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ABSTRACT

A number of influential policy circles have championed sustainable intensification as an approach to meet the challenge of a growing population under increasing land constraints. Various definitions exist for sustainable intensification, but most have been focused on the environment and on the needs of developing countries. Fewer studies have applied the concept to developed economies, where the pursuit of output increases is less justified, nor extended the definition to include social, economic and ethical parameters.

This paper develops an approach to defining and measuring sustainable intensification on a regional basis. We test this approach using data from the Farm Account Data Network for a balanced panel of 42 beef farms within Scotland. Indicators of economic, ecosystem and social parameters are derived from this database and measured over the period 2000-2010. These variables are objectively weighted within an overall index using Positive Matrix Factorisation (PMF), a form of Factor Analysis which constrains results to positive loadings and offers less ambiguity with relation to rotation. We find little change in Scottish Beef farming with respect to Sustainable Intensification, which reflects both a policy which has not supported intensification or output expansion over this period, nor has it increased the economic, social or ecosystem sustainability over this period.

We argue that regions should adopt a definition of sustainable intensification that i) is specific to the production trajectories of that region and offers clarity within estimation and 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 avoid future projected problems in food production.

KEY WORDS: Sustainable Intensification; Scottish Cattle Farming; Positive Matrix Factorisation
1.0 Introduction
Emerging global research and policy agendas are now based on the sustainable management of agricultural land. 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 (Pretty et al., 2011; Foley et al., 2011).

Most of the concern has centered on the limited land for agricultural activity which must maintain and enhance productivity and yields to meet the forecasted demand from a growing population (Royal Society, 2009; Geraldo et al., 2012). The result of this has been support for the sustainable intensification of agricultural production within agriculturally dominant landscapes (Ambler-Edwards et al. 2009; FAO, 2010; Jaggard et al. 2010). A common definition of sustainable intensification (Pretty, 2008; Royal Society, 2009; Godfray et al., 2010; Conway and Waage, 2010; Pretty et al., 2011) is:

*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*

Intensification has been the main cause of loss in the range of ecosystem services provided by agriculture (Firbank et al., 2011; Storkey et al., 2011) and this definition clearly aims to address these specific impacts. Nevertheless, there are clearly other impacts from intensifying a system which are not covered within this definition, such as redistributive effects from reliance on technology (David et al., 1994; Evenson and Golin, 2001) and the loss of social value from diverse landscapes (WRI, 2005; MEA, 2005). Accordingly, the concept of sustainable intensification must meet the multiple aspirations of society, in terms of securing and increasing yield, but also preserving the functional and cultural benefits society values.

Furthermore, when applied to a developed country the argument for output growth is more questionable than for a developing country, where nutritional standards are lower than OECD recommended levels. Specifically, the traditional developed economies within the US, EU and Australasia are slowing down or have reached a plateau in agricultural productivity growth rates (Fuglie, 2010). Some commentators have suggested that this is a result of over-exploitation of the natural resource base for production (Pimentel et al, 1995; Doran and Safley, 1997; Cassman, 1999). Overall, the history of over-exploitation of resources that have occurred in developed countries, in addition to issues related to over-consumption and waste presents a complex paradigm for assessing progress towards sustainable intensification within these countries.

The aims of this paper are two-fold; firstly it develops a conceptual approach which can be applied to a developed country to assess progress towards sustainable intensification; secondly, this outline will be tested using a regional case study and an index of sustainable intensification will be derived. This would, therefore, enable policy makers to explore measurement metrics using the available data, but also identify possible opportunities for development of these databases.

A number of measures are available for analysing environmental, social and economic sustainability (Alberi and Parker, 1991; Welsch, 2005; Zhou et al., 2006; Mundaand
These are all based on the presumption that no single indicator could offer enough information for policy-makers. Esty et al. (2005) argued that a composite environmental index offers condensed information for policy evaluation, benchmarking and, ultimately, decision-making. Most of these studies have focused on country level estimates of progress (Böhringer and Jochem, 2006), whereas only a few focus specifically on the agricultural sector (Barnes, 2002; Ball et al., 2004; Barnes et al., 2011; Arel et al., 2012). However, no work has been directed at the specific issues of measuring sustainable intensification within an indicator framework.

The paper is structured as follows; a conceptual framework is applied which highlights proposed definitions of sustainable intensification, this is then used as the basis for a proposed approach to develop an index of sustainable intensification over time. This definition is then applied to Scottish agriculture, which has multiple aspirations and provides a wide mixture of regional environmental and economic climates to test this approach on. Then indices are reconciled with the use of a novel aggregation approach. Finally, discussions and conclusions are drawn from this approach.

2.0. Conceptual Outline
This concept of sustainable intensification 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 (Russell, 2005; Pretty et al, 2011). Generally, most policy and research towards farm management have examined ranges of intensivity and the effect on ecosystems services from agriculturally dominated landscapes (Kristensen, 1999; Caraveli, 2000;). 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 (Boatman et al., 2007; Postma-Blaauw et al., 2012). Other services from agriculture, such as the social value of maintaining landscapes are also higher under extensive, compared to intensive, management (Drake, 1992; Hall et al., 2004; Vanslembrouck et al., 2005). Recent policy relevant reports have also highlighted concerns that farming activity has become too extensive which leads to a potential loss of these ecosystems services. This is especially true for the hill and upland areas after decoupling of CAP support from production (IEEP et al., 2004; SAC, 2009; Thomson, 2011; Barnes et al., 2011). There is consequently an argument that in this situation intensifying activity, to prescribed levels, will support some of the ecological goals within intensifying production.

Some thought is therefore needed towards how sustainability could be defined. Sustainable development can be comprised of three components, namely environmental, economic and socio-political (Brundtland Commission, 1987). This definition is a useful basis for framing the areas to apply to the concept of sustainable food production. However, the socio-political component, which attempts to capture social and cultural needs is less definitive for the policy approaches directed at sustainable intensification. Accordingly, we modify this to apply to the regional farming context within which we plan to analyse, namely Scotland. Here, specific issues pertinent to that system will help to frame the components that are to be analysed. Hence, Figure 1 provides four components which are applicable to Scottish agriculture, namely economic, social, ecosystem and ethics-based.

Figure 1. Proposed four dimensions of sustainable intensification for Scottish Agriculture
Economic sustainability encompasses the income aspects of farming, covering both farmer and employer incomes. The standard definition (Bruntland, 1987) could be applied as the ability of a farmer to support a defined level of economic production indefinitely. Farming income is a clear indicator of sustainability, but is compounded by the role of debt and how it dictates the long-term viability of these enterprises. Barnes et al (2011) found that a number of Scottish 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. Naturally, therefore, development paths must also respect the distribution of benefits throughout the system in order to maintain farming activity.

Social sustainability is under-defined within Brundtland Commission (1987) as it is based on quality of life goals. Within the Scottish context, we apply this concept to embed the impact of farming within the rural communities within which they operate. Studies have found a decoupling of farm income from rural communities (Johnson et al, 2010; Roberts et al., 2012) and this leads to loss of social infrastructure within these communities. In addition, the social function of farming covers the production of food and further enhances the attributes related to provenance. Growing consumer segmentation within Scottish culture 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 sustainability. FAO(2004) explored a number of dialogues related to intensification within proposed ethical frameworks. Significant issues raised by this approach has been the impact on both animal and human health and welfare. Specifically, intensification leads to issues related to transmission of disease, increasing the burden on resource use and the distribution of benefits across income-based strata. The growth in intensity of production has also to have an ethical dimension as the simple increase in stocking densities 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 (Matson et al, 1997; Bronik and Lal, 2005). 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 set of development paths are outlined below and a graphic
representing these is provided in Figure 2. These four possible trajectories for the agricultural industry aim to capture sustainability criteria under intensification pressures.

**Figure 2. Conceptual Trajectories for Sustainable Intensification**

**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) 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.

Accordingly, given both the requirement to balance sometimes opposing goals over a temporal background, the next section presents a proposed approach which aims to capture some of the more salient issues within developing an index. Hence, allowing some mapping of progress against the four sustainable intensification trajectories outlined above.

2.0 Data and Methods

2.1. Data
The beef sector is the most prominent livestock enterprise within Scottish agriculture. Whereas it contributes to around 20% of total value of primary output (RESAS, 2011), it provides nearly 60% of all livestock output value within Scotland. In addition, it provides a high quality consumption segment which generates significant returns throughout the supply chain. Scotland is also characterised by limited productive capacity and over 80% of agricultural land in Scotland is classified as Less Favoured Area. Thus, beef farms have a range of characteristics which capture intensive production, within lowland systems, and sustainability criteria, through the large areas of rough grazing which offer ecological benefits, and by remoteness factors, thus embedding a range of social factors (Holland et al., 2010; Barnes et al., 2011).
The Farm Account Survey (FAS), which covers a sample of around 500 farms per year, 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 can be generated. A balanced panel of 42 farms over the 11 year period 2000 to 2010 was extracted from the FAS. Table 1 shows standard descriptive statistics for these farms, averaged over the 11 year period and with prices, where relevant, provided in constant 2000 year prices.

Table 1. Descriptive Statistics of the LFA Cattle Farms, 2000 to 2010 averages

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 (RESAS, 2011). The average farm has around 30% of their total land in rough grazing, whereas the remainder of the area is 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.

2.2. Methods
The key decision when searching for an overall indicator is the approach to deriving and applying weights. In relation to sustainable intensification the various dimensions need weighting criteria, as do the underlying variables which characterise these dimensions. For example, in Figure 1 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, from a policy perspective, 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. Nevertheless, the rise of national and international policy documents tend to suggest that food production is certainly a rising concern and should have a higher weight within an overall index of sustainable intensification when compared to five years ago (World Bank, 2008; FAO, 2009; Defra, 2010; DAFF, 2010; IAASTD, 2009).

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 (FAO, 2004). Under intensification scenarios this is critical as, if food scarcity increases, then perhaps ethical weightings will be reduced. 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 dimension on how weighting of demands from agricultural production would change. Ripoll-Bosch et al. (2012) used workshops to generate weightings on a farm by farm basis. However, focusing on specific policy, public and farmer dimensions could lead to bias and conflicting weights attached to various factors within intensification strategies. Eliciting fair weights and analysing the trade-offs between stakeholders involved within sustainable food production and consumption is a key area for future research (Esty et al., 2005; Diaz and Romerio, 2004; Gómez-Limón and Sanchez-Fernandez, 2010).
In order to generate an objective and quantifiable approach to weighting, we propose the use of multivariate techniques (Zhou et al., 2006; Wu et al., 2012). Positive matrix factorisation (PMF) (Paatero and Tapper, 1994; Paatero, 1997) is a form of factor analysis but has the attractive property of constraining scores and loadings to be non-negative. Within the research question posed here, it would seem counter-intuitive to have a negative weight attached to a physical component of an overall index when quantities are positively related, i.e. there is no impact of these activities which are below 0. In addition, the inclusion of negative weights for an environmental variable may cause confusion within policy decision making. This constraint also leads to reduction in rotational ambiguity. A range of possibilities are available for rotating the results of an FA and PCA (Jennrich, 2007) and this will lead to different outcomes with respect to the final weightings. Constraining the solution space to a positive outcome reduces this ambiguity (Paatero and Tapper, 1994; Norris et al., 2008). Specifically, PMF can be written as:

\[ x_{ij} = \sum_{k=1}^{p} g_{ik} f_{kj} + e_{ij} \]  

(1)

Where a matrix of observed data (X) has i and j dimensions, \( x_{ij} \) is an element of this matrix. The rows are variables with the columns the time series data. In addition, p is the number of factors identified, f are the factor profiles and g represents the scores contributed by each factor. Finally, \( e_{ij} \) is the residual of the model at each data point. The solutions are constrained to be non-negative.

The PMF approach aims to maximise an objective function (Q) based on the uncertainty \( u_{ij} \) of the observed values \( x_{ij} \). Where n and m are rows and columns of the matrix X of observed data:

\[ Q = \sum_{i=1}^{n} \sum_{j=1}^{m} \left( \frac{e_{ij}}{u_{ij}} \right)^2 \]  

(2)

Accordingly, uncertainties need to be derived with respect to the data estimation. In relation to data collection, the farm account scheme data offers a fairly robust data set due to trained operators collecting financial and physical information at a farm level. Within Scotland, each farmer receives a farm visit and data collection and input are conducted by the advisors based on invoices collected. This is further assured by national and European quality standards criteria. However, it is not impossible for error to enter the process of data collection. When compared to environmental pollution data (Norris et al., 2008; Henman et al., 2009; Alleman et al., 2010) these uncertainties will be small. Accordingly, we follow Wu et al. (2012) and take the standard deviations of each time series. Nevertheless these are starting values and estimation was conducted using the software PMF v 3.02 (Norris et al., 2008) which allows these uncertainties to be adjusted over separate runs to enable a more robust solution to be found.

3.0. Measuring sustainable intensification in Scotland

3.1. Generating indicators of intensification

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.

The simplest measure of intensification in the livestock sector is a ratio of output to a particular input, such as grazing livestock units\(^1\). Figure 3 shows stocking densities per farm, that is the 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**

What is noticeable is that little has changed with respect to stocking density of this period for the 42 farms. 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 period\(^2\). This was implemented in Stata and rejected the null hypothesis of a unit root ($\rho=0.09; z=-5.13; p$-value=0.000). Consequently, we find no trend in the intensification series over this period. This would be expected as policies directed at this sector have not promoted increasing intensification over this period.

### 3.2. Generating indicators of sustainability

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. Whilst not as specific as collection of primary data, the benefits offer the wider use of an available dataset and, hence, provide a cost-effective solution for offering insights into the process of SI for policy makers.

**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 a criteria for identifying Higher Nature Value farming systems (Barnes *et al.*, 2011), and also as a proxy for environmental outputs (Areal, 2012). Similarly, total farmed woodland to total area presents another dimension to this, as it may provide a wider range of habitats for species which exist within the landscape and, indeed, loss of area to agricultural production, would indicate loss of this diversity of service. The ratio of permanent to temporary grassland is an important indicator 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 reflect some aspect of the ecological and climatic value of this natural stock and, indeed, is strongly related to the intensity of livestock production.

\(^{1}\) Grazing livestock units is the result of multiplying all animals on a farm by a corresponding conversion factor related to their grazing intensity.

\(^{2}\) Testing with and without these assumptions led to the same rejection of the null hypothesis, i.e. the data are stationary.
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 and hence the inherent quality within the system) 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

**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 reliance factors (such as the level of subsidy within a system).

Table 3. Indicators of economic aspects of sustainable intensification

**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

Notably, other indicators could be explored such as the ratio of farm business income (reflecting total profits from all activities) to net farm income (reflecting profit from agricultural activities), however this is only available from 2008 onwards and therefore is disregarded from within this study. Other factors considered were age related, namely farmer and partner ages which could reflect some element of innovation and succession. The literature on this is mixed however 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. 2011: Hansen et al., 2011). A further factor to explore is the ratio of rent expenditure to total land owned to reflect redistribution of ownership and equity within the industry. However, this is distorted both by market pressures but also has an imputed value within the farm account survey. It is therefore not an accurate indicator that could be usefully employed to assess ethical aspects. Hence, the ethical aspects of sustainable intensification could not be progressed here and methods to address this are discussed further in the conclusion.
3.3. **Estimation procedure and results**

The first critical choice to be made is the number of factors and for this study, three were chosen at the outset, to reflect the economic, ecosystem and social aspects of sustainable intensification as explained above. The data were examined over time and breaks were identified in three of the time series. This was most explicit in the woodland to total area series. A significant factor in the creation of farm woodland is the availability of grants and within this series high variabilities were found. Paatero et al. (2003) recommend that signal to noise ratios (which reflect whether the variabilities are real or within the data collection process) below 0.2 should lead to a time series to be discounted and this was the case with woodland.

The other two series, the subsidy ratio (SUB) and specialisation (SPEC) had signal to noise ratios of above 0.2. Principally, changes occurred from 2005 onwards in subsidy apportionment due to CAP reform which reflects this change and a knock-on effect has been a destocking of animals within this sector and a dilution of specialised activities (SAC, 2008; Thomson et al., 2011). Hence to account for this greater variability, these two series had uncertainties tripled before modelling began. PMF software allows inspection of individual fits across scatter plots to assess fit and gives diagnostics. After these two series were categorised as weak, the R² improved substantially from 0.13 to 0.33 (spec) and 0.34(sub).

The initial approach was to take a run of 20 base model runs, using a random seed, which ensures that the model begins with a different starting value each run. The aim is to identify the global minimum Q value. All runs converged and the chosen base run gave normally distributed residuals for each variable and inspection of the output graphs indicated a good fit between predicted and observed values. However, examination of the independence of the 3 factors (through a scatter plot) were not convincing and most had edging (indicating lack of independence) which were not improved after rotation. Accordingly, re-testing the data found a better solution (with the lowest Q-values) emerging from using 5 factors within the data set. Nevertheless, within the base run there was still lack of independence between some factors. Figure 4 illustrates this for factor 2 against factor 5. The red line highlights the edging between the two factors, which is indicative of a relationship. Accordingly, these would benefit from rotation.

**Figure 4. ‘G-Space’ Plot of Base Run for factor 2 against Factor 5**

The parameter FPEAK (Paatero, 2000) allows various rotational results to be compared with the base run. The aim is to minimise the distance between the resulting Q value against the same value with no rotational forcing (i.e. FPEAK = 0). In order to rotate the base results the FPEAK values was tested across a range from -2 to +2. Solutions, where the Q-value did not vary significantly were found within the region 1.0 to 2.0. The minimal variance between the two Q values was observed using a value of 1.5. An example of the impact of this rotation is shown in Figure 5 below which again maps Factor 2 against Factor 5. Clearly, the edging has been removed.

**Figure 5. ‘G-Space’ Plot for factor 2 against Factor 5 after rotation**

The extension from three to five factors highlights a more complex picture within the sample towards the different dimensions of sustainable intensification. Variables were attributed to factors which contributed to over 40% of the sum of loadings for that variable.
This led to an extension of the economic and the social factors. These are shown in Table 5 below.

**Table 5. Description of factor profiles, percent scores by variable**

The weightings are displayed as means of the 42 farms in Figure 6. Weightings seem to fluctuate over time. In 2002, an economic factor, representing the resilience aspects (debt and subsidy) of farming shows a high peak in weighting in the early period which eventually fell rapidly in the later stage of the analysis. This may reflect the changes to subsidy over this period which occurred in 2005. This was at the cost of the weighting of social factor (F4) which is an approximation of the social aspects, reflecting changes to labour mixes and farmer stress levels. Nevertheless most of the weighting tend to be between 0.9 to 1.1 within each year. The most stable series of weightings comes from the environmental factor (F5) which, reflects the fairly fixed levels of rough grazing and permanent grazing held by these farms throughout this period.

**Figure 6. Mean weights for each factor over time, 2000 to 2010.**

The Sustainable Intensification Index is calculated as the geometric mean of these weightings (Zhang and Yang, 2007; Wu et al., 2012). The geometric mean is the appropriate way to calculate the average value in this case because the change indexes represent proportions, however other aggregation methods have been proposed (Saisana and Cartwright, 2007; Saltelli et al., 2004; Munda et al, 2009) and could be explored in future research. Figure 7 shows the result, presented as a chained index, in order to reflect yearly change within sustainable intensification for the 42 farms.

**Figure 7. Index of Sustainable Intensification, 2000 to 2010**

The figure shows little change over the 11 year period, which reflects the lack of variation in the weightings of the five factors. Indeed, the policy background over this period has been one of stasis towards intensification and sustainability generally. Accordingly, with respect to the conceptual schema in Figure 2, this has characteristics of trajectory path D, namely ‘failure to launch’. Though, it would be useful to assess progress towards the other pathways proposed within Figure 2 if policy reconfigures towards sustainable intensification.

Figure 8 shows the distribution of the 42 cattle farms over the same period in terms of their sustainable intensification score. Clearly, there is no trend, but a small number of farms have high SI index scores and these are maintained over the whole period.

**Figure 8. Distribution of sustainable intensification scores by farm, 2000 to 2010**

4.0 Conclusions

Developed country goals now must address sustainability factors and accommodate debates concerning intensification within their decision-making. Reconciling sustainability and intensification indicators is a key methodological challenge for researchers.

Conceptually, the dimensions of sustainable intensification should cover four areas, however this could vary dependent on the regional and the policy context. This presents difficulty for policy makers as most data sets would not cover some aspects of sustainable
intensification that need to be addressed. Even so, an index using secondary data offers an attractive approach to understanding change and provides a baseline to debate these changes as policies which support sustainable food production become more entrenched.
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Table 1. Descriptive Statistics of the LFA Cattle Farms, 2000 to 2010 averages

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Std. Dev.</th>
</tr>
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<tbody>
<tr>
<td>Total Grass (Ha)</td>
<td>90.2</td>
<td>45.2</td>
</tr>
<tr>
<td>Rough grazing (Ha)</td>
<td>34.8</td>
<td>56.5</td>
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<tr>
<td>Farm Business Income (£2000)</td>
<td>6,724.1</td>
<td>16,230.8</td>
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<tr>
<td>Total Output (£2000)</td>
<td>77,381.6</td>
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<td>Cows (No.)</td>
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<tr>
<td>Total Animals (Grazing Livestock Units)</td>
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<td>69.5</td>
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<td>Farmer Age</td>
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<td>Annual Farmer Hours Worked</td>
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<tr>
<td>Variable</td>
<td>Calculation</td>
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<tr>
<td>RGA</td>
<td>Total Rough grazing Area / Total Area</td>
<td></td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
<td></td>
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<tr>
<td>WGA</td>
<td>Total (farmed) woodland area to total area</td>
<td></td>
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<tr>
<td>Rationale</td>
<td>Indicative of managed woodland and hence greater biodiversity capture. Higher levels of woodland would lead to greater mixes of biodiversity and carbon capture.</td>
<td></td>
</tr>
<tr>
<td>TPG</td>
<td>Ratio of permanent to temporary grass area</td>
<td></td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
<td></td>
</tr>
<tr>
<td>LAND</td>
<td>Total output value to total area</td>
<td></td>
</tr>
<tr>
<td>Rationale</td>
<td>Indicator of land productivity. Higher levels indicate some preservation of the natural stock of biophysical capital.</td>
<td></td>
</tr>
<tr>
<td>SPEC</td>
<td>Value of livestock output to total output (*)³</td>
<td></td>
</tr>
<tr>
<td>Rationale</td>
<td>A proxy for specialisation of activity. Higher levels indicate less diversity in the resources for ecological preservation.</td>
<td></td>
</tr>
</tbody>
</table>

³ For some indicators the inverse of the ratio was taken, this ensured consistency of measurement across the indicators. Where an inverse was taken in what follows a (*) symbol is attached.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>INTC</strong></td>
<td>Interest cover to total debt (*)</td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
</tr>
<tr>
<td><strong>SUB</strong></td>
<td>Total subsidies to farm gross margins (*)</td>
</tr>
<tr>
<td>Rationale</td>
<td>Higher levels of subsidy burden mean less resilience within the business to market forces.</td>
</tr>
<tr>
<td><strong>RE</strong></td>
<td>Total rent and interest paid to farm gross margin (*)</td>
</tr>
<tr>
<td>Rationale</td>
<td>Reflects the burden of the land and machinery and building factors on profitability. Higher levels indicate financial stress within the business.</td>
</tr>
<tr>
<td><strong>LABC</strong></td>
<td>Total costs of paid labour to gross margin (*)</td>
</tr>
<tr>
<td>Rationale</td>
<td>This reflects the amount of the external labour on profitability. Higher levels indicate more financial stress within the business.</td>
</tr>
<tr>
<td><strong>CONT</strong></td>
<td>Total costs of contracting to total variable costs (*)</td>
</tr>
<tr>
<td>Rationale</td>
<td>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.</td>
</tr>
<tr>
<td><strong>ECONEFF</strong></td>
<td>Total output value to total fixed and variable costs</td>
</tr>
<tr>
<td>Rationale</td>
<td>This reflects the efficiency within the farming business of converting total costs to total output. Higher levels indicate higher levels of efficiency.</td>
</tr>
<tr>
<td>Variable</td>
<td>Calculation</td>
</tr>
<tr>
<td>----------</td>
<td>-------------</td>
</tr>
<tr>
<td>LABFAMIX</td>
<td>Total farmer hours to total hours worked (*)</td>
</tr>
<tr>
<td>Rationale</td>
<td>Indicator of farmer work intensity relative to total farm hours needed</td>
</tr>
<tr>
<td></td>
<td>Higher levels indicate increasing stress</td>
</tr>
<tr>
<td>HIRDMIX</td>
<td>Total hired labour to total hours worked</td>
</tr>
<tr>
<td>Rationale</td>
<td>This indicates the amount of external labour entering the farm. It therefore provides a proxy for rural income opportunities and income generation.</td>
</tr>
</tbody>
</table>
Table 5. Description of factor profiles, percent scores by variable

<table>
<thead>
<tr>
<th>Factor</th>
<th>Parent Group</th>
<th>Characteristic Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>ECONOMIC</td>
<td>LAND, SPEC, EEF, LABC, SD, TPG, RGA</td>
</tr>
<tr>
<td>F2</td>
<td></td>
<td>RE, SUB, INTC</td>
</tr>
<tr>
<td>F3</td>
<td>SOCIAL</td>
<td>CONT, LAND, SD</td>
</tr>
<tr>
<td>F4</td>
<td></td>
<td>HIRDMIX, LABFAMMIX</td>
</tr>
<tr>
<td>F5</td>
<td>ECOSYSTEM</td>
<td>TPG, RGA, SUB</td>
</tr>
</tbody>
</table>
Figure 1. Proposed four dimensions of sustainable intensification for Scottish Agriculture

- **Economic**
  - Maintaining income to fair standards of living
  - Fair distribution of incomes
- **Social**
  - Strengthen resilience of rural communities
  - Maintaining nutritional standards
- **Ecosystem**
  - Protect and enhance natural capital and the flow of ecosystems goods and services
- **Ethical**
  - Maintaining fair treatment of animals
  - Access to land and ownership of land based assets
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
Figure 3. Overall variation of stocking density over time for LFA cattle farms
Figure 4. ‘G-Space’ Plot of Base Run for factor 2 against Factor 5
Figure 5. ‘G-Space’ Plot for factor 2 against Factor 5 after rotation
Figure 6. Mean weights for each factor over time, 2000 to 2010.
Figure 7. Index of Sustainable Intensification, 2000 to 2010
Figure 8. Distribution of sustainable intensification scores by farm, 2000 to 2010