SUSTAINABLE BENCHMARKING OF FOOD SUPPLY CHAINS

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Sustainable Benchmarking of Food Supply Chains

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Abstract: An organization's long-term viability and competitiveness should not be evaluated solely in terms of financial measures. Investors, policy makers, and other stakeholders increasingly seek to evaluate performance with respect to sustainability—the environmental, social, and economic performance of an organization. But measuring and improving the sustainability performance of supply chains is challenging. We introduce a framework to help evaluate sustainability performance of supply chains. We have collected sustainability data on food supply chains within the United Kingdom. These data are then transformed into indicators. In addition, as part of this benchmarking framework and to more accurately determine performance of food supply chains, we have utilized food supply chain experts' opinions about which factors contribute the most to sustainability. Using the Analytic Hierarchy Process (AHP), these opinions are translated into importance ratings. The indicators are weighted by these importance ratings to generate an overall index of sustainability. Stakeholders can use the index to evaluate supply chains, and supply chain members can use this approach to guide improvement efforts. Strengths and opportunities, as well as limitations of the methodology are discussed, and sensitivity analysis is performed.

Keywords: Sustainability, Supply Chain Management, Performance Measurement, Analytic Hierarchy Process, Food Supply Chain.

INTRODUCTION

Sustainability benchmarking is gaining importance within industry. Expanding the boundaries of benchmarking for sustainability beyond the organization and across the supply chain is a necessity, as stakeholders demand that organizations consider the broadened lifecycle influences of products and processes. The process for internal organizational performance evaluation, which includes internal sustainability benchmarking, has made some relatively well-established headway. Yet the methodologies and frameworks for effective supply chain and sustainable supply chain performance evaluation and benchmarking are not well advanced in the literature (Hervani *et al.* 2005). To help address this gap we provide a framework and approach to help organizations and policy makers benchmark the sustainability performance of a supply chain. In this case we focus on a critical supply chain, the food supply chain (Marsden *et al.* 1999).

The concept of sustainability has become increasingly important in supply chain management as companies respond to external pressure from policy makers and consumers as well an internal pressure from their leaders' values and sense of responsibility (Seuring and Müeller 2008). In terms of practice, there is a significant and growing need to measure and benchmark the overall sustainability of entire supply chains rather than single processes or firms. Despite this increased interest and various efforts to measure sustainability within organizations and across the supply chain, no method has yet emerged which can effectively incorporate three dimensions of sustainability and measure and benchmark sustainability across all stages in the supply chain. The absence of such a method has implications for practice. Specifically, how can managers determine if their efforts to improve sustainability are effective—or even moving things in the right direction? The lack of a measure also has implications for theory and research development: how can researchers test hypotheses about the mechanisms of sustainability without a method to measure it? This paper fills this void by developing a method to evaluate and benchmark sustainability across the supply chain, and demonstrating how the method is used by applying it to data from two food supply chains (chicken and potatoes) and utilising various expert opinions.

This paper aims to make three contributions. First, the paper contributes to supply chain theory by building towards a mechanism to test hypotheses regarding sustainability. Second, the paper makes a strong empirical contribution by applying the proposed methodology to data from actual food supply chains. This process also produces an implicit sustainability framework (Kinra and Kotzab 2008), which can be compared to others (e.g., Carter and Rogers 2008). Finally, the paper makes a contribution to supply chain management practice by developing and demonstrating a method to measure sustainability. Such a measure is useful for managers, policy makers, and citizens to assess the overall sustainability of a chain as well as the contributions of individual links.

The paper starts with the review of literature on sustainability and supply chain management; then it moves on to review of sustainability benchmarking and its application for the supply chain. We explain our methodology for benchmarking sustainability in the supply chain through detailed exposition of sustainability indicators development and scoring for the food supply chain. The proposed framework is evaluated using 2002 statistical data for potato and chicken supply chains in the United Kingdom (U.K.). Further we introduce weighting schemes using the Analytic Hierarchy Process (AHP) and describe the results of a sensitivity analysis. Finally, the discussion and conclusions section outlines the implications of the proposed sustainability benchmarking framework.

SUSTAINABILITY AND SUPPLY CHAIN MANAGEMENT

Companies are experiencing growing pressure from various stakeholders such as governmental agencies, communities, workers, advocacy groups and non-governmental organisations and some customer segments to deal with social and environmental issues related to their supply chains (Vachon and Klassen 2006; Welford and Frost 2006). Stakeholders demand corporate responsibility to go beyond product quality and extend to areas of labour standards, health and safety, environmental sustainability, non-financial accounting and reporting, procurement, supplier relations, product lifecycles and environmental practices (Bakker and Nijhof 2002; Waddock and Bodwell 2004; Teuscher *et al*. 2006). Companies are increasingly expected to deliver with a focus on the triple bottom line, a simultaneous balance of economic, environmental and social goals, which will positively affect the natural environment, society and also result in long-term economic benefits and competitive advantage (Elkington 1997; Carter and Rogers 2008).

Sustainable supply chain management expands the concept of sustainability from a company to the supply chain level (Carter and Rogers 2008). Following Fritz and Schiefer (2008), sustainable supply chain management should provide companies with tools for improving their own and the sector's competitiveness, sustainability and responsibility towards stakeholder expectations. Sustainable supply chain management, however, presents greater challenges for integration of actors along the supply chain to address impacts of production and consumption within the wider sets of performance objectives that incorporate economic, social and environmental dimensions of sustainability (Teuscher *et al*. 2006; Linton *et al*. 2007; Carter and Rogers 2008; Seuring and Müller 2008).

Principles of accountability, transparency and stakeholder engagement are highly relevant to sustainable supply chain management (Waddock and Bodwell 2004; Teuscher *et al*. 2006; Carter and Rogers 2008). In response to stakeholder pressures for transparency and accountability companies need to measure, benchmark, and report sustainability performance of their supply chains, whilst policy makers need to measure the performance of sectors within the supply chain context for effective target setting and decision-making. So far, environmental dimensions have been successfully integrated in the supply chain management as green supply chain management that covers areas such as green design, green operations, lifecycle assessment and reverse logistics (Srivastava 2007).

Often it is the focal companies of supply chains, such as retailers and brand manufacturers, that are held responsible, under growing stakeholder pressure, for environmental and social performance of their suppliers and products and forced to restructure supply chain performance in relation to sustainability concerns (Hughes 2001; Welford and Frost 2006; Seuring and Müller 2008). If focal companies are to demonstrate accountability for sustainability implications of their operations, then there is a need for companies to engage in measuring and benchmarking sustainability performance of their supply chains. Stakeholder concerns should influence performance measures (Manning *et al.* 2008), and it is the next step for companies to expand the boundaries of benchmarking for sustainability to outside the organization across the supply chain.

Apart from the lack of methodologies, there is also a significant gap in theoretical development with respect to measuring and benchmarking sustainability (Hervani *et al. 2005*). For example, *stakeholder theory* challenges the traditional concept of a firm's responsibilities by arguing that parties outside the firm and its shareholders — such as trade unions, communities, and governmental bodies — should have their needs and wishes taken into consideration by the firm (Freeman 1984). This theory, which has gained wide acceptance among researchers and practitioners, has been discussed and extended in various ways (Donaldson and Preston 1995; Mitchell *et al.* 1997; Friedman and Miles 2002), including the expansion of its scope beyond single firms to supply chains (Post *et al.* 2002) and the examination of connection between stakeholder relations and financial performance (Ruf *et al.* 2001, Scholtens and Zhou 2008).

Complexities of sustainability theory (Carter and Rogers 2008) argue that consideration of sustainability factors can more effectively and transparently provide insights into supply chain management and operations. As a result, it becomes more important to address supply chain management design and benchmarking from a sustainability perspective. Stakeholder theory and institutional theory helps to further evaluate sustainability and its implementation within the supply chain (Zhu and Sarkis 2007). To test this type of relationship, one requires a measure of sustainability. This observation is not unique to stakeholder theory. Carter and Rogers (2008) develop a number of propositions about sustainable supply chain management, which are based on a variety of theories such as population ecology and a resource-based view of the firm. The question still remains about how does one evaluate changes in supply chain sustainability without a way to measure it?

Evaluating overall supply chain performance requires that multiple sustainability dimensions — economic, environmental and social factors — be included. The problem of structuring these dimensions within a benchmarking perspective remains of great interest to both practitioners and researchers as we still lack a unifying theory or literature stream which deals exclusively with the issue of stakeholder involvement and balancing the triple bottom line (sustainability) dimensions of supply chains (Hervani *et al*. 2005).

Thus, we seek to apply a triple bottom line approach to a benchmarking exercise for an integrated food supply chain and propose a methodology to measure and benchmark sustainability within the supply chain taking into account the opinion of experts. In addition we provide practitioners with a useable and practical technique to help evaluate their own supply chains.

The Food Supply Chain

Production and distribution of food could be viewed as a supply chain (Barrett *et al.* 1999; Marsden *et al*. 1999), which is a system of stages that represent a sequence of economic activities, through which resources, materials and information flow downstream and upstream for production of goods and services for ultimate consumption by a consumer (Stevens 1989).

The food supply chain is also seen as a network of organisations that do not necessarily map directly on to economic stages of the food supply chain as they often integrate several stages in the food supply chain (Fine *et al.* 1996). This paper adopts a definition of the food supply chain that comprises the following stages: agricultural production, food processing, food wholesaling, food retailing and food catering, following the approach used by the United Kingdom Department of Environment, Food and Rural Affairs (DEFRA 2006).

The food supply chain has significant implications for sustainability such as the fulfilment of human needs, provision of employment and economic growth, and impacts on the natural environment. Growing environmental, social and ethical concerns and increased awareness of effects of food production and consumption on the natural environment and developing world have led to increased pressure from consumer organisations, environmental advocacy groups, policy makers and other stakeholders on food companies and food retailers to assess and improve environmental and social performance within product lifecycles from 'farm to folk' (Courville 2003; Weatherell *et al.* 2003; Ilbery and Maye 2005; Maloni and Brown, 2006; Matos and Hall 2007).

The food supply chain is pervasive and is one of the most globalized supply chains. In the food supply chain, sustainability is clearly seen in terms of the wider production and consumption system that has broad implications for the economy, health, development, communities and the environment (Marsden *et al.* 1999; Hinrichs and Lyson 2008; Roth *et al.* 2008). Food supply chains are now making various claims on their sustainability with alternate supply chain models being introduced that promote specific agricultural/craft products or individual places/regions through product marketing, labeling and accreditation schemes (Ilbery and Maye 2007; Holt and Watson 2008). For these labeling schemes to work, for organizations to manage their food supply chains more sustainably, and for consumers to build trust in these supply chains, tools to help in controlling and auditing food and agricultural supply chains are needed. For these sustainable management reasons, benchmarking and managing the food supply chain will be a critical necessity for government, organizations, and communities.

BENCHMARKING AND SUSTAINABILITY

Benchmarking is an evaluation process for organizational products, services, and processes in relation to best practice (Camp 1995; McNair and Leibfried 1995). The term is often associated with efforts by individual firms to identify and imitate best practices within their own industry. Benchmarking is frequently cited as an important tool in continuous improvement of organisational performance, total quality management programs and in gaining competitive advantage (McNair and Leibfried 1995; Simatupang and Sridharan, 2004; Manning *et al.* 2008). Benchmarking has gained considerable popularity in industry (Camp 1995; Zairi and Youssef 1995a; Wever *et al.* 2007) and has been well reviewed in practitioner-oriented literature (Zairi and Youssef 1995b, 1996; Sarkis 2001a). Based on the types of benchmarking provided by Ahmed and Rafiq (1998), for the purposes of this paper, we refer to benchmarking as the process of defining operational measures of performance and appraising firms (supply chains) with respect to these measures.

Tools for Competitive Analysis: Effective benchmarking relies heavily on data analysis. Dozens of tools for benchmarking have been recommended and include flowcharts, cause-and-effect diagrams, radar/spider charts, and *Z* charts (Camp 1995), the European Foundation for Quality Management (EFQM) business excellence model, the balanced scorecard, service quality (SERVQUAL) framework, gap analysis, AHP, scatter diagrams (Ahmed and Rafiq 1998), computational geometry (Talluri and Sarkis 2001), data envelopment analysis (DEA) (Zhu 2002), and the Operational Competitiveness Ratings Analysis (OCRA) (Oral 1993; Parkan 1994; Jayanthi *et al.* 1999). All of these techniques have their advantages and disadvantages. The feature that makes them very similar is that they are all data driven. One of the characteristics that makes AHP unique among these tools is that it can consider multiple attributes and factors and that the data can be both qualitative and quantitative. We will utilize AHP in this study, because these characteristics are evident in sustainability benchmarking.

Benchmarking typically focuses on a single link—or even a single process within a link—rather than on the entire supply chain and there are challenges in measuring overall supply chain performance. Gunasekaran *et al.* (2001) develop a framework for measuring the strategic, tactical, and operational performance of a supply chain. They identify and discuss a variety of financial and non-financial metrics that firms can use to evaluate different dimensions of performance. Gunasekaran *et al.* (2004) build on this work by surveying U.K. firms on their practices and perceptions about supply chain management performance. In short, the survey indicates that managers care a great deal about performance measurement and believe that such efforts pay dividends; however, the use of and beliefs about the importance of specific metrics varies considerably. Some have recommended benchmarking supply chains using DEA and the Supply Chain Operations Reference (SCOR) model (Reiner and Hofmann 2006). AHP has also been recommended as a technique for benchmarking supply chains (Min and Galle 1996). The extension of any tools to sustainability and supply chain benchmarking has yet to occur.

Sustainability Benchmarking

In addition to the evaluation of financial, inventory, and responsiveness performance, some effort has been devoted to assessing the sustainability of supply chains and their subsystems. Even though some early efforts of incorporating the three dimensions of sustainability (economic, social and environmental) into supply chain analysis have occurred (New 1997; Kärnä and Heiskanen 1998; Sarkis 2001b), frameworks for analysis of sustainability parameters in a supply chain usually cover economic and environmental dimensions and to a much lesser extent embrace all three dimensions of sustainability (Seuring and Müller 2008).

By examining the kinds of sustainability indicators currently being reported voluntarily by the pharmaceutical industry, Veleva *et al.* (2003) demonstrate that firms use measures with environmental and local (plant level) performance foci. There is a significant need to increase awareness of and measures of supply-chain level performance.

Corporate environmental management systems (EMS) can be used as a tool for internal benchmarking of environmental performance (Matthews 2003), however, EMS frameworks such as ISO 14001 may need adjustment to enable effective benchmarking, and extending it beyond the internal operations of an organization. Economic input-output life-cycle analysis (EIO-LCA) to perform high-level benchmarking also shows promise (Matthews and Lave 2003). EIO-LCA uses economic industry averages to estimate the impact with respect to energy usage, greenhouse gases, toxic releases, etc. The data presented in our study fits within this broader economic data development.

We propose to use data for general industrial level analysis (e.g., potatoes or flowers or other general agricultural products) rather than for specific organizational product level (e.g., Schvaneveldt 2003). Although strategic information for product and process design practices can be gleaned from product-level benchmarking for improved environmental performance (Boks and Stevels 2003; Wever *et al.* 2007), we use a higher-level perspective for our analysis for increased cooperation within the industry toward sustainability improvement.

In relation to the food supply chain, large supermarket retailers and branded food manufacturers are often seen as focal companies within the food supply chain (Marsden *et al*. 1998; Hughes 2001). And it seems most appropriate for supermarkets and food manufacturers to measure and report on sustainability performance of their supply chains and also for policy makers to measure the performance of supply chains in relation to policy goals for reduction in pollution, improvement of labour standards and achieving economic growth. It is not surprising that the food sector was amongst the first to look into aspects of sustainability within the supply chain. Indeed, Fritz and Schiefer (2008, p. 443) emphasize that "comparative benchmarking studies within the food sector as well as across sectors are required to understand the complex interdependencies between chain organization alternatives and their performance in economic and noneconomic … aspects".

Although sustainability assessments have traditionally focused on agriculture (McNeeley and Scherr 2003; Filson 2004), recently researchers and policy makers have made attempts to develop more holistic approaches by incorporating stages of food processing, food retailing and specifically transportation in the assessment frameworks of food supply chains (Heller and Keoleian 2003; Green and Foster, 2005). Various approaches have been developed to measure sustainability of the food supply chains that identify effects at regional, industrial, and firm levels. Some specific sustainability assessment frameworks developed for the food sector include: lifecycle approach to sustainability impacts (Heller and Keoleian 2003); farm economic costing (Pretty *et al.* 2005); food miles (Garnett 2003); energy accounting in product lifecycle (Carlsson-Kanayama *et al.* 2003); ecological footprint (Gerbens-Leenes *et al.* 2002; Collins and Fairchild 2007); mass balance of food sectors (Linstead and Ekins 2001; Biffaward 2005); and farm sustainability indicators (OECD 2001). In the United Kingdom, public bodies produced several sustainability measures and guidelines for the food supply chain (MAFF 1999; MAFF 2000; DEFRA 2002a; DEFRA 2002b; DEFRA 2005; DEFRA 2006), and the private sector has also made attempts to measure its sustainability impacts (FDF 2002; J. Sainsbury Plc 2005; Marks and Spencer 2005; Tesco 2005; Unilever 2005).

In summary, there has been an emergent set of investigations related to benchmarking and performance measurement. Most of this research, however, is oriented toward improvement of individual firms or processes rather than toward analysis of entire supply chains. Some efforts have been made to measure supply chain performance, but the focus has primarily been on efficiency and other economic-related performance. There have also been attempts to measure sustainability; however, most of these efforts focus on firm- or product-level performance. Furthermore, there is a strong emphasis on environmental performance. Thus, there is a significant need to measure sustainability across the supply chain. Advancing these measurements incorporating stakeholder aspects and additional sustainability dimensions is rare or does not exist. Incorporating stakeholder and sustainability theoretic perspectives in sustainable supply chain benchmarking activities encourages normative development and advances theory development. In the next section, we describe a methodology to do complete sustainability benchmarking in the context of a food supply chain.

A METHODOLOGY FOR BENCHMARKING SUSTAINABILITY

We propose a sustainability benchmarking methodological framework consisting of five major stages:

1. Identifying sustainability indicators.
2. Raw data gathering.
3. Data transformation using performance rescaling.
4. Data gathering and adjustment using AHP.
5. Sensitivity analysis of results.

The first three stages will be briefly introduced in this section. The fourth stage will be covered in detail in the next section. The final stage will be introduced after the AHP stage (stage 4) case study example is presented.

Development of sustainability indicators

The first stage of the framework is determination of the sustainability indicators in order to set the stage for benchmarking the food supply chain sustainability. For this paper, stages of the food supply chain include agriculture (farming), food processing, food wholesale, food retail and food catering. Our framework assesses the effects of the food supply chain on the three dimensions of sustainability: economic, social and environmental. Firstly, objectives of sustainable development applicable to the industry level and specifically for the food sector have been selected from the objectives of sustainable development outlined for the industry by UNCSD (1998) and those stated in Agenda 21 (UN 1992). Overall, the following important objectives of sustainable development have been considered for the assessment: 1) within the economic dimension: promotion of economic growth, encouragement of open and competitive economy, and changing consumption patterns; 2) within the social dimension: creation of productive employment, achieving equality; 3) within the environmental dimension: reduction of resource use and protection of natural environment. Then, appropriate criteria for measuring the progress towards an objective were selected and followed by the choice of a final indicator. An attempt was made to select indicators that apply to all stages in the food supply chain in order to be able to compare the sustainability performance between the stages. The indicators in this study are purposefully fairly generic, which enables comparison between the stages and between different food products.

For example, the sequence for selection of an indicator within the economic dimension could be demonstrated as follows. Promotion of economic growth is an important objective of sustainable development within the economic dimension. Within industry, it could be measured by productivity. A specific indicator is selected to measure productivity, such as Gross Value Added per workforce, data for which is ready available with statistical services. Potential users of this framework may choose industry specific sustainability objectives and indicators that are crucial for demonstrating progress towards sustainable development.

Initially, more than 50 indicators were drawn for five stages of the supply chain (Yakovleva and Flynn 2004); however, due to data limitations and to help exemplify the methodology proposed in this paper, a final set of nine indicators is selected for the framework, three per dimension. Thus, we have a total of 45 indicators (nine sustainability indicators for each of the five stages) for the framework, which are reported in Table 1. Data collection for the sustainability indicators involved statistical data, data from trade associations and various market data.

Insert Table 1 Approximately Here

The framework in this study will use data from potato and chicken food supply chains in the U.K. Chickens and potatoes represent different production processes within the food supply chain (chicken is the most popular meat category, and potato is the most popular vegetable). Both products are important in relation to their domestic production and consumption in the U.K. Chicken and potatoes penetrate various stages of the food supply chain and are important for both fresh and processed food markets. These products are truly global products, produced, traded and consumed in many countries around the world. The data for these supply chains were collected for 2002 (see Table 2).

Insert Table 2 Approximately Here

Data Gathering: Since we are focusing on U.K. food supply chains, statistical information is collected from two different organisations within the British Government: Department for Environment, Food and Rural Affairs (DEFRA) collects information on the agricultural sector, while the Office for National Statistics (ONS) collects information on the production industries including the food sector.

Data Transformation using Performance Rescaling and Normalization: In order to analyse and compare the data for various stages in the supply chain and between two products, the indicators are normalized. U.K. economy average or food supply chain average values are used as a benchmark for the development of normalized scores. Indicators are allocated scores on a scale of 1 to 6. The 0 score stands for no available information, a score of 1 reflects a low benefit to sustainability and a score of 6 a high level of sustainability benefit (the ranges could be adjusted depending on what level of granularity is sought for comparison purposes; six levels and a non-reporting/value level were seen as appropriate for discrimination in performance). The scale for each indicator was developed based on general notions of maximum and minimum desirable sustainability benefit or value and unacceptable or undesirable sustainability values. Then there was a linear interpolation on the six levels based on maximum and minimum scores. This is one example of linear normalization, additional assumptions or characterizations (e.g. non-linearity along scales or expert evaluation of minimum and maximum scores) could be used. The indicator scores are defined in Table 3. It must be noted that three indicators were chosen for each dimension of sustainability (economic, social and environmental) in the final scoring system (see Yakovleva 2007). The actual scores for each supply chain stage and food type are reported in Table 4.

Insert Table 3 Approximately Here

Insert Table 4 Approximately Here

Adjusting the Benchmarked Scores Using AHP

This is the fourth and most intricate stage of our methodological framework and will have its own section.

The values in Table 4 represent an adjusted score based on ranges as defined in Table 3. But, this rough estimate may not be adequate since it does not take into consideration the relative importance of each of these factors with respect to each other. To further this methodology we introduce a weighting scheme based on expert opinion to more accurately represent the performance of these actual supply chains. We complete this portion of the methodology by introducing a multi-attribute rating scheme, AHP.

Saaty (1980) first introduced AHP for decision structuring and decision analysis. AHP allows for a set of complex issues, factors and relationships, which have an impact on an overall objective, to be compared with the importance of each issue relative to its impact on the solution of the problem. Other approaches that can define the factor utilities and how well each of the alternatives may rank on the various factors may also be used, but AHP is a robust and easy-to-implement approach.

AHP utilizes a decision-making framework that assumes a unidirectional hierarchical relationship among decision levels. Thus, the first major step in the AHP process is to define the decision hierarchy. The top element of the hierarchy (objective) is the overall goal for the decision model. The hierarchy decomposes to a more specific attribute until a level of manageable decision criteria is met. The hierarchy is a type of system where one group of entities influences another set of entities. The decision hierarchy may have had additional levels and clusters, as well as added complexities of feedback mechanisms, but at this point, for the sake of parsimony, those additional levels and variations in the relationships are not included.

The second major step in the AHP process is to elicit the preferences through pairwise comparisons of the various factors. This step is completed by asking a series of questions that compare the relative importance or influence of one factor (technique) when compared to another factor (technique) on a "controlling" factor. Saaty (1980) suggests that the comparisons of the factors be made in the range *1/9* to *9*. A *9* indicates that one factor is *extremely more important* than the other, a *1/9* indicates that one factor is *extremely less important* than the other, and a *1* indicates equal importance. Also, if the importance of one factor with respect to a second is given, then the importance of the second factor with respect to the first is the reciprocal. These pairwise comparisons are summarized in a matrix, and one matrix is used for each controlling variable. One pairwise comparison matrix will be formed for the comparisons of the categories on each of the factors.

The third step in the AHP process is to complete the evaluations of the factors and alternatives relative importance weights by determining a local priority vector is computed as the unique solution to:

$$Aw = \lambda_{\max} w, \qquad (1)$$

where $\lambda_{\max}$ is the largest eigenvalue of A, the pairwise comparison matrix of the factors under consideration. Saaty (1980) provides several algorithms for approximating w, the final relative importance weights of the factors. We used Web HIPRE3+ (Mustajoki and Hämäläinen 1999), an Internet, interactive software decision support tool available for decision analysis (http://www.hipre.hut.fi/), to compute the eigenvalues and relative importance weights for our study.

The final stage in the overall benchmarking methodology is the sensitivity analysis and will be described fully at the end of the case example.

CASE STUDY: APPLYING THE METHODOLOGY TO THE FOOD SUPPLY CHAIN

We now apply the AHP process described above to the food supply chain. The first step is to define the hierarchy, illustrated for this study in Figure 1. The ultimate objective is to measure supply chain sustainability, which is often defined in terms of the "triple bottom line" of planet, people, and profit (Elkington 1997). The top level of our hierarchy consists of these three corresponding dimensions: environmental, social, and economic dimensions. These are only exemplary dimensions, other dimensions may be used to define sustainability; however, these three are generally accepted as the primary factors. The hierarchy is further decomposed into various sub-elements. The food supply chain itself, represented by five distinct stages, is the next level. The stages include agriculture, processing, wholesale, retail, and catering. Again, one could argue that there should be more stages or fewer stages. We feel that a five-stage model captures the essence of the supply chain, including an appropriate level of detail. The third and final level of the hierarchy is made up of the specific measures used to evaluate the sustainability of the supply chain stages. These measures are the indicators summarized in Table 3, which include labour productivity, number of employees, cost of waste disposal, and so on.

Insert Figure 1 Approximately Here

For this study, we chose to survey a small group of food supply chain experts to determine relative importance weights. Several experts, who specialize in one type of food product (chicken or potato) or have general food supply chain knowledge at a national level and have significant work experience (13 or more years) at a specific supply chain level (agricultural production, food manufacturing, food wholesale, food retail and industry association) have been approached to participate in the study by filling in the questionnaire. All the experts were previously interviewed on the subject of sustainability in the food supply chain. Out of eighteen experts approached for the study, five responded by filling in the questionnaire; for this study we selected four fully completed questionnaire responses from the actual respondents. Experts whose responses were used for the AHP development include: a) a potato expert who is a senior manager at a national industry association with marketing expertise and 30 years work experience in food retailing; b) a chicken expert who is a senior manager within a national industry association with expertise in food safety and food technology and 13 years work experience in the food industry; c) retail expert 1 is a senior manager at a large supermarket chain with expertise in product development and quality assurance and 15 years work experience in food retail; d) retail expert 2 is a senior manager at a large supermarket chain with expertise on technical development with 17 years work experience in the food industry.

As part of this weight elicitation process, a questionnaire was developed. The initial portions of the questionnaire provided some definitions of the factors to be evaluated. These definitions are important to help respondents be more consistent in their evaluations. An excerpt from the full questionnaire is shown in Appendix A. All of the questions in the questionnaire are formulated as pairwise comparisons and are used to construct the pairwise comparison matrices. For this hierarchy we needed responses to 88 pairwise comparison questions. Respondents were asked to make a series of pairwise comparisons for each level of the hierarchy discussed above. For example, with respect to the top level, the following three questions were posed:

- How significant are *environmental factors* when compared to *economic factors*?
- How significant are *environmental factors* when compared to *social factors*?
- How significant are *social factors* when compared to *economic factors*?

The responses were represented on a 1–9 Likert-type scale with a “1” response representing the *1/9* value, meaning *extremely less important*, and a “9” response meaning *extremely more important*. Table 5 reports the importance ratings derived from the responses of a potato supply chain expert. The numbers listed in boxes reflect the responses to the three groupings of questions above. The diagonal elements of the matrix are 1’s, by definition, since they represent the comparison of an item with itself. As discussed above, once the importance of one factor with respect to a second is given, then the importance of the second factor with respect to the first is the reciprocal. This process is how the remaining elements of the matrix are derived. In this way, the three questions completely characterize the nine pairwise comparisons of the environmental, social, and economic factors. Using these numbers as inputs, AHP determines the relative importance scores of each of the factors. These importance rating scores, reported in the last column of Table 5, represent the relative weight that this expert places on each top-level dimension (note that the values sum to 1). These results show that this expert felt the environmental issues were of less significance than both social and economic issues in the potato supply chain.

Insert Table 5 Approximately Here

Similarly, Table 6 reports the results of the pairwise comparisons based on the responses of a chicken supply chain expert. As expected, different responses to the survey questions yield different importance ratings. It is interesting to note, however, that although the ratings are different, the rank orderings correlate perfectly, i.e., *environmental* has the lowest weight and *economic* has the highest weight for both experts.

Insert Table 6 Approximately Here

This process of eliciting responses is repeated for each level of the hierarchy, comparing each stage of the supply chain with respect to each dimension of sustainability and then comparing each indicator (such as labour productivity) with respect to each stage of the supply chain. A similar process was used to obtain ratings from the retail experts for each level of the hierarchy (to conserve space, the ratings are not reported here).

Once the responses to all of the questions have been elicited, AHP is used to compute the relative adjustment ratings. The final output is a set of importance ratings for each expert for all of the indicators at the bottom of the hierarchy illustrated in Figure 1. The final AHP output for one potato expert is displayed in Table 7. The relative importance weighting from Table 6 for the potato expert's environmental sustainability dimension (0.177), appear as "local" importance ratings, the second column, for the environmental factor in Table 7. The relative importance rating for the impact of each of the supply chain stages is shown in the fourth column of Table 7. For example the agricultural stage of the potato supply chain has the highest (local) relative importance rating (0.535) in its influence on the environmental sustainability dimension. The (local) relative importance of each of the sustainability indicators for a given sustainability dimension and supply chain stage appears in the sixth column of Table 7. The environmental sustainability dimension at the agricultural stage has energy consumed as the most important of the three sustainability indicators with a local score of 0.567 (when compared to water consumed, 0.323, and waste generated, 0.110). The global importance rating is determined by taking the product of each of the local scores for a given row. For example for the energy consumed by the agriculture supply chain stage's environmental sustainability dimension, the global importance rating is the product of (0.567)*(0.535)*(0.177) = 0.05369. The mathematical expression is simply:

$$GIR_{ijk} = SD_i * SCS_j * SI_k \quad (2)$$

Where: SD_i= local relative importance rating for the Sustainability Dimension i
SCS_j= local relative importance rating for the Supply Chain Stage j
SI_k=local relative importance rating for the Sustainability Indicator k
GIR_{ijk}= global relative importance rating for Sustainability Indicator k of Supply Chain Stage j, Sustainability Indicator i.

Insert Table 7 Approximately Here

An overall sustainability index is computed by weighting the indicator scores reported in Table 4 by the global ratings of Table 7. The index is simply the sum of the indicator scores multiplied by the global ratings. Table 8 shows the results for one potato expert. The overall sustainability of the potato supply chain, based on the data in Table 4 and the opinions in Table 7, is 3.016. Each element of the table equals the indicator score times the global importance rating. For example, the value for labour productivity (the first economic dimension) for the retail link in the potato supply chain is computed as (0.166)*(2.06) = 0.341, where 0.166 is the global relative importance rating for the labour productivity indicator (Table 7) and 2.06 is the indicator score for the retail link of the potato supply chain (Table 4). Similar computations are performed for each sustainability indicator and supply chain link combination; these products are then summed to get the total index of 3.016.

An advantage of the scoring and the weighting scheme is that we can arrive at a single sustainability index score for each stage and overall supply chain. We can also evaluate the sustainability of each level within the supply chain. As shown in Table 8, the processing stage of the potato supply chain has the largest influence on sustainability when aggregated and weighted, although the data for the stage of agriculture for calculating the indicators were not complete. Policy makers or supply chain managers seeking to improve performance should see what aspects of this stage make it sustainable. The analysis could also focus on the various elements and their scoring. Practically, policy makers or supply chain managers may seek to help improve the relative performance of poorly performing stage members to help them achieve better overall sustainability. Additionally, poorly performing members of a supply chain, after scoring and identification, may be able to identify practices used by better performing members to improve their own performance.

Insert Table 8 Approximately Here

This methodology was also applied to the chicken supply chain, using the data reported in Table 2 and the evaluations of a chicken supply chain expert (see Table 6 for the top-level ratings). Translating the opinions into numerical importance ratings and multiplying the indicator scores by these ratings yields an overall sustainability index of 3.178, as reported in Table 9. The overall score shows that based on the expert opinions of relative importance and the baseline performance numbers we arrive at a higher overall rating for the chicken supply chain's sustainability index. Although data collected for calculation of indicators (especially at the stage of agriculture) are not complete, this result would mean that in comparison with the potato supply chain, the chicken supply chain is closer to achieving sustainability objectives within three dimensions: economic, social and environmental.[1]

Insert Table 9 Approximately Here

The retail experts do not have in-depth knowledge of specific supply chains and were not asked to evaluate the potato or chicken supply chains specifically; therefore, we use their opinions to complement the area experts. Specifically, we first computed global importance ratings for each retail expert for each supply chain using the same process described above. We then computed an average global importance rating for the potato supply chain using the potato expert and the two retail experts. The average was computed as a weighted geometric mean, as is usual when combining separate ratings of individual experts (Forman and Peniwati 1998). Since the potato supply chain expert has more detailed knowledge of this chain, we placed a weight of 0.5 on his/her ratings and placed a weight of 0.25 on the ratings of each of the retail experts (for a total weight of 1.0). Various other weighting schemes were examined — including equal weights for all experts — and each produced similar results. Combining the ratings in this way recognizes the experts' area knowledge while reducing the possibility of extreme bias. The average global importance rating was then used to compute the overall sustainability index (as described above), yielding an average overall result of 2.859 for the potato supply chain. Using the same process for the chicken supply chain yields an average overall sustainability index of 3.004. To further understand the robustness of these results and to attain additional insights, we perform a sensitivity analysis.

Sensitivity Analysis

The final stage of our overall benchmarking methodology is the sensitivity analysis stage. We seek to determine the overall robustness of the sustainability numbers to perturbations in the data. That is, if other experts were asked to rate the importance of different supply chain dimensions and indicators, how much would the final results change? The sensitivity analysis also shows the tradeoffs that are implicitly assumed by the various experts. Some tradeoffs have greater marginal implications for experts and supply chains. This type of tradeoff analysis is critical to identify potential stakeholder responses to various valuations as well as implications to performance of stages and overall supply chain sustainability. Sensitivity analysis is also useful in providing insights due to the dynamics of sustainability perceptions and importance over time. To demonstrate some of these issues, we perform sensitivity analysis on the economic dimension of the top-level hierarchy for both the potato and chicken supply chains. We chose this dimension because the area expert for each supply chain gave it the highest weight, but the process discussed below could be used for any dimension or link. Based on the questionnaire

[1] To ensure a fair comparison, when one supply chain is missing a value for an indicator (Table 4), the corresponding value for the other supply chain is also set to 0. This process only affects one indicator (Employees per enterprise in the Agriculture stage). Including the original, non-zero value for this indicator would make the overall sustainability index higher for the chicken supply chain.

responses from the potato supply chain expert, the economic dimension has a weight of 0.519, the social dimension has a weight of 0.304, and the environmental dimension has a weight of 0.177. To understand how sensitive the overall sustainability index is to changes in the weight on the economic dimension, we vary this weight from 0 to 1, while keeping the ratio of the other two dimensions the same. The ratio of social to environmental is currently 0.632 (= 0.304/[0.304 + 0.177]), and the ratio of environmental to social is currently 0.368 (= 0.177/[0.304 + 0.177]). Thus, if the economic dimension has a score of 0, then the social dimension will have a score of 0.632 and the environmental dimension will have a score of 0.368, maintaining the same ratios. If the economic dimension has a score of 0.2, then social dimension will have a score of 0.506 (= 0.632*[1–0.2]) and the environmental dimension will have a score of 0.294 (= 0.368*[1–0.2]). Changing the top-level weights will also change the global importance ratings and yield a different overall sustainability index. Figure 2 illustrates how the overall sustainability index changes as the weight on the economic dimension changes. The same process was used to generate results for the chicken supply chain and for the average indices computed using the retail experts' opinions. All of the results are shown in Figure 2, along with the actual (original) scores.

Insert Figure 2 Approximately Here

In Figure 2 there are four sensitivity ranges (lines) and four original points identified. The four include: (1) The chicken supply chain sensitivity of the chicken expert only; (2) The average chicken supply chain sensitivity that is the weighted average for the chicken expert and the two retail experts; (3) The potato supply chain sensitivity of the potato expert only; and (4) The average potato supply chain sensitivity that is the weighted average for the potato expert and the two retail experts.

As the figure indicates, the sustainability index of potato supply chain is more sensitive than that of the chicken supply chain to changes in the weight on the economic dimension (this result is true for the basic potato supply chain and the averaged potato supply chain). While the index for potato chain ranges from 2.3 to 3.7, the index for the chicken chain only ranges from approximately 2.8 to 3.3. Similarly, the averaged sustainability index for the potato supply chain ranges from approximately 2.4 to 3.8, and the averaged sustainability index for the chicken supply chain ranges from approximately 2.7 to 3.4. The data in Table 4 suggest that the potato supply chain performs better than the chicken supply chain in terms of the economic indicators. It is likely that the improved performance in one area is coming at the expense (trading-off) of other areas. The potato chain is less sustainable overall, according to the experts and the proposed measures. In any case, this situation illustrates how focus on a single dimension may miss the mark in terms of evaluating the overall health and sustainability of the supply chain and the importance of the consideration of tradeoffs within and between factors. Another general observation is that each of the overall sustainability scores tends to increase for each supply chain based on the increasing importance of economic factors. Sensitivity analyses were carried out for both of the other two factors (to conserve space, the details have been omitted), and their overall sustainability scores decrease due to their lesser weighted importance than the economic factor.

DISCUSSION AND CONCLUSIONS

One effective way for managers and policy makers to improve the sustainability of supply chains is to complete a benchmarking exercise to determine how well specific supply chains perform. In addition management and supply chain researchers may find approaches that can help develop and integrate factors and scales for sustainable supply chains useful for theory testing and development. Stakeholder theory and emergent sustainable supply chain management theory, can both inform the development and application of a benchmarking tool for sustainable supply chains. To complete this evaluation for sustainability performance evaluation we have introduced a methodological framework that can help benchmark supply chains based on sustainability factors. Using one of the world's most critical supply chains, the food supply chain, we introduce and apply a multi-stage procedure to help analytically evaluate a supply chain's sustainability performance. The method uses statistical data for two food supply chains in combination with expert opinion to construct an overall index of sustainability.

The results show that the chicken supply chain performs better than the potato supply chain. Given that we have missing data, especially for the part of agriculture, judging from the results we can state that chicken supply chain (from agricultural production to catering) is closer to achieving sustainability objectives within economic, social and environmental dimensions. According to the experts, the economics dimension is the most significant contributor to sustainability, although the supply chain that performed best on these factors (potato) was not the one that as appears to be the most sustainable. But, this overarching economic stance by our two area experts is realistic since most supply chains are primarily driven by economic factors. Also, as is the problem with most sustainability discussions and evaluations, social and environmental issues will tend to get lost amongst the economic discussion. Alternative weighting schemes and a more comprehensive analysis by completing a 'what-if' analysis would see a shift in the results. Also, the relative importance of sustainability factors will tend to shift over time. This shift is becoming even more pronounced as governments and communities are seeking ways to reduce environmental burdens while maintaining or improving social benefits. A benchmarking methodology such as the one proposed here can help to more effectively manage these tradeoffs.

Social investors, consumers and environmental organisations, customers and policy makers can use the developed framework of assessment to inform their decisions. The developed framework can be useful for policy makers to measure sustainability performance across various supply chains (major commodities and products). Focal companies within food supply chains such as food manufacturers and supermarket retailers may adopt this framework to assess the sustainability performance of their products and compare within the sector. Sustainability scorecard development, becoming more common in commercial products, can be enhanced by more effectively considering and integrating multiple dimensions and scores. The framework can be used to make relative comparison between various commodities, but most importantly can be applied for comparison of various methods of production (e.g. organic and conventional) for the same product or products produced by different supply chains (companies or retailers). If applied to a company level, the developed benchmarking framework could assist consumers to evaluate sustainability performance of equivalent product lines and inform their purchasing behaviour.

Since we construct and range indicators between 1 and 6, where 6 is the desirable sustainability performance or sustainability target, we can say that the closer the overall sustainability score of the supply chain the closer the supply chain is conforming to sustainability objectives or targets. Potential users of the framework (such as policy maker and individual companies) can set the maximum score as a desired target for sustainability performance (either policy target or individual corporate performance target) and using the framework can measure how the supply chains are performing in accordance with set targets. The higher the score the closer the supply chain overall in achieving sustainability targets within the three dimensions: economic, social and environmental.

Involvement of independent third party in management of sustainable supply chain (Teuscher *et al*. 2006) is considered an advantage. This assessment framework involves expert opinion in assessing relative values of indicators in sustainability of the supply chain. Potential users of the framework may wish to consult stakeholders during selection of sustainability indicators to be included in the assessment as suggested by Courville (2003) and also consult them on what would be those desirable sustainability performance targets before ranging the indicators from 1 to 6. Even though not tested in this manuscript, researchers wishing to develop multiple scoring levels (factors and/or stages within the supply chain) have a framework for integrating and disaggregating scores. These type of alternative scoring and measurement schemes will aid in further understanding and advancing sustainability and supporting theory.

There are clear limitations in our approach, which include the development and setting of ranges, the selection and inclusion of experts, and the integration of actual data. Unfortunately, we could not collect the complete data for the assessment of the case study supply chains; however, we see that there should be no limitations for future use of the proposed methodology. Although, this framework does not specifically address the element of food miles and impacts associated with imported goods. This framework concentrates on food products produced within boundaries of a state. However, food supply chains are becoming increasingly globalized, and the reflection of the environmental and social burdens associated with importing products from abroad could be incorporate through including specific indicators to reflect carbon emissions associated with all stages of the supply chain (agricultural production, food manufacturing, food wholesale (including food imported from abroad), food retail and food catering).

Rating of sustainability indicators on 1–9 scale requires detailed expert knowledge on operations and impacts of specific supply chains. As different experts were used for two different supply chains, experts may be biased and their opinion may affect the final scores. In this study we decided to place more weight on the opinion of product specialists, but equal or other combinations for distributing the weights of expert opinions may be utilized. Perhaps, in order for companies to improve the sustainability performance, which is often interpreted by organizational stakeholders, companies and policy makers need to incorporate stakeholders in determining relative weights of indicators. Integrating more experts from various stakeholder groups (not just industry) may provide more evidence of what types of tradeoffs are willing to be made. Industry expert biases may focus on the importance of economic achievements, government and communities may focus more on social issues, while NGO's and environmental groups may seek to put more emphasis on environmental issues. A broader perspective, incorporating additional stakeholders can be completed using the geometric weighting scheme proposed in this study. The relative importance of these various stakeholders will also need to be established. Finding common footing may actually occur. Further negotiation on weighting schemes with sensitivity analysis will allow for a more complete picture of supply chain sustainability.

Broader application, studies, and developing better data acquisition systems and performance measurement systems in the future may address these limitations. We provide one of the few studies to actually benchmark entire supply chains, and the example we provide represents a strong foundation upon which to build.

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Appendix A: Questionnaire Excerpt

Definitions:

Sustainability - Sustainable development involves the simultaneous pursuit of economic prosperity, environmental quality and social equity. Companies aiming for sustainability need to perform not against a single, financial bottom line but against the triple bottom line.

Agriculture – includes processes that involve growing of plants (e.g. food crops, vegetables, fruit, etc) and crops combined with farming of animals; farming of birds and animals (poultry, cattle, sheep, goats, horses, asses, mules, hinnies and swine); and agricultural services activities.

Food processing – includes processes that involve production and preserving of meat, poultry (including slaughtering of birds and animals); processing and preserving fish and vegetables; manufacture of food products and drinks.

Food wholesale – includes processes that involve wholesale of agricultural raw materials, live birds and animals; wholesale of food, beverages and tobacco; and wholesale of grain, seeds and animal foods.

Food retail – includes processes that involve retail sale of food products, drinks and tobacco to consumers in specialised food stores shops and non-specialised stores.

Food catering – includes processes that involve preparation and distribution of food products and drinks to consumers in hotels, hostels, camping sites, restaurants, cars and canteens.

Energy use – includes use of petrol, diesel, electricity, gas, etc.

Water use – include use of water for industrial purposes.

Waste – includes sewage and waste.

Employment – provision of jobs including part-time, full-time, seasonal and permanent.

Wages – includes gross wages and salaries (in cash or kind).

Employment gender ratio – ratio between full-time equivalent male and full-time equivalent female employment.

Productivity – is an indicator that measures the efficiency of the economy and could be measured by output per filled job.

Market concentration - concentration ratio for distribution is market share of total goods by largest enterprises.

Import dependency – is a share (%) of imported goods in total volume of goods.

Questionnaire on comparative importance of sustainability indicators in the food supply chain

On a scale of one to nine please rate the significance of one issue over the other issue. Please mark with X one of the nine boxes provided for each answer.

No.	Questions	Extremely less important	Very much less important	Less important	Slightly less important	Equal	Slightly more important	More important	Very much more important	Extremely more important
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	***In terms of SUSTAINABILITY OF THE FOOD SUPPLY CHAIN***									
A	How significant are **environmental factors** when compared to **economic factors**?									
B	How significant are **environmental factors** when compared to **social factors**?									
C	How significant are **social factors** when compared to **economic factors**?									
2	***In terms of their ENVIRONMENTAL IMPACT***									
A	How much more important are **agricultural activities** when compared to **food processing activities**?									
B	How much more important are **agricultural activities** when compared to **food wholesale activities**?									
C	How much more important are **agricultural activities** when compared to **food retail activities**?									
D	How much more important are **agricultural activities** compared to **food catering**?									
E	How much more important are **food processing activities** when compared to **food wholesale activities**?									
F	How much more important are **food processing activities** when compared to **food retail activities**?									
G	How much more important are **food processing activities** when compared to **food catering activities**?									
H	How much more important are **food wholesale activities** when compared to **food retail activities**?									
I	How much more important are **food wholesale activities** when compared to **food catering activities**?									
J	How much more important are **food retail activities** when compared to **food catering activities**?									
3	***In terms of their SOCIAL IMPACT***									
A	How much more important are **agricultural activities** when compared to **food processing activities**?									
B	How much more important are **agricultural activities** when compared to **food wholesale activities**?									
C	How much more important are **agricultural activities** when compared to **food retail activities**?									
D	How much more important are **agricultural activities** compared to **food catering**?									
E	How much more important are **food processing activities** when compared to **food wholesale activities**?									

Table 1: Sustainability indicators for the food supply chain

Supply chain stage	Environmental	Social	Economic
Agriculture/ Food processing/ Food wholesale/ Food retail/ Food catering	• Energy consumption • Water consumption • Waste arising	• Employment • Wages • Employment gender ratio	• Labour productivity • Market concentration • Import dependency

Source: Adapted from Yakovleva and Flynn (2004).

Table 2: Sustainability indicators for the chicken and potato supply chains (data for 2002) [2]

Stage of the food supply chain/ *Dimension of sustainability/* Indicators					
Agricultural production	Units	Chicken	Potato	Agriculture	Total UK economy
Economic indicators					
Number of enterprises		725	4,581	142,840	1,619,195
Total output	£'000	821,000	544,000	15,508,000	1,948,458,000
Total output	'000 tonnes	1,202	6,663	n/a	n/a
Output per enterprise	£'000	1,132	118	108	1,203
Output per enterprise	'000 tonnes	1.65	1.45	n/a	n/a
GVA	£'000	n/a	n/a	7,137,000	926,275,000
Labour productivity (GVA per workforce)	£	n/a	n/a	12,976	35,600
Large enterprises	%	12%[3]	16%[4]	14%[5]	2%[6]
Imported products vs. domestic	%	0.007%	9%	38%	n/a
Social indicators					
Total employment, average per year	people	9,200	n/a	550,000	26,000,000
Employee per enterprise	people	12.7	n/a	3.8	16.1
Average gross wages per employee (min)	£ per year	n/a	n/a	15,735[7]/3,467[8]	21,685
Male vs. female employment full time labour	%	n/a	n/a	n/a	63%
Environmental indicators					
Purchase of energy for own consumption per enterprise	£'000	n/a	n/a	n/a	n/a
Purchase of water for own consumption per enterprise	£'000	n/a	n/a	n/a	n/a
Cost of sewage and waste disposal per enterprise	£'000	n/a	n/a	n/a	n/a
Food processing	Units	Poultry	Potatoes	Food & drink manufacturing	Total UK industry
Economic indicators					
Number of enterprises		107	60	7,535	164,366
Total output	£'000	2,063,000	1,400,000	67,576,000	531,081,000
Total output	'000 tonnes	1,314	1,940	n/a	n/a
Output per enterprise	£'000	19,280	23,333	896	3,238
Output per enterprise	'000 tonnes	12.28	32.33	n/a	n/a
GVA	£'000	467,000	585,000	19,643,000	179,061,000
Labour productivity (GVA per workforce)	£	23,350	53,182	40,252	45,160
Large enterprises, turnover £5m+	%	37%	27%	15%	7%
Imported products vs. domestic	%	9%	7%	15%	26%
Social indicators					
Total employment, average per year	people	20,000	11,000	488,000	3,965,000
Employee per enterprise	people	186.92	183.33	64.76	24.1
Average gross wages per employee	£ per year	16,800	19,273	18,193	20,635
Male vs. female employment full time labour	%	73%	62%	70%	63%

[3] Holdings with more than 100,000 and over broilers are classified as large.
[4] Potato holdings with 20 ha of land and over.
[5] Agricultural holdings with 100 ha of land and over (data from *Agriculture in the UK 2002*).
[6] Enterprises with a turnover of more than £5m.
[7] Average wages per person per year, full-time labour.
[8] Average wages per person per year, gross wages in agriculture divided by total employment in agriculture in 2002.

Environmental indicators					
Purchase of energy for own consumption per enterprise	£'000	794	1,535	634	484
Purchase of water for own consumption per enterprise	£'000	121	208	67	27
Cost of sewage and waste disposal per enterprise	£'000	257	299	133	43
Food wholesaling	Units	Poultry	Potatoes	Agri-food wholesale	Total UK wholesale
Economic indicators					
Number of enterprises		586	880	17,218	113,812
Total output	£'000	1,345,500	2,245,700	70,032,000	388,989,000
Output per enterprise	£'000	2,296	2,552	4,067	3,412
GVA	£'000	165,300	349,400	7,678,000	52,643,000
Labour productivity (GVA per workforce)	£	24,309	47,216	34,124	42,834
Large enterprises, turnover £5m+	%	9%	13%	7%	7%
Imported products vs. domestic	%	22%	21%	38%	n/a
Social indicators					
Total employment, average per year	people	6,800	7,400	225,000	1,229,000
Employee per enterprise	people	11.6	8.4	13.1	10.8
Average gross wages per employee	£ per year	16,452	13,888	16,876	19,129
Male vs. female employment full time labour	%	83%	71%	73%	73%
Environmental indicators					
Purchase of energy for own consumption per enterprise	£'000	161	75	21	161
Purchase of water for own consumption per enterprise	£'000	13	5	1	8
Cost of sewage and waste disposal per enterprise	£'000	40	18	3	16
Food retailing	Units	Chicken	Potatoes	Food and drink retail	Total UK retail
Economic indicators					
Number of enterprises		1,800	1,400	66,703	207,513
Total output	£'000	2,742,000	3,415,000	71,000,000	265,211,000
Total output	'000 tonnes	1,414[9]	3,338	n/a	n/a
Output per enterprise	£'000	1,523	2,439	1,064	1,275
Output per enterprise	'000 tonnes	0.79	2.38	n/a	n/a
GVA	£'000	144,500	86,800	17,510,000	53,185,000
Labour productivity (GVA per workforce)	£	17,000	12,765	13,820	17,285
Large enterprises, turnover £5m+	%	0.3%	0.2%	1%	1%
Imported products vs. domestic	%	22%	21%	38%	n/a
Social indicators					
Total employment, average per year	people	8,500	6,800	1,267,000	3,077,000
Employee per enterprise	people	4.7	4.9	18.9	14.8
Average gross wages per employee	£ per year	6,538	4,840	7,812	8,798
Male vs. female employment full time labour	%	75%	54%	54%	50%
Environmental indicators					
Purchase of energy for own consumption per enterprise	£'000	15	13	477	173
Purchase of water for own consumption per enterprise	£'000	1	1	32	13
Cost of sewage and waste disposal per enterprise	£'000	3	2	28	12
Food catering (non-residential)	Units	Chicken	Potatoes	Non-	Total UK

[9] The calculation of physical outputs in food retailing and non-residential catering is based on proportions that 15% of chickens are sold via food service and 85% via retail (Baxter 2003).

				residential catering	economy
Economic indicators					
Number of enterprises		2,062	8,500	107,739	1,619,195
Total output	£'000	488,000	700,000	46,436,000	1,948,458,000
Total output	'000 tonnes	255	3,141	n/a	n/a
Output per enterprise	£'000	236	82	431	1,203
Output per enterprise	'000 tonnes	0.12	0.36	n/a	n/a
GVA	£'000	234,000	324,000	18,002,000	926,275,000
Labour productivity (GVA per workforce)	£	12,251	12,226	12,221	32,200
Large enterprises, turnover £5m+	%	1%	1%	1%	2%
Imported products vs. domestic	%	22%	21%	38%	n/a
Social indicators					
Total employment, average per year	people	19,100	26,500	1,473,000	26,000,000
Employee per enterprise	people	9.3	3.1	13.7	16.1
Average gross wages per employee	£ per year	6,327	6,327	6,327	21,685
Male vs. female employment full time labour	%	49%	49%	49%	63%
Environmental indicators					
Purchase of energy for own consumption per enterprise	£'000	124	124	124	n/a
Purchase of water for own consumption per enterprise	£'000	22	22	22	n/a
Cost of sewage and waste disposal per enterprise	£'000	15	15	15	n/a
Total food supply chain	Units	Chicken	Potatoes	Food and drink	Total UK economy
Economic					
Number of enterprises		5,280	15,421	342,035	1,619,195
Total output	£'000	7,459,500	8,304,700	270,552,000	1,948,458,000
Total output	'000 tonnes	1,698	6,479	n/a	n/a
GVA	£'000	1,010,800	1,345,200	69,950,000	926,275,000
Labour productivity (GVA per workforce)	£	15,887	26,019	17,474	32,200
Large enterprises	%	12%	11%	7%	2%
Imported products vs. domestic	%	17%	16%	30%	n/a
Social					
Total employment, average per year	people	63,624	51,700	4,003,000	26,000,000
Average gross wages per employee	£ per year	9,223	8,866	9,842	21,685
Male vs. female employment full time labour	%	70%	59%	61%	63%
Environmental					
Purchase of energy for own consumption per enterprise	£'000	274	437	314	n/a
Purchase of water for own consumption per enterprise	£'000	39	59	30	n/a
Cost of sewage and waste disposal per enterprise	£'000	79	83	45	n/a

Source: Adapted from Yakovleva (2007).

Table 3: Scoring Sustainability Indicators

Indicators	0	1	2	3	4	5	6
Mark	n/a	Very poor	Poor	Fair	Average	Good	Excellent
Productivity (GVA per workforce, thousand pounds)	n/a	0	12.0	24.0	36.0	48.0	60
Market concentration (% of large enterprises)	n/a	40	32.0	24.0	16.0	8.0	0
Trade importance (import dependency, %)	n/a	100	80.0	60.0	40.0	20.0	0
Employment (employees per enterprise, number of people)	n/a	0	4.0	8.0	12.0	16.0	20
Wages (average gross wages per employee per annum, thousand pounds)	n/a	0	5.4	10.8	16.2	21.6	27
Gender balance (male vs. female employment full time labour, %)	n/a	100	90.0	80.0	70.0	60.0	50
Energy use (purchase of energy for own consumption per enterprise, thousand pounds)	n/a	1000	800.0	600.0	400.0	200.0	0
Water use (purchase of water for own consumption per enterprise, thousand pounds)	n/a	80	64.0	48.0	32.0	16.0	0
Waste (cost of sewage and waste disposal per enterprise, thousand pounds)	n/a	100	80.0	60.0	40.0	20.0	0

Note: 0-information not available, 1-lowest score, 6-highest score

Source: Adapted from Yakovleva (2007).

Table 4: Indicator Scores for each Stage of Supply Chain and Food Type

	Indicators								
	Economic			Social			Environmental		
Supply Chain Stage/Food Type	A	B	C	D	E	F	G	H	I
Agriculture									
Chicken	0.00	4.50	6.00	4.18	0.00	0.00	0.00	0.00	0.00
Potato	0.00	4.00	5.55	0.00	0.00	0.00	0.00	0.00	0.00
Benchmark: Food	2.08	4.25	4.10	1.95	1.64	0.00	0.00	0.00	0.00
Food processing									
Chicken	2.95	1.38	4.90	6.00	4.11	3.70	2.03	1.00	1.00
Potato	5.43	2.63	5.65	6.00	4.57	4.80	1.00	1.00	1.00
Benchmark: Food and drink	4.35	4.13	5.25	6.00	4.37	4.00	2.83	1.81	1.00
Food wholesale									
Chicken	3.03	4.88	4.90	3.90	4.05	2.70	5.20	5.19	4.00
Potato	4.93	4.38	4.95	3.10	3.57	3.90	5.63	5.69	5.10
Benchmark: Agro-food wholesale	3.84	5.13	4.10	4.28	4.13	3.70	5.90	5.94	5.85
Food retail									
Chicken	2.42	5.96	4.90	2.18	2.21	3.50	5.93	5.94	5.85
Potato	2.06	5.98	4.95	2.23	1.90	5.60	5.94	5.94	5.90
Benchmark: Food and drink	2.15	5.88	4.10	5.73	2.45	5.60	3.62	4.00	4.00
Food catering									
Chicken	2.02	5.88	4.90	3.32	2.17	6.00	5.38	4.63	5.25
Potato	2.02	5.88	4.95	1.78	2.17	6.00	5.38	4.63	5.25
Benchmark: Non-residential catering	2.02	5.88	4.10	4.42	2.17	6.00	5.38	4.63	5.25

Notes:
A = Labour productivity (GVA per workforce)
B = Large enterprises, turnover £5m+
C = Imported products vs. domestic
D = Employees per enterprise
E = Average gross wages per employee
F = Male vs. female employment full time labour
G = Purchase of energy for own consumption per enterprise
H = Purchase of water for own consumption per enterprise
I = Cost of sewage and waste disposal per enterprise

Table 5: Pairwise Comparisons and Ratings of Sustainability Dimensions by Potato Expert

Dimension	*Environmental*	*Social*	*Economic*	**Importance Rating**
Environmental	1	1	1/5	0.177
Social	1	1	1	0.304
Economic	5	1	1	0.519

Table 6: Pairwise Comparisons and Ratings of Sustainability Dimensions by Chicken Expert

Dimension	*Environmental*	*Social*	*Economic*	**Importance Rating**
Environmental	1	1/7	1/3	0.085
Social	7	1	1/9	0.215
Economic	3	9	1	0.700

Table 7: AHP Final Output — Global Importance Ratings for Potato Expert

Sustainability Dimension	Importance Rating	Supply Chain Stage	Importance Rating	Sustainability Indicator	Importance Rating	Global Importance Rating
Environmental	0.177	Agriculture	0.535	Energy consumed	0.567	0.05369
Environmental	0.177	Agriculture	0.535	Water consumed	0.323	0.03059
Environmental	0.177	Agriculture	0.535	Waste generated	0.110	0.01042
Environmental	0.177	Food Processing	0.264	Energy consumed	0.319	0.01491
Environmental	0.177	Food Processing	0.264	Water consumed	0.460	0.02149
Environmental	0.177	Food Processing	0.264	Waste generated	0.221	0.01033
Environmental	0.177	Food Wholesale	0.035	Energy consumed	0.778	0.00482
Environmental	0.177	Food Wholesale	0.035	Water consumed	0.111	0.00069
Environmental	0.177	Food Wholesale	0.035	Waste generated	0.111	0.00069
Environmental	0.177	Food Retail	0.134	Energy consumed	0.333	0.00790
Environmental	0.177	Food Retail	0.134	Water consumed	0.333	0.00790
Environmental	0.177	Food Retail	0.134	Waste generated	0.333	0.00790
Environmental	0.177	Food Catering	0.032	Energy consumed	0.333	0.00189
Environmental	0.177	Food Catering	0.032	Water consumed	0.333	0.00189
Environmental	0.177	Food Catering	0.032	Waste generated	0.333	0.00189
Social	0.304	Agriculture	0.233	Employment	0.715	0.05064
Social	0.304	Agriculture	0.233	Wages/employee	0.218	0.01544
Social	0.304	Agriculture	0.233	Gender Ratio	0.067	0.00475
Social	0.304	Food Processing	0.342	Employment	0.460	0.04783
Social	0.304	Food Processing	0.342	Wages/employee	0.221	0.02298
Social	0.304	Food Processing	0.342	Gender Ratio	0.319	0.03317
Social	0.304	Food Wholesale	0.041	Employment	0.742	0.00925
Social	0.304	Food Wholesale	0.041	Wages/employee	0.203	0.00253
Social	0.304	Food Wholesale	0.041	Gender Ratio	0.055	0.00069
Social	0.304	Food Retail	0.218	Employment	0.633	0.04195
Social	0.304	Food Retail	0.218	Wages/employee	0.304	0.02015
Social	0.304	Food Retail	0.218	Gender Ratio	0.063	0.00418
Social	0.304	Food Catering	0.166	Employment	0.701	0.03538
Social	0.304	Food Catering	0.166	Wages/employee	0.204	0.01029
Social	0.304	Food Catering	0.166	Gender Ratio	0.095	0.00479
Economic	0.519	Agriculture	0.078	Labour productivity	0.701	0.02838
Economic	0.519	Agriculture	0.078	Market Concentration	0.202	0.00818
Economic	0.519	Agriculture	0.078	Import Dependency	0.097	0.00393
Economic	0.519	Food Processing	0.302	Labour productivity	0.429	0.06724
Economic	0.519	Food Processing	0.302	Market Concentration	0.143	0.02241
Economic	0.519	Food Processing	0.302	Import Dependency	0.429	0.06724
Economic	0.519	Food Wholesale	0.033	Labour productivity	0.685	0.01173
Economic	0.519	Food Wholesale	0.033	Market Concentration	0.234	0.00401
Economic	0.519	Food Wholesale	0.033	Import Dependency	0.080	0.00137
Economic	0.519	Food Retail	0.466	Labour productivity	0.685	0.16567
Economic	0.519	Food Retail	0.466	Market Concentration	0.234	0.05659
Economic	0.519	Food Retail	0.466	Import Dependency	0.080	0.01935
Economic	0.519	Food Catering	0.121	Labour productivity	0.726	0.04559
Economic	0.519	Food Catering	0.121	Market Concentration	0.198	0.01243
Economic	0.519	Food Catering	0.121	Import Dependency	0.076	0.00477

Note: Global importance ratings may not sum to 1 due to rounding error.

Table 8: Overall Sustainability Index Based on Potato Expert

	Economic			Social			Environmental			
	Labour Prod. (A)	Market Concen. (B)	Import Depend. (C)	Employ-ment (D)	Wages /Emp. (E)	Gender Ratio (F)	Energy Usage (G)	Water Usage (H)	Waste Generated (I)	**Total**
Agriculture	0.000	0.033	0.022	0.000	0.000	0.000	0.000	0.000	0.000	0.055
Food processing	0.365	0.059	0.380	0.287	0.105	0.159	0.015	0.021	0.010	1.402
Food wholesale	0.058	0.018	0.007	0.029	0.009	0.003	0.027	0.004	0.004	0.157
Food retail	0.341	0.338	0.096	0.094	0.038	0.023	0.047	0.047	0.047	1.071
Food catering	0.092	0.073	0.024	0.063	0.022	0.029	0.010	0.009	0.010	0.332
Total	0.856	0.521	0.528	0.472	0.175	0.214	0.099	0.081	0.070	3.016

Note: Sustainability index is the sum of indicator scores times global important ratings = 3.016.

Table 9: Overall Sustainability Index Based on Chicken Expert

	Economic			Social			Environmental			
	Labour Prod. (A)	Market Concen. (B)	Import Depend. (C)	Employ-ment (D)	Wages /Emp. (E)	Gender Ratio (F)	Energy Usage (G)	Water Usage (H)	Waste Generated (I)	**Total**
Agriculture	0.000	0.038	0.087	0.000	0.000	0.000	0.000	0.000	0.000	0.137
Food processing	0.633	0.142	0.146	0.072	0.034	0.021	0.032	0.003	0.002	1.085
Food wholesale	0.072	0.104	0.019	0.035	0.017	0.006	0.024	0.002	0.005	0.285
Food retail	0.221	0.544	0.064	0.084	0.041	0.031	0.041	0.003	0.018	1.049
Food catering	0.093	0.082	0.105	0.194	0.061	0.081	0.014	0.003	0.001	0.635
Total	1.019	0.911	0.422	0.396	0.154	0.139	0.111	0.012	0.026	3.178

Note: Sustainability index is the sum of indicator scores times global important ratings = 3.178.

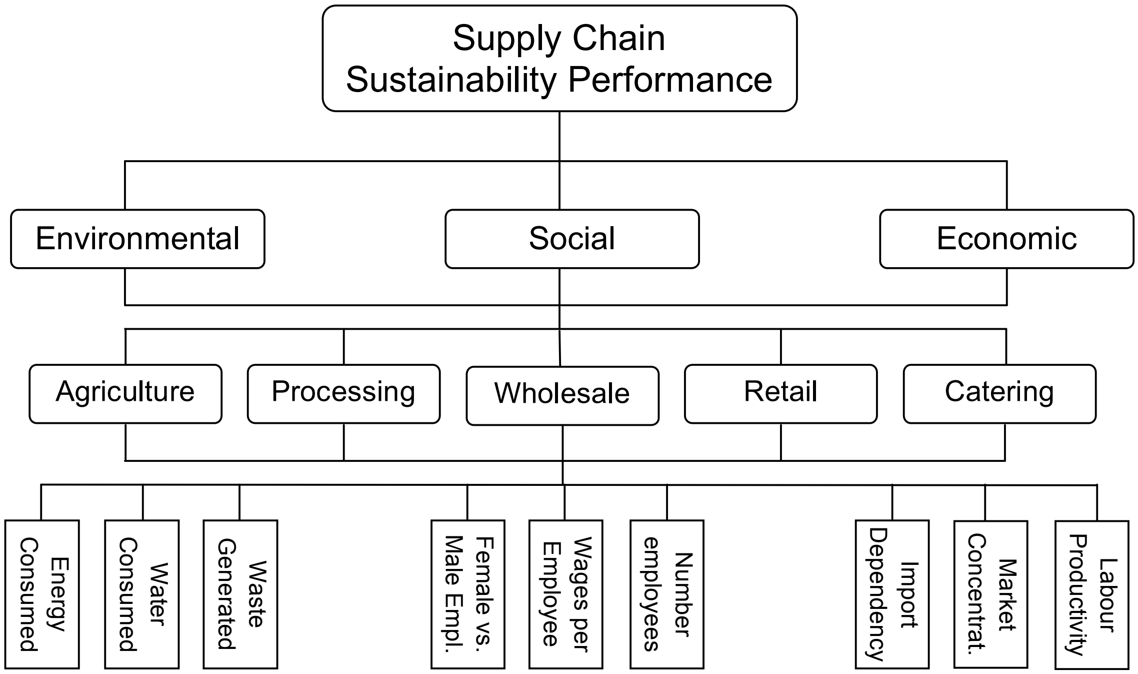

Figure 1: Supply Chain Sustainability Hierarchy

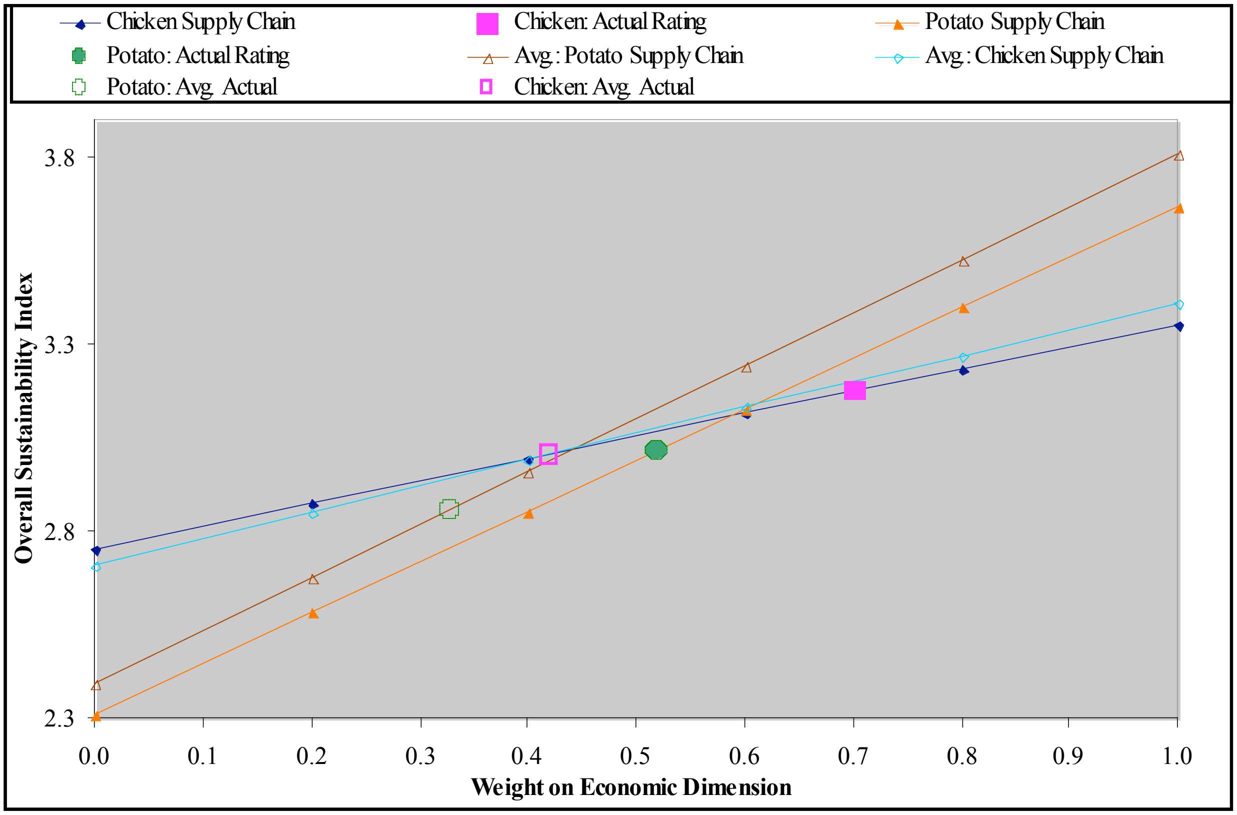

Figure 2: Changes in Overall Sustainability Index as a Function Weight Placed on Economic Dimension of Hierarchy