability, 9, 1, 5-24

Cruel gobbledegook? "[the] British Government …is currently using tax-payers money to fund research in 'sustainable intensification' of the livestock industry… Compassion is calling this a policy of gobbledygook…. The real truth is that "sustainable intensification" [is] a contradiction in terms."

Philip Lymbery, Compassion in World Farming

http://www.acompassionateworld.org/2011/10/gobbledygook/

Finally: sustainable intensification is "virtually meaningless"

Colin Tudge, author, Farmers Guardian Debate, 7 October 2011 http://www.farmersguardian.com/home/latest-news/watch-again-food-security-debate/42133.article

17 The authors of the Foresight Report would object to this characterisation.

2.2. Production or productivity?

The second assumption about sustainable intensification is that it is inherently bound up with arguments about the 'need' to produce a fixed amount of additional food over the next forty years to feed an additional two billion people. Different analyses come up with varying estimates of the increase in food required but typically a 60-120% increase on today's output is described[18] based on assumptions about future income growth and its relationship with increased consumption and changing dietary preferences. The academic and policy studies underlying these estimates typically look only at the production side and do not factor in what might be done to influence the demand side of the equation, in particular the demand for resource intensive foods such as animal products.

Broadly speaking, views on the mainstream 'more food' estimate fall into several camps. First, are those who endorse these figures; advocates are generally drawn from the farming, agribusiness or production research communities. They tend to be technological optimists and often believe demand side approaches to the problem are unlikely to be successful or desirable.

A second group question the assumptions underlying the growth estimates, emphasising the point that increases in food supply do not guarantee reductions in hunger; hunger is most often a consequence of a lack of economic access to food rather than a lack of supply (See Box 2 for a definition of food security)[19,20]. While some but not all agree that food production will need to increase, they are more cautious about giving estimates, and argue that the non supply-based determinants of food security require greater attention and may be sufficient in achieving sufficient food for all. They highlight a growing body of academic work that explores different dietary approaches to achieving food security, often assessing these in relation to their impacts on land use and greenhouse gas emissions[21,22,23].

In addition to shifting diets away from resource intensive foods such as meat and dairy products, they argue that action is needed to improve governance (influencing the affordability of and access to food), and reduce food losses and waste throughout the supply chain (representing unconsumed production). More broadly critics of the 'more food' arguments tend to challenge the current economic growth paradigm: sophisticated technologies are unlikely to reconcile economic development and environmental goals, and

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18 Conforti, P. (ed.). (2011). Looking Ahead in World Food and Agriculture: Perspectives to 2050, Rome: Food and Agriculture Organization; Foley J A, Rarmankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnstone M, Mueller N D, O'Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Seibert S, Tilman D and Zaks D P M (2011). Solutions for a cultivated planet, Nature. doi:10.1038/nature10452; Tilman, D., Balzer, C., Hill, J. & Befort, B.L. (2011) Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the United States of America, 108, 20260-20264.

19 Fischer J, Batáry P, Bawa K S, Burssaard L, Chappell M J, Clough Y, Daily G C, Dorrough J, Hartel T, Jackson L E, Klein A M, Kremen C, Kuemmerle T, Lindenmayer D B, Mooney H A, Perfecto I, Philpott S M, Tscharntke T, Vandermeer J, Wanger T C and Von Wehrden H V (2011). Conservation: Limits of Land Sparing, Science, 334, 594

20 A. Sen, Poverty and Famines (Oxford Univ. Press, Oxford,1981

21 Stehfest E, Bouwman L, van Vuuren D P, den Elzen MGJ, Eickhout B, Kabat P. (2009). Climate benefits of changing diet, Climatic Change, Volume 95, Numbers 1-2

22 Popp A, Lotze-Campen H and Bodirsky B (2010). Food consumption, diet shifts and associated non-CO_2 greenhouse gases from agricultural production, Global Environmental Change 20 451–462.

23 Pelletier N, Pirog R, Rasmussen R (2010). Comparative life cycle environmental impacts of three beef production strategies in the Upper Midwestern United States, Agricultural Systems 103 (2010) 380–389.

Box 2. Definition of Food Security

Food Security obtains when people have physical, economic and social access to sufficient and varied food for a healthy diet. This definition encompasses four key dimensions: food availability, access, utilization and stability:

Physical availability: addresses the supply side of food security and is determined by food production, stock levels, trade and other factors.

Economic and physical access to food: determining factors include household incomes and expenditure, markets and food prices.

Food utilization: this relates to the body's ability to make use of food nutrients and includes the need for sufficient energy and nutrients as well as good care and feeding practices, safe food preparation, dietary diversity, food distribution within households and individual health status.

Stability: The concept of stability reflects the presence of the other three elements over time. Sudden economic, climatic or other shocks, or cyclical events such as seasonal food insecurity affect the stability of supply.

Source: FAO (2008). An introduction to the basic concepts of food security, FAO, 2008 EC – FAO Food Security Programme

The **Food System** as used here describes the web of social and economic processes determining the production, distribution and consumption of food. It includes agriculture, food processing and distribution, as well as the factors affecting demand for and use (including waste) of different food types.

Source: Foresight (2011). The Future of Food and Farming. Final Project Report. The Government Office for Science, London.

hence economic growth is ultimately incompatible with sustainability. Moreover, the use of GDP to measure development and progress is seen as of limited value. In short, the notion that more (or much more) food production is actually needed is characterised as part of a problematic mindset that privileges 'more' over 'fairer,' or 'wants' over 'needs.' The concern here is with the perceived insatiability of human demand, that there are no limits to what people consider to be 'enough.'

A third intermediate camp argues that the challenges are so great that action must be taken today on all fronts, on supply, demand, waste, efficiency - and population[24,25]. Given the uncertainties ahead, it makes little sense to plan for any particular stipulated level of production. It argues for a policy framework wherein the natural economic

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24 Beddington J (2009). Food, energy, water and the climate: a perfect storm of global events? http://www.bis.gov.uk/assets/goscience/docs/p/perfect-storm-paper.pdf

25 IAP (2012). IAP Statement on Population and Consumption, IAP: The Global Network of Science Academies, 14 June 2012

response of actors to price signals along the whole food supply chain - including farmers, manufacturers, retailers and consumers - gives rise to production and consumption that is both economically efficient and environmentally sustainable.

How does this relate to the debate on sustainable intensification? Evidently, what we do to address issues of distribution, demand and waste as well as population growth will influence how much of an increase in food production is needed, with the appropriate balance of these actions varying by region and by socio-economic context. This in turn will affect the extent to which the food system potentially impacts upon the environment and upon other aspects of society. The greater the success in these other areas, the less requirement there will be to raise yields in order to increase food supplies. Indeed many, especially in the third camp described above, would argue that the goal of sustainable food security for all is not possible without action on these fronts[26,27].

Thus, it does not follow that sustainable intensification as a concept should be predicated on particular assumptions about how much more food is needed. Our argument here is that the 'need' for sustainable intensification is independent of the 'need' to produce more food. The prime goal of sustainable intensification is to raise *productivity* (as distinct from increasing *volume of production*) while reducing environmental impacts. This means increasing yields per unit of inputs (including nutrients, water, energy, capital and land) as well as per unit of 'undesirable' outputs (such as greenhouse gas emissions or water pollution).

The required 'intensity' of productivity to meet an increase in overall demand for food will depend upon progress on improving governance, reducing waste, altering dietary patterns and addressing population growth. Sustainable intensification should thus be seen as a complement to, not a substitute for actions on these fronts (Figure 1).

In principle, in a world that was highly successful in all these other areas, no increase in food production might be required. In this case sustainable intensification could enable current levels of food to be produced on a smaller area of land, enabling land to be released and allocated to other purposes, including rewilding or afforestation or the provision of other ecosystem services.

In practice, however, some increases in production to meet demand will almost certainly be required, particularly in certain regions such as sub-Saharan Africa where agriculture is a critical and underperforming driver of rural economies. Rather than setting an arbitrary global goal for the level of intensification required (which itself presupposes certain production targets) the task at the local level is to consider how yields can be increased in ways that enhance sustainability. In other words, the 'optimum' level of productivity increase is likely to be highly context specific.

Inevitably, situations will arise where there are tradeoffs between increasing yields and impact on the environment, or with the social and ethical consequences of food production. In some casesthese tradeoffs may be avoidable through changes to governance systems but in many cases they will not be, and society will need to make difficult decisions, ideally

26 Foley J A, Rarmankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnstone M, Mueller N D, O'Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Seibert S, Tilman D and Zaks D P M (2011). Solutions for a cultivated planet, Nature. doi:10.1038/nature10452

27 Foresight (2011). The Future of Food and Farming. Final Project Report. The Government Office for Science, London

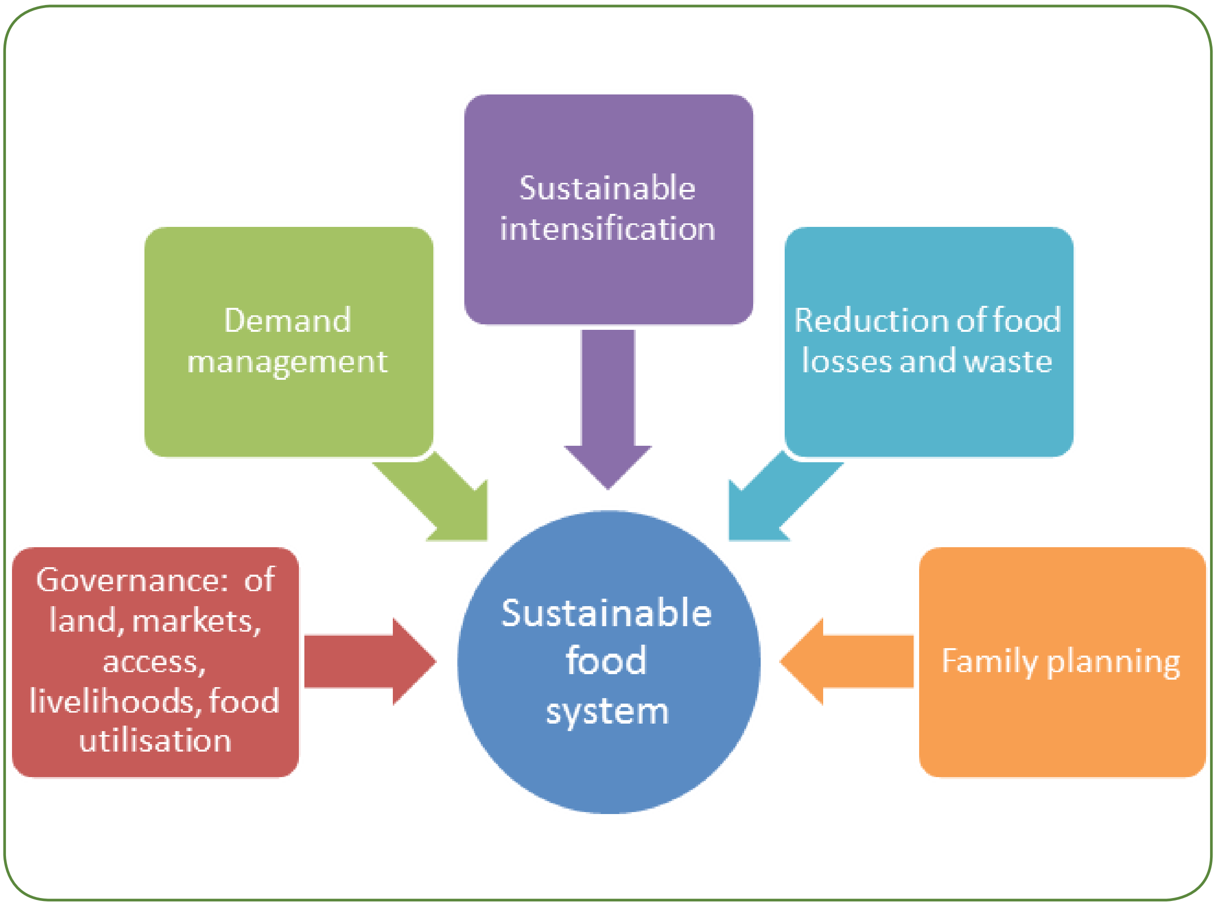

Figure 1: Sustainable intensification in relation to food demand, waste, governance and population

based on an informed scientific and socio-economic evidence base, and taking into account long-term resilience as well as short-term costs and benefits. However society resolves the tradeoffs, the challenges of combining sustainability with intensification arise. It is therefore inaccurate to link sustainable intensification with a defined requirement for a specific increase in food production. The link between the two must be broken.

2.3. The meanings of 'sustainable' and 'intensification' and their relative importance

A third set of disagreements revolves around the relationship between the 'sustainable' and the 'intensification' side of the phrase, as well as a lack of clarity on what each of these words actually means. Where major increases of yields have occurred in the past through intensification, for example after the Industrial Revolution or during the Green Revolution, they have been accompanied by environmental harm and reductions in sustainability. Critics understandably fear that the drive to increase yields will take precedence over ensuring sustainability. 'Intensification' is often associated in people's minds with systems that rely heavily on high levels of inputs such as fertilisers, water and pesticides many of which come from, or are produced using, non-renewable resources. This is in stark contrast to the Royal Society's definition of 'intensive' in the context of sustainable intensification, as a system of production which is "knowledge-, technology-, natural capital- and land-intensive"[28] and its emphasis that the "intensity of use of non-renewable inputs must in the long term decrease." It is perhaps more helpful to understand 'intensification' as referring to 'environmental factor productivity' or 'eco-efficiency' – that is the efficiency with which inputs are used relative to desired outputs; and the desired outputs achieved from the system in relation to the undesirable outputs (such as water pollution or greenhouse gases). However even with this clarification, there is an additional question that needs to be considered: what do we want to increase productivity of? For example, the agroecology movement places emphasis on the importance of local, indigenous foods; discussion of sustainable intensification has as yet failed to engage with this issue – a failing that this paper identifies, arguing that there is need for more focus in this area.

The word 'sustainable' is, if possible, even more contentious. For some it denotes purely environmental goals (themselves multiple) whereas for others it additionally encompasses – as in the original Brundtland report definition[29] – social, economic and ethical dimensions. The original definition of sustainable intensification referred only to high-level environmental objectives. It was silent on many of the things that a large number of constituencies feel are essential to discussions on sustainability, such as the nutritional quality of what is being produced and the wellbeing of both the people who farm and the animals who are farmed. This is another gap that this paper seeks to assist in filling, mindful of the often complex interactions among environmental, social, ethical and economic goals.

Whereas most discussions of sustainable intensification have concentrated on agronomy and the environment, the discourse on agroecology normally explicitly includes social and ethical objectives within its definitional compass; it includes goals such as changes in diet, fairness and redistributive justice and a smallholder agrarian vision of agriculture. Agroecology, in short, is often held to be a movement rather than a set of farming techniques, even though not all its advocates are happy with this. While this bundling of multiple issues into the phrase gives it emotional and possibly organisational strength, it complicates assessments of the value of individual agroecological practices. Moreover, movements tend to define themselves against an "other", a negative counter-vision against which their strengths can be compared. Sustainable intensification appears, unfortunately, to be serving this purpose for many proponents of agroecology.

Interestingly, while sustainable intensification's critics may view the goals of intensity and sustainability as being incompatible, many nevertheless argue that agroecological methods can indeed achieve this union – the implication of course being that higher yields are indeed desirable, at least in certain contexts[30]. Once again this suggests that the problem with sustainable intensification in people's minds may be less with the goal of more food, with less negative impact, but rather with assumptions about the agricultural model it is assumed to be advocating.

28 that is, it makes intensive use of land, rather than using a lot of land

29 Our Common Future, Report of the World Commission on Environment and Development, World Commission on Environment and Development, 1987

30 UN (2010). Report submitted by the Special Rapporteur on the right to food, Olivier de Schutter 17 December 2010, United Nations Human Rights Council Sixteenth session, United Nations General Assembly

It is argued in the paragraphs that follow that sustainable intensification is not wedded to any one agricultural approach. It is based upon the principle that in a complex world with a growing population, the more effective use of inputs and the reduction of undesirable outputs in order to achieve greater yields – intensification – is fundamentally required in order to achieve sustainability.

3. Is sustainable intensification a useful concept?

There are many other terms currently in use to capture the goal that sits at the heart of sustainable intensification – of using land, water and other inputs in better ways to provide the food we need as well as to achieve other goals – including agro-ecology and climate smart agriculture, to name but a few (see Box 2). These phrases often tend to carry more favourable associations in people's minds than those attributed to sustainable intensification. This point cannot be ignored. Whatever the 'true' semantic origin of sustainable intensification, the reality is that what any given word or phrase stands for depends upon the meanings which have accrued over time and, consequently, how these meanings resonate with decision makers and the public. The question then arises – if the phrase is so contentious, why not abandon it and use one of the others – or coin an entirely new one instead?

That is certainly an option for policy makers and merits careful consideration. However, our view is that new phrases do not magically deliver easy solutions. With all its imperfections the phrase sustainable intensification is already becoming embedded in policy and contributing to new thinking about ways of producing food[31]. It is also the case that the other concepts currently in use, such as agro-ecology an climate-smart agriculture, are themselves the focus of considerable debate and uncertainty and both their proponents and their critics have differing views on what they actually 'mean.' Also there is inevitably a risk that any new phrase will similarly be co-opted by interest groups who use it in ways that were not originally intended.

Moreover, when specific interventions are examined, removed from their rhetorical context within particular food production philosophies, there is very substantial overlap between sustainable intensification and the terms and concepts described in Box 3. Somehow, as a global society we will need to work out how to put in place a different type of agriculture – one that is capable of feeding humans but which does not damage the biodiversity and ecosystem services upon which it ultimately depends, nor the fabric of what we consider to be ethically and socially acceptable. While the different terms that have been coined may differ in what they believe may or may not be inputted to the system, and in what they feel the outputs should be, all will have to engage with the reality that there are hard tradeoffs between different desirable outcomes and uncomfortable choices for all stakeholders whatever their prior beliefs. Changing any one phrase will not alter the nature or the difficulty of the challenge. There is a need for stakeholders to come together, focus on the 'knotty' issues and identify points of commonality, instead of focusing excessively on terminological differences.

31 FAO (2011). Save and grow: A policymaker's guide to the sustainable intensification of smallholder crop production, Food and Agriculture Organisation, Rome

Box 3: Concepts related to sustainable intensification

Ecological intensification: This phrase was coined by Cassman[32] in a 1999 paper on cereal production that anticipates many of the analyses of the last few years: "At issue, then, is whether further intensification of cereal production systems can be achieved that satisfy the anticipated increase in food demand while meeting acceptable standards of environmental quality. This goal can be described as an ecological intensification of agriculture." This concept is essentially synonymous with an environmentally oriented interpretation of sustainable intensification.

Agroecology: This has been defined as "the application of ecological concepts and principles to the design and management of sustainable agricultural ecosystems... This approach is based on enhancing the habitat both above ground and in the soil to produce strong and healthy plants by promoting beneficial organisms while adversely affecting crop pests (weeds, insects, diseases, and nematodes)[33]. However it can also been seen as a "scientific discipline, as a movement, and as a practice" – sometimes all three – and the way it is used varies by context[34].

Permaculture: A movement that incorporates many ideas from agroecology but very specifically advocates certain design principles derived from observations of natural ecosystems in order to create sustainable settlements and agriculture. The concept has been much influenced by the writings of Bill Mollison[35] who at one time claimed proprietary rights on the concept.

Organic agriculture: This has been defined as "a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved"[36]. Organic agriculture is regulated by bodies such as the Soil Association in the United Kingdom; these specify which practices, methods of pest control, soil amendments and so forth are permissible if products are to achieve organic certification. It is a specific type of food production, defined by process rather than product, that emphasises the sustainability of the local agro-environment and reductions in the use of synthetic inputs.

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32 Cassman, K.G. (1999). Ecological intensification of cereal production systems: Yield potential, soil quality, and precision agriculture PNAS, 96, 5952-5959

33 S. R. Gliessman, Agroecology (Ann Arbor: Ann Arbor Press, 1998); M. A. Altieri,Agroecology: The Science of Sustainable Agriculture (Boulder: Westview Press, 1995); M. A. Altieri and C. I. Nicholls, Biodiversity and Pest Management in Agroecosystems (New York: Haworth Press, 2005

34 Wezel, A., Bellon, S., Doré, T., Francis, C., Vallod, D., David, C. (2009). Agroecology as a science, a movement or a practice. A review. Agronomy for Sustainable Development

35 Mollison, Bill (1988). Permaculture: A Designers' Manual. Tagari Publications.

36 International Federation of Organic Agricultural Movements (http://www.ifoam.org/growing_organic/definitions/doa/index.html)

Ecofunctional intensification: A term promoted by the organic movement, its goal is a more efficient use of natural resources and processes, improved nutrient recycling, and innovative agro-ecological (q.v.) methods for enhancing the diversity and the health of soils, crops and livestock. Eco-functional intensification is seen as characterized by cooperation and synergy between different components of agro-ecosystems and food systems, with the aim of enhancing the productivity and stability of the agro-ecosystems, and the health of all components.

Climate smart agriculture: This term was coined by the FAO who define it as "agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation), and enhances achievement of national food security and development goals"[37].

Eco-efficiency: A term that first appeared as a proposal from the World Business Council for Sustainable Development (WBCSD) that was endorsed by the 1992 Earth Summit in Rio de Janeiro as an approach by which the private sector could achieve sustainability. Eco-efficiency, as defined by WBSCD, means producing "competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing environmental impacts of goods and resource intensity throughout the entire life-cycle to a level at least in line with the Earth's estimated carrying capacity."[38] More recently, the International Centre for Tropical Agriculture has adopted eco-efficiency as its mission statement and is working with partners to identify more precisely what eco-efficiency in agriculture means for policy and practice[39].

Technological optimism: Though we have not found a single phrase that encapsulates it, there is a strong strand in contemporary agricultural thinking that sees technological innovation as making a major, even the majority, contribution to producing more food with less environmental impact. Proponents point to the potential and promise of precision agriculture, hydroponics, desalination, high-tech urban agriculture, artificial meat and many other technologies. The Keystone Center[40] in the United States, for example, seeks to incorporate existing innovations within a largely conventional agriculture setting but other commentators are far more ambitious. Within this broad school people differ in the importance of the role accorded to the private sector in delivering these goals, and in whether they see genetic manipulation as part of the solution or rendered unnecessary by other technological advances. and where decision makers have to act now and make hard decisions in the face of trade offs and conflicting stakeholder interests.

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37 FAO (2010). "Climate-Smart" Agriculture: Policies, Practices and Financing for Food Security, Adaptation and Mitigation, Food and Agriculture Organisation, Rome.

38 Schmidheiny, S. 1992. Changing Course: A Global Business Perspective on Development and the Environment MIT Press, Massachusetts Institute of Technology ISBN 0-262-69153-1

39 International Centre for Tropical Agriculture 2012. Eco-efficiency: from vision to reality. http://www.ciat.cgiar.org/publications/Pages/eco_efficiency_from_vision_to_reality.aspx

40 Field to Market: The Keystone Alliance for Sustainable Agriculture http://www.fieldtomarket.org/

Policy decisions made about food production should be based on evidence from both the natural and social sciences but also on political, ethical and value judgments. It would be naïve to suggest that the two can always be kept separate, yet greater clarity in distinguishing the grounds upon which decisions are made may help resolve some of the misunderstandings among groups who may be arguing for similar things. In the sections that follow we explore some of values underpinning stakeholders' approaches to agricultural production so that ongoing discussions can be based upon a shared grammar and vocabulary. Greater clarity will also help identify where strengthening the evidence base is important and where decision makers have to act now and make hard decisions in the face of trade offs and conflicting stakeholder interests.

Our purpose here is twofold: to recapture sustainable intensification from those who have sought to redefine it; and to contribute to making it an operational tool of value to practitioners and policy makers. We believe that as a conceptual framework, it provides a valuable approach to negotiating the food-environment challenges we face. Like the other concepts in Box 3 it has a vision of what needs to be achieved, but unlike many of them it does not prescribe in advance the particular route to achieving it. It is likely to draw upon principles set out in Box 3 above, but it does not inherently proscribe or advocate the use of particular inputs or techniques. As with agroecology, sustainable intensification emphasizes the importance of understanding natural processes in agro-ecosystems but it nevertheless holds that the application of any particular intervention based on ecological observation or insight requires evaluation and testing on an equal footing with any other type of intervention. An agricultural practice that emulates natural ecological processes may or may not be desirable: the point is that judgements as to its merits need to be tested empirically and supported by evidence. The same principles apply to consideration of technologies such as genetic modification. Sustainable intensification is not designed to garner support for one particular set of possible social and economic outcomes. Instead, it is best envisaged as a pragmatic process of enquiry and analysis for navigating the issues and concerns.

4. Debating sustainable intensification

What are the key issues of concern as regards food production and consumption today? Clearly there are many, but three of those that appear to be particularly contentious and come up repeatedly in discussions about sustainable intensification are issues relating to

1. environmental objectives
2. animal welfare
3. nutritional quality and what the desired outputs are from agriculture.

The first centres around defining the environmental objectives of sustainable agriculture. Do we sufficiently understand environmental impacts and interactions? What metrics are we using and what more do we need? How do we assess sustainability over space and time, taking into account human behaviour and governance issues? What is the knowledge and what are the values that we bring to the discussion?

Sustainable intensification raises many ethical issues and the focus of the second topic is on animal welfare. The consequences for the wellbeing of livestock are frequently cited as a major concern about sustainable intensification. How do people define animal welfare, what is its relationship both with environmental sustainability and with productivity, and what do we do with this knowledge?

The third focus is on the 'outputs' of sustainable intensification that are of immediate value to humans. What is it that we wish to 'intensify' productivity of? Food is the most obvious output but what foods in particular do we want or need? What about non-food outputs and outcomes?

All these issues interact with one another and certain themes or questions come up again and again. These are drawn out and discussed further in section 5. For now, two linked premises are taken as a starting point. The first is that there is still much that we do not understand. The second is that even where we have 'facts,' people assign different values and meanings to them. The task is therefore not only to work out what we know and what more we need to know, but also to understand how different stakeholders interpret and assign value to this knowledge.

We stress that the aim here is not to provide answers to all the questions about what sustainable intensification should or should not be, but rather to define the issues that need to be considered when making decisions, or when investing in research to strengthen the evidence base.

4.1. Environmental concerns: land use, biodiversity and ecosystem services

This section on environmental considerations is divided into three subsections: it begins by outlining a few general issues (4.1.1.) before looking at how definitions of environmental sustainability shift when considered over different temporal and spatial frameworks

(4.1.2). Third, (4.1.3) it considers the arguments in a debate that is core to discussions around agricultural sustainability: the land sparing versus land sharing issue.

4.1.1. General environmental issues

Food can be viewed as a type of "good" whose production relies on natural and socio-economic capital. Natural capital constitutes the components of the environment that provide ecosystem services upon which agriculture and other forms of food production rely[41]: for example soil fertility, regulation of water supply for crop and pasture growth, pollination, as well as direct provisioning services such as the supply of fish for capture fisheries. Socioeconomic capital provides the human, social and economic resources required to produce food, including inputs such as labour and fertilisers. Natural and socio-economic capital are to some extent substitutable: poor soil quality can be improved by artificial fertilisers, or natural pollinators augmented by apiculture. They also overlap – for example, artificial fertilisers are manufactured from natural capital, and natural capital only becomes a human good through application of socioeconomic or human capital. How the natural capital is managed, and the nature of the way the socioeconomic capital is deployed, can affect natural capital stocks and the flow of future ecosystem services of value to food production.

In addition to food, agroecosystems also produce other outputs of importance to humans. These may be straightforward economic goods such as fibre, wood or energy, whose value is captured directly by the farmer or landowner. Other positive but less direct outputs include supporting and regulating services such as water purification, flood control and carbon sequestration that are also of monetary value to society; these affect the wellbeing of society but do not necessarily impact upon the farmer or landowner in direct economic terms. There can also be other positive impacts whose economic value is far harder or even impossible to quantify – for example the provision of habitats for wild animals and plants (over and above those that do not directly benefit the landowner, such as pollinators and the natural enemies of pests and weeds) and the agricultural landscape itself, which is often cherished by society.

Similarly, agroecosystems can produce negative outputs that may directly impact the landowner, such as poor soil management leading to reduced fertility; or that affect other stakeholders in damaging ways. Some may be straightforward, at least conceptually, to value economically - for example greenhouse gas emissions through carbon accounting - but assigning a value to others, such as the loss of biodiversity, may be much harder to quantify and the values assigned may be highly contested.

Nitrogen run-off from agricultural land that pollutes water bodies, carbon sequestered in soils, and the wild animals that find a home on farmland, are all examples of the direct impacts of the way farming is practised. Thus the decisions made by farmers not only affect their own livelihoods but also, indirectly, the wealth, livelihoods and general well-being of a much broader set of people - from those living locally to (in the case of greenhouse gas emissions) everyone on earth.

In addition there are perhaps even more indirect impacts that operate through the

41 Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC.

workings of the global food system, leading to often unpredictable consequences. For example, the production of more food will tend to reduce its price; in some cases this will benefit poor people and reduce smallholder pressures on land use while in others it may stimulate further agricultural land use change by agricultural producers (large and small) in an effort to compensate for falling farm-gate prices.

All serious discussions of the future of agricultural production today consider the importance of reducing the direct (i.e. on farm) negative environmental impacts of food production and most also are concerned with increasing the direct positive environmental impacts. Their current prominence in policy debates is at least partly due to the tireless work of the organic, agroecological and other environmental movements. The effect of production and productivity on global food prices has always been a core area of concern for food and commodity economists, and one that has dramatically risen up the political agenda in the last five years since the first food price spike of 2007/8. However, the indirect negative environmental consequences of decisions made about the way we produce food (particularly in relation to land use change) have received far less attention, although recently the debates about biofuels have highlighted their importance. The much greater emphasis placed on these indirect effects by those arguing for sustainable intensification explains some of the disagreements and frictions that arise when in discussion with proponents of other approaches to sustainable agriculture.

One harmful indirect consequence of failing to increase production on *existing* agricultural land is the resulting economic pressure to convert more land to agriculture. Most of the land potentially available for conversion to agriculture is currently forest (both in tropical and temperate regions), wetland or pasture. Conversion nearly always results in the substantial release of greenhouse gases – today, approximately half the greenhouse gas emissions attributable to food production are incurred indirectly through land conversion[42]. The negative climate changing consequences of land conversion are so great that a number of groups have argued that it should stop – that policy should be made on the assumption of no new land for agriculture[43]. Arguments to halt land conversion centre not only on the need to reduce greenhouse gas emissions. Existing non-agricultural land harbours a considerable portion of global biodiversity, the majority of which would be lost if conversion occurred. This land also provides other ecosystem services that would be very hard for humanity to replace. For example, the existence of large blocks of forest in the Amazon and central Africa seems likely to regulate the patterns of rainfall over much of their respective continents in ways whose disruption would be very harmful.

The imperatives of reducing hunger and achieving food security are often invoked to justify treating food production in a special way - what critics refer to as "agricultural exceptionalism"[44]. In its most naive form, arguments run along the lines that, with nearly a billion people on earth suffering from hunger, there is a "moral duty" to produce more food. This of course ignores the fact that sufficient food is available – the problem for most hungry people is that they are simply too poor to buy it or the necessary market and other distribution mechanisms are not in place – or both. The "duty" to produce food has been

42 Bellarby, J., Foereid, B, Hastings, A. and Smith, P. (2008). Cool Farming: Climate impacts of agriculture and mitigation potential. Greenpeace, Amsterdam

43 Foresight (2011). The Future of Food and Farming. Final Project Report. The Government Office for Science, London

44 Daugbjerg, K & Swinbank, A. (2009). Ideas, Institutions, and Trade; The WTO and the Curious Role of EU Farm Policy in Trade Liberalization. Oxford University Press, Oxford

used to justify many interventions in the market that bolster local agricultural industries or that support farming and rural communities. This can be thought of as social sustainability and we discuss briefly below whether these broader social goals should be included within the concept of sustainable intensification.

If demand for food does increase then this will be reflected in higher food prices. The question then arises as to the role that sustainable intensification might play in meeting demand for food in ways that are affordable for poor people. Sustainable intensification can be thought of as a set of farming techniques that equips food producers to respond both efficiently and sustainably to these price signals, provided that the right governance framework is in place – for example one that assigns economic value to environmental impacts (what economists call externalities). However, reliance on market mechanisms is only likely to work in countries with relatively mature agricultural markets. In low income regions of the world poor financial and physical infrastructure, as well as an insufficient institutional capacity and skills base, may require more interventionist approaches to help increase productivity sustainably. Critically, broader governance structures regulating land use, together with effective enforcement need to be in place so that the price signals caused by higher demand lead to sustainable intensification rather than to agricultural expansion.

The environmental argument for sustainable intensification is thus founded on three principles:

- The consequences of converting more land to agriculture are so harmful to the environment that any increase in production must be achieved with as little additional land conversion as possible.

- Producing more from the same amount of land must be done in ways that reduce the direct negative environmental impacts of food production. This will require much more efficient use of water, energy and other inputs (increased production must be accompanied by increased productivity) and attention to the long-term sustainability of agro-ecosystems. Opportunities for positive environmental impacts (for example carbon sequestration on agricultural land) should be pursued where possible.

- While some growth in food demand is inevitable, the extent of the increase will depend upon how far policy on the demand side is successful in modifying diets, reducing waste and reducing the rate of population growth. However, relying on successes in these areas to achieve food security is as risky as relying on increases in production alone. Action is needed on all fronts in order to keep food supply and food prices within societal accepted bounds; and the role of sustainable intensification is to deliver productivity gains in ways that are environmentally and societally acceptable.

Thus at the heart of sustainable intensification are the twin goals of delivering yields high enough to remove the 'need' to encroach further on uncultivated land at the global aggregate level; but of doing so in ways that optimise the use of non-renewable inputs, and do not cause environmental damage to soils, water, air and ecosystem services on and around farmland. Achieving both goals will not always be possible and trade offs are inevitable. Different regions will need to balance objectives in ways that best reflect local environmental conditions and priorities - and these individual decisions will have implications for global sustainability. How to negotiate an acceptable balance between local and global sustainability objectives is the subject for discussion here.

4.1.2. How can we define environmental sustainability?

Sustainable food production implies a form of farming that can be continued indefinitely into the future. But what we actually mean when we talk about sustainable agriculture in an environmental context is often not clear (we return to other dimensions of sustainability below). Sometimes it represents a general aspiration to reduce the environmental harm that may undermine future food production. At other times it describes particular food production processes that only use renewable inputs. In thinking about what environmental sustainability means we need to consider how its definition changes when viewed through different spatial and temporal perspectives. For example:

- **Sector boundaries.** To what extent should agriculture's environmental costs and benefits be 'vired' to and from other sectors? For example, might greenhouse gas emissions in the production of synthetic fertilisers be mitigated by carbon capture and storage, or biodiversity losses on farmland be compensated for by the establishment of nature reserves on non-agricultural land elsewhere (see also below)? On the other hand, could ongoing growth in another economic sector (aviation, for example) be compensated for by paying for carbon sequestration activities in the agricultural sector? Or should agriculture be treated as a socio-economic activity distinct from others? Where cross-sector national strategies exist, perhaps for greenhouse gas emissions or biodiversity, then the scope to develop policy across different areas offers the prospect of more effective responses. In their absence, shifting the responsibility to other sectors risks being an excuse for inaction.

- **Spatial extent.** At what spatial scale should sustainability be defined? Might the reduction in farmland bird populations in some regions be considered sustainable if their populations increased elsewhere? If non-renewable agricultural inputs were proscribed in one area or country, leading to a decrease in yield, how might its sustainability be judged if it led to more demand for food produced in regions or countries with poor environmental regulations? On the other hand, the larger the spatial scale at which sustainability is assessed, the more stakeholders become involved. The risk is that the responsibility to increase sustainability becomes dissipated and any potential benefits lost.

- **Temporal issues.** Thinking about forms of farming that can continue indefinitely is of limited value given our inability to look into the distant future. In practice a comprehensible timespan for consideration is usually a matter of decades or perhaps a century. Beyond that the uncertainties about what technology may deliver, the nature of demand, and the state of the climate render policy making largely pointless. Nevertheless, what may happen in the next few decades can influence today's decisions about what is sustainable. For example, one may argue for investment in organic agriculture, even though yields are generally lower, in the expectation that research will identify ways of closing the productivity gap. On the other hand one may support the continued application of synthetic fertilisers in the anticipation of technological developments that will mitigate their negative effects. Moreover, farming decisions made today about what to produce and how will influence societal norms and expectations about choice, quality, price and so forth. This socio-technical interdependence can mean that new problems emerge from old solutions and vice versa.

- **Use of non-renewable resources.** A sustainable food production strategy should explicitly plan for the exhaustion of non-renewable resources. We know that there are only finite reserves of fossil fuels or mineral phosphate. Much of the water used to irrigate agriculture comes from reserves such as underground aquifers that are replenished so slowly that they are essentially non-renewable. Where reliance on non-renewable resources involves negative impacts such as greenhouse gas emissions then reductions in their use prior to them becoming exhausted may improve overall sustainability (though it is important to consider all indirect impacts – some biofuels, though renewable, have more negative effects for the environment than fossil fuels). In other cases where any negative impacts are relatively small or absent, using up non-renewable resources may make both economic and environmental sense (for example, less water extracted from rivers and more food produced) provided that plans are made in preparation for a future in which they will have been exhausted.

- **Baselines.** Farming environments deliver landscapes and provide habitats for biodiversity and one goal of sustainable food production, as typically conceived, is that they should continue to do so in the future. But the rural landscape today is not what it was even a few decades ago, and the biodiversity present today is different from what it was in the past - in most places it has been diminished. Sustainability can only be defined relative to a temporal baseline; and its identification is a political process, even though it will be informed by scientific knowledge. A concern of many conservationists is that as we lose biodiversity the baseline keeps shifting downwards, since society is unaware of or simply accepts what it has lost.

The complexities of the issues that make up sustainability, even when defined just in environmental terms, are so great that they can hamper progress towards its achievement. In practice policy makers need to set pragmatic goals and targets that can be in place long enough to justify investment by the private sector actors involved and are consistent with the best available environmental science. Examples of such targets already in place in many high income countries include directives on water quality in the farm landscape (for example nitrate and pesticide concentrations) and on different biodiversity measures. Targets for greenhouse gas emission reductions from food production are increasingly been considered, although none are yet binding. Determining exactly what these targets should be is an intensely political process and involves consideration of many non-environmental aspects of food production. There are numerous difficulties and dangers: different interest groups will attempt to align targets with their particular goals and policies; targets, to be effective, must be relatively simple to administer yet avoid perverse and possibly self-defeating incentives; and care needs to be taken to ensure that the different policy objectives set do not negate each other, and that they take into account the trade-offs among their different components. Critically, the indirect impacts need to be considered – what effects the targets may have on global food markets and how this may influence the environment elsewhere (for example the effect a GHG reduction target may have on embedded water use in agricultural production). There are also different approaches to implementing policy goals: are carrots (incentives) better than sticks (penalties for failure); should food producers be directed to adopt certain practices or judged purely by results; and what if any role does consumer information play in influencing purchasing decisions that in turn drive best practice?

Achieving targets requires metrics to assess progress. It is doubtful whether a single sustainability metric could be devised, even for the environmental aspects alone of sustainable intensification. In some areas the development of metrics is likely to be fairly straightforward. For example, the concentration of pollutants in water bodies can be measured with relative ease, while better methods for assessing the full greenhouse gas emission consequences of different farming measures is the subject of much current effort, even if capturing all the indirect consequences remains a major challenge. However, metrics for other aspects of sustainability are far harder to formulate. Biodiversity is, by definition, multidimensional and comprises everything from genetic through species to habitat diversity. It is literally impossible to measure all aspects of biodiversity and so identifying proxies is essential. But exactly what to measure among the myriad of possibilities is very hard to decide. In practice the choice is influenced by factors such as the scientific evidence base (what measures correlate best with other aspects of biodiversity), pragmatics (measuring some things is easier than others) and politics (organisations that campaign for birds and plants naturally place great value on these particular groups). Biodiversity metrics are also particularly influenced by the scale of measurement. For example, is it enough that sustainable populations of a particular species exist in some places - or should they be found everywhere?

To make these arguments more concrete we now focus on a particular environmental aspect of sustainable intensification - how to manage the land to produce multiple services in the presence of tradeoffs. This argument has been portrayed as one of specialisation: should land be managed simultaneously to produce, say, biodiversity and yield (the land is "shared" between services), or should land be specialised in some places to produce yield and in others to produce biodiversity (land "sparing")? Given that there is an inherent trade off assumed in this argument, a larger yield in agricultural land implies that land can be "spared" for biodiversity.

4.1.3. Land sharing versus land sparing for biodiversity and greenhouse gas reduction

As discussed above, on farm decisions that affect yield can have profound off-farm consequences, through their impacts on the total area of land under farming. Land conversion leads to major emissions of greenhouse gases and also to the loss of biodiversity. One line of argument holds that since further land clearance for agriculture is undesirable, policies that promote greater wildlife on farm and the use of fewer synthetic inputs, while likely to be locally environmentally beneficial, may lead to lower yields and hence generate price signals that trigger land clearance in another region. Such 'extensification' should thus be avoided even if this means accepting greater environmental damage on existing agricultural land. Alternatively, it (must be acknowledged that greater levels of intensification will be required elsewhere if land conversion is to be avoided. On farm environmental impacts should nevertheless be minimised. At a global level one of the main arguments for sustainable intensification, that land conversion elsewhere should be avoided, can be characterised as a type of land sparing.

The idea of accepting Proponents of organic or "wildlife friendly" farming however, have voiced concerns about the land sparing approach. Some believe that compromising on biodiversity and other desired environmental outcomes on farm can be seen as a form of moral hazard that ultimately impedes progress towards sustainable agriculture. There are also concerns about the social implications of land sparing. There is evidence to suggest that the drive to raise yields in existing agricultural areas in order to reduce greenhouse gases and preserve natural habitats can occur at a cost to other benefits that may be derived from less intensive production. These include not only environmental 'goods' (such as on farm biodiversity) but also socio-economic benefits such as diverse food and non-food products, and smallholder livelihoods and cultures[45]. Finally, it is argued that without the governance structures in place to enforce land sparing, only one side of the contract will be realised (high yields but not spared land), a point we return to below.

Are these criticisms justified? Several groups have tried to investigate the merits of land sharing versus land sparing approaches from various environmental perspectives. Burney et al. for example calculate at a global level that in the absence of the Green Revolution, the amount of land that would need to have been dedicated to agriculture to meet current food requirements would be much greater than it is today, even under a scenario where diets remained the same as in pre-Green Revolution times[46]. Looking ahead, Tilman et al.[47] use a simple statistical projection to estimate the level of food demand by mid-century, assuming current patterns of correlation between dietary change and income and World Bank estimates of economic growth. They then calculate the greenhouse gases generated in meeting this need either by converting new land to agriculture and maintaining today's average yields or by using artificial fertilisers to boost yields without area expansion. They conclude that increasing yields is better for climate change than land conversion.

Different aspects of both studies can be criticised. In the case of Burney et al., they compared Green Revolution agriculture with low-yielding conventional food production. However, a better counterfactual might have been a scenario where Green Revolution levels of investment were focused on organic agriculture or related approaches. Tilman et al. similarly do not consider an agroecological alternative that might enable higher yields and a lower level of land conversion. On the other hand their estimates of the greenhouse gas emissions that would result from the application of synthetic fertilisers do not take into account the potential savings that would arise if they were applied more judiciously and effectively, for example through precision agriculture techniques. The study also fails to take account either of the potential for achieving in changes in demand or reducing waste in the food system, both of which would moderate the increase in supply needed).

We are not aware of a "macro" level estimate of the global loss of biodiversity that was avoided or caused by the Green Revolution, nor what might be the consequences for biodiversity of different strategies for meeting the future demand for food. Indeed, only recently have quantitative studies sought to explore the relative advantages of land sparing and land sharing at a landscape scale. An important recent study by Phalan et al. sought to

45 Homewood K, Lambin E F, Coast E, Kariuki A, Kikulai I, Kivelia J, Said M, Serneels S and Thompson M (2001). Long-term changes in Serengeti-Mara wildebeest and land cover: Pastoralism, population, or policies? PNAS 98, 22, 12544–12549

46 Burney J A, Davis S J and Lobell D B (2010). Greenhouse gas mitigation by agricultural Intensification, PNAS, www.pnas.org/cgi/doi/10.1073/pnas.0914216107

47 Tilman, D., Balzer, C., Hill, J. & Befort, B.L. (2011) Global food demand and the sustainable intensification of agriculture. Proceedings of the National Academy of Sciences of the United States of America, 108, 20260-20264.

shed light on this issue[48]. Taking originally forested tropical and sub-tropical landscapes as its focus, it looked at the distribution of birds and plants across a spectrum of land use types (from continuous forest to pure farmland) in India and Ghana. For a given agricultural yield target, they calculated whether less intensive agricultural practices on a greater area of land are more supportive of biodiversity than more intensive practices on a lesser area of land with greater preservation of forest. The study found that for realistic yield targets, land sparing 'wins,' and that this is particularly the case when the analysis is restricted to species with small geographical ranges, which are often of the greatest conservation interest. It concluded that in principle, the best strategy in these regions for conserving biodiversity is to set aside protected forest reserves, while simultaneously investing in relatively high-yield intensive agriculture to meet food demand and support rural livelihoods.

This study thus appears to provide strong scientific evidence for the biodiversity benefits of land sparing – although it does not thereby conclude that a greener version of conventional farming is sufficient and the way forward. It should be reiterated at this point that 'sustainable intensification' does not denote simply a greening of the status quo. There are important scientific and non-scientific caveats and provisos in the study (most mentioned by the authors) whose elaboration may be of help in the development of sustainable intensification policy.

Consider first the more scientific issues:

- Biodiversity is only one environmental outcome, and birds and plants only one component of biodiversity. The study did not examine or quantify the impacts of intensive agriculture on ecosystem services of benefit to the farmer (for example soil structure), to the broader community (for example water quality) or to the world (greenhouse gas emissions). The effects that nitrogen and pesticide applications might have if they leaked into the environment, especially into freshwater bodies, were not measured. All these would need to be tested against impacts arising from less intensive systems.

- The study only looked at one type of habitat (tropical forests); studies in other areas might have drawn different conclusions. For example, in regions such as the Mediterranean, the present mix of plant and animal species has been shaped by millennia of human agricultural activity and flourishes in areas of low-intensive food production. Exactly what pure "land sparing" would be in this context is not clear and past land sharing has essentially sustained the biodiversity we now value[49].

- The study considered a single spatial scale; issues of land sparing and land sharing can arise at multiple spatial scales from within a farm to across the globe.

A similar methodology can be applied to issues of extensification and intensification in the UK. It has been shown that British organic farms support greater butterfly biodiversity that conventional farms - although more species still exist on what the UK designates "sites of special scientific interest" (SSSIs). If the landscape is required to produce a specified

48 Phalan P, Onial M, Balmford A and Green R E (2011). Reconciling food production and biodiversity conservation: Land sharing and land sparing compared. Science 333, 1289

49 Benton, T.G., Dougill, A.J., Fraser, E.D.G. & Howlett, D.J.B. (2011) The scale for managing production vs the scale for managing ecosystem service production. World Agriculture 2: 14-21

amount of food, then for most realistic assumptions butterfly biodiversity is maximised by farming conventionally, provided that the resulting spared land is converted to SSI-quality habitat[50]. The optimal solution thus depends on the way any spared land is managed[51].

Further research is clearly needed to explore these issues in a broader array of habitats. Such work should ideally incorporate a broader range of environmental outputs and ecosystem services and consider how they interact. There is a need to understand these interactions both at fine grained resolutions and at larger spatial scales, as well has how these change over time. Science in these areas is still evolving and new technological aids such as Geographic Information System (GIS) mapping can help.

But these technical discussions can yield only partial insights. Studies such as Phalan et al. provide important and relevant evidence but not clear direction to policy makers. Decisions have to be made within a much more complex multi-dimensional socio-political environment that takes into account issues such as the following:

- As noted, birds and plants are just two aspects of biodiversity and biodiversity just one amongst many environmental outputs of the way we use land. There is no non-arbitrary metric that we can use to compare the relative importance of, for instance, mitigating greenhouse gas emissions against reducing the loss of bird species. There may even be conflicts between goals of protecting one species versus another. Although the economic valuation of ecosystem services can provide a limited framework for comparing different consequences, ultimately the relative weightings given to the different outcomes reflect individual and societal values and beliefs.

- Land sparing requires that the governance of land use is sufficiently sophisticated and operates on a sufficiently large scale that the bargain is met[52,53] – that land really is spared for biodiversity in the face of possibly strong economic, social and political pressure for its exploitation. There is a profound asymmetry in land conversion: converting natural environments to land suitable for agriculture is quick, taking weeks or months and seldom more than a year. Taking agricultural land and managing it for nature or returning it to nature (rewilding) can be achievable but is much slower. Moreover, it may be impossible if the soil has been dramatically altered (for example by long periods of fertiliser application) or if species composition has been severely altered or reduced, or if species have gone extinct. There is a concern that intensification in the name of land sparing may only result in immediate loss of on-farm diversity with no long term guarantees that the “spared land” will remain in its current state. Equally, good governance is also essential to ensure that land sharing strategies yield real benefits for on farm biodiversity and other ecosystem services. Assessments of agri-environmental schemes applied under the Common Agricultural Policies (a form of

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50 Hodgson, J; Kunin, W E.; Thomas, CD; Benton, TG; Gabriel, D (2010) Comparing organic farming and land sparing: optimising yield and butterfly populations at a landscape scale. Ecology Letters 13, 1358-1367.

51 Benton TG (2012) Managing agricultural landscapes for production of multiple services: the policy challenge. International Agricultural Policy 1: 7-18.

52 Fischer J, Batáry P, Bawa K S, Burssaard L, Chappell M J, Clough Y, Daily G C, Dorrough J, Hartel T, Jackson L E, Klein A M, Kremen C, Kuemmerle T, Lindenmayer D B, Mooney H A, Perfecto I, Philpott S M, Tscharntke T, Vandermeer J, Wanger T C and Von Wehrden H V (2011). Conservation: Limits of Land Sparing, Science, 334, 594

53 Perfecto, I. and J. Vandermeer. (2010) The agricultural matrix as an alternative to the land-sparing/agricultural intensification model: facing the food and biodiversity crises. Proceedings of the National Academy of Science 107:5786-5791

institutionalised land sharing) suggests that this approach does not necessarily deliver on its environmental objectives with potentially very large costs.

- A by-product of increasing yields in certain areas to allow land sparing may be that agriculture becomes more profitable, and that local financial and physical infrastructure, as well as the skills base associated with food production, are all improved. This might lead to a type of moral hazard, a greater incentive to renege on the land sparing agreement, or at least to renegotiate it. It may also lead to more subtle changes such as increased specialisation in the most profitable crops – intensification beyond that originally envisaged[54]. Critics see biodiversity loss as a ratchet with these types of feedback turning the wheel through more and more notches. On the other hand, these concerns apply equally to 'land sharing' strategies. There is nothing inherent in land sharing that acts as a restraint on human demand for certain foods or other agricultural products. In the absence of effective governance farmers practicing land sharing strategies may nevertheless seek to increase their profits by specialising (so reducing on farm biodiversity benefits) or bringing additional land into production, with damaging environmental consequences.

Promoting local intensification also has consequences for the stakeholders involved, and how the benefits are distributed will be of concern both to policy makers and others. The beneficiaries might be large national or international corporations, local small or medium-sized enterprises, or small-scale farmers. In some contexts there will be concern that intensification will favour some groups over others. In particular, where land rights are poorly defined or protected, smallholders may be excluded from their land which may undermine their livelihoods, culture and human rights, and may cause them either to encroach further onto uncultivated land (undermining land sparing and damaging livelihoods) or to migrate into the cities. Urbanisation tends on the whole to be correlated with more land- and resource-intensive dietary patterns, such as increased meat consumption[55,56], as well as increased removal of nutrients from agricultural systems into the oceans, and so enforced urbanisation may dilute the land sparing effect. In other words, 'leakage' of environmental impacts can occur not only over space, but over time as certain systems of production lock people into unsustainable patterns of consumption. This said, where policies to promote wildlife friendly farming fails to ensure financial security for poor farmers, there will be substantial social costs translating into poorer outcomes for health and education. Both the scientific and the non-scientific issues around biodiversity and greenhouse gas emissions emphasise the importance of land use governance. No matter what the scientific evidence, without a trustworthy regulatory framework in place, the complex trade-offs underlying land sparing can probably never be made to work. A similarly dysfunctional regulatory environment likely renders formal land sharing unworkable. The question then becomes whether the adoption of one strategy over the other leads to a greater number of perverse incentives, both environmental and social.

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54 Fischer J, Batáry P, Bawa K S, Burssaard L, Chappell M J, Clough Y, Daily G C, Dorrough J, Hartel T, Jackson L E, Klein A M, Kremen C, Kuemmerle T, Lindenmayer D B, Mooney H A, Perfecto I, Philpott S M, Tscharntke T, Vandermeer J, Wanger T C and Von Wehrden H V (2011). Conservation: Limits of Land Sparing, Science, 334, 594

55 Stage J, Stage J and McGranahan G (2010). Is urbanization contributing to higher food prices? Environment and Urbanization 22:199.

56 Nutrition and the Prevention of Chronic Diseases, Report of a Joint FAO/WHO Expert Consultation, WHO Technical Report Series 916, WHO, Geneva, 2003

The difficulties of developing and implementing effective systems of governance are clearly enormous. At one level this challenge is technical - it is about ascertaining what mix of policies - including regulations (for example prohibiting cultivation on certain areas of land), fiscal measures (from payments for ecosystem services to taxes on nitrogen inputs) and voluntary agreements (industry cooperation on shared goals) - might be most effective. Policy makers can, to an extent, develop strategies based on assessing the success of existing land use legislation (such as protected areas), as well as on market mechanisms such as product certification schemes and codes of conduct. However, it is difficult to see how local or national governments can make decisions for global benefit in the absence of global agreements on land use, or globally implemented measures to internalise the economic costs of environmental damage and benefits. Policy makers also face the difficult task of developing policy in the face of future unknowns – of deciding whether to base decisions on social and economic norms today or in anticipation of social, economic and governance changes or technical innovations tomorrow.

Ultimately, however, technical judgements on what constitutes sustainability will be interpreted by the values people hold and these will in turn shape the policies that are developed in response. People will prioritise objectives on the basis of their attitudes to risk and to trust, their assumptions and aspirations around broader social and economic governance of the food system and their views about what food production 'should' look like – economically, socially and aesthetically. Is smallholder production a 'good' in itself? Is diversity of agricultural outputs and outcomes better than a narrow focus on a particular crop (discussed further below)? Separating issues of science (natural and social) and issues of values is important but can be difficult, and both have a rightful place in how society develops agricultural and land use policy.

Finally, while so far the discussion has focused on difficult choices and uncertainties surrounding understanding, values and governance, the picture is not always murky. It will be possible to identify 'hotspot' areas where there are very clear win-wins between productivity gains, land sparing and reduced on farm environmental impacts. For example, in parts of Sub-Saharan Africa – the birthplace of the sustainable intensification concept[57,58] where yields are low, farmland soils are degraded and deforestation is ongoing, measures to improve soil fertility are likely to have benefits across all these areas of concern.

4.2. Animal welfare and ethics

The environmental impacts caused by the livestock sector have been well documented. Livestock have been estimated to account for 12-18% of current global greenhouse gas emissions and occupy around 70% of agricultural land – a figure that includes a third of all arable land. They are also major users of available freshwater consuming 8% of the global total. Livestock are implicated in deforestation and associated biodiversity loss and carbon dioxide release, in water contamination and in land degradation[59,60]. Food and Agriculture

57 Reardon T, Crawford E, Kelly V and Diagana B (1995). Promoting farm investment for sustainable intensification of African agriculture. MSU International Development Paper No 18, Michigan State University, Michigan, United States

58 Pretty J (1997). The sustainable intensification of agriculture, Natural Resources Forum, Blackwell Publishing Ltd.

59 Livestock's Long Shadow, FAO, Rome, 2006.

60 Environmental Balance: Summary. Bilthoven, Netherlands Environmental Assessment Agency (PBL), Bilthoven, 2009.

Organisation (FAO) estimates suggest that, assuming current trajectories, demand for, and associated production of, livestock is set to increase substantially by 2050 – by 73% for meat and 58% for dairy on today's levels[61]. Unless something is done, livestock's share of global emissions and its contribution to other impacts is set to grow. Hence sustainable intensification has been proposed as a critical way forward for the livestock sector.

Sustainable intensification has its origins in crop production, but has sparked controversy when applied to animal production because of ambiguity of what it means in this context. One meaning is simply an increasing use of indoor systems where waste emissions, food, water and temperature are more under control. There is potential here to develop systems that actually improve animal welfare. Another meaning, however, is that intensification refers to the efficiencies that would be achieved by demanding more of individual animals[62] – yet more eggs from hens already developing brittle, easily broken bones because of the demands of egg-laying, more milk from cows already showing metabolic disorders and shortened life spans and broiler chickens already at risk of lameness and cardiovascular disorders[63,64]. It is this second sense of intensification that causes concerns about animal welfare, implying as it does that individual animals will be under even greater stress than they are now. Almost by definition, there will be an inevitable decline in the animals' welfare. In discussing the relationship between sustainable intensification and animal welfare, it is therefore important to be clear which meaning of intensification is being proposed and what exactly is meant by animal welfare.

Most of the thinking on animal welfare has been undertaken in high income countries and is thus influenced by their particular sets of values and traditions, a strong focus on scientific enquiry and the pastoral romanticism that developed in parallel with industrialisation. Welfare is a complex concept that involves several different elements but in general, welfare definitions tend to include the requirement not only that animals are in good health, but also that they are somehow experiencing a 'life worth living.' So, by many accounts good animal welfare requires that: animals are healthy; unpleasant affective states such as fear, pain and frustration are avoided or minimized; and that animals can live in ways that suit their natural adaptations, including being able to carry out types of behaviour that they are strongly motivated to perform. These elements are present, for example, in the "Five Freedoms" of the United Kingdom's Farm Animal Welfare Council[65], and in the definition of animal welfare of the World Organisation for Animal Health[66]. However, disagreements about animal welfare often arise because different people emphasize these different elements to different degrees. For example, farmers who keep hens in small cages often emphasize the hygiene and control of parasites that cages allow, while critics point to the frustration that arises because the cages severely limit the birds' behaviour. Stakeholders also differ in the weight they place upon achieving animal welfare as compared with economic considerations, issues of food security or simply food

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61 FAO (2011). World Livestock 2011: Livestock in food security, Food and Agriculture Organisation, Rome

62 Pew Commission on Industrial Farm Animal Production, 2009. Putting Meat on the Table: Industrial Farm Animal Production in America, A Project of The Pew Charitable Trusts and Johns Hopkins Bloomberg School of Public Health.

63 Webster, J., 2005. Limping Towards Eden. Wiley-Blackwell, UK

64 Fraser, D., 2008. Understanding Animal Welfare: The Science in its Cultural Context. Wiley-Blackwell, UK

65 Five Freedoms, Farm Animal Welfare Council http://www.fawc.org.uk/freedoms.htm

66 OIE (2011). Article 7.1.2. Introduction to the recommendationsfor animal welfare Chapter 7.1 in Terrestrial Animal Health Code, World Organisation for Animal Health, http://www.oie.int/index.php?id=169&L=0&htmfile=chapitre_1.7.1.htm

preferences. The challenge is to develop systems that are geared to improving animals' quality of life but that also meet the need to reduce emissions and waste.

The 'good health' aspect of animal welfare is generally uncontested since there is a clear economic case to be made for keeping animals healthy: healthy animals are more productive. However the arguments for ensuring 'quality of life' go beyond the instrumental –they are essentially normative and therefore subject to more disagreement. While in high income countries, the principle that animal welfare is desirable and a good in itself (over and above its contribution to animal health) is fairly prevalent, this is much less so in low income countries where, importantly, good welfare for humans has not yet been achieved. In these contexts a better standard of human living is considered to be the priority, with greater access to affordable animal-source foods an important component of this. Animal welfare may often be dismissed as a rich world luxury, although this sometimes reflects lack of awareness of the benefits that better welfare in animals can bring to humans, as discussed later in this section.

All this is relevant to the discussion on sustainable intensification because in recent years life cycle analyses have shown that intensive systems (that is, systems based on high external inputs) tend to deliver more meat, milk or eggs per unit of greenhouse gases emitted than their more extensive counterparts. This is because intensive systems are more productive. While an individual more productive animal may generate more emissions than an individual less productive one in absolute terms, fewer animals are required to deliver a given amount of edible output, the overall effect being a reduction in emissions measured per given volume of output. Measures to improve productivity further might therefore, by reducing the number of livestock needed to deliver a specified quantity of meat, milk or eggs, lead to additional greenhouse gas savings. This finding has provoked concerns that the climate mitigation imperative will override ethical considerations and the goal of sustainable intensification will be used to justify systems of production that cause animal suffering.

The shift towards larger, more productive units has been accompanied by a rise in livestock numbers overall and a significant growth in per capita, as well as absolute consumption of animal products. It has been argued that intensification stimulates demand (through greater efficiency leading to reduced food prices) so that reductions in greenhouse-gas emissions per unit output are outweighed by an overall absolute increase in impact. In the absence of measures to address consumption of these resource intensive foods, the risk is that more efficient production will generate a 'rebound' effect; these arguments are similar to those that have been advanced in criticism of land sparing, discussed above. These arguments merit further investigation: while there is certainly an association between the growth in commercial intensive livestock production and consumption of low cost animal products further research is needed to ascertain the direction of causation: that is, whether intensification stimulates growth in consumption, or whether it represents a response to increased demand that might mitigate some of its negative consequences while exacerbating others. In practice, causation may run different ways in different circumstances.

Returning to the relationship between intensification and animal welfare, the issue can perhaps be usefully explored through two conceptual lenses. The first considers what intensification means, and looks like, in different contexts. The second looks at intensification in the context of governance.

4.2.1. What does 'intensification' imply in different contexts?

The first lens considers what 'intensification' - with either meaning - looks like and means for welfare in different contexts. Livestock systems in high and low income countries are currently very different and intensification has potentially different outcomes for welfare. When considering what 'intensification' actually means, it is important to consider the baseline against which productivity gains are measured as well as the meanings that are attributed to the word in different contexts, by different stakeholders.

In low income countries, yields in the extensive and smallholder systems that characterise a large part of livestock production are on the whole very low. Measured in terms of milk or meat output per unit of greenhouse gases emitted, these systems are inefficient (although see discussion in 5.3 below) since the energy they do obtain is spent on maintenance rather than on growth. At the same time, welfare even in its most uncontroversial sense - good health - can also be low since many livestock are not only malnourished but suffer from endemic diseases and a lack of adequate veterinary care. These diseases also affect human health (since livestock diseases can pass to humans) both directly and indirectly through economic losses.

When development agencies promote intensification in these contexts, the term tends to mean replacing subsistence production with systems that range from the very small-scale (such as the 'zero grazing' systems involving one or two cows) to medium-scale commercial production. In such cases, intensification is likely to mean a certain degree of confinement in pens, stalls, barns or fields; access to more nutritious feeds, potable water and vaccines; and specialized skills in animal health, care and nutrition.

These developments can yield significant productivity gains and can potentially be achieved through relatively simple adjustments to practices, combined with appropriate market incentives and institutional support[67]. With the right research and development, animal welfare can even be improved. Farmers are also likely to benefit both economically and in terms of their health. What is more, since the existing productivity baseline is very low, improvements in productivity can deliver substantial environmental benefits, both relative (impact per kg of output) and absolute (total impact)[68,69]. In short, human, animal and economic win-win-wins are possible.

In high income countries, intensification has different connotations. Productivity is already high since significant investments have been made in selecting productive breeds, in formulating and feeding diets that are high in energy- and protein-rich cereals and oilseeds, and in the construction of often confined housing systems that control the conditions in which livestock are reared.

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67 McDermott JJ, Staal S J, Freeman HA, Herrero M and Van de Steeg J A (2010). Sustaining intensification of smallholder livestock systems in the tropics, Livestock Science 130 (2010) 95–109

68 Thornton P K and Herrero M (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics, PNAS www.pnas.org/cgi/doi/10.1073/pnas.0912890107

69 FAO (2010). Greenhouse Gas Emissions from the Dairy Sector: A Life Cycle Assessment, Food and Agriculture Organisation, Rome

Moreover, at the herd level, the greenhouse gas efficiency of highly productive animals can be questionable. For example, in dairy farming higher mortality rates due to ill health and infertility-related culling mean that more initially unproductive (yet still greenhouse gas emitting) replacement heifers need to be reared to compensate[70]. Hence the productivity of any individual animal needs to be viewed in relation to the overall health and fertility of the herd as a whole. Policy makers and the farming industry are increasingly recognising the need for a broader definition of productivity that considers the livestock group over time, and are starting to breed for 'robustness' rather than yields alone, at least in some high income countries.

The relationship between intensification and infectious diseases is similarly complex. Livestock kept indoors are less likely to come into contact with and so contract diseases from wild animals. For example, poultry kept indoors are less likely to be exposed to avian influenza from wild birds. On the other hand the densities at which animals are kept in intensified systems increases the risk of infectious disease spread and can encourage the use (including the prophylactic use) of greater amounts of antibiotics. The emergence of resistant bacteria strains poses concerns for human health and has led to, for example, recent guidance by the United States Food and Drug Administration that antibiotics that are medically important in human disease treatment should not routinely be used for animals[71]. The greatest risks of disease outbreaks are likely to occur in situations where smallholders (less extensive) and commercial (intensive) units coexist[72].

Overall, the relationship between health, productivity and environmental impact can be summarised as follows. Where productivity is low, measures to increase productivity by providing more nutritious food and medication and care that reduces diseases is likely to lead to a triple win: food production is increased, environmental harm per unit of production is reduced, and the animals are likely to have better quality of life.

However, at higher levels of productivity, the relationship is likely to be more clouded and cannot be predicted without empirical study. Measures to increase productivity may or may not have overall benefits when viewed over time or at the herd level (as in the case of dairy cows, above) due to the effects on fertility and longevity. Moreover, the level of intensification that is optimal for reducing environmental effects may not be optimal for animal welfare, particularly measured according to criteria related to the animal's ability to perform natural behaviours. The challenge in such cases will be to identify the various wins and losses for each of food production, animal welfare and environmental cost, and arrive at acceptable trade-offs.

It is important to recognise that what is acceptable may vary from culture to culture depending on the level of importance attached to animal welfare. There are many societies, especially among the industrialising transition economies, where for different reasons there is little tradition of concern about the conditions in which animals are kept. There are fears, particularly by animal welfare advocates, that an emphasis on sustainable

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70 Garnsworthy, P.C., 2004. The environmental impact of fertility in dairy cows: a modelling approach to predict methane and ammonia emissions. Animal Feed Science and Technology 112, 211–223.

71 FDA News Release: FDA takes steps to protect public health, April 11, 2012, http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm299802.htm

72 Slingenbergh J, Gilbert M, Balogh K de and Wint W (2004). Ecological sources of zoonotic diseases Rev. sci. tech. Off. int. Epiz., 23 (2), 467-484.

intensification, while focusing on yields and the environment, will do nothing to advance the cause of animal welfare and may even impede it. The question then is: could this risk be managed by ensuring that sustainable intensification has something explicit to say about the need to achieve good welfare? This question leads onto the issue of governance - the second lens through which one might consider the sustainable intensification-animal welfare relationship.

4.2.2. Governance

The policy context within which livestock production occurs will determine the welfare outcome. If society decides that the safeguarding of whatever it regards as good animal welfare is an ethical non-negotiable then 'intensification' will have to be constrained by the standards that it specifies. Just as we accept a ban on slavery or child labour in the UK, however economically effective it might be, so a society can choose to prioritise particular moral objectives over environmental efficiency. In other words, since intensification 'at all costs' is something that society can choose to avoid, the question then arises as to whether the definition of sustainable intensification should incorporate some kind of internal "ethical control mechanism" into its definition - for example that it should require environmentally sustainable increases in productivity without unacceptable (however defined) costs to animal welfare. This can be seen as an ethical version of BATNEEC – modified to BATNEEEC - Best Available Technology not Entailing Excessive *Ethical* Cost – as it were.

Of course, the difficulty would be finding common ground within society to define "unacceptable." Alternatively, sustainable intensification could retain a purely environmental definition but be viewed and operate within the context of laws, standards and codes of practice that determine farm practice in relation to welfare (equivalent to cross-compliance). The merits of folding multiple goals into the definition of sustainable intensification or maintaining a narrow ecological definition which is then situated within these wider concerns, are discussed further in 5, below.

Ultimately, reconciling environmental, economic and welfare goals will be much easier to achieve if greater efforts are made in one key area of governance – demand management. As noted elsewhere, demand management has in any case been highlighted as an important strategy in achieving a sustainable food system. Measures to reduce consumption of animal products in high consuming countries, to moderate the growth in demand elsewhere, and to reduce waste and losses throughout the supply chain, will reduce the level of intensity required to meet demand for these foods. This, by lowering the level of supply needed to match demand, can enable the welfare risks that can arise in very highly productive systems to be avoided.

4.3. Human-centred outcomes: nutrition

One of the goals of sustainable intensification is to increase agricultural productivity. But productivity of what? Sustainable intensification needs to focus on delivering goods and other outcomes that have societal value and exactly what they are will determine how it is implemented.

What does society – or rather the multiple and competing stakeholders who comprise society – value? While the main purpose of agriculture is to provide food, it is not the only one. Other desired outputs and outcomes include fodder (grains and crop residues), fibres, traction, soil fertilisation (manure, legumes), bio-energy, economic benefits such as livelihoods and employment, security in the form of liquid assets such as land and livestock, and status, cultural, environmental and aesthetic outcomes. Different stakeholders prioritise these differently; for example farmers and the agricultural industry may place greatest emphasis on profits; consumers are generally most interested in their individual welfare (including not only nutrition but also the provision of non-food 'goods' such as tobacco, coffee or alcohol) while governments seek to balance these many competing interests. Biofuel production is fast becoming a major desired output from the system for many stakeholders.

Even taking food as a single output, there are further questions to consider. Productivity is often measured in terms of volume or kilocalories per unit of input, but other nutritional metrics could be and have been used, such as protein, or certain vitamins or minerals[73,74,75]. Beyond nutrition, one might wish to measure individual or cultural food preferences or even reliability of yield – a metric that encapsulates the food security definition of stability over time.

Which metrics are selected, and how the 'answers' they give are interpreted, give rise to different conclusions as to which systems of production are most likely to deliver the desired intensity of outputs in a sustainable way. As noted in the discussion on land sparing/sharing, much of the criticism surrounding sustainable intensification stems from concerns that the multiple outputs and outcomes that some farming systems achieve will be ignored. Instead simple, and single metrics, such as volumes, or kilocalories are used to measure success on the food side, and by these measurements conventional monocultural systems tend to score highly. These metrics might indeed be telling us something important but there is a risk that a focus on simple measures of efficiency can lead to investment only in high yielding production systems that deliver high output per unit of greenhouse gas emissions (or other metric), but may not fully serve the full nutritional needs of the global population or provide other outputs important to sustainable livelihoods, including those that are harder to define.

Taking nutritional objectives to start with, worldwide, malnutrition affects billions of people. Nearly a billion people are under-nourished; their diets lack sufficient calories and other nutrients, leading to stunting and long term impacts on cognitive development and health. Even more people, two billion, have diets lacking in the right mix of nutrients, particularly essential micronutrients, for healthy development[76]. These include a growing number of people suffering from "over-nutrition" and energy dense, nutrient poor diets that lead to obesity and chronic disease.

As incomes increase, many people are shifting to diets dominated by meat and dairy products, oils and refined carbohydrates. As a result around 1.5 billion people worldwide

73 Smedman, A., Månsson, H., Drewnowski, A., Edman, A (2010). Nutrient density of beverages in relation to climate impact. Food & Nutrition Research, 54: 10.3402/fnr.v54i0.5170.

74 Davis J, Sonesson U, Baumgartner D U and Nemecek T (2010). Environmental impact of four meals with different protein sources: Case studies in Spain and Sweden. Food Research International 43 1874–1884

75 Scarborough P (2010). Nutrient Density to Climate Impact index is an inappropriate system for ranking beverages in order of climate impact per nutritional value. Food & Nutrition Research, 54 10.3402/fnr.v54i0.5681

76 http://www.wfp.org/hunger/faqs

are obese or overweight. Obesity is no longer only a rich world problem – most of these people are citizens of low and middle income countries, and many of them are poor[77]. These people are at risk of a range of diet-related illnesses including cardiovascular disease, strokes, diabetes and some cancers. Some of them may, at the same time, suffer from micronutrient deficiencies.

How does sustainable intensification engage with this complex problem of malnutrition, including in its over- and under-nutritional forms ? How can approaches be developed that allow for and enhance dietary quality? Is it possible to have a discussion about sustainable nutrition without addressing broader systemic issues about what people should be incentivised and disincentivised to consume – and where does sustainable intensification sit within this debate?

One approach that has been advocated to address the diet-related problems we face is to seek to contain or reverse the trend towards diets increasingly rich in refined carbohydrates, meat, vegetables oil and sugars. This could be done by regulating food supply or price to make healthy foods more accessible and affordable relative to unhealthy foods, and by incentivising production of a diverse range of grains, tubers, fruits and vegetables, including those that may be less commercial varieties indigenous to the locality of production. Proponents argue that this approach combats not only macro- and micronutrient deficiencies (by supporting local production for local consumption) but also addresses dietary imbalance and micronutrient deficiencies which contribute to the incidence of obesity-related chronic diseases. It may also be seen as supporting some environmental sustainability objectives. The FAO, for example, explicitly links nutritional diversity with crop biodiversity, and considers diversity not just in terms of the range of foods produced and consumed (maize, beans, carrots) but the diversity within type (different varieties of carrot, for example)[78].

In principle, these measures, if effectively implemented, are likely to lead to improvements in people's diets; individuals consuming a wide variety of foods are more likely to be able to obtain all the nutrients that they require, including those that are likely to be needed in the diet but whose role is not fully understood and that are therefore not the focus of current fortification programmes. Dietary diversity can thus be seen as providing nutritional resilience in so far as it provides more than the sum of its known parts. We do not, however, know what impact this approach might have on overall land requirements for agriculture and hence what its environmental impacts might be. Moreover these approaches require structural change in the food system, and even assuming that the political will is there, these change will take time.

A more immediate response to the problem of malnutrition is to enhance, through fortification, the nutritional content of the foods that people are most likely to eat. Fortification and biofortification programmes have a particular value in addressing the dietary problems of those too poor to have access to more diversified, healthy diets, and who generally subsist on small amounts of cereal staples. Beyond this, fortification may be seen as politically and culturally simpler to implement than more diverse systems of production and consumption. It also has the advantage of reaching net food purchasers in

77 http://www.who.int/mediacentre/factsheets/fs311/en/ accessed 13 February 2012

78 FAO (2010). Final document: International Scientific Symposium Biodiversity and Sustainable Diets: United against Hunger. 3-5 November 2010, Food and Agriculture Organisation, Rome

urban and rural areas who cannot afford to buy micronutrient rich food such as vegetables, fruit, pulses and animal products. The foods most likely to be fortified are those based on the production of high yielding commodity crops that may be more efficient to produce, measured in terms of greenhouse gas emissions per yield per area. Consumption of these crops is also growing world-wide and in this sense, fortification programmes such as Harvest Plus run *with* rather than counter to global dietary trends. However, while fortification can help address micronutrient deficiencies, the foods that tend to be the focus of fortification programmes (vegetable oils, salt and refined grains) are those that are implicated in the rise of overweight, obesity and associated chronic diseases. In contrast, recent efforts to increase the nutritional content of food by traditional plant breeding or genetic interventions (biofortification) are often targeted at crops grown by very poor people. This includes species such as sorghum, millet and cassava which are the few crops that can be grown in very dry, marginal conditions. These are much more likely to have positive rather than negative nutritional outcomes.

While advocates of fortification and biofortification might argue that the "best" (nutritional adequacy through diversity) is the enemy of the "good" (action now to combat malnutrition), critics might respond that these interventions do not so much 'top up' inadequate diets, as prolong food systems that are inherently inadequate and contribute to the growing problem of overweight and obesity. They would argue that the fortified diet is based on an only partial understanding of nutrition and the role of, and interactions among different micro nutrients, and so it risks being nutritionally inadequate. A focus on fortification as a substitute for more systemic change may also skew policy decisions and business investments that in turn shape agricultural developments into the future.

Once again, which approach is favoured very much depends not just on our values about what we should be producing and consuming, but on our beliefs about governance, the role of the market, and about how far decision makers should and can alter policies, regulations and pricing structures to alter current patterns of production and of consumption.

The role of meat and dairy products in the context of 'sustainable' diets – that is, the demand management aspect of the sustainable food security equation (see Figure 1, above) – is complex and nuanced. On the one hand, animal products are micronutrient rich and have a key role to play in addressing malnutrition, particularly in children[79,80,81]. On the other hand, they are a major contributor to greenhouse gas emissions and are consumed in quantities excess to requirements, both in high income countries and increasingly in transition economies.

In principle, restraining demand for meat and dairy foods by high consumers could help reduce the burden of chronic diseases, deliver greenhouse gas reductions and free

79 Neumann C G, Murphy S P, Gewa C, Grillenberger M and Bwibo N O (2007). Meat supplementation improves growth, cognitive, and behavioral outcomes in Kenyan children. J Nutr.;137(4):1119-23.

80 Murphy S P and Allen L H (2003). Nutritional Importance of Animal Source Foods, Journal of Nutrition, 133, 11 Supplement: 2, 3932S-3935S

81 Dror D K and Allen L H (2011). The importance of milk and other animal-source foods for children in low-income countries, Food & Nutrition Bulletin, 32, 227-243(17)

up substantial areas of land[82,83,84,85]. Demand restraint will undoubtedly make it easier to align the 'sustainable' and 'intensification' sides of the production challenge, and, by reducing pressure on land use, help avoid indirect leakage effects over space and time. Arable and pasture land currently used to rear livestock could then be "spared" not only for environmental and other purposes but also to grow a more diverse range of nutrient-rich plant and tree-based foods.

The question then arises: should the definition of sustainable intensification encompass health, as well as environmental objectives? Clearly healthy diets are an important policy goal. Achieving it will require actions to influence both supply (what food is produced) and demand (what is consumed). Equally it can be argued that an environmentally sustainable food production system may well be impossible if demand for foods with particularly large environmental footprints, such as meat and dairy products, is not modified[86] – and these are the foods whose over consumption often causes health problems. However while measures to align health and environmental goals are an urgent policy priority for the food system as a whole, it is less clear whether sustainable intensification *per se* should be tasked with nutritional objectives. In the same way that sustainable intensification should not become embroiled in discussions about how much food is needed (2.2 above) , it could be argued that it should it concern itself with what kind of food is produced. Rather, it is for society, to define what its production and consumption goals are. The role of sustainable intensification is then to deliver higher productivity (however defined) in ways that are sustainable (however defined). This question of whether non-environmental goals should be included in the definition of sustainable intensification is an important subject for debate, with valid arguments on both sides, and is discussed further below.

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82 Stehfest E, Bouwman L, van Vuuren D P, den Elzen MGJ, Eickhout B, Kabat P. (2009). Climate benefits of changing diet, Climatic Change, Volume 95, Numbers 1-2

83 Friel S, Dangour A, Garnett T, Lock K, Butler A, Butler CD, Chalabi Z, Roberts I, Waage J, McMichael A J, Haines A. (2009), Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture The Lancet, 374: 2016–25

84 Westhoek H, Rood R, van den Berg M, Janse J, Nijdam D, Reudink M and Stehfes E (2011), The Protein Puzzle, The Hague: PBL Netherlands Environmental Assessment Agency.

85 Scarborough P, Allender S, Clarke D, Wickramsinghe K and Rayner M (2012). Modelling the health impact of environmentally sustainable dietary scenarios in the UK European Journal of Clinical Nutrition doi: 10.1038/ejcn.2012.34

86 Foley J A, Rarmankutty N, Brauman K A, Cassidy E S, Gerber J S, Johnstone M, Mueller N D, O'Connell C, Ray D K, West P C, Balzer C, Bennett E M, Carpenter S R, Hill J, Monfreda C, Polasky S, Rockström J, Sheehan J, Seibert S, Tilman D and Zaks D P M (2011). Solutions for a cultivated planet, Nature. doi:10.1038/nature10452

5. Cross cutting themes and questions

In the discussion above, certain themes and questions come up over and again. The purpose of this section is to explore these in more detail and if possible to identify research questions whose exploration could further understanding in these areas.

5.1. Our goals for the food system and the role for sustainable intensification within it

One important theme to emerge is that we, as a society, need to define what the goals are for the food system – bearing in mind that in reality multiple, often interacting food systems operate within this concept. Broadly speaking, one might define the overarching vision for a food system as one that is nutrition-driven, equitable and ethically acceptable and that sits within long-term environmental limits. However this sort of definition is too broad; there is a need to develop a more detailed, context-specific vision of what a sustainable food system might look like, within which more localised food systems operate and taking into account the multiple factors that constitute both sustainability and food security. What is also essential is that different stakeholders recognise that they bring not just their knowledge, but also their values and ethical concerns to the discussion which are influenced by their own particular contexts.

Figure 2 identifies just some of the issues that need to be taken into account when considering the food system as a whole.

Sustainable intensification sits somewhere within this framework – but where? As the analysis above has indicated, sustainable intensification, if it is to be a meaningful aspiration, needs to be mindful of the social, economic and ethical context within which food production activities take place. A key question to consider therefore, is how formally these other concerns should be connected with the definition of sustainable intensification. Should the definition limit itself to environmental criteria or should it also encompass broader social and ethical concerns such as labour standards, animal welfare, or human nutrition (Figure 3)?

There are advantages and disadvantages to both approaches. A narrow environmental definition would leave society to define goals for food production (what type of food, limited by what sort of ethical requirements) and seek to deliver these in a way that is as ecologically sustainable as possible. This definition is simpler, although still complex in view of the difficulties of assessing sustainability over space and time, and in recognition of people's different value sets. It also has the advantage of not being normative – it allows for various sustainable food systems to be envisaged, based on different social and economic models, not one.

The danger with this narrow approach is that if non-environmental goals, such as improved working conditions, animal welfare or better nutrition, are excluded, they may be sidelined or given less prominence. For example, in many parts of the world the concept

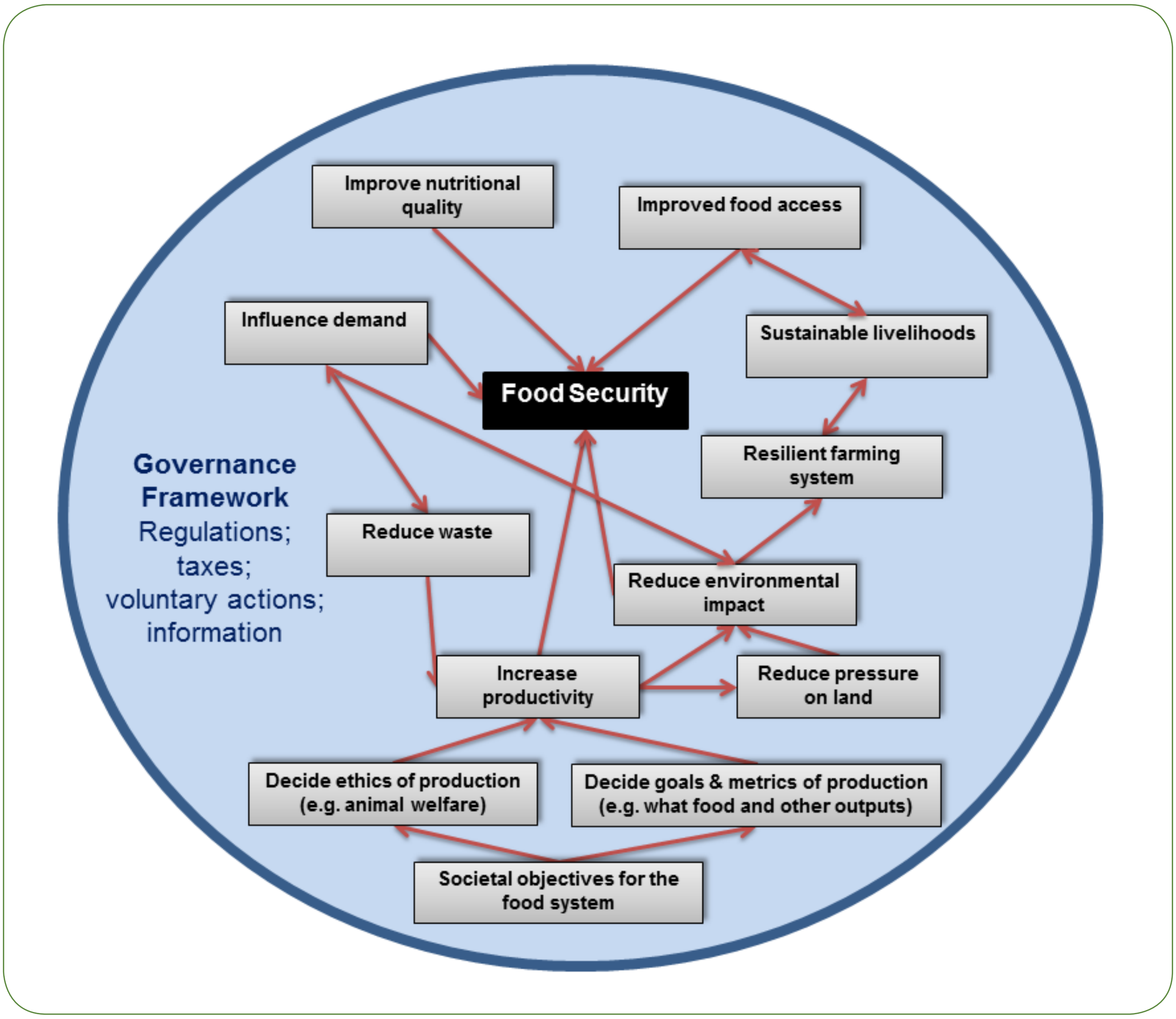

Figure 2: Elements of a sustainable food system

of animal welfare is weak or missing. Where sustainable intensification is used to justify systems of production that cause suffering to animals, the definition will continue to be treated with hostility by those from within the animal welfare community. It may therefore be desirable to define certain ethical parameters that constrain productivity objects – the BATNEEEC approach suggested above. Safeguarding welfare can also help production and environmental sustainability goals in the many contexts where win-wins are achievable. This is an issue that urgently needs to be investigated and resolved.

5.2. The need for better scientific understanding and refined metrics

Any decisions that society makes on changing the food system clearly need to be based on sound scientific knowledge. A major theme to emerge from the discussions above is that our understanding of how complex systems function over space and time needs to be improved. We also need to develop better metrics for measuring progress against targets.

In the environmental domain, further research into the interactions among water, carbon and nitrogen cycles is needed, as well as the relationship of all these factors to the different components of biodiversity. In a globally connected food system actions taken in one place

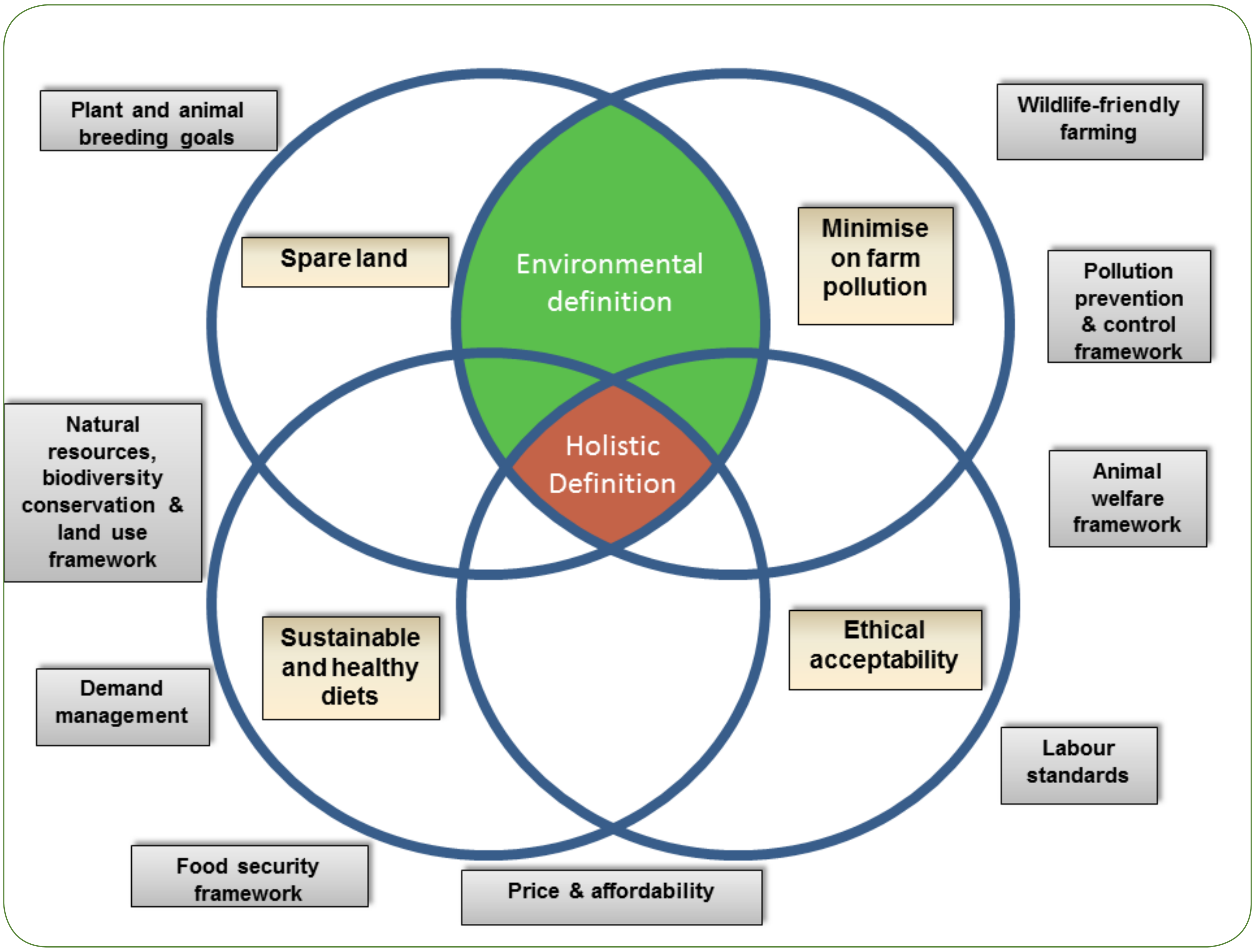

Figure 3: What is the scope of sustainable intensification?

are very likely to have indirect consequences in geographically distant areas as well as multiple effects that ramify into the future. It is therefore essential to understand system interactions both at very fine grained resolutions and at broader spatial and temporal scales. A greater understanding of these interactions needs to be accompanied by the development of better metrics for assessing environmental outcomes.

Taking livestock production as an example, intensive systems can, as noted above, achieve high outputs of meat, eggs or milk per unit of greenhouse gases emitted. Defined according to this metric they can be seen as preferable to more extensive systems although the relationship between these systems and the absolute growth in demand for livestock products (and associated absolute increase in emissions), requires further investigation (see above). They often score less well when viewed from the perspective of the use of irrigation water and fossil fuels. While intensive systems may use less land than extensive systems, they make use of different types of land and this may have implications for sustainability in the longer term. Intensively reared livestock, particularly monogastrics, are highly dependent on soy, a high quality source of protein; there have been concerns about the effects that interactions between the soy and cattle ranching industries have in driving both direct and indirect land use change in the Amazonian region and the Cerrado[87]. These interactions are complex, not fully understood, fluctuate in relation

87 Barona E, Ramankutty N, Hyman G and Coomes O T (2010). The role of pasture and soybean in deforestation of the Brazilian Amazon, Environ. Res. Lett. 5 024002

to changing commodity prices[88] but nevertheless have been confirmed to exist.[89] Also requiring investigation are the consequences of 'efficient' meat production on consumption trajectories over time. It can be argued that technological transformations, by massively increasing the supply of these foods, potentially foster new consumption habits and norms that in turn feed future growth in demand. A different perspective, however, is that this form of production allows currently disenfranchised people to eat the types of food that are enjoyed by those with high incomes. The contribution of system innovations to the 'consumption rebound effect' needs to be explored further in view of, on the one hand, the policy imperative to address hunger and malnutrition and, on the other, to address overconsumption and environmental damage.

Extensively grazed ruminants have the advantage of utilising land unsuited to crop production, are less reliant on grain inputs that require the use of scarce arable land, and potentially also have a role to play in contributing to soil carbon sequestration. However, there are also many examples where the landscape is over-grazed, causing soil degradation and soil loss, or where land with large carbon stores (or with great carbon storage potential) is converted to extensive pasture – deforestation in the Amazonian region being a prominent case in point. Moreover, the role of well managed grazing livestock in contributing to soil carbon sequestration is context dependent; in many regions pasture has achieved carbon equilibrium and no longer continues to sequester carbon. Grazing livestock may provide an economic, aesthetic or cultural rationale for not converting the land to other uses, but they do not always actively contribute to additional carbon uptake.

As regards nutrition and the broader livelihood outputs from the farm system, it is important to move beyond crude metrics such as yield, or calories, or income. As in the case of the environment, there is a need to understand the interactions and interdependencies of different elements of the farm system, to develop better metrics for measuring the multiple nutritional and non-nutritional goods and services that obtain and to link them to key anthropometric indicators of health status such as stunting or wasting. A key research priority is to understand how nutritional, environmental and economic outcomes interact.

It is often pointed out that farmers seek to hedge against risks not only by planting a variety of crops on farm (perhaps in combination with livestock) but also by engaging in a diverse range of on- and off-farm income and livelihood promoting activities. Hence to measure the output of just one crop from the farm system would give a misleading indication of the value the farmer gains from the system in relation to its environmental impacts. There is a real need to develop metrics that capture the multiple nutritional and non-nutritional outputs that can be obtained from agriculture, and to assess these against environmental objectives. For example, in a mixed farm system can we measure the diverse outputs that are obtained from the system, including the nutrients from different sorts of food and the values of non food goods (fodder, soil fertilisation timber), and examine how these outputs inter-relate? Can we develop ways of comparing these yields with those from specialised systems where the same outputs are produced by a number of individual single-output farms? Can an integrated system deliver more than the sum of its

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88 Macedo M N, DeFries R S, Morton D C, Stickler C M, Galford G L and Shimabokuro Y E (2012). Decoupling of deforestation and soy production in the southern Amazon during the late 2000s, PNAS, doi:10.1073/pnas.1111374109

89 Arima E Y, Richards P, Walker R and Caldas M M (2011). Statistical confirmation of indirect land use change in the Brazilian Amazon Environ. Res. Lett. 6

parts or are more specialised systems more effective in delivering outputs? How do these systems compare in relation to environmental impacts? Once again, understanding these interactions both at different spatial and temporal scales is needed.

5.3. Resilience and its relationship with diversity and productivity

This need for a systems perspective links to another major theme: the concept of resilience.

Resilience and sustainability are related but not identical concepts. Ways of producing food that can continue indefinitely into the future are by definition sustainable (though see above for discussion of the complexities involved). Part of this "continuability" is the ability to withstand perturbation – be it environmental (weather), biological (pests and diseases) or human (recessions, civil unrest). The resilience of a system is its ability to recover from a shock. Some resilience is essential for sustainability but a highly resilient system that bounces back rapidly after a perturbation possesses both stability and sustainability. One particular system might show high resilience to one type of perturbation but low resilience to another. For example, closed-system hydroponics using renewable inputs may be highly stable and sustainable and have high resilience to drought and other weather shocks, but because of high running costs low resilience to economic shocks.

Are diverse systems more resilient than simpler systems? In the ecological sciences this is a complicated question that has been the subject of intense research over the last two decades[90]. There is evidence that some properties of ecosystems show greater resilience (often equated with stability or a reduced tendency to fluctuate) in more diverse communities. The two main reasons for this are that (i) more complicated communities are statistically more likely to contain at least some species that are relatively little affected by the perturbation and (ii) in diverse communities one species is more likely to be able to compensate for damage done to another. There may thus be an "insurance effect" of biodiversity. But while ecologists have demonstrated that diversity can be associated with resilience, the effect is subtle and has not always been found where looked for. Perhaps the most consistent finding is not at the community level but at the level of the species: within-species genetic diversity increases the resilience of that species to perturbations involving pathogen attack.

Do these ecological insights help us to design resilient agricultural systems? The disease risks of genetically homogenous crops and livestock have been recognised since the dawn of modern agriculture. In principle genetic diversity can be maintained in the field by growing different varieties of crops or keeping different breeds of livestock; or it can be maintained "on the shelf" in seed banks or germplasm. Agronomists have long explored different disease management strategies and it is clear that the best approach for optimising resilience depends both upon the ecology of the disease system and on the socio-economic context. In-field genetic diversity is likely to be the best strategy for low-income smallholder farmers. Moving from within- to between-species diversity there is plentiful evidence that monocultures are more susceptible to pests, especially because the natural enemies of the pest frequently do not prosper in such landscapes. Greater resilience to pests and diseases can normally be obtained by diversifying crops, though often (but by no means always) at the expense of yields. The optimum level of diversity is then determined by the environmental costs and benefits of different cropping and crop

90 Cardinale, B.J. et al. (2012) Biodiversity loss and its impact on humanity Nature, 486, 59-67.

defence strategies. Diversity is more likely to be favoured when the full costs of agricultural externalities are included (for example the costs of pollution) and in low-income contexts where advanced crop protection is not available or feasible. There is also an argument that in high-input conventional agriculture some of the potential benefits obtained in more diverse systems (for example those that integrate livestock and crops) are poorly appreciated and hence are not included in considerations about how production systems might be optimised. Further research here is clearly needed.

The potential advantages of mixed, diverse systems in providing the full range of human nutrients was discussed in Section 4.3. To understand what a nutritionally *resilient* diet might be we need to know the response to perturbation of, for example, the mix of crops. For example, if the perturbation is a drought then it is important that the most drought-resistant crops are able to support healthy human life until better conditions return. A problem in arid Africa is that the most drought-resistant crops are often nutritionally unbalanced. Biofortification may thus have a role in improving dietary resilience in the short term. On the other hand if the biofortified crop is relied upon as the main food source over long periods of time, the risk is that people may not obtain the full of range of nutrients required for optimal health.

There are deep parallels between the theories of ecological and economic resilience. Intensification may change the balance of economic risks that producers are exposed to and there is clearly a need for greater understanding of the relationship between environmental and economic resilience. Concentrating on single agricultural outputs increases exposure to negative price movements or to weather shocks; on the other hand it leads to economies of scale and increases the pay-off in normal years. More generally, livelihoods that depend purely on agriculture are susceptible to economic or physical conditions that affect the whole sector. As with ecology and agronomy these risks can be hedged either from outside the system by taking out insurance against future unwelcome eventualities, or from within the system by diversifying into multiple agricultural commodities (or non-agricultural sources of income). Which of these strategies leads to more resilient and hence sustainable outcomes again depends upon context - in the absence of insurance, biological diversity strategies are likely to work best in low-income situations.

5.4. Values and ethics

When considering the desired outputs from the system, the metrics we use and the notion of what constitutes resilience, scientific information will only get us so far. The values and ethical perspectives we bring to the discussion are equally important. This is not at all to say that values substitute for scientific knowledge – on the contrary. But facts needs to be contextualised, and meaning assigned to numbers. Beyond a certain point the values and ethical perspectives we bring to the discussion will influence what we want the food system to deliver, how we prioritise the different indicators of sustainability that science provides, the power and motivations we attribute to individuals, businesses and governments and the scale and time frame we adopt. All these shape what the 'right' course of action is judged to be.

Many of the disagreements about sustainable intensification arise because while differences in values underpin the different approaches proposed, they are implicit, and not made clear. This means that people are often talking at cross purposes. There is a real need for policy makers to take values more seriously and to explicitly incorporate analysis of the different perspectives that people bring into discussions about food security and sustainability.

5.5. Governance

Many of the uncertainties around sustainable intensification reflect uncertainties about governance in the food system, both by governments and other actors. In the absence of global controls on land use change, on GHG emissions from agriculture or indeed on any of the concerns that arise when considering sustainability and the food system, it is very hard to ascertain how theory will translate into practice. Will land sparing work or will it be undermined by the workings of economic markets? How will national level policies on agriculture influence global food prices and what will the knock on effects be on people's health and on the environment? Can knowledge about the relationship between environmental sustainability and diets be turned into a set of policies that influence people's consumption patterns? What policies will enable farmers and other stakeholders to make decisions that are sustainable not just in the short but in the long term?

The absence of global agreements on all these issues cannot be an excuse for inaction by individual governments and other key stakeholders in the food supply chain. Leadership by individual countries can benefit not only their national interests but also contribute to collective progress in developing transnational regulations. Policy makers can make a start by prioritising the easy wins, where there are clear synergies among competing goals and less risk of leakage. Obvious areas for more work include collaborative action to raise productivity in sub-Saharan Africa and in other low yielding regions; to improve animal welfare in situations and countries where there are clear synergies between animal health and productivity; and to fund scientific research that focuses on systems thinking and the development of metrics that better reflect the inter-relatedness of agriculture's multiple inputs and outcomes.

What is also clear is that governance around sustainable intensification can never be 'just' about the environment since agricultural production has impacts that go far beyond the ecosystem. How food is produced, who produces it, what and how much is consumed and by whom, are all factors that have far reaching consequences for people's health, for human development, and for the welfare of animals reared for consumption. A system of food production that is socially, economically or ethically unacceptable to a large fraction of the population will lack "continuability", or resilience, however ecologically attuned it may be.

6. Conclusion

Sustainable intensification is still a new and evolving concept. For now, it is most accurate to see it as providing an intellectual framework, or process of enquiry and analysis for navigating the issues and concerns, rather than a clearly defined set of principles and practices. Further work is needed to see what sustainably intensive systems might look like in the field, and how they vary from context to context.

However, we believe that certain key insights do emerge from the discussion above as to what sustainable intensification needs to be – and what it is not. They are summarised as follows:

- Both words in the phrase sustainable intensification need to carry equal weight. Intensification, by reducing pressure on land and other resources, underpins sustainability. Equally, food production in the context of a growing population, must ultimately be sustainable if it is to continue to feed people in the future.
- Sustainable intensification is not a movement or a grand socio-political vision. It is not a strategy for the food system as a whole but just for one component within that strategy.
- Sustainable food security requires actions on multiple fronts. On the demand side actions are needed to reduce population growth rates and to curb high levels of per-capita consumption, particularly for resource intensive foods. The food system needs to be more efficient by improving governance and reducing food losses and waste throughout the food chain, from farm to plate. On the supply side more food will need to be produced with much less impact on the environment through, we conclude, sustainable intensification. No one of these actions on its own is able to achieve sustainability and security in the food system. Sustainable Intensification should therefore be seen not as a substitute for, but as a complement to these other necessary measures.
- Sustainable intensification as a concept should be decoupled from specific production targets. Sustainable intensification is about optimising productivity and a range of environmental and possible other outcomes.
- Sustainability needs to be viewed over space and time in order to include the indirect effects and consequences of different policies that may impact on other regions and future generations. The indicators used to measure sustainability may also vary according to temporal and spatial scales.
- Societies need to negotiate what outputs and outcomes from the system they want to intensify production of and to develop metrics that enable us to measure progress against targets.
- Much can be done with existing knowledge but there is also a need for more research that takes a more systemic approach to food production. Greater understanding of how

the various elements of complex systems interact is needed, both at fine grained and broader spatial and temporal scales. This understanding needs to encompass not just environmental interactions but also the relationship between the environment, human health, ethics and livelihoods. In short, there is a need to recognise better that human technical and societal innovations and the environment influence one another, and to understand these interactions further.

- More work is needed to translate this thinking into the development of metrics that are relevant to different stakeholders in different contexts, to assist them in implementing appropriate strategies.

- It is necessary to decide whether sustainable intensification is most helpfully defined only in environmental terms, or whether it should specifically incorporate a broader range of social and ethical concerns. If the former, sustainable intensification nevertheless needs to be mindful of these other concerns, and of the potential for tradeoffs and perverse outcomes.

- There are major opportunities for improving environmental and productivity outputs simultaneously in agricultural systems with current low levels of production. However, trade-offs between yields and environmental outputs are more prevalent in high external input production systems.

- More work is needed to ascertain what mix of policies is needed to transform thinking about sustainable intensification into practice. In particular it is important to identify what can be achieved at the national or even more local level, and where further work is needed to improve the international governance framework.

- While there is a need for more scientific knowledge, it must be recognised that values shape stakeholders' different attitudes to the food system and their views on what the way forward should be. More deliberate exploration of these different values will help society obtain a deeper and shared understanding of what the challenge is and of what solutions might work.