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Applying the concept of sustainable intensification to Scottish Agriculture

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Abstract: A number of influential policy circles have championed the concept of sustainable intensification (SI) as a technology to meet the challenge of a growing population. Various definitions exist for sustainable intensification, but the concept is driven by future constraints on land use. Most of the work directed at SI has been focused on developing countries, where the imperative for output increases are paramount. Fewer studies have applied the concept to developed economies. This paper examines this concept for Scotland, which is experiencing falls in productivity and has a complex policy arena based on quality rather than quantity improvements.

We develop a schema for understanding the concept of sustainable intensification which we argue must develop beyond the provision of eco-systems services and encompass social as well as economic and ethical parameters. We apply these concepts and apply data from the Farm Account Survey for a balanced panel of 42 beef farms within Scotland over the period 2000-2010. A principal components analysis was applied to these data to provide a basis for understanding weighting structures within the various dimensions of sustainability and we find five main components, one of which strongly represents the intensivity but under-represents other sustainability factors.

We recommend that regions adopt a definition of sustainable intensification that i) is specific to the production trajectories of that region, ii) provides adequate representation across actors within the food supply chain, and iii) offer clarity for measurement. The conceptualisation of sustainable intensification along these lines would, we recommend, allow key members of the food supply chain to develop specific solutions to divert from future projected problems in food production.

Keywords: sustainable intensification, beef production, Scotland

JEL code: O33; Q16;

Introduction

Intensification of agricultural activity has been the main cause of loss in the range of ecosystem services provided by UK agriculture (Firbank *et al.*, 2011). The notable exception has been the yield provisioning function of agriculture which, since the Second World War, has improved substantially.

The main driver of this yield growth have been increases in productivity (Thirtle *et al.*, 2003; Barnes *et al.*, 2010). Future economic and social change suggest that intensification of agricultural production is still an option for the management of agriculturally dominant landscapes. Influential policy and academic circles are beginning to explore the concept of '*sustainable intensification*' (Ambler-Edwards *et al.* 2009; FAO, 2010; Jaggard *et al.* 2011). This concept aims to meet the multiple aspirations of society, in terms of securing and increasing yield, as well as the functional and cultural benefits society values, e.g. protecting and enhancing bird species abundance.

There are also emerging global research and policy agendas based on the sustainable management of agricultural land and its synergies with the production of multifunctional benefits from these landscapes (Pretty *et al.*, 2011; Foley *et al.*, 2011) and this aligns with the requirements of a number of countries and international bodies which are searching for land management solutions aimed at balancing socio-economic and ecosystem service management provision.

However, the bulk of studies have applied this approach to the developing country context where sustainable trajectories are required for maximising output growth (Pretty *et al.*, 2011). Within a developed country context the argument for output expansion within the panacea of attaining food security may be questionable, as it vies for arguments related to sustainable consumption (Foley *et al.*, 2011). In addition, most Western developed countries have experienced a stagnation in productivity growth rates (Fuglie, 2010) which may signify a substantial reexamination of how production resources should be allocated and what technologies are required to shift output upwards.

Scottish Policy context

The Government Economic Strategy, published in 2007, identified that the food and drink sector offers opportunities for growth (SG, 2007). This was embodied in the 'refreshed' Food and Drink industry strategy (Scotland Food and Drink, 2010). Principally this aims to grow industry turnover from £10bn to £12.5bn by 2017 and this would be achieved by focusing on '*the global growth markets of premium, provenance and health*'. This strategy mostly aims for growth through value-added processing.

The five strategic objectives of the Scottish Government (SG) are to be: to be '*Greener*', '*Safer and Stronger*', '*Healthier*', '*Wealthier and Fairer*', and '*Smarter*' and the SG seek sustainable economic growth under these parameters. The focus is on a wider set of challenges, such as increasing skills and employment opportunities within the Food and Drink Industry. The emphasis for the primary sector within this strategy tends to infer quality improvements rather than actual physical increases in output. Government strategies also strongly embed sustainability within the growth scenarios. The Food and Drink Industry strategy understands sustainability of Scotland's food and drink industry to be:

‘..that we continue to make a healthy and growing contribution to the Scottish economy; and that by continuing to behave responsibly towards the environment we benefit our reputation and growth.’

(SG, 2010, pp. 6)

Scottish agriculture also operates within the framework European Union policy which is principally reflected in the Common Agricultural Policy (CAP). The CAP will be reformed in the near future and recent statements have promoted the continuation of a similar structure but with two main changes. First, the formal objectives of the CAP will reflect the priorities of ‘*Europe 2020*’ which, much more explicitly, promotes resource efficiency along with ‘smart, sustainable and inclusive growth’. Second, money will be diverted towards so-called ‘greening’ measures. This is currently under discussion and it is not clear exactly how agriculture will be greened under the new proposals. Nevertheless, this may provide a basis for joining the environmental aspects of the policy to production related goals within farming.

The focus on resource use efficiency at the EU level also allows some of the goals for the Scottish Government’s smart sustainable growth to be achieved and feeds into wider SG aspirations for reducing environmental impact. Hence, concentration on reducing waste within the production process helps to achieve commitments on water quality and also on climate change, through mitigating greenhouse gas emissions from reduced application of fertiliser, as well as increased efficiency within livestock production.

The aim of this paper is to develop both a conceptual approach to sustainable intensification and how to translate the technology of sustainable intensification to a specific Scottish context. Scotland is an example of a developed Western economy with a unique mix of ecosystem provision and production-attributes. It then applies this approach using Farm Account Data for a balanced panel of Scottish beef producers, which enables consideration of the biophysical and structural parameters under which Scottish farming operates. The relationship between sustainability and intensification and possible indicators for sustainable intensification are discussed. Multivariate statistical techniques are applied to examine the relationships between these indicators. The final section offers discussion and conclusion points in terms of the policy implications and research questions which should be directed towards sustainable intensification issues within a Scottish context.

Conceptual Approach

It is important if we are to identify the potential for sustainable intensification to be clear on how it is defined. This concept aims to meet the multiple aspirations of society in terms of securing and increasing yields, as well as the benefits it values, such as protecting landscapes and wildlife. A common definition can be found below (Pretty et al, 2011):

Sustainable agricultural intensification is defined as producing more output from the same area of land while reducing the negative environmental impacts and at the same time increasing contributions to natural capital and the flow of environmental services

(Royal Society, 2009; Godfray et al., 2010).

There are disciplinary differences in perceptions towards intensification and sustainability (Russell, 2005; 2011). He argues that within an economic view, there is ‘*a short-run search*

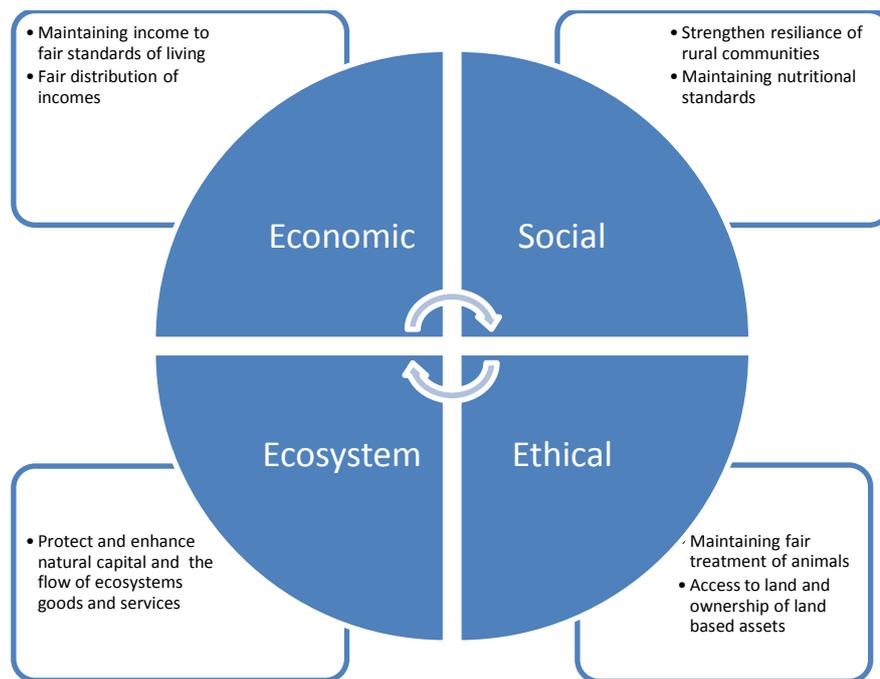
for ways to increase variable inputs and output per hectare without compromising the integrity of the ecosystem within which production is embedded'. A longer term view, adopted by natural science disciplines, defines intensification as any increase in inputs per hectare plus any increase in output per hectare whether or not it is accompanied by an increase in inputs.

Generally, most policy and research towards farm management have supported ranges of activity to generate ecosystems services from agriculturally dominated landscapes. This tends to be in the support of extensive activity, for example research finds that maintaining low stocking densities will encourage maintenance of nesting habitats and support for invertebrates. Other services from agriculture, such as the social value of maintaining landscapes are also higher under extensive, compared to intensive, management (Moran, 2005). However, recent policy relevant reports have highlighted concerns that farming activity has become too extensive, leading to a potential loss of these ecosystems services. This is especially true in the hill and upland areas after decoupling of CAP support from production (SAC, 2009; Thomson, 2011). There is consequently an argument that intensifying activity, to prescribed levels, will support Scotland's goals for sustainable growth.

Nevertheless, it seems that sustainable intensification is a difficult thing to wedge into current policy goals. As the focus on improving the quality of the product may be compromised by increasing intensification. The main selling point of the Food and Drink Strategy is that Scotland promotes its natural assets and capital. A clearer route to sustainable intensification may rely on resource use efficiency, for example reducing wastage from over application of agro-chemicals into the system. The impact may be to improve outputs but is focused on improving the efficiency of inputs, which by implication reduces costs and thus supports economic sustainability within agriculture.

Some thought is needed towards how sustainability could be defined. Sustainable intensification emerged from the ecological arena and, as such, policy and research documents seem to have a bias towards this area of sustainability. However, sustainability can cover a number of dimensions. Within the Scottish context we propose the following four dimensions which could be used a basis for understanding sustainability within agricultural intensification.

Figure 1. Proposed four dimensions of sustainable intensification for Scottish agriculture



Thus economic sustainability encompasses the income aspects of farming, covering both farmer and employer incomes, in terms of maintaining a sustainable level of income¹. This implies that the maintenance of a fair standard of living is indicated by economic factors. Net Farm Income will also have effects on the long term sustainability of the system, through reducing debt ratios and maintaining capital to ensure efficiency of operation. For example a recent analysis of ‘uneconomic’ farmers has found that a number of producers are operating at low or negative levels of Net Farm Income and these are further characterised as having long term, and increasing, debt to asset ratios (Barnes et al., 2011).

Social sustainability embeds the impact of farming within the rural communities under which they operate. Most studies are now finding a decoupling of farm income from rural communities (in terms of the input output impacts), i.e. evidence of leakage of monetary payments. In addition, the social function of farming covers the production of food and further enhances its provenance. Growing consumer segmentation has led to a wide set of demands on aspects of food production which need to be addressed, ranging from income related (e.g. access to cheap food) to environmental and welfare related criteria that are deemed important to consumers.

Little work has been conducted on the ethical dimensions of sustainable intensification. Indeed, some commentators may not include this within a definition of sustainable. However, it should be considered within the Scottish context as, firstly, livestock produce is

¹ Notably here we could also include cost efficiency, but most studies focus on the changing physical relationships between inputs and outputs. Thus, farming income effects are imputed through the increasing technical efficiencies in the production process, but this ignores the supply chain aspects of sustainable intensification, in which input and output prices are distorted by relationships with suppliers and the retailers and the overall definition of sustainability may be biased against the producer, rather than in favour of the ecological and biophysical aspects of this definition.

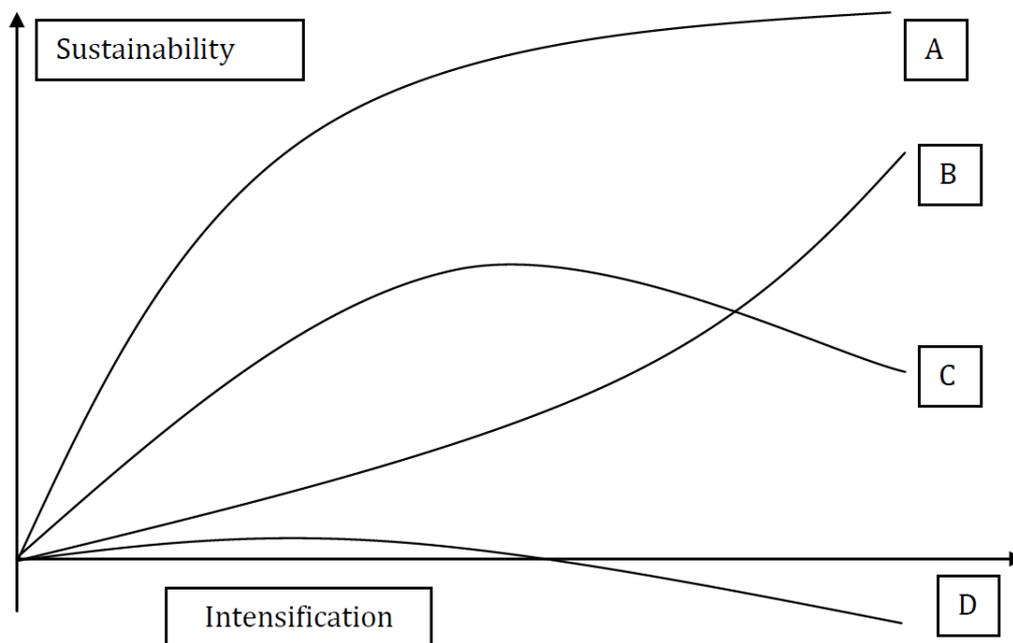
considered of high quality and the extensive production systems evident in Scotland may be a significant factor in providing a key attribute to defining Scottish produce. The growth in intensity of production has to have an ethical dimension as the simple increase in stocking densities can increase incidence of disease and health issues, but also the achievement of greater yield per livestock unit may rely on a technology fix that could lead to harm within the production system, e.g. genomics for yield growth may have a negative impact on welfare factors.

Ecosystem sustainability and intensification is intrinsically linked with the biophysical capacity of primary inputs (MEA, 2005). The most comprehensively studied aspects of intensification have been the relationship with other ecosystem services (Firbank et al., 2011; Storkey et al., 2011). This literature has generated a wealth of sustainable management recommendations, including initial explorations of sustainable intensification itself (Pretty, 1995; Matson et al., 1997).

The noticeable reduction in the quality and structure of soil and other primary factors have been found to be a consequence of industrial agricultural methods. In addition, the increased carrying capacity needed to maintain yield growth has been generated by the application of chemical nutrients. However, there is growing evidence that plateaus have been reached in global yields, which are strong indicators of the limits to biophysical capacity (Licker et al., 2003).

Sustainable intensification must also be defined against a temporal background, and, indeed, is a significant factor for change within an agricultural system, as it encompasses the trajectory of 'extensification to intensification' just as much as the 'unsustainable to sustainable' trajectory. A graphic representing this conceptual approach is provided in Figure 2 and is illustrated with four possible trajectories for the agricultural industry, capturing sustainability criteria under intensification pressures.

Figure 2. Conceptual Trajectories for Sustainable Intensification



Trajectories: A: Quick Start, Sustained Growth; B: Slow Start, Rising Growth; C: Post-Optimal Decrease; D: Failure to Launch

These four pathways are:-

A: Quick Start, Sustained Growth: This is perhaps the most desirable for policy makers with short term goals as it implies a switch to technologies which offer quick rewards in terms of the differing dimensions of sustainability (Figure 1.1) but also improves as intensification rises. There will be some optimal point which is reached and is sustained as intensification rises, perhaps through development and adoption of further production focused technologies and techniques.

B: Slow Start, Increasing Growth: Much like the first trajectory, this offers benefits for the policy makers and society in general but encompasses low initial adoption and development of technologies which cross the paradigm of increasing intensification and sustainable growth. However, the successful adoption of these technologies will sustain growth and hence encourage uptake of sustainable practice.

C: Post-Optimal Decrease: This provides the reverse of B, offering quick short-term wins, through perhaps the uptake of technologies which already exist that provide so called win-win situations. However, this is not sustained through lack of results, investment in throughput of technologies or, more critically, achieving actual limits to yield growth. Hence, as intensification increases the damage levels increase.

D. Failure to Launch: Sustainable intensification may, like a number of technologies fail to be adopted as a practice on farms. Agriculture does provide a 'graveyard' of technologies which seem to offer benefits to both sustainability and intensification which have not been

adopted. A great deal of behavioural work is being conducted on encouraging uptake, and this trajectory perhaps has the most prominent precedent within most developed country farming systems.

Data and Methods

The beef sector is the most prominent livestock enterprise within Scottish agriculture. Whereas it contributes to around 20% of total value of primary output (ERSA, 2011), it provides nearly 60% of all livestock output value within Scotland. In addition, it provides a high quality segment which generates significant returns throughout the supply chain. Scotland is also characterised by limited land use and over 80% of agricultural land in Scotland is classified as Less Favoured Area. Thus cattle farms are characterised by large areas of rough grazing which offer significant ecological benefits and by high remoteness factors, thus embedding social factors within their existence.

The Farm Account Survey, which covers a sample of around 500 farms per year and offers detailed indicators on inputs, outputs and socio-economic data on the farms themselves. The Farm Account data are collected yearly under EU FADN quality guidelines and using these data, indicators of intensification and sustainability were generated. A balanced panel of 42 farms over the 11 year period 2000 to 2010 could be extracted from the FAS. Table 1 shows standard descriptive statistics of the 42 farms.

Table 1. Descriptive Statistics of the Scottish Beef sector farms, 2000 to 2010 averages

	Mean	Std. Dev.
Total Grass (Ha)	90.2	45.2
Rough grazing (Ha)	34.8	56.5
Farm Business Income (£2000)	6,724.1	16,230.8
Total Output (£2000)	77,381.6	38,593.8
Cows (No.)	88.0	42.6
Total Animals (Grazing Livestock Units)	139.5	69.5
Farmer Age	57.8	10.9
Annual Farmer Hours Worked	3,244.5	1,494.8

Farm Business Income represents total profit to the business and these fluctuate over the period and have recently increased to an average of £38,335 due to the increasing value of beef (ERSA, 2011). The average farms have around 30% of their total land from rough grazing, whereas the remainder are from mostly permanent pasture. Though again, there is some significant fluctuation over time and across farms. Average cows are below 100 but even specialist cattle farms have mostly some mixtures of beef production, along with sheep. Very few farms have off-farm labour, employing seasonal labour rarely.

Measuring sustainable intensification in Scotland

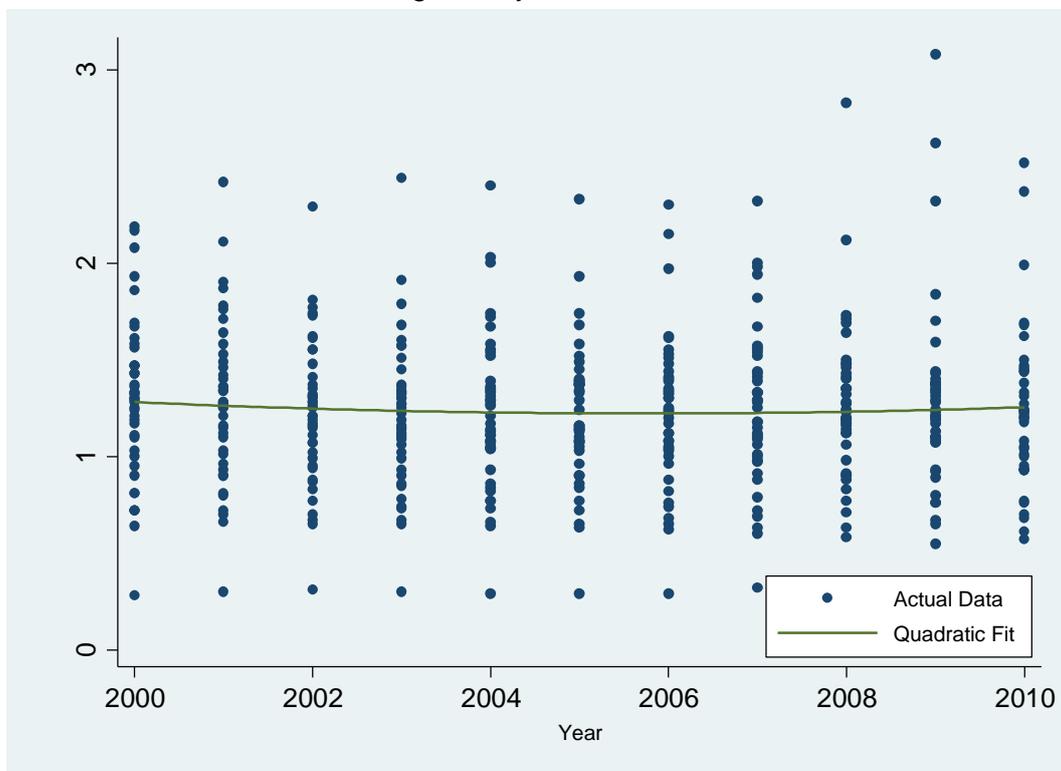
The purpose of this section is to attempt to outline a baseline for measuring sustainable intensification within the Scottish context. The four dimensions presented in Figure 1 are discussed and, where possible, indicators are presented from the Farm Accounts Survey. Furthermore, indicators of intensive production are also discussed in order to understand

how intensification has developed over this period and the underlying potential that exists for growth in the system. It is important to note the observation of Dietrich *et al* (2010), that a number of indicators exist for measuring land use intensity, but fewer studies define land use intensification, that is the process of an increase in land use intensity. Accordingly, by tying the analysis to secondary data collected annually some indication of the temporal dimensions of sustainable intensification can be provided.

Intensification indicators

The simplest measure of intensification in the livestock sector is a ratio of output to a particular input, such as grazing livestock units². Figure 3 shows stocking densities per farm type, that is the mean grazing livestock units (GLU) per hectare of grassland and rough grazing over the period 2000 to 2010, along with a fitted quadratic trend.

Figure 3. Overall variation of stocking density over time for LFA cattle farms



Average stocking density for the 42 farms fell from 1.29 to 1.22 in the ten year period. The stocking density series were tested for stationarity applying the Harris–Tzavalis test for balanced panel data. This is applicable when time periods are small (10) relative to the number of panels (42). This assumes that the number of panels tends to infinity while the number of time periods is fixed. Furthermore we add a linear time trend. In addition to reduce any cross-sectional dependence we subtract the cross-sectional mean from each time period³. This was implemented in Stata and rejected the null hypothesis of a unit root ($\rho=0.09$; $z=-5.13$; $p\text{-value}=0.000$). Consequently, we find no trend in the intensification

² Grazing livestock units is the result of multiplying all animals on a farm by a corresponding conversion factor related to their grazing intensity. These can be found in the SAC Farm Management Handbook.

³ Testing with and without these assumptions led to the same rejection of the null hypothesis, i.e. the data are stationary

series over this period. This would be expected as policies directed at this sector have not promoted improving intensification.

Sustainability indicators

A small number of studies have attempted to generate indicators of sustainable intensification, the most relevant being Ripoll-Bosch et al. (2012). These authors used a combination of secondary and primary data and on-farm monitoring to develop indicators of sustainability. However, the bulk of their indicators were collected through primary data. This is not the ambition of this study, as we wish to examine changes over time, i.e. intensification rather than intensity. Accordingly, we present a practical approach for policy makers to measure SI within their agricultural systems.

Ecosystem Indicators

Table 2 shows the variables that may give some indication of change in supply of ecosystem services from the FAS. The principal one being the level of rough grazing area to total area. This has been used as a criteria for identifying Higher Nature Value farming systems (Barnes et al., 2011) and thus presents a useful proxy for generation of ecological habitats. Finally, the ratio of permanent to temporary grassland is an important indicator for Scotland as permanent grassland represents a stronger level of lock-in of carbon and soil structure compared to temporary grass. Hence, changes in the relative area of these two can give some dimension on the ecological and climatic value of this natural stock and, indeed, is strongly related to the intensity of livestock production.

A further three variables are added which reflect dimensions of biophysical stress within the system (and hence damage to natural capital). Long-term productivity (which encapsulates the process of conversion of inputs to outputs) can be measured by examining output growth relative to input growth. In addition, specialisation of production reflects an increase in mono-production and the loss of species diversity that emerge from a mixed farming system. This latter indicator, however, is fraught with difficulties as we must weigh the ecological services higher than the yield provision services that comes from specialisation within the system itself.

Table 2. Proposed Indicators of ecosystem aspects of sustainable intensification

Variable	Calculation
RGA <i>Rationale</i>	Total Rough grazing Area / Total Area <i>Rough grazing is reflective of the biodiversity mix relative to managed agricultural land. Higher levels of rough grazing per total area leads to increased biodiversity and related improvements.</i>
TPG <i>Rationale</i>	Ratio of permanent to temporary grass area The level of permanent grass area reflects maintained soil structures and preserves carbon sinks effects. Higher levels of permanent grassland lead to greater carbon capture.
LANDPROD <i>Rationale</i>	Total output value to total area <i>Indicator of land productivity. Higher levels indicate some preservation of the natural stock of biophysical capital.</i>
SPEC <i>Rationale</i>	Value of livestock output to total output (*) ⁴ <i>A proxy for specialisation of activity. Higher levels indicate less diversity in the resources for ecological preservation.</i>

Economic Indicators

The main purpose of the farm account survey is to examine financial changes within farming. Hence, a comprehensive range of factors can be found to demonstrate some aspects of economic sustainability. These range from debt factors (such as interest cover) to resilience factors (such as the level of subsidy within a system).

Table 3. Indicators of economic aspects of sustainable intensification

Variable	Calculation
INTC <i>Rationale</i>	Interest cover to total debt (*) <i>The level of interest paid to total debt is a proxy for financial stress. Higher levels of risk indicate more financial stress on the business.</i>
SUB <i>Rationale</i>	Total subsidies to farm gross margins (*) <i>Higher levels of subsidy burden mean less resilience within the business to market forces.</i>
RE <i>Rationale</i>	Total rent and interest paid to farm gross margin (*) <i>Reflects the burden of the land and machinery and building factors on profitability. Higher levels indicate financial stress within the business.</i>
LABC <i>Rationale</i>	Total costs of paid labour to gross margin (*) <i>This reflects the amount of the external labour on profitability. Higher levels indicate more financial stress within the business.</i>
CONT <i>Rationale</i>	Total costs of contracting to total variable costs (*) <i>This reflects the amount of total contracting within the cost profile of the farm business. Higher levels indicate a higher burden on the farm business.</i>
ECONEFF <i>Rationale</i>	Total output value to total fixed and variable costs <i>This reflects the efficiency within the farming business of converting total costs to total output. Higher levels indicate higher levels of efficiency.</i>

⁴ For some indicators the inverse of the ratio was taken, this ensured consistency of measurement across the indicators, i.e 0 = low, 1 = high. Where an inverse was taken in what follows a (*) symbol is attached.

Social Indicators

In capturing social aspects of sustainability a number of factors related to on-farm work can be derived. However, such aspects as rural impact can only be hinted at through these indicators, as they can reflect both the numbers of non-family farmers, but also the levels of diversification within the farming enterprise.

Table 4 . Indicators of social aspects of sustainable intensification

Variable	Calculation
LABFAMIX	Total farmer hours to total hours worked (*)
<i>Rationale</i>	<i>Indicator of farmer work intensity relative to total farm hours needed Higher levels indicate increasing stress</i>
HIRDMIX	Total hired labour hrs to total hours worked
<i>Rationale</i>	This indicates the amount of external labour entering the farm. It therefore provides a proxy for rural income opportunities and income generation.

Notably, other indicators could be explored such as the ratio of farm business income to net farm income, however this is only available from 2008 onwards and therefore is disregarded within this study. Other factors considered were age related, namely farmer and partner ages which would reflect some element of innovation and succession. The literature on this is mixed and hence no definite impact of age could be used to assess social sustainability.

Ethical indicators

No ethical dimensions could be found through the farm account survey. Suggested variables were related to cow yield or feeding rates, which may be a proxy for ethical treatment of animals. However, this is probably not the case as the management of the animal is a significant factor in meeting ethical desires regarding welfare and these are not measured in the FAS. Some studies have collected on-farm data and reconciled this against farm management performance (e.g. Barnes et al. 2011c; Hansen et al., 2011). Hence, the ethical aspects of sustainable intensification could not be progressed here and require further research.

Reconciling sustainability with intensification indicators

Key decisions are how to weight the various dimensions of sustainable intensification, and also the indicators themselves within the various dimensions. For example, food production is presented within the ecosystem dimension through land productivity. Food production related issues have had an interesting and fluctuating influence on policy makers throughout the last twenty years. In 1989, it could be argued from a policy perspective that food production was the central concern of farming, as both the EU and UK were promoting output expansionist policies. However, society was becoming increasingly critical of the loss of environmental quality at the public expense of generating output surplus from these policies.

Furthermore, the ethical dimension is a critical aspect of understanding change over time, as perceptions of animal welfare and, overall equity, within the food production system have grown. Under intensification scenarios this is critical as, if food scarcity increases, then

perhaps ethical considerations are reconfigured. Consequently, there is an element of future uncertainty that could be mapped within, perhaps, a textual analysis of documents related to agriculture. This may provide a way to weight demands from agricultural production which would change. Ripoll-Bosch (2012) used workshops to generate weightings on a farm by farm basis, which is perhaps the correct approach. Nevertheless for an exploratory study such as this we rely on an objective and quantitative approach to reducing the numbers of variables within the data to derive weightings, namely principal components analysis.

As we have time series data, the sustainability series were tested for stationarity, like the intensification series, by applying the Harris–Tzavalis test for balanced panel data. The results are shown below and indicate no trend in these indicators of the 2000 to 2010 period.

Table 5. Unit Root Tests on Balanced Panel, H-Z unit root test

	ρ	z	Ho: Unit Root
RGA	-0.03	-7.07	**
TPG	0.00	-6.82	***
LANDPROD	-0.04	-7.46	***
SPEC	-0.11	-8.89	***
ECONEFF	-0.18	-10.04	***
INTC	-0.36	-13.36	***
SUB	-0.18	-10.04	***
RE	-0.06	-7.80	***
LABC	0.24	-2.51	***
CONT	-0.09	-8.46	***
LABFAMIX	0.23	-2.61	**
HIRDMIX	0.06	-5.70	***

PCA is a correlation based technique which can be used over time, using time segments to chart progress. If the data were non-stationary then PCA correlation coefficients would not be stable however all time series reject the null hypothesis of a unit root. Accordingly, none of the indicators have any strong trend elements and they can be compiled under a stationary PCA (Yang and Shabibi, 2005). The importance of variables, representing social, economic and ecosystem sustainability and intensification over time are revealed within this approach.

Table 6 shows the eigenvalues and degree of variation explained for the first five components. Using the standard Kaiser criterion of 1.0 as the cut-off, 5 components appear in the data, explaining 69% of the observed variance in the data.

Table 6. General statistics for principal component analysis

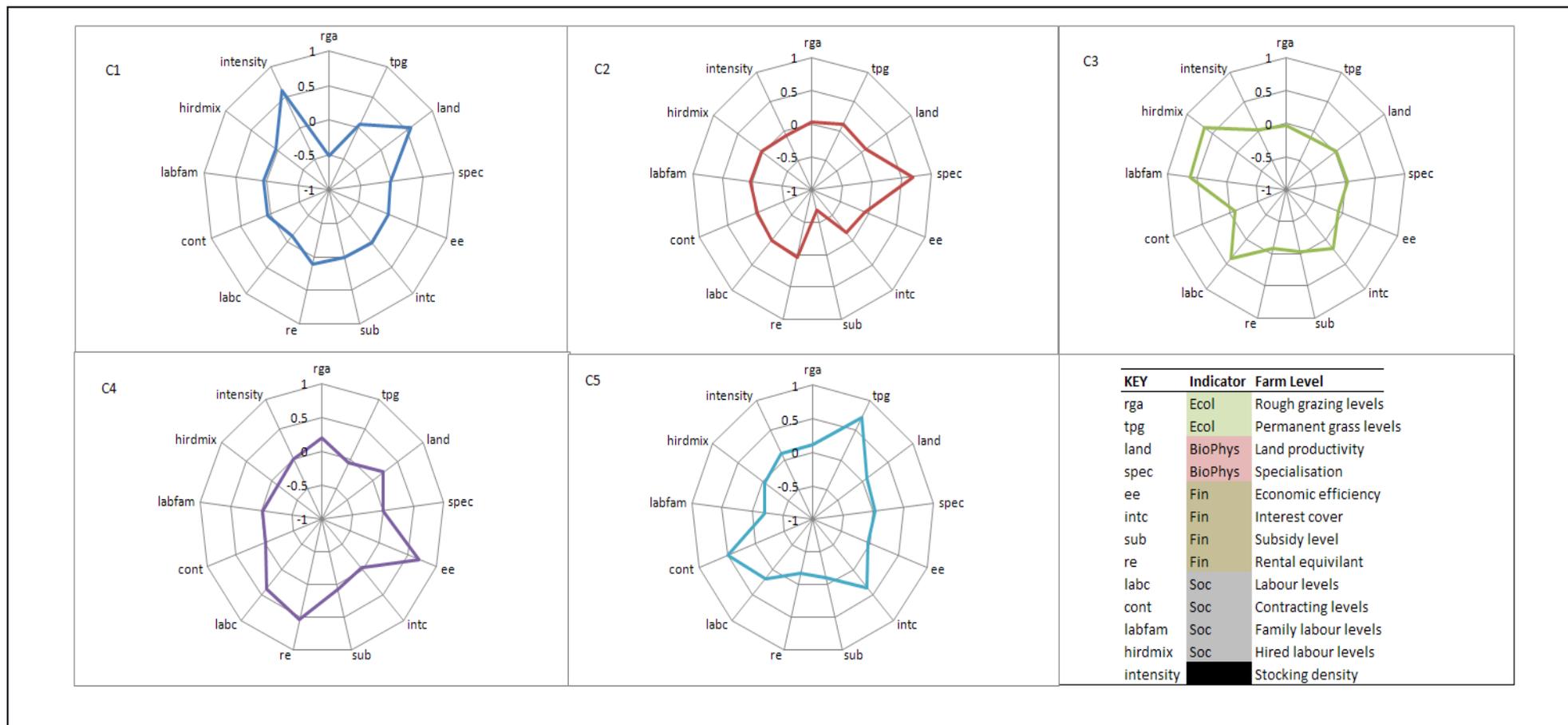
Component	Eigenvalue	Proportion Variance	Cumulative Variance
1	2.47	19%	19%
2	1.98	15%	34%
3	1.73	13%	48%
4	1.69	13%	61%
5	1.09	8%	69%

The components were rotated using an oblique promax rotation, which maximised the variation captured by the five components, compared to orthogonal rotations. The rotated values of components for each of sustainability and intensification variables are presented in Figure 4 as a series of web-graphs.

The five components capture the heterogeneity of the 42 farms with respect to sustainability and intensification. Clearly, component 1 has the strongest loading and represent the intensity of production, coupled with land productivity. Component 2 has a strong specialisation index, Component 3 has a strong social aspect, Component 4 is strong orientated towards economic efficiency, whereas the final component has the rough grazing, i.e. ecological component.

If we are to obey the rule that sustainable intensification must satisfy all four dimensions as presented in Figure 1, high scores across all these variables would be required. Consequently, this does not seem to emerge from this analysis. Hence, the figures may give some indication of aspiration for future policy and research development for sustainable intensification in the Scottish beef sector. Namely, farms which are intensive are under-represented on the economic, social and ecological aspects.

Figure 4. Mean scores for the main components of the 42 Cattle Farms, web graph by component



Discussion and Conclusions

Tailoring definitions of sustainable intensification are important for key members of the food supply chain to understand and conceptualise solutions towards policy-relevant problems. Sustainable intensification has a broad scope by definition, but the output enhancing aspects seem more suited to developing country contexts. Whereas perhaps of more relevance are productivity based measures, which include input efficiency within its metric.

For Scotland, we suggest, intensification of agricultural production requires four dimensions to be examined; i) it must maintain equity in incomes throughout the supply chain and across producers; specifically a fair return throughout the supply chain; ii) it must strengthen the resilience of rural communities and maintain nutritional standards; iii) it must maintain or enhance the stock of Scotland's natural capital and the flow of ecosystem services emerging from this stock; and iv) it must maintain or enhance the ethical dimension of agricultural production. This seems to be an underexplored area of sustainable intensification, which should include the treatment of animals under intensification systems, but also encompasses land ownership issues and access to land.

In terms of definitional problems, Defra have recently abandoned the term 'sustainable intensification'⁵ to embrace the term '*climate smart agriculture*'. The FAO defines this term as '*an agriculture that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) while enhancing the achievement of national food security and development goals.*'

The requirement for '*an agriculture which sustainably increases productivity*' would seem to encompass sustainable intensification strategies for developed countries, and the four requirements above still hold to justify the sustainable dimension. However, the focus away from intensification *per se* deflects from the basis of the concerns related to future production, i.e. land availability will diminish for agricultural land. In addition, productivity simply allows for increasing levels of inputs into the production process, including land. As long as the rate of output is higher than the rate of input into the production system then productivity grows. Hence the focus needs to be on supply chain issues which address the quality and quantity of inputs into the production process. Finally, we argue that if any definition of sustainable intensification were adopted within Scotland, then some ethical debate is required over the treatment of people, land and animals to gain any higher output potential. Arguably, climate smart agriculture becomes a more nebulous term, and may mask some of the underlying debates surrounding how to sustainably feed a growing population.

Measuring sustainable intensification presents both conceptual and measurement difficulties. It is no inconsiderable task to ensure that progress is being made towards increased sustainability, whilst also reconfiguring a farming system towards more intensive production. This firstly requires appropriate monitoring. Whilst the FAS provides indicators of input usage, it does not provide any spatial focus, nor activity at field or system level. Other data sets, such as IACS and census data could be merged with the FAS to provide a clearer picture on sustainable intensification. However, the intricacies of sustainable intensification could only be captured through detailed on-farm assessments over time

⁵ No explanation could be found at time of writing but we presume this is due to the negative connotations related to the term intensification.

which, naturally, has cost associations for policy makers. Secondly, strong multi-disciplinary working is needed to set measurement goals. If the four dimensions outlined above are adopted it infers that ecologists should work in conjunction with sociologists, economists and even ethicists, as well as perhaps wider disciplines, to ensure that these dimensions are fully captured within the measurement process. Furthermore, it requires greater understanding of how to reconcile the (sometimes conflicting) indexes of sustainability and intensification which requires methodologies to extract weightings for individual indexes over different farming landscapes and, also, over time.

Scottish policy does not seem to support increases in output but focuses more on quality and adding value within the supply chain. Intensification seems to be a clear driver of output growth or for resource use efficiency. However, it is not the only driver. Farm production levels are the result of a complex nexus of present and future commodity prices, as well as production and non-production related subsidies; it also encompasses attitudinal and behavioural underpinnings, as well as the bio-geophysical constraints of farming. Nevertheless, the increasing supply of produce, from an output-expansionist approach, could, all things being equal, lead to lower food prices. Though, again, there are complex issues of maintaining equity within food commodity supply chains to achieve this.

This study finds differences in indicators of intensification and sustainability across farms. In addition, the land capability profile of Scotland suggests that production is quite polarised by bio-geographic factors. The less favoured areas of Scotland provide a series of market and non-market benefits but may benefit from an alternative approach to managing and supporting development towards sustainable intensification.

Most farmers are continually adapting their systems to meet weather, biophysical, economic and policy related factors. These changes be classified as changes in machinery, labour and resource use. The process of intensification itself implies the adoption of a technology to manage change within a system. Encouraging adoption of new technologies which offer multiple 'non-farm' type benefits may require different approaches towards engagement. Thus, whilst policy ambitions may change to encourage sustainable intensification, the key actors within the framework may be reluctant to adopt these production trajectories due to lifestyle and other factors.

We suggest a number of areas are needed for future research within this field, namely i) linking data sets to gain a better picture of change over time; ii) using more participatory approaches to appreciate the level and perception of sustainable intensification within members of the supply chain, including the consumer iii) developing multidisciplinary working on this topic to gain insights into how to measure some of the multi-faceted aspects of sustainability and intensification; and iv) examination of behavioural change within the farming context and how farmers, and indeed Scottish farming, can be nudged towards the adoption of practices which meet the multiple needs of present and future societies.

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