FEED-A-GENE

Adapting the feed, the animal and the feeding techniques to improve the efficiency and sustainability of monogastric livestock production systems

Deliverable D6.5

Evaluation of the Sustainability of the Proposed Production Systems

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1. Summary

Objectives

(i) To construct a weighted composite indicator of the sustainability of a selection of the new management systems proposed in the Feed-a-Gene project

(ii) To compare the relative sustainability of a selection of management systems proposed by the Feed-a-Gene project.

Rationale: This Deliverable uses the findings of the different elements of work package 6 to construct a weighted composite indicator of the sustainability of a selection of the new management systems proposed in the Feed-a-Gene project. The composite indicator was constructed using weights based on the results of the Delphi Experiment reported in D6.1 and populated with data on individual indicators generated in Tasks 6.2 and 6.3. The resulting composite indices will allow the comparison of a range of proposed feeding solutions in terms of their relative sustainability based around a set of component indicators.

Teams involved: UNEW; KU

Species and production systems considered: Pigs and poultry across Europe

2. Approach

Feed-a-Gene aims to improve and adapt monogastric livestock production systems with the objective of improving their efficiency and reducing their environmental impacts. To achieve this, the project developed alternative feed resources and feed technologies, while at the same time identified robust animals that are better adapted to fluctuating conditions and optimized feeding techniques to ensure the most efficient use of feeds. The successful achievement of these objectives has economic, environmental, and social implications. Task 6.5 of the project was designed to compare different management systems proposed by the project in terms of their overall sustainability as measured by a range of economic, environmental, or social indicators.

The main element of this Task was to design and implement a composite indicator that allows us to compare the relative sustainability of different feeding solutions based on innovations developed in the project. The composite indicator is constructed using weights based on the results of the Delphi Experiment reported in D6.1 and populated with data on individual indicators generated in Tasks 6.2, 6.3, and 6.4. The resulting indices allows the comparison of a range of proposed feeding solutions in terms of sustainability based around their estimated economic and environmental impacts.

2.1 Sustainability indicators

Nearly 40 years ago the 1980 World Conservation Strategy (IUCN et al., 1980) presented one of the first attempts to define the concept of sustainability (Hueting and Reijnders, 2004). In 1987, this was followed by the publication of the Brundtland Report, which introduced what is probably the best-known definition of sustainable development:

"Sustainable *development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"*

This definition has been the source of much discussion and controversy and a few years later Munro and Holdgate (1991) proposed an alternative definition that sought to address some of the perceived flaws of its predecessor *"development that improves the quality of human life while living within the carrying capacity of supporting ecosystems."* Since then, many different definitions of sustainability have been proposed, highlighting the different values, priorities, and goals of the authors.

Alongside the many different definitions of sustainability, a large number of indicators have been proposed as measures of our progress towards sustainability. These indicators cover both the economic, environmental, and social pillars of sustainability, as well as attempting a more holistic assessment of sustainability as a whole.

As early as 2001, Riley (2001) reported on the "indicator explosion" that had occurred over the last decade, while King *et al*. (2000) described the development of an "indicator industry" as academics, policy-makers, and practitioners jumped onto the sustainability bandwagon. In many cases, these indicators were reductionist in nature, focussing on particular elements of sustainability or addressing specific spatial scales often neglecting the potential end users of their indicators. Indeed, according to the Compendium of Sustainable Development Indicator Initiatives (IISD, 2015), which provides information on initiatives carried out at different levels worldwide, to date; there is a list of 895 attempts to develop sustainability indicators.

Table 1.1 - Technical characteristics of some indicators

Indicator initiative	Scale	Units of analysis	Selection criteria	Aggregation method
CSD	Global, present year	Country and year	Data availability and must meet specified scope and units of analysis	None
CGSDI	Global, present year	Country (most recent year available)	Data availability and must meet specified scope and units of analysis	Weighted index
Wellbeing Index	Global, present year	Country (most recent year available)	Data availability and must meet specified scope and units of analysis	Weighted index
Environmental Sustainability Index	Global, present year	Country (most recent year available)	Data availability and must meet specified scope and units of analysis	Weighted index
Global Scenario Group	Global, 1995 to 2050	Region and year	Data availability/ model output and must meet specified scope and units of analysis	None
Ecological footprint	Global, 1961 to most recent year available	Country and year	Data availability, must support aggregation to a common scale, and must meet specified scope and units of analysis	Common scale
Genuine Progress Indicator	United States, 1950 to most recent year	Sectors	Data availability, must support aggregation to a common scale, and must meet specified scope and units of analysis	Common scale
Global Reporting Initiative	Global, current year	Corporate/ nongovernmental organization entities	Theoretically	None

Source: Parris and Kates, 2003.

Spangenberg (2002) argued that the purpose of sustainability indicators in general, is to serve as simplifying communication tools helping to guide political decision making towards sustainable development. To achieve this purpose, indicators should reduce complexity, be easily understandable and limited in number.

To provide a sound basis for decision making Indicators should be:

- general, i.e., not dependent on a specific situation, culture or society;
- indicative, i.e., truly representative of the phenomenon they are intended to characterise;
- sensitive, i.e., they have to react early and sensibly to changes in what they are monitoring, to permit monitoring of trends or the successes of policies; and
- robust, i.e., directionally safe with no significant changes in case of minor changes in the methodology or improvements in the data base (Spangenberg, 2002).

Indicators are necessary to help us measure progress towards sustainable development goals, such as those proposed by the United Nations. However, their application can be complex and dependent on context, purpose and scale (Freebairn and King, 2003). Parris and Kates (2003) illustrated the technical characteristics of some early sustainability indicators (Table 1.1), illustrating some of the differences that emerge in the design of different indicators around the data used, geographical scale, and method of aggregation. Other key motivations underlying indicator development include: scientific accountability; responding to societal preferences and values; measuring progress towards national and global targets; learning, altruism, and stewardship (Freebairn and King, 2003).

Ultimately, indicators can be used to guide us towards the better management or resources by allowing us to take better account of the different impacts that activities have on the economy, society, and the environment. Depending on the goals of those developing the indicators, they may attribute a greater or lower weight on these different components of sustainability. Choosing the data to be included within an indicator and the weights that should be used to account for the importance of different components is a significant challenge for the practitioner. Early studies, such as Hueting and Reijnders (2004), suggested that studies should present a range of relevant environmental, social, and economic indicators, but argued that combining these separate elements in a single composite indicator was undesirable because they were often in conflict with one another. Becker (1997) also argued that the choice of components and the assignment of weights in a composite indicator are subjective and that the aggregation of different dimensions is often not meaningful.

Despite such arguments, it has been acknowledged that progress towards sustainability requires an understanding of the implications that projects, programmes, and policies have on the three dimensions of sustainability. This three-pillar approach to sustainability, sometimes referred to as economic growth, social progress, and protection of the environment and natural resources (Annan, 2002) or, more simply, profit, people, and planet (Wheeler and Elkington, 2001) has become increasingly common in the literature.

According to the United Nations Commission on Sustainable Development (UN-CSD, United Nations Department of Economic and Social Affairs, 1999), which developed and tested a number of indicators, the environmental dimension can be defined to be the sum of all bio-geological processes and the elements involved in them (“environmental capital”), the social dimension (“human capital”) consists of the intra-personal qualities of human beings: their skills, dedication, and experiences. The economic dimension (“man-made capital”) includes not only the formal economy, but in addition informal activities that provide services to individuals and groups and thus increase the standard of living beyond the monetary income. Economic indicators can be based around profitability (such as income, efficiency, and productivity) or on other economic measures generally expressed in monetary terms or as ratios (OECD, 2001). Zoeteman (2004) suggested some of the different elements that could be included in a composite sustainability index (Table 1.2).

Table 1.2 - Environmental, social and economic elements to be included in a sustainability index

Environmental elements	Social elements	Economic elements
Natural capital	Life expectancy at birth	% Labour force in services
Annual withdrawal of water resources	Urban population connected to sewer	Number of cars per 1000 population
Forest in % of original forest	Murders in urban environment per 10,000 population	Number of telephone lines per 100 population
CO_2 emissions/capita	Social security benefits expenditure in % GDP	Produced assets in US dollars
CO_2 emissions/dollar of GDP	Combined first, second and third education level enrolment ratio	
Maximum concentration of lead in gasoline		

Source: Zoeteman (2004).

There have been several attempts to develop aggregate indicators (indices) able to capture elements of sustainable development. Most aggregate indicators are primarily used for raising public awareness and receive considerable attention in the media. Rather than offering a comprehensive view of sustainable development, many of these indices are specifically focussed on the environmental dimension of sustainable development and resource management (UN- ISD, 2007). Examples of such indices include the Ecological Footprint (EF), the Environmental Sustainability Index (ESI), and the Environmental Performance Index (EPI).

All these indicators face significant challenges to aggregation related to data availability, methodologies, selection of variables, and, in case of indices, weighing of variables. Nonetheless, this ongoing work represents an important effort to aggregate a broad range of variables to convey a message that is easy for both decision-makers and civil society to understand.

At an international level, the Millennium Development Goals (MDG) indicators originally comprised a set of 48 indicators linked to the eight goals derived from the United Nations Millennium Declaration. However, the revised MDG monitoring framework presented by the Secretary-General of the United Nations in 2007 contained 58 indicators. Like the earlier UN Commission on Sustainable Development (CSD) indicators, the MDG Indicators were driven by policy relevance, rooted in major inter-governmental development summits and applied at the national level (UN-ISD, 2007). Since then, the MDGs have been updated with a revised set of Sustainable Development Goals (SDGs) and associated targets from the 2030 Agenda for Sustainable Development. A total of 232 indicators has been agreed to provide a global indicator framework for the SDGs.

2.2 Composite indicator design

2.2.1 Composite indices

Sustainability indicators are a useful means of assessing the relative merits of competing projects or policies. Composite indices of sustainability allow us to combine different variables into one measure so that a more complete story can be told using fewer numbers. The usefulness of such indices depends on our ability to adequately define and measure their components. What is technically possible in terms of indicator design and measurement should be distinguished from aspirational concepts, which may be difficult to robustly operationalise (Stapleton and Garrod, 2008).

A composite indicator (index) is an aggregation of individual indicators that can be weighted to reflect the relative importance of each indicator (Nardo et al., 2005). According to Stevens (2005), the rationale for developing and using such composite indices to inform public policy is that they integrate a mass of information into easily understood formats for a general audience. Stevens (2005) also notes how *"... their construction is not straightforward, they can provide misleading information...".* Similarly, Bossel (1999) notes how composite indices can hide serious deficits. To elaborate, a composite index could show positive increases over time suggesting that development is becoming more sustainable but this aggregate rise could mask declines in some components of the index, which is obviously converse to the notion of sustainability. Not surprisingly therefore, the development and use of composite indices of sustainable development has proponents and opponents.

An appropriate composite indicator should encapsulate important elements of the environmental, economic and social systems that may be subject to change as a result of a policy or project. In the development of a single composite indicator, each of the component indicators may be given equal weighting, or have differential weights applied to reflect their relative importance. In this study, work package 6 includes several tasks that estimate the environmental, social and economic impact of various feeding scenarios. Task 6.1 was concerned with identifying a coherent set of indicators for livestock production and also defining weights based around expert judgements around their relative usefulness in assessing the sustainability of livestock systems. Task 6.2 conducted a Life-Cycle Assessment (LCA) of different feeding solutions and Task 6.3 conducted a cost-benefit analysis (CBA) of the same solutions. Task 6.4 explored the opinions and preferences of the general public for different livestock feeding solutions. The outputs from these tasks were combined to form a composite indicator that allow different feeding scenarios to be compared in terms of their relative sustainability. Relative weights for the different environmental, economic, and social components of the indicator were provided using the outputs of the Delphi Experiment conducted in Task 6.1.

There is no single "correct" set of indicators or indicator weights. Parris and Kates (2003) concluded that – due to the confusion of terminology, data, and methods of measurement – there are no indicator sets that are universally accepted, backed by compelling theory, rigorous data collection and analysis, and also influential in policy. Since indicator selection influences the conclusions (Lebacq *et al*., 2013), "a well-defined and transparent procedure is thus necessary to enhance credibility and reproducibility of the evaluation" (Niemeijer and de Groot, 2008). Hence, reliable procedures are needed for selecting indicators that are valid (Dale and Beyeler, 2001). For questions such as this where judgement is required, expert elicitation methods may be used to identify appropriate indicators and weights. Different experts will express different opinions based on their knowledge, experience, and preferences. Consequently, an appropriate technique for identifying indicators and possible weightings is a Delphi study by which the opinions of experts can be elicited and pooled.

2.2.2 The proposed composite indicator

The following composite indicator S_i is used to compare the relative sustainability of *i* different feeding scenarios explored by the Feed-a-Gene project. The comparisons are based around a set of available economic, environmental and social component indicators generated by the project, which ae weighted using a set of weights based on the earlier Delphi Study (see Deliverable D6.1).

$$S_i = WEC*NEC_i + WENV*NENV_i + WSOC*NSOC_i) \quad (2.2.1)$$

Where:
S_i = Normalised comparative sustainability indicator for feeding scenario i [-1, 1]
WEC = Relative weight of economic component of sustainability indicator [0, 1]
WEC = (Econscore)/(Econscore+Envscore+Socscore)
WENV = Relative weight of environmental component of sustainability indicator [0, 1]
WENV = (Envscore)/(Econscore+Envscore+Socscore)
WSOC = Relative weight of social component of sustainability indicator [0, 1]
WSOC = (Socscore)/(Econscore+Envscore+Socscore)
Where:
Econscore = Usefulness score of economic indicators (from Delphi)
Envscore = Usefulness score of social indicators (from Delphi)
Socscore = Usefulness score of social indicators (from Delphi)

Also, for scenario i, relative to a total of n scenarios being compared:
$NEC_i = (RWEC_1*NEC_{i1} + RWEC_2*NEC_{i2} + \ldots + RWEC_p*NEC_{ip})$ (from empirical data) [-1, 1] (assuming p available economic indicators) (2.2.2)

$NENV_i = (RWENV_1*NENV_{i1} + RWENV_2*NENV_{i2} + \ldots + RWENV_q*NENV_{iq})$ (from empirical data) [-1, 1] (assuming q available environmental indicators) (2.2.3)

$NSOC_i = (RWSOC_1*NSOC_{i1} + RWSOC_2*NSOC_{i2} + \ldots + RWSOC_r*NSOC_{ir})$ (from empirical data) [-1, 1] (assuming r available social indicators) (2.2.4)

Where:
$RWEC_i$= Relative weight of economic indicator i (from Delphi) [0, 1] (i=1,…,p)
$RWENV_i$ = Relative weight of environmental indicator i (from Delphi) [0, 1] (i=1,…,q)
$RWSOC_i$ = Relative weight of social indicator i (from Delphi) [0, 1] (i=1,…,r)
$RWEC_i = (WEC_i) / (WEC_1 + WEC_2 + \ldots + WEC_p)$ (2.2.5)
$RWENV_i = (WENV_i) / (WENV_1 + WENV_2 + \ldots + WENV_q)$ (2.2.6)
$RWSOC_i = (WSOC_i) / (WSOC_1 + WSOC_2 + \ldots + WSOC_r)$ (2.2.7)

and
WEC_i = Weight of i^{th} economic indicator (from Delphi)
$WENV_i$ = Weight of i^{th} environmental indicator (from Delphi)
$WSOC_i$ = Weight of i^{th} social indicator (from Delphi)

NEC_{ip} = Normalised value of p^{th} economic indicator for scenario i (from empirical data)
$NENV_{iq}$ = Normalised value of q^{th} environmental indicator for scenario i (from empirical data)

$NSOC_{ir}$ = Normalised value of r^{th} social indicator for scenario i (from empirical data)

$NEC_{ip} = EC_{ip}/RangeEC_{pn}$ (2.2.8)
EC_{ip} = Value of the p^{th} economic indicator in scenario i
$RangeEC_{pn}$ = Range of p^{th} economic indicator across all n scenarios including baselines

$NENV_{iq} = ENV_{iq}/RangeENV_{qn}$ (2.2.9)
ENV_{iq} = Value of the q^{th} environmental indicator in scenario i
$RangeENV_{qn}$ = Range of q^{th} environmental indicator across all n scenarios including baselines

$NSOC_{ir} = SOC_{ir}/RangeSOC_{rn}$ (2.2.10)
SOC_{ir} = Value of the r^{th} social indicator in scenario i
$RangeSOC_{rn}$ = Range of r^{th} social indicator across all n scenarios including baselines

This indicator is designed to ensure that all component indicator variables (NEC_{ip}, $NENV_{iq}$, and $NSOC_{ir}$) are normalised to take values between -1 and 1 relative to a baseline. This ensures that all individual component indicator values are in the same range and have the same potential impact in the calculation of the composite indicator. Negative values show that, for a given scenario, sustainability impact, as measured by a particular component indicator, is lower than the baseline (e.g., higher costs, lower profits/greater losses, higher greenhouse gas emissions). Conversely, a value greater than 0, shows that in a scenario, performance in that particular dimension of sustainability is an improvement on the baseline (e.g., lower costs, higher profits, lower greenhouse gas emissions). For the baseline scenario the values of all indicators, and the composite indicator S_i, are zero.

The indicator weights (WEC_i, $WENV_i$ and $WSOC_i$) allow those component indictors judged to be most important for sustainable livestock production to have a relatively higher weight in the calculation of S_i. The weights are normalised as shown above to ensure that the combined weights total 1. This means that the values of NEC_i, $NENV_i$ and $NSOC_i$ used to calculate S_i in equation 2.2.1 will always be in the range [-1, 1], regardless of how many component indicators are used in their calculation.

Consequently, the value of S_i will also always fall in the range [-1, 1], where for a given scenario a negative value indicates that sustainability performance (as measured by a given set of component indicators) is lower than that of the baseline. By contrast, a value greater than zero indicates that the sustainability performance of the scenario is an improvement compared to the baseline. When comparing different scenarios against the same baseline, the scenario with the highest S_i value is relatively more sustainable than the other scenarios based on its performance around the set of component indicators used in its calculation.

The choice of the set of component indicators used in the calculation of S_i is determined by the availability of relevant data. In this case, the available data includes some of the economic and environmental factors judged by the panel of experts in the Delphi study as among the most useful indicators of sustainability. These indicators cover aspects where the feeding scenarios examined perform both better and worse than the baseline scenario. Here, as in many studies attempting to derive composite indices, some relevant component indicators are absent. Therefore, it is important to appreciate that the estimates of S_i calculated here only provide an evaluation of sustainability based on the set of component indictors available to the study. Results could be different if other indicators used in the estimation of S_i gave the opposite message about sustainability (e.g., if indicators suggesting sustainability gains were replaced by alternatives suggesting the opposite). In this study, to avoid issues around practitioner bias, all of the available indicators with associated weights from the Delphi study were used in the calculation of S_i (see below). As these indicators cover some important aspects of sustainability (i.e., economic performance, impacts on climate change, energy and land use), we expect S_i to provide a meaningful evaluation of the relative sustainability of different feeding scenarios compared to the baseline situation.

2.2.3 Indicator weights

In the Delphi Study, respondents were asked to consider the three domains of sustainability (economic, environmental, and social) and to rate their usefulness for evaluating the sustainability of livestock production. They were then asked to rate the usefulness of three sets of individual indicators, corresponding to each domain of sustainability. A 5-point rating scale (anchored between 1= "least useful" and 5 = "most useful") was used for all indicator questions and two rounds of questioning were used. The questions concerning indicators were identical in the two rounds of the experiment, though in the second round they were augmented with the group mean and standard deviation and the individual participant's own first round scores.

Table 2.1 - Delphi study: Perceived usefulness and relative weights of general indicator groups

Indicator group	Mean scores	Relative weights Econ. vs Env. vs Soc.)	Relative weights (Econ. vs Env.)
Economic	4.51	WEC = 0.365	0.506
Environmental	4.09	WENV = 0.331	0.494
Social	3.75	WSOC = 0.304	-

Table 2.1 shows the mean scores given by respondents for general categories of indicator and calculates the relative weights of each category to be used in the calculation of the composite indicator. Tables 2.2 to 2.4 provide the mean scores for candidate indicators within the economic, environmental and social domains.

Not surprisingly, given that farming is a business and is only viable if profitable, the general economic indicator group was rated most highly. Consistent with this, the top economic indicators were those related to the ability to sustain a business in the short term (profitability, animal performance, and costs). The second-ranked general indicator group concerned environmental indicators, although for individual indicators there was a narrower range of mean scores between the top and bottom-ranked indicators compared to economic indicators. The general social indicator was third and, of the individual indicators, Public Health was rated most highly. In second place was 'Farm Livelihoods', again reflecting the need for activities to be commercially viable for them to continue. The ability to ultimately sell the output (reflected by 'Product quality') also ranked highly.

Table 2.2 - Delphi study: Perceived usefulness of economic indicators.

Indicator	Mean scores	Relative weights
Profit	4.42	0.506
Animal performance	4.35	-
Costs	4.32	0.494
Investment	3.84	-
Distribution of profits	3.81	-
Labour required	3.51	-
Robustness	3.51	-
Land required	3.46	-
Supply chain	3.23	-
Subsidy	2.76	-

Table 2.3 - Delphi study: Perceived usefulness of environmental indicators

Indicator	Mean scores	Relative weights
Energy consumption	3.95	0.276
Water consumption	3.91	-
Climate change	3.74	0.262
Pesticide use	3.72	-
Nitrogen	3.71	-
Phosphorus	3.64	-
Farm waste	3.61	-
Acidification	3.33	0.233
Biodiversity	3.33	-
Land competition	3.28	0.229

Table 2.4 - Perceived usefulness of social indicators

Indicator	Mean scores
Public health	4.43
Farm livelihoods	4.32
Product quality	4.08
Farm household welfare	3.82
Technology adoption	3.81
Societal preferences	3.74
Community viability	3.68
Availability to consumers	3.64
Neighbours impacts	3.38

2.3 Data

Environmental and economic indicators for various feeding scenarios were taken from the work of Tasks 6.2 and 6.3 respectively. Task 6.2 undertook Life Cycle Analyses (LCAs) of a selection of proposed feeding scenarios within a sample of production systems. Similarly, Task 6.3 undertook Cost-Benefit Analyses (CBAs) of some of the same scenarios. Task 6.4 looked at some of the social benefits associated with the innovations being introduced by Feed-a-Gene. However, at present too little is known about how these feeding systems would be implemented in practice, so we were unable to estimate anything other than broad societal preferences for some of the associated innovations. This meant that the composite indices could only be based on the set of economic and environmental indicators with relative weights presented in Table 2.1. These include two of each of the three most important economic and environmental indicators identified in the Delphi study.

As this is a comparative, rather than an absolute analysis, based on normalised data, any variations in the scope of the data provided by the two tasks can be reconciled by ensuring that comparisons are made against a consistent set of baseline assumptions. The LCA data in Deliverable D6.2 are provided as mean values across a range of economic contexts and countries and can be compared to baseline values to indicate whether a scenario delivers an improvement or reduction in the associated environmental indicator. By contrast, the CBA data in Deliverable D6.3 are presented by country and year and cover a range of feed cost scenarios compared to a set of baseline data that enable us to evaluate the economic performance of feeding scenarios.

Here we base our composite indices on the difference between the mean LCA data and the baseline data. The CBA data used is that estimated for France in 2015, assuming no changes in existing feed prices when the new feeds are introduced. The latter assumption is not particularly realistic but the study cannot predict how prices for the new commercially produced feeds, incorporating the innovations from the project, would compare with current feed prices. We can, however, explore how changes in feed costs would alter the ordinality of the estimated composite indicator values.

The LCA data provided empirical values for four of the environmental indicators reported in Table 2.3 (i.e., energy consumption, climate change, acidification, and land competition). Similarly, empirical values for two of the economic indicators in Table 2.3 were available from the CBA data: costs (i.e., input values) and profits (i.e., margin over total inputs). Relative weights for the available economic and environmental indicators are presented in Tables 2.2 and 2.3 respectively. Data are only available for certain feed scenarios. For example, while the LCA included scenarios based around the use of European soybean meal, green protein from biomass, and fine fraction rapeseed meal, the CBA only provided data on feeds incorporating the green protein and rapeseed meal. While both the LCA and CBA provided estimates of the consequences of adopting restricted and *ad libitum* precision feeding strategies, only the CBA provided data on the implications of adopting particular breeding strategies. Both the LCA and CBA provided data on the implications of adopting novel feeding strategies for poultry incorporating European soybean meal and green protein from biomass.

The alternative innovative feed scenarios that are compared for pigs are:

- Feeds incorporating green protein from green biomass versus feeds incorporating of a fine fraction of local rapeseed meal
- Individual precision feeding: a restricted feeding strategy versus an *ad libitum* feeding strategy

For poultry, the following three innovative feed scenarios are compared:

- Feeds incorporating green protein from green biomass
- Feeds incorporating whole European soy bean meal
- Feeds incorporating meal from de-hulled European soy beans

Details of these feed scenarios can be found in Deliverables D6.2 and D6.3.

3. Results

3.1 Novel feed ingredients: Pig feeds incorporating green protein from green biomass versus feeds incorporating of a fine fraction of local rapeseed meal

Composite indices for these two feeding solutions based around novel ingredients were calculated using equations 2.2.1 to 2.2.10 as set out in the previous section. LCA data were taken from Table 9 in deliverable D6.2 and CBA data from the Annex of deliverable D6.3. Table 3.1 below reports on the estimated indicator components and the composite indices based on these components and the weights reported in Section 2.

Table 3.1 - Comparison of composite indices for novel feeds incorporating green protein from green biomass and feeds incorporating of a fine fraction of local rapeseed meal

Feed scenario	NEC_i^*	$NENV_i$	Si (2sf)
Green protein	-0.218	-0.714	-0.46
Fine fraction rapeseed meal	0.595	-0.616	-0.0032

**Economic data based on France, 2015 with no change in feed costs.*

Current feeding solutions typically use relatively small proportions of imported soybean meal, so its replacement with an alternative protein source has only a marginal impact. Both scenarios had negative environmental impacts compared to the baseline, while only the rapeseed meal had a positive economic impact. The feeding solution using local rapeseed meal offered a similar level of sustainability to current feeding solutions, with some minor improvements from the reduction in Brazilian soybean meal were offset by the additional energy use associated with the fractionation process and increases in land utilisation. By comparison, the use of green biomass appeared to offer a relatively lower level of sustainability than the use of rapeseed meal when compared to the baseline scenario.

However, in a scenario more favourable to the use of Brazilian soybean meal, where the incorporation rate could reach as high 13% (i.e., the ‘virtual baseline’ in Table 9 in deliverable D6.2), both feed scenarios are shown to be more sustainable than the baseline with S_i increasing to 0.05 for green protein and 0.50 for rapeseed meal.

3.2 Novel feed ingredients: Poultry feeds incorporating green protein from green biomass; (ii) meal from whole European soybeans; and (iii) meal from de-hulled European soybeans

Composite indices for the three feeding solutions for broiler hens based around novel ingredients were again calculated using equations 2.2.1 to 2.2.10, with LCA data derived from Table 12 in deliverable D6.2 and CBA data from the Annex of deliverable D6.3. Table 3.2 reports on the estimated values of NEC_i and $NENV_i$ and the composite indices S_i.

Table 3.2 - Comparison of composite indices for novel feeds incorporating green protein from green biomass; feeds incorporating meal from whole European soybeans and feeds incorporating meal from de-hulled European soybeans

Feed scenario	NEC_i^*	$NENV_i$	S_i (2sf)
Green protein	-0.071	-0.244	-0.16
European soybean meal from whole beans	-0.059	0.337	0.14
European soybean meal from de-hulled beans	-0.105	0.328	0.11

**Economic data based on France, with no change in feed costs.*

Both scenarios involving European soybeans offered positive environmental benefits for all indicators apart from land utilisation. This is a direct result of the substitution of European soybeans for imported Brazilian soybean meal, which has the effect of reducing transportation impacts and deforestation. Broiler feeds incorporating green protein still require the use of Brazilian soybean meal, the proportion of which is only slightly reduced, and therefore lead to only small changes in climate change and energy use impacts. Their use does, however, increase the impacts on acidification and land occupation. All three scenarios had negative economic impacts where feed costs remain unchanged.

Overall, both scenarios involving European soybeans offered an improvement in the sustainability position compared to the baseline situation, with the use of whole bean meals performing a little better in comparison with meals using de-hulled beans. While the incorporation of green protein paste in broiler feed lead to a slightly lower energy use, its overall impact on sustainability was negative as it increased other environmental impacts and reduced profitability (unless feed costs were to be significantly reduced compared to current prices).

3.3 Precision Feeding for pigs: Multiphase individual ad libitum feeding system compared to a multiphase individual restricted feeding system

Composite indices for the two precision feeding solutions for pigs devised by the project were calculated, with LCA data were taken from Table 17 in deliverable D6.2 and CBA data from the Annex of deliverable D6.3. Table 3.3 reports on the estimated indicator components and the composite indices.

Here the *ad libitum* feeding system was clearly superior to the restricted system in terms of its positive impact on sustainability. For the *ad libitum* strategy, all environmental impacts were reduced compared to the biphase baseline. For the restricted precision feeding strategy, there was some improvement around acidification but not for the other environmental impacts. Similarly, while profitability improved with the adoption of the *ad libitum* system, it was reduced for the restricted system. Therefore, while the use of the *ad libitum* system resulted in production becoming more sustainable, the use of a restricted system had the opposite effect.

Table 3.3 - Comparison of composite indices for individual precision feeding approaches for pigs comparing an *ad libitum* system with a restricted system

Feed scenario	NEC_i^*	$NENV_i$	Si (2sf)
Ad libitum	0.1216	0.9049	0.51
Restricted	-0.8784	-0.1325	-0.51

**Economic data based on France, with no change in feed costs.*

4. Conclusions and discussion

The feeding solutions generated by the Feed-a-Gene project offer a number of opportunities for livestock producers to be more sustainable. In particular, the replacement of Brazilian soybean meal in the feed mix with a locally-produced protein can reduce energy costs linked to transportation and the impacts on climate change associated with deforestation. The level of environmental benefits associated with novel feeds depends largely on the amount of Brazilian soybean meal being incorporated into feeds. In scenarios where the price of soybean meal is low, larger amounts are likely be used in feed. Therefore, its replacement with a more local protein alternative, such as European soybean, rapeseed meal or green protein, can reduce some environmental impacts, though at the same time could lead to an increase in the cost of production if the resulting weight gains are smaller or feed costs higher.

Profits, and therefore net farm income, can be improved by the adoption of novel feedstuffs, for example green protein and rapeseed meal for pigs. This result is, however, highly dependent on the costs of feedstuffs. A key issue that cannot be resolved by this study is the potential impacts that incorporation of novel feedstuffs will have on the cost of animal feeds faced by producers. Deliverable D6.3 suggested that in a number of scenarios small price increases, or even price reductions, would be required to ensure that production remained profitable. This is confirmed by the economic indicators reported in this study, which are often negative, even when feed costs remain unchanged. This suggests that a key objective in the commercialisation of these novel feedstuffs would be the need to maximise production efficiency and reduce associated costs (provided that this can be done without increasing the negative environmental impacts). Cost reduction is not always straightforward, for example lower transportation costs from reducing the use of imported soybeans may be offset by increased production and processing costs.

Precision feeding solutions offer another route to more sustainable livestock production and this study provides clear evidence that the adoption of individual *ad libitum* feeding systems for pigs reduces key environmental impacts and increases profitability compared to a conventional biphase feeding alternative. By contrast, a precision feeding system based around a restricted feeding strategy results in a reduction in profitability as well as an increase in some negative environmental impacts.

The sustainability evaluation presented in this report is based on a relatively small set of component economic and environmental indicators. Even so, the composite indicator is based on some important indicators and should provide a useful measure of the relative sustainability of different feeding solutions relative to the baseline. Future studies could extend the set of indicators used and could include social indicators. The latter are hard to derive in a robust fashion without the feeding solutions being put into operation – economic and environmental costs and benefits can be modelled but social costs and benefits will depend on the precise nature and implementation of the feeding scenario which is as yet unknown.

5. References

Annan, K.A. (2002). *The Secretary-General's message on World Environment Day*, June 5, 2002, United Nations, New York.

Bossel, H. (1999). *Indicators for sustainable development: Theory, method, applications*. Manitoba: International Institute for Sustainable Development.

Dale, V.H. and Beyeler, S.C. (2001). Challenges in the development and use of ecological indicators. *Ecological Indicators* 1: 3-10.

European Union (2013). *A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development.* https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:l28117.

Freebairn D.M. and King C.A. (2003). Reflections on collectively working toward sustainability: indicators for indicators. *Australian Journal of Experimental Agriculture* 43: 223-238.

Hueting, R. and de Boer, B. (2001). Environmental valuation and sustainable national income according to Hueting. In: Van Ierland, E.C, vander Straaten, J., Vollebergh, R.J. (eds.), *Economic Growth and Valuation of the Environment: A Debate*. Edward Elgar, Cheltenham, pp.17-77.

IISD (International Institute of Sustainable Development (2015). *Compendium of Sustainable Development Indicator Initiatives*. http://www.iisd.org/measure/compendium/

Lebacq, T., Baret, P.V., and Stilmant, D. (2013). Sustainability indicators for livestock farming. A review. *Agronomy for Sustainable Dev*elopment 33: 311-327.

Mayer, A. (2008). Strengths and weaknesses of common sustainability indices for multidimensional systems. *Environment international* 34, 277-291.

Miller, C.A. (2007) *Creating Indicators for Sustainability*. Canada: International Institute for Sustainable Development.

Moldan B., Janouskova S., and Hak T. (2012) How to understand and measure environmental sustainability: Indicators and target. *Ecological Indicators* 17: 4-13.

Mori, K. and Christodoulou, A. (2011). Review of sustainability indices and indicators: Towards a new City Sustainability Index (CSI). *Environmental Impact Assessment Review* 32: 94-106.

Munro, D.A. and Holdgate, M.W. (1991). *Caring for the earth: a strategy for sustainable living*. IUCN, Gland.

Nardo, M., Saisana, M., Saltelli, A., and Tarantola, S. (2005). *Tools for composite indicator building*. Ispra: Institute for the Protection and Security of the Citizen, European Commission Directorate-General Research Centre.

Niemeijer, D. and de Groot, R. (2008). A conceptual framework for selecting environmental indicator sets. *Ecological Indicators* 8: 14-25.

OECD (2001). *Environmental Indicators towards Sustainable Development*. http://www.oecd.org/site/worldforum/33703867.pdf

Omann, I. and Spangeberg, J.H. (2002). *Assessing Social Sustainability*. http://seri.at/wp-content/uploads/2010/05/Assessing_social_sustainability.pdf

Parris T. and Kates R. (2003). Characterizing and measuring sustainable development. *Annual Review of Environment and Resources* 28: 559-586.

Pretty, J.N. (1995). *Regenerating agriculture: policies and practice for sustainability and self-reliance*. Earthscan, UK: London.

Riley, J. (2001). The indicator explosion: local needs and international challenges. *Agriculture, Ecosystems and Environment* 87:119-120.

Sachs, J., Schmidt-Traub, G., Kroll, C., Lafortune, G., and Fuller, G. (2019). Sustainable Development Report 2019. New York: Bertelsmann Stiftung and Sustainable Development Solutions Network (SDSN).

Spangenberg J.H. (2002). Institutional sustainability indicators: An analysis of the institutions in Agenda 21 and a draft set of indicators for monitoring their effectivity. *Sustainable Development* 10: 103-111.

Stapleton, L. and Garrod, G.D. (2008). Policy preceding possibility? Examining headline composite sustainability indicators in the United Kingdom. *Social Indicators Research* 87: 495-502.

Stevens, C. (2005). *Measuring sustainable development*. Paris: Organisation for Economic Co-operation and Development.

United Nations Department of Economic and Social Affairs (1999). *Work Programme on Indicators of Sustainable Development of the Commission on Sustainable Development*. UN Division for Sustainable Development, Geneva.

Wheeler, D. and Elkington, J., (2001). The end of the corporate environmental report. *Business Strategy and the Environment* 10: 10-14.

Zoeteman, K., (2004). Sustainability of nations. In: Boersema, J.J., Reijnders, L. (Eds.), *Principles of Environmental Science*. Kluwer Academic Publishers, Dordrecht.