The Two Faces of Sustainability

Fuzzy Evaluation of
Sustainable Development

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Fuzzy Evaluation of Sustainable Development

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Aan Pap en Mam

ABSTRACT

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An evaluative framework of sustainable development operates at both the production system level and the society level: objective information gathered at the production system level is given subjective meaning at the society level. The evaluative framework constitutes a complete cycle to monitor sustainable development: Phases 1 through 4 establish evaluative conclusions, and Phase 5 closes the cycle by acting upon the conclusions. Emphasis in this thesis is on methodological aspects to identify (Phases 1 through 3) and interpret (Phase 4) sustainability criteria. The objectives of this study were to construct a support to identify appropriate sustainability criteria, and to obtain relevant information with respect to sustainable development; and to construct a method to interpret this information, and to draw evaluative conclusions about sustainable development. Based on Koestler's metaphor of the Janus-faced holon, the «two faces of sustainability» provide a two-way perspective by integrating ecocentric and anthropocentric rationales on sustainability in a system imperative and a societal imperative. These two imperatives of sustainability identify common ground for sustainable development that allows proper identification of sustainability criteria. If appropriate sustainability criteria have been identified, then giving meaning to the information obtained from sustainability criteria, by way of measuring or observing sustainability indicators, is the next phase in drawing conclusions about sustainable development. Fuzzy set theory was suggested as a formal mathematical basis to support Phase 4. The main body of research presented in this thesis deals with the feasibility of fuzzy set theory to interpret and integrate available information. Fuzzy models can interface information between the society level and the production system level, because linguistic variables provide a bridge between subjective interpretation of objective measurements. If expert knowledge is thoughtfully applied to construct both the essential membership functions and fuzzy rule bases, then fuzzy models can draw valid evaluative conclusions with respect to sustainable development. The evaluative framework of sustainable development that identifies sustainability criteria on the basis of the point of view provided by the two faces of sustainability, and that gives meaning to sustainability criteria on the basis of fuzzy evaluation, provides a novel and valuable contribution to the sustainability debate.

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CHAPTER 1

INTRODUCTION

1.1 Point of Departure

In 1994, the Tropical Animal Production Group and the Sustainable Animal Production Group within the Department of Animal Sciences of Wageningen University merged into the Animal Production Systems Group (APS). Thus, APS incorporates research experience in the development of tropical agricultural production systems into a wider economic, ecological and societal context (e.g., de Wit et al., 1992; Schiere, 1995; Ifar, 1996; Bosman et al., 1997; Cornelissen et al., 1997; Udo, 1997; Udo and Cornelissen, 1998), with a new challenge of realizing sustainable animal production. A principal objective of APS was to develop a «systems approach» and to make «sustainability» in agricultural production systems operational.

The research project described in this thesis was one of several initiatives to contribute to realization of the principal objective of APS, and aimed at moving beyond the polemics of sustainability by quantifying the concept. At the project's base lay the hypothesis that a method allowing identification of an explicit quantitative measure of sustainability might help to consistently assess agricultural production systems with respect to their degree of sustainability. The hypothesis held three presuppositions with respect to an approach to realize that objective.

The first presupposition was in the word ‹assess›. The hypothesis assumed that interpreting information derived from sustainability criteria could be expressed in a commensurable unit. The commensurability of the unit would allow integration of information into an overall assessment so as to enable a comparison of sustainability. The second presupposition was in the word ‹consistently›. The hypothesis assumed that a universal set of criteria could be identified that unequivocally defined sustainability. The universality of the set would allow a comparison of sustainability, consistent among production systems. The third presupposition was in the word ‹degree›. The hypothesis assumed that an overall assessment of sustainability would be by degrees. The gradedness of sustainability would allow ranking of agricultural production systems on a continuous scale, ranging from completely unsustainable to completely sustainable.

For this thesis, two objectives were formulated to develop a quantitative measure of sustainability. First, a method was needed to establish relevant criteria that define sustainability. Second, a method was needed to establish an assessment of sustainability by degrees, based on information derived from relevant criteria. Hence, first a decision had to be made on a perspective from which to select relevant criteria, and to establish a definition of sustainability.

1.2 PERSPECTIVES ON SUSTAINABILITY

1.2.1 THREE ORIENTATIONS TO SUSTAINABILITY

The concept of sustainability is rooted in 18th century German forestry. A mining engineer, von Carlowitz, used the German equivalent term *Nachhaltigkeit* to express his concern about maintaining the long-term productivity of timber plantations that had provided construction poles for the mining industry (Becker, 1997). Much later, a similar concept of sustainability echoed in Conway's approach to agroecosystem analysis: "sustainability is the ability of a system to maintain productivity in spite of a major disturbance" (Conway, 1985). Considering the predicted growth of the world population, those who regard sustainability primarily as a matter of food security and who approach agriculture as an instrument for feeding the world, typically use economic cost-benefit analyses as a tool to guide the development of agriculture (Douglass, 1984).

In this «farm productivity orientation», sustainability is considered equivalent to a guarantee of maintaining productivity of agricultural production systems, and sustainability is referred to in terms of «sustainable yield» or «sustainable production» (Altieri et al., 1984; Conway, 1985; Marten, 1988; Viglizzo and Roberto, 1998). This orientation to sustainability emphasizes economic consequences of system behavior and aims at maintaining a certain level of income based on continuity in system output (Blatz, 1992). Problems that relate to sustaining the resource base or respecting the social significance of agriculture seem less important than problems that relate to producing enough to meet global market demands (Douglass, 1984).

The inadequacy of such a one-sided economic emphasis already was evident during the introduction of *Nachhaltigkeit* in German forestry some 200 years ago. The renunciation of harvesting wood to secure the long-term availability of timber for the mining industry - forced on traditional smallholders by aristocratic landowners - deprived smallholders of their source of fuel wood and fodder (Becker, 1997).

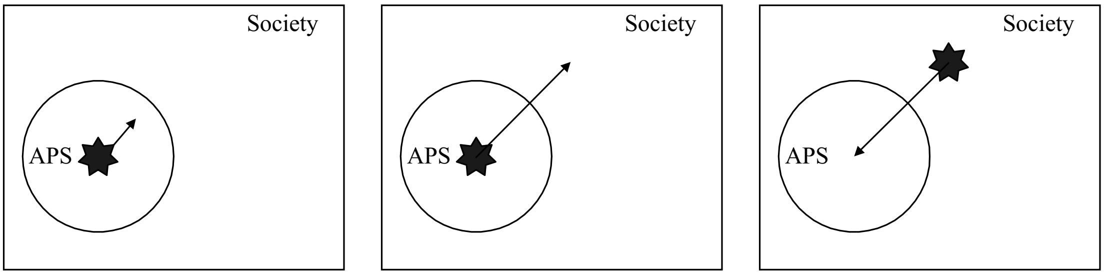
Since the publication of *Limits to Growth* by the Club of Rome (Meadows et al., 1972), *Blueprint for Survival* by The Ecologist (Goldsmith et al., 1972) and *Our Common Future* by the Brundtland Commission (WCED, 1987), and under the influence of the UN conferences on *Human Environment* in Stockholm (1972) and *Environment and Development* in Rio de Janeiro (1992), a more comprehensive perspective on sustainability has developed (Mebratu, 1998). Essentially, the common denominator in these milestones is the anticipated failure of society, because of key resources becoming unavailable through degradation, depletion or pollution, ultimately resulting in a disintegration of social cohesion. In reference to agriculture, this perspective on sustainability was often couched in terms of concern that conventional agricultural activities endanger future continuity of agricultural production systems because of, for example, undesirable side effects in a system's environment (Blatz, 1992). Possible undesirable side effects include erosion of the soil, nutrient emissions to the environment, exhaustion of non-renewable resources, decline of rural communities, and negative impact on the welfare of animals (Kelly, 1998).

In this «farm continuity orientation»[1], sustainability is considered equivalent to a guarantee of maintaining the agricultural production system itself, and sustainability is referred to in terms of «sustainable agriculture» (Olson, 1992; Torquebiau, 1992; Ikerd, 1993; Stockle et al., 1994; Dalsgaard et al., 1995; Spedding, 1995; Steinfeld et al., 1997). Emphasis here is on stable patterns of agricultural activities rather than on maintenance of farm output, and repair of actual and potential damage to an agricultural production system's environment is acknowledged to be essential for its continuation (Blatz, 1992). Keeny (1989) aptly expresses the farm continuity orientation by defining sustainable agriculture in terms of "agricultural systems which are environmentally sound, profitable, and productive and maintain the social fabric of the rural community".

More recently, a third perspective on sustainability directly associates the concept with societal quality of life (Mitchell et al., 1995; Clayton and Radcliffe, 1996; Giampietro, 1997; Bell and Morse, 1999). This perspective emphasizes continuity of society as a whole, to which agricultural production systems can contribute by providing sufficient, safe and inexpensive food products, adhering to accepted values regarding, for example, environmental quality, animal welfare, and attractiveness of the landscape.

In this «societal continuity orientation», sustainability is considered equivalent to a guarantee of human quality of life, and sustainability is referred to in terms of «sustainable development» (cf. WCED, 1987). Emphasis here is on the dynamic development of society as driven by human expectations about future opportunities, and concurrently considers economic, ecological and social issues relevant in a specific context (Bossel, 1999).

The three perspectives on sustainability are presented in Figure 1.1. The farm productivity orientation (1A) and the farm continuity orientation (1B), on the one hand, regard sustainability as a characteristic that is an inherent and objective property of agricultural production systems (Hansen, 1996). Starting from either orientation 1A or 1B, research projects typically aim to design production systems that guarantee sustainability through applying «sustainable technology» or «sustainable management» (Douglass, 1984). Technology and management selection may be grounded in ideology, for example, as is the case in organic agricultural production (Blatz, 1992; Pretty, 1997)[2]. Hence, both orientations select relevant criteria - and define sustainability - from a perspective that originates within agricultural production systems.



1A **1B** **1C**

Figure 1.1: ***Three orientations to sustainability.*** In the farm productivity orientation (1A) and the farm continuity orientation (1B), the perspective on sustainability (✶) originates within society: sustainability is seen as a characteristic inherent to agricultural production systems (APS) more (1B) or less (1A) taking into account the system's environment. In the societal continuity orientation (1C), the perspective on sustainability originates within society: sustainability is seen as a public concern.

The societal continuity orientation (1C), on the other hand, regards sustainability as a public concern that emerges within society. Relevant criteria, therefore, are selected from a perspective that originates within society. To explore the suitability of each perspective as an appropriate foundation to select sustainability criteria, the concepts of «hierarchy» and «holon» can be helpful tools.

1.2.2 Hierarchy and Holons[3]

A «part» commonly carries the meaning of something incomplete, that in itself has no claim to autonomous existence, whereas a «whole» carries the meaning of something complete in itself whose autonomous existence is founded in the organization of its constituent parts. Parts and wholes, however, are not independent entities. An agricultural production system, for example, can be considered a whole, in terms of an organization of constituent parts such as crops and livestock. An agricultural production system, however, also can be considered a part in terms of it being an element in a larger societal organization. Figure 1.2 presents an agricultural production system as level L in a hierarchy of systems; crops and livestock as level L-1; and the larger societal organization - of which an agricultural production system is a part - as level L+1. An agricultural production system, therefore, simultaneously is both part of system L+1 and a whole as system L.

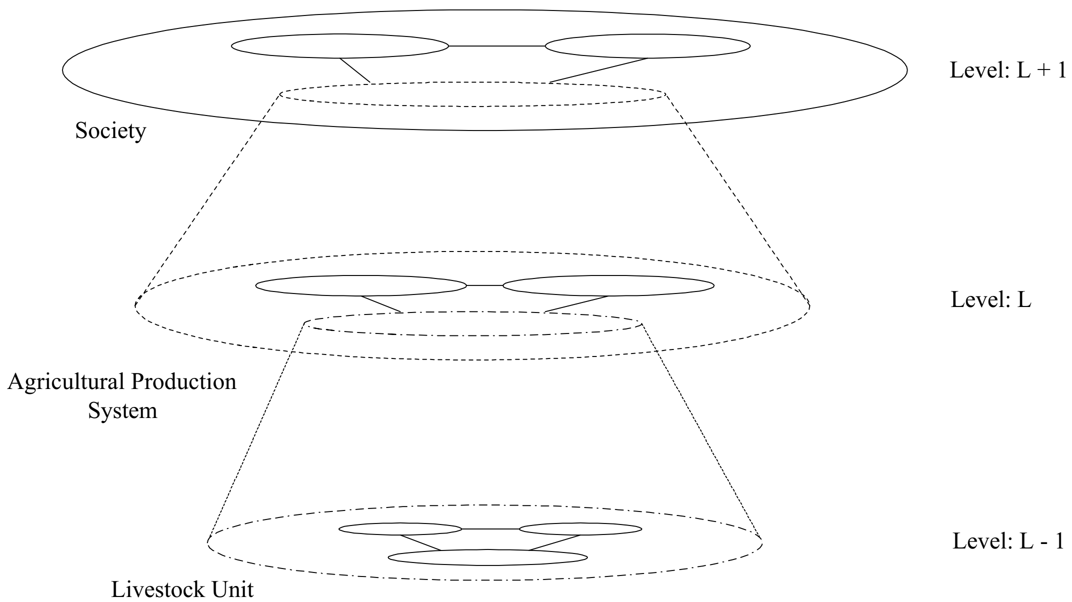


Figure 1.2: ***A hierarchy of systems.*** An agricultural production system as Level *L* in a hierarchy of systems; a livestock unit as a part of an agricultural production system as Level $L - 1$; and society, of which an agricultural system is a part, as level $L + 1$.

Each constituent part of a system hierarchy at each level can be considered a stable structure, equipped with means of self-regulation and enjoying a considerable degree of autonomy. Each system is subordinated to the higher levels in the hierarchy, but at the same time functions as an autonomous whole. According to Koestler (1967, 1978), a system is *Janus-faced*, after the two-faced Roman god Janus[4]. The face turned upward, toward the higher levels, is that of a dependent part; the face turned downward, toward its constituents, is that of an autonomous whole. Koestler refers to such a Janus-faced structure as «holon», which originates from the Greek *holos* meaning *whole*, with the suffix *-on*, as in neutr*on*, suggesting a *particle* or *part*. Koestler's concept of the «holon», therefore, suggests that no system can exist in full autonomy. In reference to agriculture, a farmer - looking downward - can rightly assert that his farm (i.e., an agricultural production system) is a complete and unique entity, a whole. But looking upward, a farmer is constantly - sometimes pleasantly, sometimes painfully - reminded that his farm also is an elementary part of society. The danger that is hidden in the farm productivity orientation and the farm continuity orientation, therefore, lies in their implicit utopian scheme that typically views sustainable production or sustainable agriculture as an autonomous and tangible endpoint in itself.[5] Consequently, a system's environment is considered important to the extent that it affects a system's autonomy as the face looking upwards turns a blind eye to views held in society.

1.2.3 Two Faces of Sustainability

The two faces of Janus bestow on each holon two apparently opposite tendencies: an «autonomous tendency»[6] preserving each holon's independence, and an «integrative tendency» making each holon function as part of the larger whole. The autonomous tendency is expressed in the holon's internal organizational pattern of relations and activities, which accounts for its coherence, stability and behavior. The autonomous tendency, however, is kept in check by the integrative tendency of the holon which accounts for its role and function as a subordinate part within the higher level.

Society can be seen as a hierarchic organization of holons, which derives its stability from the fact that holons are Janus-faced[7]. If an agricultural production system is considered a holon, then - under favorable conditions - its autonomous and integrative tendencies are balanced. An agricultural production system interacts in dynamic equilibrium with the encompassing whole and the two faces of Janus complement each other. Under unfavorable conditions, however, this equilibrium is upset and concern for sustainability emerges.

Following the societal continuity orientation, the autonomous tendency of an agricultural production system - manifested in agricultural practices and as such affecting society's sustainable development - is kept in check at the societal level[8]. Sustainability in reference to agricultural production systems, therefore, has two faces: one face is turned upwards to observe the boundary conditions set by society; and one face is turned downwards to initiate a contribution to sustainable development.

1.2.4 Sustainability's Changing Moods

If society defines the boundary conditions for an agricultural production system's contribution to sustainable development, then defining the relevant criteria that direct such development will become the responsibility of a diverse group of stakeholders[9]. Sustainable development, therefore, is considered to be a construct of human subjects reflecting their attempts to sort out a problematic reality (cf. Rawls, 1973; Achterhuis et al., 1999). Rawls' constructivist view on society substantiates, albeit hypothetically, that sustainable development as a societal construct should be the result of fair negotiations among those who have a stake in the concern for sustainability[10]. Consequently, because stakeholders play a pivotal role in sustainable development, a definition of sustainability based on a ‹consistent› set of sustainability criteria seems unattainable, mainly because public concern will be subject to change (e.g., Mitchell, 1996)[11]. If sustainability criteria will change, then the emphasis in sustainable development will change accordingly, which makes the possibility of quantitative ‹prediction› of future sustainability disputable at the least.

Although the emphasis in sustainable development may change over time, the quintessence of sustainable development, however, will not. This quintessence, for example, was formulated - in political terms - in the report of the Brundtland Commission, *Our Common Future* (WCED, 1987). In that report, WCED (1987) presents sustainable development as an economic strategy which "meets the needs of the present generation without compromising the ability of future generations to meet their own needs". The quintessence, therefore, is that the present mode of economic development seems inconsistent with respect to means and ends. The general goal of economic development - a better life for human beings - is being pursued in a way that eventually may result in human suffering (Shearman, 1990).

Sustainability now is a core element of government policies, of university research projects, and of corporate strategies, and cannot simply be discarded as a buzz-word. Considering sustainability's importance for development strategies as well as its temporal dynamics, it seems to be more useful to continuously monitor sustainable development, then to predict sustainability.

1.3 RESEARCH OUTLINE

1.3.1 MONITORING AND EVALUATION

Monitoring can be thought of as a guarantee of quality that aims at closing the gap between intention and realization in a societal development program (Rossi and Freeman, 1989). Monitoring, therefore, guides development by continuously evaluating the results of an ongoing development program, and then acting upon the conclusions drawn from the evaluation to (re-)direct development. Such conclusions, according to Scriven (1980), can provide feedback to stakeholders that are trying to dispel concern for sustainability through sustainable development, and can provide information for policy makers who are in doubt whether to support or terminate a development program.

For whatever purpose the conclusions of an evaluation ultimately will be used, however, Scriven (1980) emphasizes that «to evaluate», in the strict grammatical sense, means to determine the merit or worth of that what is evaluated (i.e., the evaluand). Fournier (1995) builds on Scriven's interpretation as she states that evaluation is a special kind of inquiry that follows a «general logic», i.e., a general pattern of reasoning to establish justifiable evaluative conclusions. Fournier's general logic of evaluation is:

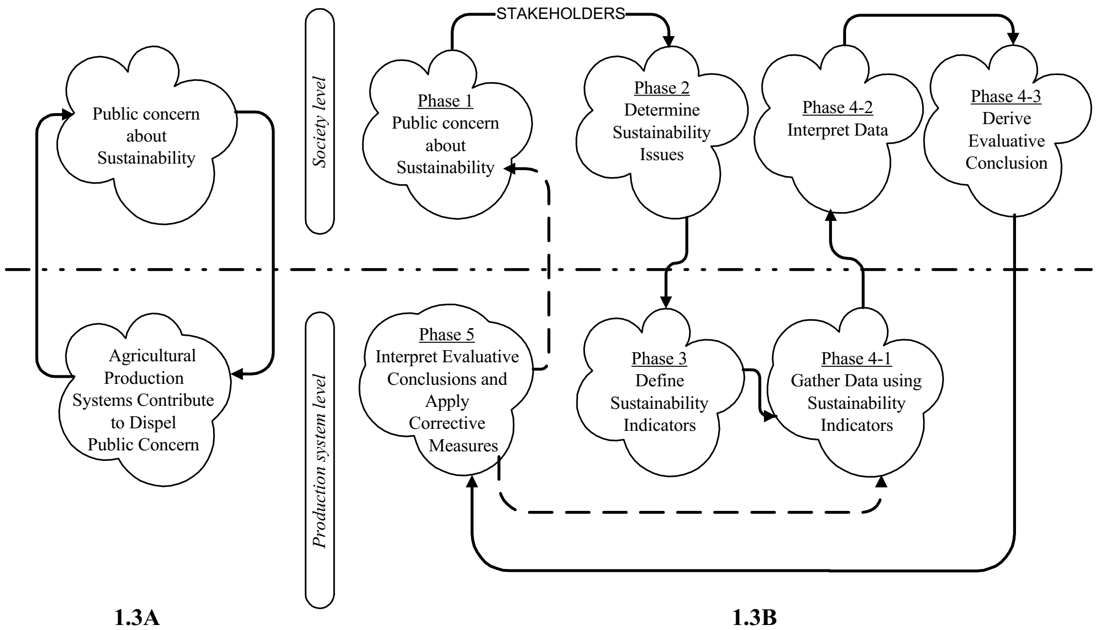
1. *to establish criteria of merit*: on what issues must the evaluand do well?
2. *to construct standards*: how well should the evaluand perform?
3. *to measure performance and compare with standards*: how well did the evaluand perform?
4. *to integrate data into a judgment of merit or worth*: what is the merit or worth of the evaluand?

Proper evaluation, therefore, means setting criteria and standards, measuring the performance of the evaluand along these lines, and synthesizing the information into a final judgment about the merit or worth of the evaluand[12].

Fournier uses the term «working logic» to express the practical variation when the general logic of evaluation is actually made operational. By analogy, general logic outlines the strategy, whereas working logic develops the specific tactics (Fournier, 1995). Hence, a working logic brings together explicit methods to identify criteria, construct standards, measure performance, and synthesize data in an evaluative framework. Differences in the way the general logic is applied originate from the particular type of problem addressed.

1.3.2 AN EVALUATIVE FRAMEWORK OF SUSTAINABLE DEVELOPMENT

In Figure 1.3A, agriculture's contribution to sustainable development is depicted as a societal construct, building on public concern about the impact of current agricultural activities on society's sustainable development. Figure 1.3A is elaborated in Figure 1.3B, showing a five-phased evaluative framework that develops a working logic based on Fournier's general logic of evaluation. Figure 1.3B introduces a complete monitoring cycle in which Phases 1 through 4 evaluate the effects of agriculture's contribution to society's sustainable development and Phase 5 acts upon the conclusions drawn from the evaluation.



1.3A **1.3B**

Figure 1.3: ***An evaluative framework of sustainable development.*** In Figure 1.3A, sustainable development is considered a social construct that, with respect to agriculture, builds on public concern about the impact of current agricultural activities on society. Figure 1.3A is elaborated in Figure 1.3B, which introduces a five-phased evaluative framework to monitor sustainable development. Phases 1 to 4 evaluate the contribution of agricultural production systems to society's sustainable development, and Phase 5 acts upon the conclusions drawn from the evaluation.

In Phases 1 and 2, stakeholders acknowledge concern for sustainability by identifying issues of concern. In Phase 3, such sustainability issues are transformed into tangible «sustainability indicators». Sustainability criteria, therefore, are established by expressing public concern in sustainability issues, and by translating these issues into measurable or observable sustainability indicators. Phases 1 through 3, therefore, develop the first step in Fournier's general logic.

In Phase 4-1, information gathered at production system level using sustainability indicators are interpreted at society level in Phase 4-2, using appropriate standards. Phases 4-1 and 4-2, therefore, develop the second and third step in Fournier's general logic. The information resulting from Phase 4-2 is integrated in Phase 4-3 to derive an overall conclusion with respect to the quality of the contribution of current agricultural production systems to society's sustainable development. Phase 4-3, therefore, develops the fourth step in Fournier's general logic.

In Phase 5, finally, the monitoring cycle is closed by interpreting the evaluative conclusions and, if necessary, by applying corrective measures at production system level. Figures 1.3A and 1.3B, therefore, demonstrate that an evaluative framework of sustainable development operates at both the production system level and the society level.

At the production system level objective information is gathered, whereas at the society level subjective meaning is given to this information by using terms such as ‹acceptable›, ‹favorable› or ‹promising› (e.g., Zimmermann and Zysno, 1983; Dubois and Prade, 1998). In the 1960's, fuzzy set theory was introduced to manage subjective human communication and interpretation of objective information (Zadeh, 1965). Fuzzy set theory, therefore, seems a promising tool to integrate the perceptions of the two faces of sustainability, and develop Phase 4 in the evaluative framework of sustainable development.

1.3.3 Research Objectives and Thesis Outline

This thesis aimed at developing a working logic to evaluate the contribution of agricultural production systems to society's sustainable development. The objectives of the study, therefore, were as follows:

1. construct a support to identify appropriate sustainability criteria, and to obtain relevant information with respect to sustainable development;
2. construct a method to interpret this information, and to draw evaluative conclusions about sustainable development.

The following research questions were addressed:

1. What constitutes an appropriate support to identify sustainability criteria?
2. Can use of fuzzy set theory combine objective information, obtained at the production system level, and subjective interpretation of information, obtained at the society level?
3. Can use of fuzzy set theory establish standards that allow subjective interpretation of information?

4. Can use of fuzzy set theory draw valid evaluative conclusions through integration of information?
5. Does the evaluative framework of sustainable development provide a valuable contribution to the sustainability debate?

In Table 1.1, the five phases of the working logic that implement a practical evaluation of sustainable development (rows), are related to the six chapters in this thesis (columns). Chapter 2 identifies a common ground for sustainable development, based on Koestler's metaphor of the Janus-faced holon, to provide an explicit point of departure for identifying sustainability criteria. Chapter 2, additionally, introduces a simple graphical model that visualizes the sustainability scope of local initiatives by delineating the common ground covered using the selected sustainability indicators. A case study in a region of the Province of Overijssel, the Netherlands, illustrates how the sustainability scope reflects the common ground covered.

Chapter 3 introduces fuzzy set theory as a mathematical tool to combine objective information gathered at the production system level, and subjective interpretation of information at the society level. Two fuzzy models are developed to assess sustainable development based on selected sustainability indicators.

Chapter 4 presents a study that deals with criticism regarding the inherent subjectivity in the construction of membership functions, as membership functions are at the core of fuzzy models. Chapter 4 develops a six-step procedure that identifies criteria to select experts so as to ensure the use of appropriate expert knowledge, and compares four methods to elicit expert knowledge and construct membership functions in practical situations.

Chapter 5 applies the results of Chapters 3 and 4 in an operational situation and develops a full fuzzy model to obtain evaluative conclusions. The measurement procedure to implement a fuzzy model is illustrated using the concept of animal welfare in animal production systems. The decision to choose an illustrative example with respect to animal welfare, rather than with respect to sustainable development was made, because animal welfare and sustainable development both are entities that, as such, are not directly measurable. Both animal welfare and sustainable development can be considered as manifestations of public concern, i.e., they are a linguistic expression of a complex problem that is characterized by a variety of issues. Drawing evaluative conclusions with respect to animal welfare, therefore, also involves subjective interpretation at the society level, of objective information gathered at the production system level. Analogous to sustainability, animal welfare is evaluated on the basis of subjective human reasoning at the society level about objective data gathered at the production system level.

Table 1: ***Thesis outline.*** Five phases of a working logic to implement an evaluative framework of sustainable development (rows) are related to the six chapters in this thesis (columns)

Phase	**1**	**2**	**3**	**4-1**	**4-2**	**4-3**	**5**
Chapter							
1							
2	X	X	X				
3				X	X	X	
4					X		
5				X	X	X	
6							

Chapter 6, finally, reviews the research efforts described in this thesis, discusses the research contribution to the sustainability debate, and draws final research conclusions.

NOTES

[1] The classification of perspectives on sustainability in terms of «farm productivity orientation» and «farm continuity orientation» is adapted from Blatz (1992). Blatz respectively uses the terms «product orientation» and «process orientation».

[2] Pretty (1997) distinguishes five contrasting schools of thought with respect to technologies and management procedures to realize a sustainable agricultural production. «Business-as-usual optimists» believe that food production will continue to expand as the fruits of biotechnology ripen, boosting plant and animal productivity. «Environmental pessimists» do not consider it likely that any new technological breakthroughs will be able to stretch the ecological limits to growth and advocate, for example, a change in consumption patterns. The «industrialized-world-to-rescue lobby» believes that for a wide range of ecological, institutional and infrastructural reasons, Third World countries will never be able to feed themselves and suggest that the looming food gap will have to be filled by modernized agriculture in the industrialized countries. The «new modernists» believe that high-input agriculture is more environmentally friendly than low-input agriculture and advocate a repeat of the Green Revolution model. The «sustainable intensification group», finally, argues that regenerative and low-input agriculture can be highly productive, and suggests that productivity in agriculture is as much a function of human capacity and ingenuity as it is the result of biological and physical processes.

[3] This paragraph mainly builds on the ideas of Arthur Koestler (1905-1983) discussed in his books *The Ghost in the Machine* (1967) and *Janus. A Summing Up* (1978). In both works he argues against the dominating positivist world-view in many fields of science and proposes the concept «holon» to support a constructivist approach.

[4] Janus is the Roman god of beginning and end, the keeper of arches and doorways, of entrances and exits. He looks both forward and backward and, as such, is depicted with two faces. The Romans devoted the first month of the year, January, to him, bringing offers on New Year's Day.

[5] Hansen and Jones (1996), for example, consider a system's environment important only when society charges farmers for costs of unwanted side-effects of agricultural activities that otherwise would have to be born by all members of society. Becker (1997), in addition, states that "sustainability principles can be upheld only as long as they do not interfere with dominating economic interests".

[6] Koestler (1967, 1978) uses the term «self-assertive tendency» instead of «autonomous tendency» next to integrative tendency.

[7] Koestler (1978), in this respect, often uses the term *holarchy* rather than *system hierarchy* when he discusses a hierarchy consisting of quasi-autonomous holons.

[8] An important implication of the societal continuity orientation is that realizing a contribution to sustainable development is a social goal of the entire system of agricultural production, rather than an individual goal of specific agricultural production systems (Thompson, 1986).

[9] Persons, groups, neighborhoods, organizations, institutions, community and even the natural environment are generally thought to qualify as actual or potential stakeholders. An in-depth discussion on which groups can be considered stakeholders, and which not, is beyond the scope of this thesis: the observation that a diverse group of stakeholders will be involved in defining the emphasis in sustainable development suffices. Stakeholder theory is comprehensively discussed in papers by Mitchell et al. (1997) and Greenwood (2001).

[10] According to the American philosopher John Rawls in his book *A Theory of Justice* (1973; also extensively discussed in Achterhuis et al., 1999), society is an aggregate of institutions dividing fundamental rights and duties, as well as the advantages of societal cooperation, within which the choices of individuals and groups takes place. A constructivist approach to sustainable development can build on Rawls' idea of how society should justify those choices. A just society, according to Rawls, is founded on the basis of a hypothetical contract which is negotiated by free, equal and rational individuals, pursuing their self-interest in a context of fair relationships. Fair relationships are guaranteed by letting the negotiations take place behind a «veil of ignorance» because of which the negotiators do not know their future position and opportunities in the society they are negotiating. The veil of ignorance, thus, guarantees that a just distribution in the first place is aimed at those who will be worst of in society, because the negotiators themselves could well be those who will be worst of. Constructivism, therefore, reflects the idea that the truth of things, such as, for example, the merit of contributions to sustainable development, is a construct, i.e., the result of several non-trivial choices as to what is acceptable, favorable, promising, desirable, useful, *et cetera*.

[11] The fact that public concern is easily subject to change was recently confirmed by the Nitrofen-affair in Germany. *De Volkskrant* reported on 28 May 2002, after traces of the forbidden herbicide Nitrofen were found in eggs and chicken originating from organic farms in Germany, that consumer organizations warned the public for organic food products, that organic farms were temporarily closed, and that the credibility of organic agriculture was seriously damaged.

[12] Following Scriven's philosophy, all four steps of Fournier's «general logic», including the first step, are part of proper evaluation, not only the measuring part in steps 2 to 4. According to Reuzel (2001), this makes evaluation a constructivist activity in the sense of Rawls.

CHAPTER 2

COMMON GROUND FOR SUSTAINABLE DEVELOPMENT, AND GROUND COVERED BY SELECTED SUSTAINABILITY INDICATORS

This chapter has been submitted.
A.M.G. Cornelissen, W.J. Koops. Common ground for sustainable development, and ground covered by selected sustainability indicators. *International Journal of Agricultural Sustainability*.

2.1 INTRODUCTION

Concern for sustainability currently is an important frame of reference for development of society and its constituents (e.g., agricultural production systems), and acknowledges that human activities (e.g., agricultural production practices) might endanger continuity of society in the (near) future. Activities initiated in society to dispel concern for sustainability claim to contribute to «sustainable development» (SD), and aim at bringing society from a state that is perceived as unsustainable in a new, more sustainable state (Hardi and Zdan, 1997). Since the publications of *Limits to Growth* (Meadows et al., 1972), *Blueprint for Survival* (Goldsmith et al., 1972) and *Our Common Future* (WCED, 1987), and the UN conferences on *Human Environment* (in Stockholm 1972) and *Environment and Development* (in Rio de Janeiro 1992), an increasing number of studies report on activities initiated to realize SD.

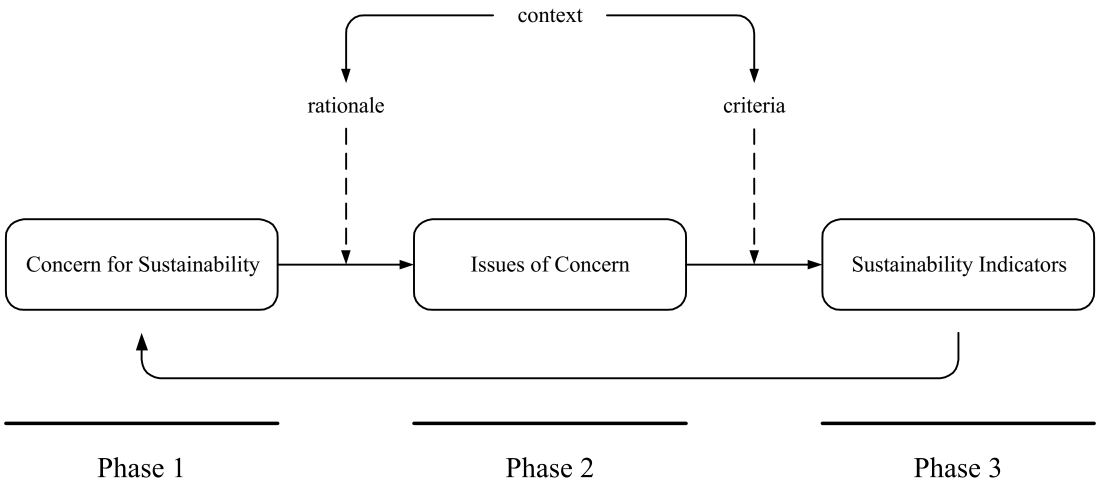


Figure 2.1: *The link between concern for sustainability and selected sustainability indicators*. In Phase 1, concern for sustainability is identified. In Phase 2, concern for sustainability is translated into qualitative issues of concern. The extent of issues being dealt with depends on the underlying rationale. In Phase 3, qualitative issues of concern are translated into tangible sustainability indicators using specified selection criteria.

As sustainability is not a measurable entity in itself, most studies use sustainability indicators (SI) to characterize their contribution to SD (e.g., Mitchell et al., 1995; Harger and Meyer, 1996; Gallopín, 1997; Bell and Morse, 1999; Nijkamp and Vreeker, 2000; OECD, 2000a). The use of SI presumes a link between concern for sustainability and selected SI. In Figure 2.1, this link is expressed in terms of «issues of concern». In practice, a wide range of SI is being operated, as different studies typically start from different rationales (cf. Dumanski et al., 1998). A rationale underlying a concern for sustainability essentially determines the extent of issues being dealt with. Some studies, for example, only consider issues related to conservation of natural resources, other studies also consider issues related to quality-of-life (cf. Blatz, 1992; Thompson, 1992).

The context in which a study takes place further influences the range of SI being operated. Initiatives to dispel concern for sustainability start at a local level, for example, at production system level or at regional level (Mitchell, 1996; Peco et al., 1999; Devuyst, 2000; Ball, 2001; Chatterton and Style, 2001). A different context, however, means a different group of stakeholders who adhere to a different rationale and prioritize different issues of concern. Local and perhaps trivial issues (e.g., noise) are sometimes considered just as important as issues of concern that originate beyond the local level (e.g., energy use) (Mitchell, 1996). Context also widens the range of SI being operated through the criteria applied to select proper SI (Table 2.1). Most of these criteria will result in context-dependent rather than context-independent SI (e.g., Peco et al., 1999).

Table 2.1: ***Selection criteria.*** Criteria to construct sustainability indicators (SI)

1	**Relevance of SI**
1.1	relevant to the issue of concern
1.2	comprehensible to all stakeholders
2	**Quality of SI**
2.1	sensitivity to change across space
2.2	sensitivity to change across social groups
2.3	sensitivity to change over time
2.4	possibility to identify a target or trend allowing assessment of progress
3	**Data Availability of SI**
3.1	consistent data support
3.2	measurement technically feasible
3.3	measurement financially feasible

Source: Cornelissen et al., 2000

In practice, the wide range of highly context-dependent SI reported in the literature confuses the meaning of SD by suggesting that concern for sustainability can be characterized at will (cf. Chatterton and Style, 2001), which inevitably will result in SD losing its momentum. Confusion with respect to SD primarily results from the *implicit* nature of the rationale underlying a concern for sustainability. Consequently, if concern for sustainability in Phase 1 is left implicit, then Phase 2 lacks a solid basis, and the link between selected SI in Phase 3 and concern for sustainability remains obscure (Figure 2.1).

The first objective of this study is to identify a «common ground for SD» that provides an *explicit* basis to define issues of concern. Common ground for SD, however, should not be counterproductive in that it discourages local initiatives by completely disregarding local issues, thus provoking a Not-In-My-BackYard sentiment (van Pelt et al., 1995; Mitchell, 1996). The second objective of this study is to develop a graphical model that makes visible the «ground covered» by the issues considered in a local initiative, i.e. the initiative's «sustainability scope». Selected SI will be used as input to the graphical model.

The common ground identified in this study builds on integrating two principal rationales underlying SD (section 2.2). A case study in a region of the Province of Overijssel, the Netherlands, illustrates how the «sustainability scope» reflects the ground covered by local contributions to SD (section 2.3).

2.2 IDENTIFYING COMMON GROUND

2.2.1 IMPERATIVES OF SUSTAINABILITY

Rationales underlying SD can be characterized as either anthropocentric or ecocentric (cf. Thompson, 1992). An anthropocentric rationale considers sustainability to be a societal construct, and claims that involvement of all stakeholders and inclusion of local issues is essential to muster public support when implementing sustainability in practice (de Graaf and Musters, 1998; Valentin and Spangenberg, 2000; Bell and Morse, 2001). An ecocentric rationale disputes such a subjective basis and claims that sustainability refers objectively and exclusively to the maintenance of life support systems, i.e., to society preserving biological and physico-chemical processes that maintain the conditions necessary for life on earth (Meadows et al., 1992; Hueting and Reijnders, 1998).

Ecocentric and anthropocentric rationales identify two imperatives of sustainability. The ecocentric rationale identifies a «system imperative» which emphasizes the *existence* of a system. A «system» is defined by its organizational pattern which allows orderly interaction of its constituent parts (Klir, 1991). Society is an open system that continuously exchanges energy and matter with its environment. More accurately, society is a dissipative system that needs a sufficient flow of energy and matter to maintain and develop its organizational pattern (de Rosnay, 1988; Buenstorf, 2000). The system imperative of sustainability, thus, guarantees that society can exist, i.e., maintain the integrity of its organizational pattern through continuous supply of resources, disposal of waste products, and prevention of environmental pollution.

The anthropocentric rationale identifies a «societal imperative» of sustainability which emphasizes the *acceptability* of society. The acceptability of society depends on people to maintain and develop its organizational pattern, and is measured by the quality-of-life that society provides: e.g., employment possibilities, recreational facilities, and safety (Mitchell, 1996). Because not all stakeholders pursue similar objectives, a compromise solution is needed with respect to the way in which energy and matter are to be used (cf. Becker, 1997; Bell and Morse, 1999; Beekman, 2001). The societal imperative, thus, guarantees that society is acceptable, i.e., can maintain a fair organizational pattern through equitable use of available resources.

2.2.2 INTEGRATION OF IMPERATIVES

The system and societal imperatives of sustainability can be integrated in a hierarchy using Koestler's «holon theory» (Koestler, 1967; Koestler, 1978; Checkland, 1991). The word «holon» is derived from the Greek *holos* meaning «whole», with the suffix *-on*, as in neutr*on*, suggesting a «particle» or «part». According to Koestler (1967: 48), society considered as a holon is Janus-faced, like the two-faced Roman god Janus (Figure 2.2). The face turned upward, toward the higher levels, is that of society as a dependent part of a larger (global) ecosystem; the face turned downward, toward its constituents (e.g., agricultural production systems), is that of society as an autonomous whole. In such a hierarchical setting, society behaves on the basis of two tendencies: an «autonomous tendency» which is reflected in self-rule and internal organization, and an «integrative tendency» which emphasizes that the functioning of society is enabled and restrained by the higher level (global) ecosystem. Under favorable conditions both tendencies are balanced, and society interacts in a dynamic equilibrium with the encompassing ecosystem: the two faces of Janus complement each other. Under unfavorable conditions the equilibrium is upset, i.e., the two faces of Janus are in disarray and concern for sustainability emerges.

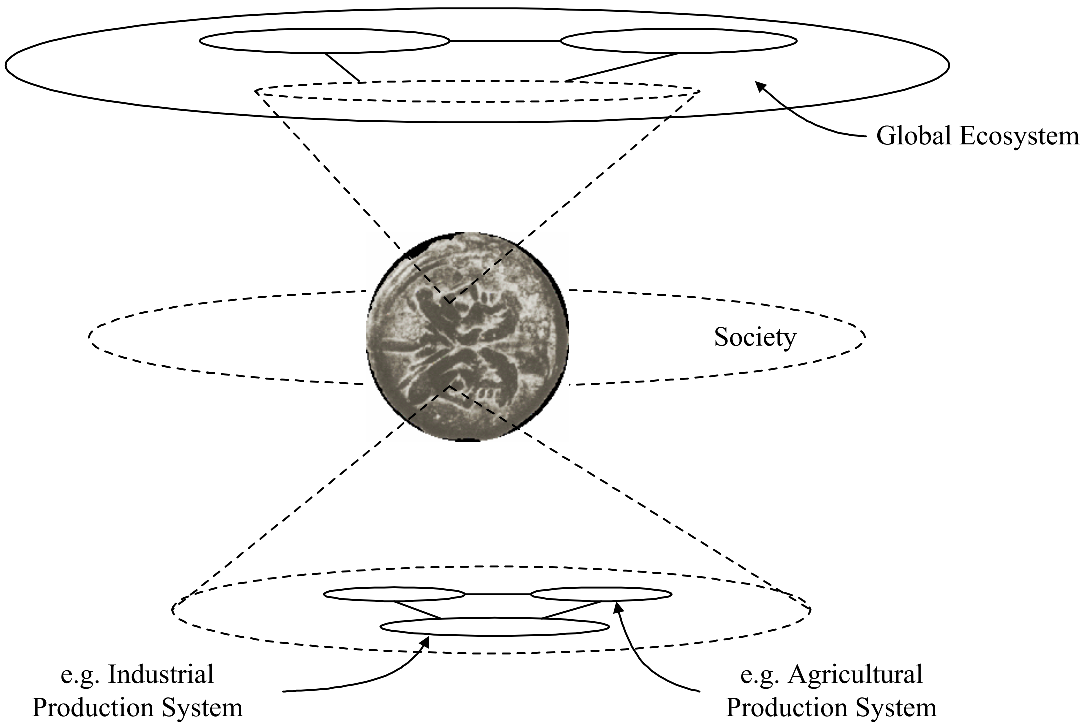


Figure 2.2: ***Society as a holon.*** Society considered as a holon is Janus-faced, after the two-faced Roman god Janus. The face turned upward, toward the higher levels, is that of society as a dependent part of the larger global ecosystem; the face turned downward, toward its constituents (e.g., agricultural production systems), is that of society as an autonomous whole.

The system imperative of sustainability, which guarantees that society can exist, originates from society's integrative tendency and, in the literature, often is referred to as ecological and/or environmental sustainability. The societal imperative of sustainability, which guarantees that society is acceptable, originates from society's autonomous tendency and often is referred to as economic, social and/or human sustainability (Dahl, 1997). From an ethical point of view, the system imperative emphasizes *inter*generational equity of society, whereas the societal imperative emphasizes *intra*generational equity of society (cf. Becker, 1997).

Table 2.2: ***Common ground for sustainable development.*** System issues and societal issues essential with respect to concern for sustainability, and possible local initiatives to dispel such concern

SYSTEM ISSUES

	Issues of Concern	Possible Initiatives
1.1	use of renewable resources (soil, water, air, biodiversity, energy not depending on fossil fuels)	• decrease soil erosion • improve soil fertility • increase water use efficiency • increase production of drinking water • prevent loss of biodiversity • increase use of environmentally friendly energy sources
1.2	use of non-renewable resources (raw materials, energy depending on fossil fuels)	• decrease depletion of fossil fuels • increase recycling of materials
1.3	prevention of area-specific pollution	• decrease soil pollution • decrease water pollution • decrease air pollution
1.4	prevention of non-area-specific pollution	• decrease emission of greenhouse gases • decrease depletion of the ozone layer

SOCIETAL ISSUES

	Issues of Concern	Possible Initiatives
2.1	deterioration of economic security	• increase employment • increase production levels
2.2	deterioration of social security & public health	• improve health care facilities • increase life expectancy
2.3	deterioration of community environment	• improve scenic quality • decrease exposure to noise
2.4	deterioration of community development	• improve public transport • improve housing conditions
2.5	deterioration of public safety	• decrease traffic casualties • decrease crime rate
2.6	deterioration of personal development	• improve educational facilities • increase literacy

Source: Daly, 1990; Meadows et al., 1992; Mitchell et al., 1995; Clayton and Radcliffe, 1996; Horlings, 1996; Dahl, 1997; Hueting and Reijnders, 1998; Bell and Morse, 1999; OECD, 2000b; Valentin and Spangenberg, 2000

2.2.3 Common Ground for Sustainable Development

Common ground for SD builds on Koestler's holon theory, integrating both imperatives of sustainability. Hence, if concern for sustainability is expressed through debate on «issues of concern», then the common ground identifies the extent of issues relevant to SD. Thus, relevant issues include «system issues» that emphasize concern for the existence of society, and «societal issues» that emphasize concern for the acceptability of society (Table 2.2). System issues emphasize use of renewable resources (soil, water, air, biodiversity, energy not depending on fossil fuels), use of non-renewable resources (raw materials, energy depending on fossil fuels), prevention of area-specific pollution (soil, water, air) and prevention of non-area-specific pollution (depletion of the ozone layer, greenhouse gases). Societal issues emphasize quality-of-life provided by society: economic security (e.g., employment, production level), social security and public health (e.g., health care facilities, life expectancy), community development (e.g., infrastructure, housing), community environment (e.g., scenic quality, noise), public safety (e.g., traffic, crime), and personal development (e.g., educational facilities, literacy).

2.3 Illustration of the Ground Covered

2.3.1 Introduction to the Case Study

In its northwestern region (NWO), the Province of Overijssel is reconsidering and changing existing claims on land use to contribute to SD. In NWO, land is used by the local community (COM), it is used for agricultural activities (AGR), for recreational facilities (REC), and for development of nature areas (NAT) (Anonymous, 1997). All relevant stakeholders (e.g., policy makers, farmers, residents, local shop keepers, tourist branch) identified local issues of concern (e.g., improvement of local sports facilities), and issues originating beyond local boundaries (e.g., issues related to the development of new nature areas as laid down in national policy documents). Based on these issues, SI were selected to monitor whether initiatives developed would contribute to SD, as well as to inform policy makers and the local community on progress made (Cornelissen et al., 2000).

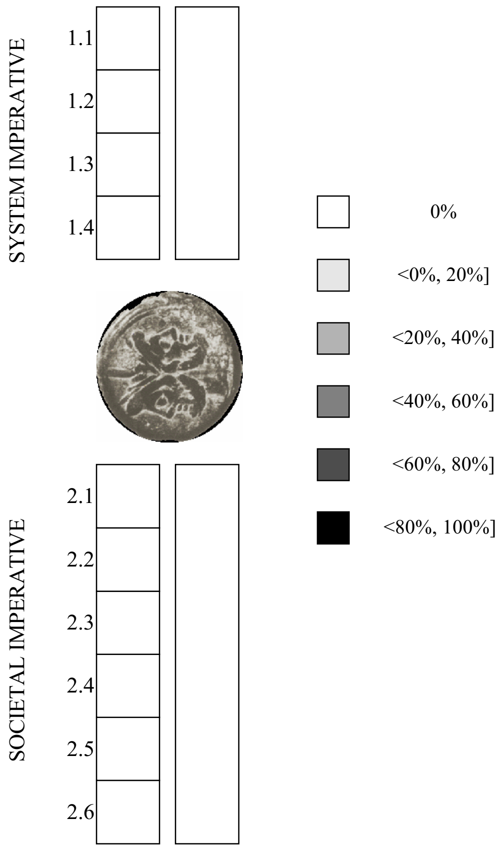


Figure 2.3: ***Illustration of the ground covered (I).*** A graphical model to express the «sustainability scope» of a local initiative. Squares represent system issues 1.1 through 1.4 and societal issues 2.1 through 2.6 (Table 2.2); rectangles represent the overall system and societal imperatives. The colors assigned to each square or rectangle (given in the key) express the emphasis given to system and societal issues.

2.3.2 METHODOLOGY

The SI selected are used to determine the sustainability scope of the case study using a simple graphical model. In Figure 2.3, squares represent system issues 1.1 through 1.4 and societal issues 2.1 through 2.6 (Table 2.2); rectangles represent the overall system and societal imperatives. The shades of grey assigned to each square or rectangle (given in the key to Figure 2.3) express the emphasis given in the case study to the corresponding system or societal issue. If emphasis given to an issue is high, i.e., if relatively more SI are selected to deal with an issue, then the square is given a darker shade of grey. The overall impression of grey tones in the model reflects the sustainability scope of the case study. If the sustainability scope is broad (i.e., system and societal issues have been given equal emphasis), then the impression will be evenly grey; if the sustainability scope is narrow (i.e., a limited number of issues has been given emphasis), then the impression will tend to a black-and-white contrast. A list of issues of concern and corresponding SI was provided by the Province of Overijssel.

First, issues of concern and corresponding SI were allocated to appropriate system and societal issues. Second, a shade of grey was assigned to each square by computing the ratio of the allocated number of SI to the total number of SI. In total, 94 SI were selected in the case study (Table 2.3). Table 2.3 distinguishes between «means-based SI» and «effect-based SI». Means-based SI indicate the degree of adherence to technologies and practices (i.e., means) applied to dispel a specific issue of concern; effect-based SI indicate the actual effect of the means applied (van der Werf and Petit, 2002). In this illustration, only effect-based SI (n = 44) have been used as input in the graphical model, because it is logically impossible to evaluate progress made in dispelling issues of concern using means-based indicators (Hansen, 1996). Moreover, application of the graphical model assumes that all effect-based SI are equally important.

2.3.3 Sustainability Scope

Figure 2.4 shows the overall sustainability scope of the case study in Northwest Overijssel. The impression of grey tones in the graphical model indicates a broad sustainability scope, i.e., equal emphasis has been given to both system and societal issues. Relatively higher emphasis has been given to system issues on renewable resources and area-specific pollution, and to societal issues on economic security. System issues on non-area-specific pollution and societal issues on personal development are not considered.

Figure 2.5 shows the sustainability scope for initiatives with respect to the four major claims on land use in Northwest Overijssel. Although as a whole, equal emphasis has been given to system and societal issues, the sustainability scope for particular land use types is more specific. AGR more or less equally emphasizes both system and societal issues: higher emphasis is given to system issues on area-specific pollution and societal issues on community development. NAT primarily emphasizes system issues on renewable resources and area-specific pollution, REC only emphasizes societal issues on economic security, and COM primarily emphasizes societal issues on economic security.

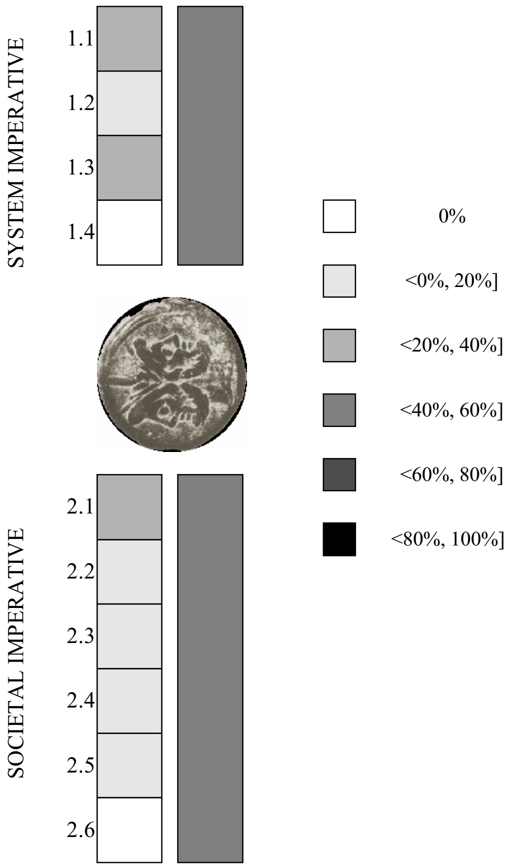


Figure 2.4: ***Illustration of the ground covered (II).*** Overall sustainability scope of a local initiative that aims at contributing to sustainable development in a region of the Province of Overijssel, the Netherlands.

2.4 DISCUSSION

The first objective of this study aimed at identifying a «common ground for SD» to avoid sustainability from being characterized at will (cf. Shearman, 1990). This common ground was identified using Koestler's metaphor of the Janus-faced holon. Society regards concern for sustainability with two faces, and these two faces of sustainability represent a two-way perspective by integrating ecocentric and anthropocentric rationales. The associated system and societal imperatives, respectively, identify system and societal issues (Table 2.2) that, in combination, define the «common ground for SD» as an explicit point of departure for local initiatives that aim at contributing to SD.

Table 2.3: ***SI selected in the case study.*** Number of effect-based and means-based sustainability indicators (SI) selected in relation to four major claims on land use (LU) in a region of the Province of Overijssel, the Netherlands

Issue[1]	LU[2]	effect-based SI	means-based SI	Total SI
1.1	AGR	2	5	7
	NAT	6	7	13
	REC	-	-	-
	COM	1	-	1
1.2	AGR	1	1	2
	NAT	-	-	-
	REC	-	-	-
	COM	-	-	-
1.3	AGR	6	-	6
	NAT	4	-	4
	REC	-	1	1
	COM	-	-	-
1.4	AGR	-	-	-
	NAT	-	-	-
	REC	-	-	-
	COM	-	-	-
2.1	AGR	2	2	4
	NAT	-	-	-
	REC	4	8	12
	COM	8	2	10
2.2	AGR	-	2	2
	NAT	-	-	-
	REC	-	-	-
	COM	1	-	1
2.3	AGR	-	3	3
	NAT	2	-	2
	REC	-	4	4
	COM	-	1	1
2.4	AGR	4	-	4
	NAT	-	-	-
	REC	-	-	-
	COM	2	13	15
2.5	AGR	-	-	-
	NAT	-	-	-
	REC	-	-	-
	COM	1	1	2
2.6	AGR	-	-	-
	NAT	-	-	-
	REC	-	-	-
	COM	-	-	-
		44	50	94

[1] System issues and societal issues as defined in Table 2.2

[2] Land is used by the local community (COM), is used for agricultural activities (AGR), for recreational facilities (REC), and for development of nature areas (NAT)

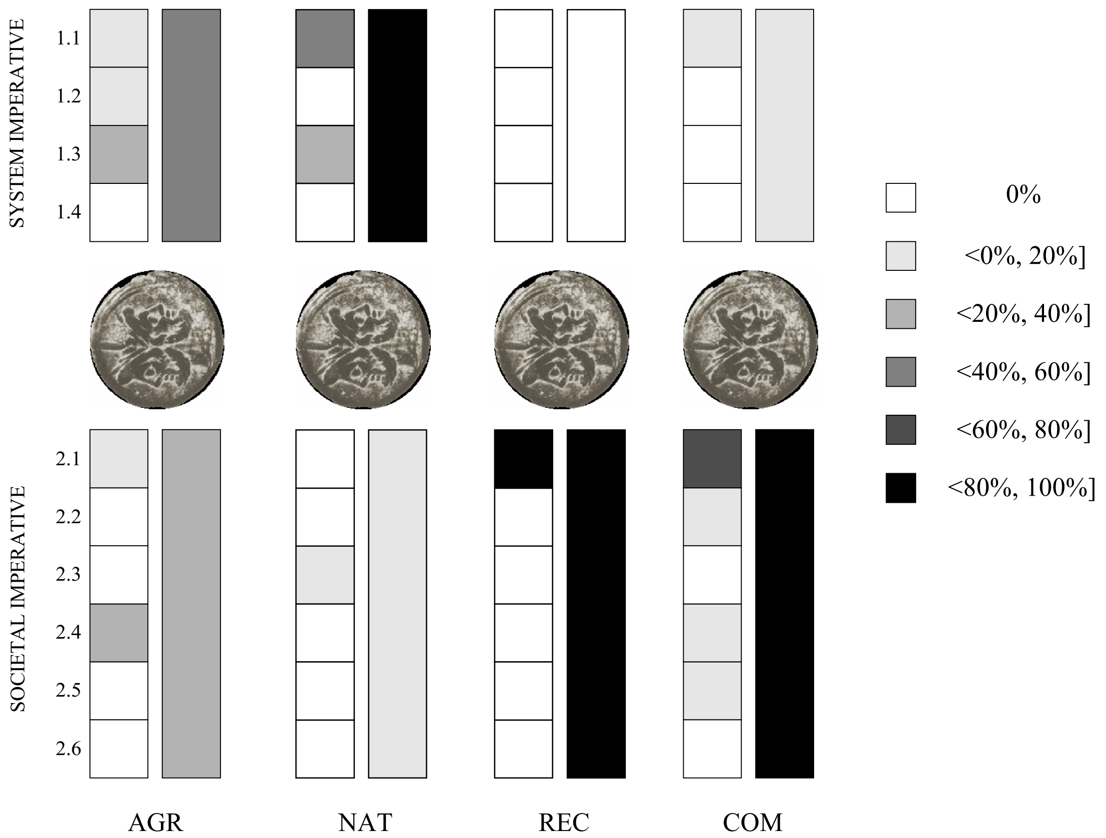


Figure 2.5: ***Illustration of the ground covered (III).*** Sustainability scopes for initiatives with respect to four major claims on land use in a region of the Province of Overijssel, the Netherlands: agriculture (AGR), nature (NAT), recreation (REC), and community (COM).

Common ground for SD as an explicit point of departure, however, does allow for different appreciation of issues in different circumstances. Some issues may not be cause for concern in a specific context, or stakeholders may decide to focus on a limited range of concerns. Van Pelt et al. (1995), for example, argue that such flexibility is essential for successfully initiating SD in developing countries. Such countries are in need of support for their efforts to simultaneously develop long-term policies emphasizing system issues (e.g., stop environmental degradation) and short-term policies emphasizing societal issues (e.g., combat poverty).

Common ground for SD, furthermore, does not require that all issues are taken into account. Those adhering to an ecocentric rationale may be reluctant to also consider societal issues, as ecocentrism originates from the sense that anthropocentrism is at the very root of current concern for sustainability (Shearman, 1990). Hueting and Reijnders (1998), for example, argue that ‹ecological constraints should be complied with, irrespective of prevailing economic conditions and policies›. Those adhering to an anthropocentric rationale, however, will argue that disregarding societal issues is the weakness of any ecocentric rationale, as disregard of issues other than those related to the existence of society can make SD an impossible task (e.g., van Pelt et al., 1995; de Graaf and Musters, 1998; Bell and Morse, 1999). Shearman (1990) adds that considering societal issues will make it easier for people to appreciate the significance of conservation and preservation activities.

Common ground for SD, therefore, makes it possible to explicitly express how concern for sustainability is identified by issues of concern and corresponding SI that are considered relevant in a specific context. Moreover, common ground for SD also explicitly illustrates that SI contribute to SD through their contribution to dispelling corresponding issues of concern (cf. Figure 2.1).

The second objective of this study aimed at developing a graphical model to express the «sustainability scope» of a local initiative, and visualize the ground covered using selected SI. The overall sustainability scope for an initiative, set up in a region of the Province of Overijssel, showed that equal emphasis was given to both system and societal issues and, therefore, that common ground for SD was evenly covered. Different stakeholders, however, generally are involved in different activities with respect to claims on land use, and the sustainability scopes for such claims did show specific differences. On the face of it, results seem to correspond to prevalent public opinion and policy: whereas AGR and NAT give higher emphasis to system issues, REC and COM give higher emphasis to societal issues. And although a limited sustainability scope is not necessarily inferior to a broad sustainability scope, the limited sustainability scope for COM, for example, can induce stakeholders to reconsider whether its specific contribution to SD is adequate. Reconsideration then may result in deciding on a broader sustainability scope by identifying additional issues of concern: e.g., concerns with respect to use of non-renewable resources in COM. In Figure 2.1, such a retrospect is illustrated as a feedback-loop from Phase 3 to Phase 1.

2.5 CONCLUSION

Concern for sustainability currently is an important frame of reference for local initiatives that aim at contributing to society's sustainable development. Although SD inherently holds subjective aspects (WRR, 1995), concern for sustainability needs an explicit point of departure to prevent SD from losing its meaning (cf. Shearman, 1990). In this study, a «common ground for SD» was identified to provide such an explicit basis. Additionally, a graphical model is presented to express the «sustainability scope» of a local initiative, and visualize the common ground covered using selected sustainability indicators. Combined, common ground and sustainability scope provide a point of departure, as well as a means for local initiatives to justify their specific contribution to SD.

ACKNOWLEDGMENTS

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CHAPTER 3

ASSESSMENT OF THE CONTRIBUTION OF SUSTAINABILITY INDICATORS TO SUSTAINABLE DEVELOPMENT: A NOVEL APPROACH USING FUZZY SET THEORY

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3.1 INTRODUCTION

The impact of «sustainability» on development of national and international policy has increased over the last decade. Sustainability is now a core element of government policies, of university research projects, and of corporate strategies (Spedding, 1995; WRR, 1995; de Graaf and Musters, 1998; Mebratu, 1998).

Despite the variety of definitions and interpretations, sustainability consistently means, either explicitly or implicitly, ‹continuity through time›. Rather than referring to continuity *per se*, sustainability associates continuity to *context-dependent* economic, ecological and societal (EES) issues (e.g., Shearman, 1990; Brklacich et al., 1991; Neher, 1992; Heinen, 1994; Clayton and Radcliffe, 1996; Hansen, 1996; Vavra, 1996; Becker, 1997; Giampietro et al., 1997; Mebratu, 1998).

«Agricultural sustainability», which is sustainability in reference to agricultural production systems, invokes concern that in the future, also in the near future, current agricultural activities might endanger the continuity of agricultural production systems (WRR, 1995). This concern is expressed through EES issues, which can range from meeting a need for sufficient, safe, and inexpensive food products to achieving agricultural production practices without undesirable side effects. Possible undesirable side effects include erosion of the soil, nutrient emission to the environment, exhaustion of non-renewable resources, decline of rural communities, and a negative impact on the welfare of animals (e.g., Ikerd, 1993; Stockle et al., 1994; Steinfeld et al., 1997; Kelly, 1998).

Sustainability does not represent the endpoint of a process; rather, it represents the process itself (Shearman, 1990; WRR, 1995). Sustainability implies an ongoing dynamic *development*, driven by human expectations about future opportunities, and is based on present EES issues and information. Sustainability *is* «sustainable development» (Bossel, 1999).

As a consequence of the impact of sustainability on agricultural production systems, a standardized framework to initiate and monitor sustainable development (SD) would have great practical utility (Heinen, 1994; Vavra, 1996; Becker, 1997). Such a framework requires a four-phased methodology to: (1) describe the problem in a defined context, (2) determine context-dependent EES issues, (3) translate EES issues into measurable context-dependent sustainability indicators (SI), and (4) assess the contribution of SI to overall SD. Phases (1) through (3) have been dealt with in the literature (e.g., Verbruggen and Kuik, 1991; Ikerd, 1993; Stockle et al., 1994; Mitchell et al., 1995; Rennings and Wiggering, 1997; Kelly, 1998; Udo and Cornelissen, 1998; Bell and Morse, 1999; Bossel, 1999; Callens and Tyteca, 1999). Phase (4), however, has not been investigated. To assess the contribution of SI to overall SD requires a formal mathematical basis. This paper, therefore, introduces the mathematical theory of fuzzy sets, which enables assessment of overall SD based on the contribution of SI information.

3.2 METHODOLOGY

3.2.1 UNCERTAINTY REGARDING SUSTAINABLE DEVELOPMENT

To decide upon a mathematical theory to model sustainable development, the *type of uncertainty* related to SD must be considered. Because SD will be assessed using selected SI, this selection determines how much we know about SD, i.e., how much information is available; and how much we do not know about SD, i.e., how much information is missing. Certainty about SD requires complete and consistent information. To reduce the description of SD to a manageable level and to obtain a feasible model, it is necessary to reduce the amount of information. Incomplete information, therefore, is a fundamental characteristic of complex concepts (Klir, 1991; WRR, 1995).

In addition to incompleteness, information regarding SD is inconsistent. Human expectations about future opportunities for agriculture may change over time. If so, EES issues and, consequently, context-dependent SI will change.

Further, SD involves trade-offs among issues that cannot be resolved simultaneously (WRR, 1995). An increasing number of Dutch consumers, for example, object to battery housing systems that interfere with the natural behavior of laying hens. Keeping laying hens in floor housing systems instead of in battery housing, therefore, is a societal issue in the Netherlands. There is a trade-off, however, because floor housing tends to have higher ammonia emissions than battery housing, and high emissions conflict with ecological issues for Dutch agriculture (Groot Koerkamp, 1994).

Due to incomplete and inconsistent information, SD has no well-defined *meaning*. The type of uncertainty regarding an assessment of the contribution of SI to SD, therefore, essentially concerns the *meaning* of SD. In mathematical terms, this type of uncertainty is known as fuzzy uncertainty (Klir and Folger, 1988).

3.2.2 PROBABILISTIC AND FUZZY UNCERTAINTY

Probabilistic uncertainty relates to events that have a well-defined, unambiguous meaning. Probability theory is based on classical set theory and on two-valued logic, e.g., true-or-false or yes-or-no statements; probability theory assesses *whether* an event will occur (Batschelet, 1975; Bethea et al., 1985; Kosko, 1992). Because SD cannot be well-defined, it is impossible to assess unambiguously whether development of an agricultural production system is two-valued: sustainable or unsustainable. Two-valued logic, therefore, yields an unsatisfactory conclusion (Klir and Folger, 1988; Fresco and Kroonenberg, 1992; Pelt et al., 1995).

Fuzzy uncertainty, in contrast, relates to events that have no well-defined, unambiguous meaning (Kosko, 1992). Fuzzy set theory is based on multi-valued logic (McNeill and Freiberger, 1993; Pedrycz, 1993; Klir and Yuan, 1995; Zimmermann, 1996). Multi-valued logic enables intermediate assessment between strictly sustainable and strictly unsustainable; i.e., fuzziness describes the *degree* to which an event occurs, not *whether* it occurs (Kosko, 1990; Kosko, 1992). We propose, therefore, that fuzzy set theory offers a formal mathematical framework to assess SD.

3.2.3 BASIC DEFINITIONS OF SET THEORY

Classical set theory is based on two-valued logic. Let the universe of discourse define a set U that consists of elements x ($x \in U$). If A is a subset of U ($A \subset U$), then each element x is either a member of A ($x \in A$) or a nonmember of A ($x \notin A$). In set theory, ‹subset› and ‹event› are interchangeable, i.e., $x \in A$ means that for element x event A has occurred (Hogg and Tanis, 1997). A «characteristic function» μ_A defines an *unambiguous distinction* between members of A and nonmembers of A. Thus, characteristic function μ_A assigns to each x one of two values: $\mu_A(x) = 1$ iff (if and only if) $x \in A$, or $\mu_A(x) = 0$ iff $x \notin A$ (Figure 3.1A).

Recall the example of housing systems for laying hens. Let U_{SI} be the universe of discourse for the SI ‹Ammonia Emission›, where x is the amount of ammonia emission (kg NH_3/hen), and let A be the subset ‹Acceptable› ($A \subset U_{SI}$). Further, assume that the Dutch government determines as acceptable a maximum (threshold) amount of ammonia emission x_T. If $x \leq x_T$, then the amount of ammonia emission is acceptable, so $\mu_A(x) = 1$. If $x > x_T$, however, then the amount of ammonia emission is unacceptable, so $\mu_A(x) = 0$ (Figure 3.1A).

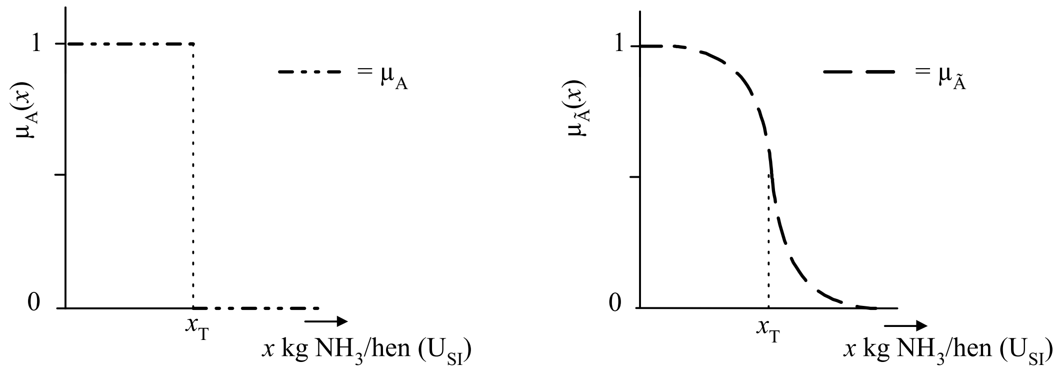

Figure 3.1: ***Basic definitions of set theory.*** U_{SI} is the universe of discourse for the sustainability indicator ‹Ammonia Emission›, and x is the amount of ammonia emission (kg NH_3/hen): $x \in U_{SI}$. (3.1A) A is the classical subset ‹Acceptable› ($A \subset U_{SI}$), and characteristic function μ_A defines a hard threshold x_T between acceptable amounts of ammonia emission ($x \leq x_T$) and unacceptable amounts ($x > x_T$): μ_A assigns to each x one of two values: $\mu_A(x) = 1$ iff $x \leq x_T$, or $\mu_A(x) = 0$ iff $x > x_T$. (3.1B) Ã is the fuzzy subset ‹Acceptable› ($\tilde{A} \subset U_{SI}$), and membership function $\mu_{\tilde{A}}$ defines a soft threshold between acceptable amounts of ammonia emission and unacceptable amounts: $\mu_{\tilde{A}}$ assigns to each x a value $\mu_{\tilde{A}}(x)$ decreasing from 1 to 0 with increasing x.

Classical set theory, therefore, requires a *hard threshold* x_T to determine an unambiguous distinction between acceptable amounts of ammonia emission ($x \leq x_T$) and unacceptable amounts ($x > x_T$). A hard threshold is often unrealistic in practice, however, because two nearly indistinguishable measurements x of SI on either side of x_T will be placed in complementary subsets (Bosserman and Ragade, 1982; George et al., 1997; Silvert, 1997).

Fuzzy set theory, in contrast, is based on multi-valued logic. Analogous to classical set theory, Ã is a fuzzy subset of U ($\tilde{A} \subset U$), and a «membership function» $\mu_{\tilde{A}}$ defines the partial membership in a set. Transition between membership and nonmembership, therefore, is gradual rather than abrupt. Thus, membership function $\mu_{\tilde{A}}$ assigns to each x a value from 0 through 1, indicating the «degree of membership» $\mu_{\tilde{A}}(x)$ of x in Ã. Membership functions, therefore, are functions that map x from U into the interval [0,1] (Figure 3.1B).

Recall again the example of housing systems for laying hens, and the universe of discourse for ‹Ammonia Emission› U_{SI}. Let Ã be the fuzzy subset ‹Acceptable› ($\tilde{A} \subset U_{SI}$). Membership function $\mu_{\tilde{A}}$ is assumed to have a nonlinear form, with degree of membership $\mu_{\tilde{A}}(x)$ for ammonia emission decreasing from 1 to 0 with increasing x (Figure 3.1B).

Fuzzy set theory, therefore, requires a *soft threshold* to determine an intermediate assessment $\mu_{\tilde{A}}(x)$ between acceptable amounts of ammonia emission and unacceptable amounts. A membership function $\mu_{\tilde{A}}$ defines a soft threshold, which enables a smooth and practical assessment of measurements *x* of SI (Bosserman and Ragade, 1982; George et al., 1997; Silvert, 1997).

3.2.4 FUZZY MODELS AND LINGUISTIC VARIABLES

Membership functions are fundamental to fuzzy models, which use such functions to operate «linguistic variables». In fuzzy set theory, a linguistic variable $\tilde{A}$ is characterized by: (1) *base variable x* of $\tilde{A}$, (2) *name* of $\tilde{A}$, (3) *linguistic value* $\tilde{A}_i$ of $\tilde{A}$ (i = 1,…,n), and (4) *membership function* $\mu_{\tilde{A}i}$ of $\tilde{A}_i$ (adopted from: Zadeh, 1975a; Zadeh, 1975b; Klir and Yuan, 1995). Characteristics of a linguistic variable are in Figure 3.2.

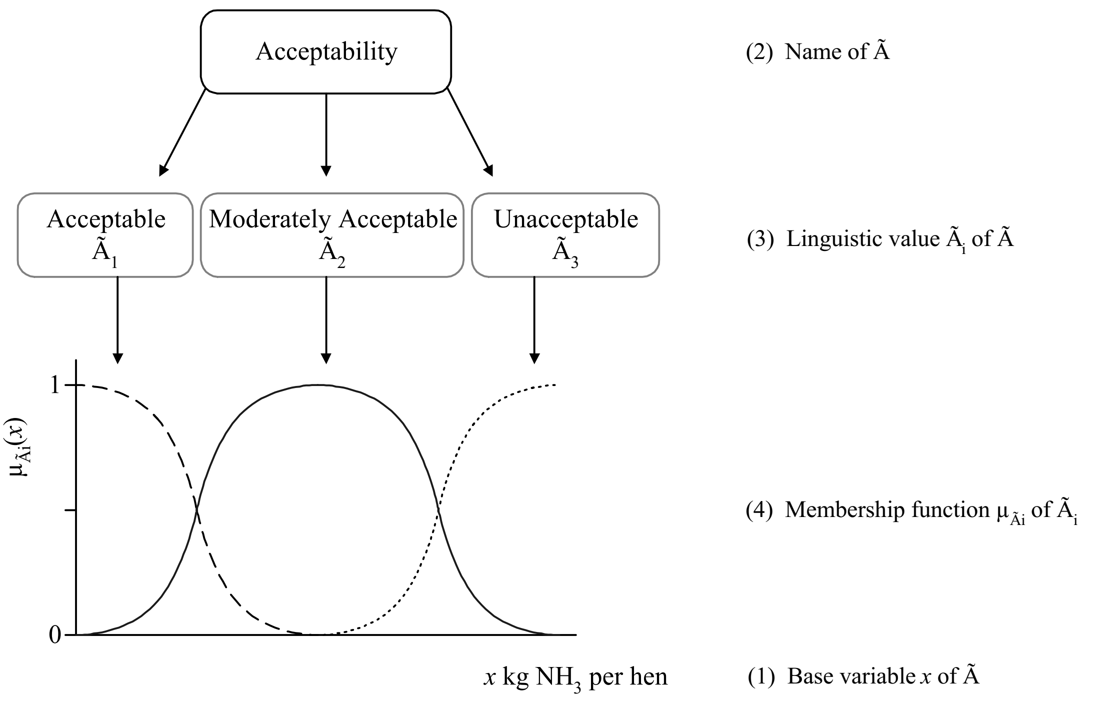

Figure 3.2: ***Linguistic variable.*** Linguistic variable $\tilde{A}$ is characterized by: (1) base variable *x* of $\tilde{A}$, (2) name of $\tilde{A}$, (3) linguistic value $\tilde{A}_i$ of $\tilde{A}$, and (4) membership function $\mu_{\tilde{A}i}$ of $\tilde{A}_i$ (based on Zadeh, 1975a; Zadeh, 1975b; Klir and Yuan, 1995).

Consider the example of housing systems for laying hens. The amount of ammonia emission *x*, which is a measurement of the SI ‹Ammonia Emission›, defines U_{SI}; hence, *x* is the *base variable* of $\tilde{A}$. If the contribution of ‹Ammonia Emission› to

SD is expressed in terms of ‹Acceptability› of base variable x, then the *name* of Ã is ‹Acceptability›.

Three *linguistic values* $\tilde{A}_i$ ($\tilde{A}_1$, $\tilde{A}_2$, and $\tilde{A}_3$) define the contribution of x to SD in linguistic terms (Figure 3.2): $\tilde{A}_1$ = ‹Acceptable›, $\tilde{A}_2$ = ‹Moderately Acceptable›, and $\tilde{A}_3$ = ‹Unacceptable›, A linguistic value, therefore, is a fuzzy subset of U_{SI} ($\tilde{A}_i \subset U_{SI}$). A *membership function* $\mu_{\tilde{A}i}$ defines each linguistic value $\tilde{A}_i$ by determining to what degree $\mu_{\tilde{A}i}(x)$ a base variable x is ‹Acceptable›, $\mu_{\tilde{A}1}(x)$; ‹Moderately Acceptable›, $\mu_{\tilde{A}2}(x)$; or ‹Unacceptable›, $\mu_{\tilde{A}3}(x)$.

In the standardized framework, human expectations about SD are expressed as EES issues, for which SI provide numerical data. Use of linguistic variables in fuzzy models enables one to link expectations about SD, expressed in linguistic propositions, to numerical data, expressed in measurements of SI (Dubois and Prade, 1998). Use of ‹Acceptability›, for example, enables one to link the proposition ‹Ammonia Emission is Acceptable› to amount of ammonia emission (x kg NH_3 per hen).

3.3 FUZZY MODELS TO ASSESS SUSTAINABLE DEVELOPMENT

3.3.1 NOTATION

Two fuzzy models are explored to assess SD: one model that applies fuzzy set aggregation operations, and another that applies approximate reasoning. Input for fuzzy models includes m sustainability indicators SI_k (k = 1,…,m) and base variable x_k. Associated with each SI_k is a membership function μ_{ik} that defines a linguistic value $\tilde{A}_i$ by mapping x_k into the interval [0,1]. Associating x_k with μ_{ik} results in m degrees of membership $\mu_{ik}(x_k)$. Numerical assessment of SD, μ_{SD}, is the output of a fuzzy model; i.e., μ_{SD} is in the universe of discourse U_{SD} ($\mu_{SD} \in U_{SD}$), which is defined as the interval [0,1].

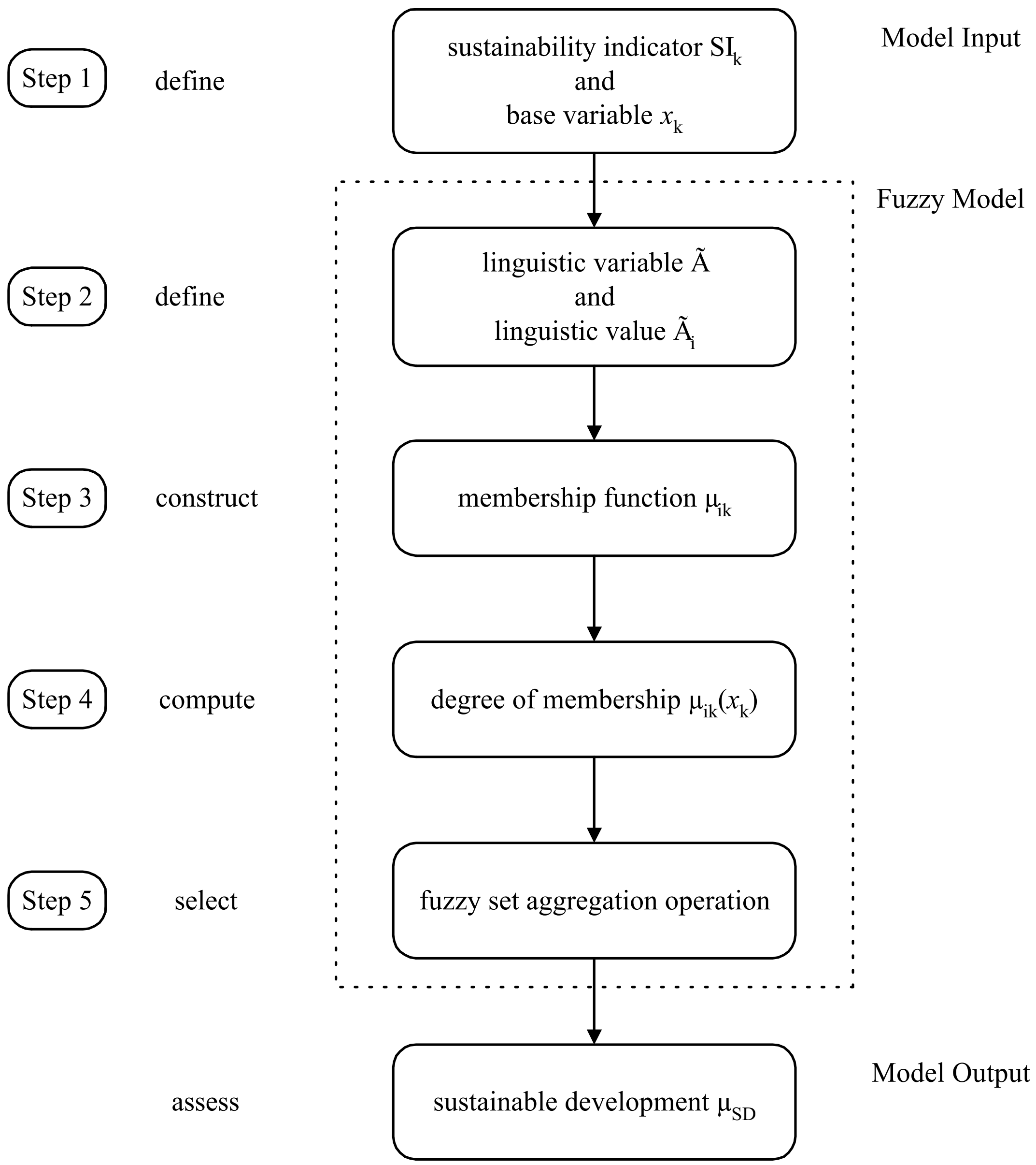

Figure 3.3: ***Scheme of fuzzy model (I).*** The scheme of a fuzzy model applying fuzzy set aggregation operations to assess the contribution of sustainability indicators (SI) to sustainable development (SD).

3.3.2 Fuzzy Model applying Fuzzy Set Aggregation Operations

3.3.2.1 Scheme of Fuzzy Model

The scheme of a fuzzy model applying aggregation operations to assess SD is in Figure 3.3. Five steps are involved: Step 1 defines model input, sustainability indicator SI_k and base variable x_k; Step 2 defines linguistic variable $\tilde{A}$ and linguistic value $\tilde{A}_i$; Step 3 constructs membership function μ_{ik}; Step 4 computes degree of membership $\mu_{ik}(x_k)$; and Step 5 selects a fuzzy set aggregation operation for $\mu_{ik}(x_k)$ so as to assess model output μ_{SD}.

3.3.2.2 Selection of Aggregation Operation

An aggregation operation expresses an attitude toward SD. A meaningful assessment μ_{SD}, therefore, requires careful selection of an aggregation operation (Dubois and Prade, 1988; Munda, 1995; Silvert, 1997).

Assume that Step 2 defines a linguistic variable $\tilde{A}$ with name ‹Acceptability› and linguistic value ‹Acceptable› ($\tilde{A}_1$). A conservative attitude toward SD means that μ_{SD} cannot be larger than the smallest degree of membership $\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)$. In fuzzy set theory, the standard fuzzy intersection enables a conservative attitude toward SD by applying the minimum operator (Dubois and Prade, 1985; Dubois and Prade, 1988):

$$\mu_{SD} = min[\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)]$$

where *min* denotes the minimum operator. Consequently, if one degree of membership $\mu_{1k}(x_k)$ is 0, then assessment μ_{SD} is 0.

A liberal attitude toward SD, in contrast, means that μ_{SD} cannot be smaller than the largest degree of membership $\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)$. In fuzzy set theory, the standard fuzzy union enables a liberal attitude toward SD by applying the maximum operator (Dubois and Prade, 1985; Dubois and Prade, 1988):

$$\mu_{SD} = max[\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)]$$

where *max* denotes the maximum operator. Consequently, if one degree of membership $\mu_{1k}(x_k)$ is 1, then assessment μ_{SD} is 1.

In political reality, economic, ecological, and societal issues inevitably will be balanced against each other (Silvert, 1997). Averaging operations allow a «degree of compromise» α among the m degrees of membership $\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)$: therefore, α determines to what degree possible low assessments in the range $\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)$ can be compensated for by possible high assessments in the range $\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)$. Averaging operations determine a value for μ_{SD} between $min[\mu_{11}(x_1),\ldots,\mu_{1m}(x_m)]$ and $max[\mu_{11}(x_1), \ldots, \mu_{1m}(x_m)]$ (Dubois and Prade, 1985; Dubois and Prade, 1988; Klir and

Yuan, 1995; Munda, 1995). In addition, if the relative importance of SI_k with respect to SD is considered to be unequal, then it is necessary to weight the contribution of SI_k, e.g., in proportion to its importance (Silvert, 1997).

If α denotes the degree of compromise among m degrees of membership and w_k denotes the relative importance of SI_k, then a generalized formulation of weighted averaging operations is

$$\mu_{SD} = \left[\frac{\sum_{k=1}^{m} \left(w_k \mu_{1k}(x_k) \right)^{\alpha}}{\sum_{k=1}^{m} w_k} \right]^{1/\alpha} \qquad [\ 3.1\ ]$$

where $\alpha > 0$, in this model. In the special case when the relative importance of each SI_k is equal, Equation 3.1 reduces to

$$\mu_{SD} = \left[\frac{\sum_{k=1}^{m} \left(\mu_{1k}(x_k) \right)^{\alpha}}{m} \right]^{1/\alpha} \qquad [\ 3.2\ ]$$

Equation 3.1, generally, includes special cases for specific values of α: (i) if $\alpha \to -\infty$, then μ_{SD} is the standard fuzzy intersection; (ii) if $\alpha \to 0$, then μ_{SD} is the geometric mean; (iii) if $\alpha = 1$, then μ_{SD} is the arithmetic mean; and (iv) if $\alpha \to +\infty$, then μ_{SD} is the standard fuzzy union (Dubois and Prade, 1985).

In the example of housing systems for laying hens, assume SD is to be assessed based on three SI: SI_1 is ‹Farm Continuity› (x_1, costs per hen), SI_2 is ‹Ammonia Emission› (x_2, kg NH_3 per hen), and SI_3 is ‹Total Dust in Air› (x_3, mg per m^3) (de Boer and Cornelissen, 2002). Further, assume that associating x_k with μ_{1k} results in three degrees of membership $\mu_{11}(x_1) = 0.2$, $\mu_{12}(x_2) = 0.3$, and $\mu_{13}(x_3) = 0.9$.

In Equation 3.1, the smallest degree of membership determines μ_{SD} to an increasingly lesser extent with increasing degree of compromise α. Using the specific values of α above results in special cases: (i) $\mu_{SD} = 0.2$, (ii) $\mu_{SD} = 0.4$, (iii) $\mu_{SD} = 0.5$, and (iv) $\mu_{SD} = 0.9$.

3.3.3 Fuzzy Model applying Approximate Reasoning

3.3.3.1 Scheme of Fuzzy Model

The scheme of a fuzzy model applying approximate reasoning to assess SD is in Figure 3.4. Six steps are involved: Step 1 defines model input, sustainability indicator SI_k and base variable x_k; Step 2 defines linguistic variable Ã and n linguistic values $Ã_i$, and also defines linguistic variable Õ and q linguistic values $Õ_p$ (p = 1,…,q) regarding assessment μ_{SD}; Step 3 constructs membership function μ_{ik} and $\mu_{Õp}$; Step 4 computes degree of membership $\mu_{ik}(x_k)$; Step 5 determines a fuzzy conclusion Ñ; and Step 6 draws a numerical assessment μ_{SD}. In approximate reasoning, Step 4 is known as *fuzzification*, Step 5 as *fuzzy inference*, and Step 6 as *defuzzification* (Bezdek, 1993; Klir and Yuan, 1995; Cox, 1998).

3.3.3.2 Fuzzy Rule Base

Reasoning is the process of inferring a conclusion regarding a problem that cannot be observed directly (viz., SD), from aspects of the problem that can be observed directly (viz., SI) (Bhatnagar and Kanal, 1992). In a fuzzy model applying approximate reasoning, the reasoning process is based on a series of r fuzzy rules R_j (j = 1,...,r), which together is referred to as the «fuzzy rule base» of the model. A fuzzy rule presents the contribution of SI_k to SD by way of linguistic *if-then* propositions.

A proposition contains a «premise», the *if*-part, and a «conclusion», the *then*-part (Boixader and Godo, 1998; Dubois and Prade, 1998). The premise contains one or more *facts* ‹SI_k is $Ã_i$›. The conclusion contains a single fact ‹SD is $Õ_p$›, where linguistic value $Õ_p$ defines a fuzzy assessment regarding SD ($Õ_p \subset U_{SD}$). Fuzzy rule R_j, therefore, reads

if ‹SI_k is $Ã_i$› *then* ‹SD is $Õ_p$›

If, for example, SI_k is ‹Ammonia Emission›, $Ã_i$ is linguistic value ‹Acceptable›, SD is ‹Sustainable Development›, Õ is linguistic variable ‹Achievement›, and $Õ_p$ is linguistic value ‹Very Good›, then fuzzy rule R_j reads

if Ammonia Emission is Acceptable *then* Sustainable Development is Very Good

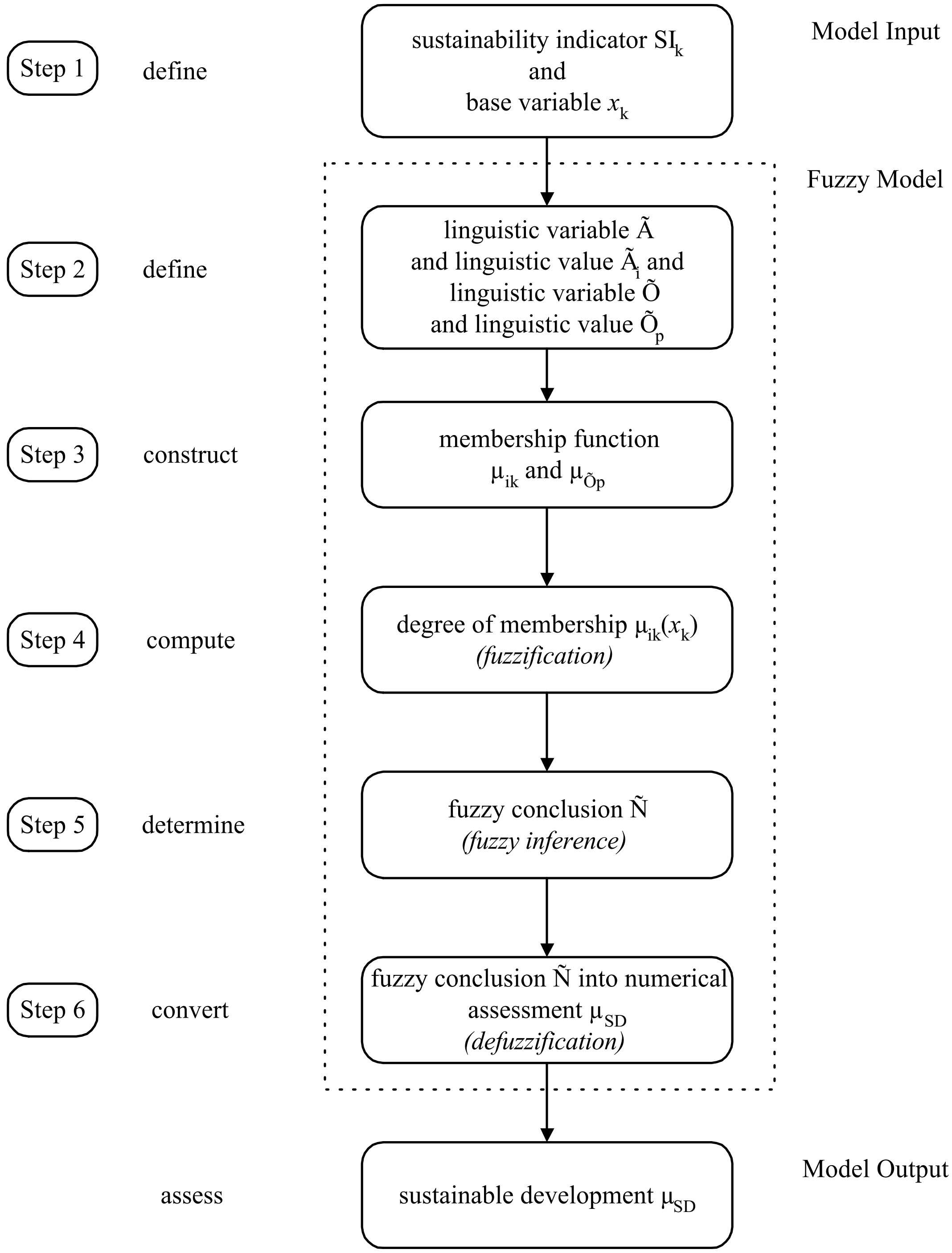

Figure 3.4: ***Scheme of fuzzy model (II).*** The scheme of a fuzzy model applying approximate reasoning to assess the contribution of sustainability indicators (SI) to sustainable development (SD).

Recall assessing the SD of housing systems for laying hens: SI_1 is ‹Farm Continuity› (x_1, costs per hen), SI_2 is ‹Ammonia Emission› (x_2, kg NH_3 per hen), and SI_3 is ‹Total Dust in Air› (x_3, mg per m^3). Further, linguistic value $\tilde{A}_1$ is ‹Acceptable› and $\tilde{A}_2$ is ‹Unacceptable›; and linguistic value $\tilde{O}_1$ is ‹Very Good›, $\tilde{O}_2$ is ‹Good›, $\tilde{O}_3$ is

‹Poor›, and $\tilde{O}_4$ is ‹Very Poor›. A fuzzy rule base comprising four fuzzy rules could read

R_1	*if* SI_1 is $\tilde{A}_1$ AND SI_2 is $\tilde{A}_1$ AND SI_3 is $\tilde{A}_1$ *then* SD is $\tilde{O}_1$
R_2	*if* SI_1 is $\tilde{A}_1$ AND SI_2 is $\tilde{A}_1$ AND SI_3 is $\tilde{A}_2$ *then* SD is $\tilde{O}_2$
R_3	*if* SI_1 is $\tilde{A}_1$ AND SI_2 is $\tilde{A}_2$ AND SI_3 is $\tilde{A}_2$ *then* SD is $\tilde{O}_3$
R_4	*if* SI_1 is $\tilde{A}_2$ AND SI_2 is $\tilde{A}_2$ AND SI_3 is $\tilde{A}_2$ *then* SD is $\tilde{O}_4$

where ‹AND› denotes a *logical connective* (Klir and Yuan, 1995). Rule R_1, for example, reads ‹*if* Farm Continuity is Acceptable AND Ammonia Emission is Acceptable AND Total Dust in Air is Acceptable *then* Sustainable Development is Very Good›. Steps 4 (fuzzification), 5 (fuzzy inference), and 6 (defuzzification) will be illustrated based on the fuzzy rule base above.

3.3.3.3 Fuzzification

Fuzzification of model input refers to computing the degree of membership $\mu_{ik}(x_k)$. In the example of assessing SD of housing systems for laying hens, fuzzification of SI_1 results in $\mu_{11}(x_1) = 0.2$; of SI_2, $\mu_{12}(x_2) = 0.3$; and of SI_3, $\mu_{13}(x_3) = 0.9$. Further, $\tilde{A}_2$ (‹Unacceptable›) is the *fuzzy complement* of $\tilde{A}_1$ (‹Acceptable›), so that $\mu_{2k}(x_k) = 1 - \mu_{1k}(x_k)$ (Klir and Yuan, 1995): $\mu_{21}(x_1) = 0.8$, $\mu_{22}(x_2) = 0.7$, and $\mu_{23}(x_3) = 0.1$ (Figure 3.5).

3.3.3.4 Fuzzy Inference

Fuzzy inference is a two-step process: the ‹implication process› and the ‹aggregation process› (Yager, 1994; Anonymous, 1998). The implication process defines a fuzzy conclusion $\tilde{N}_j$ for each rule R_j. The aggregation process then defines an overall fuzzy conclusion $\tilde{N}$ for the entire fuzzy rule base.

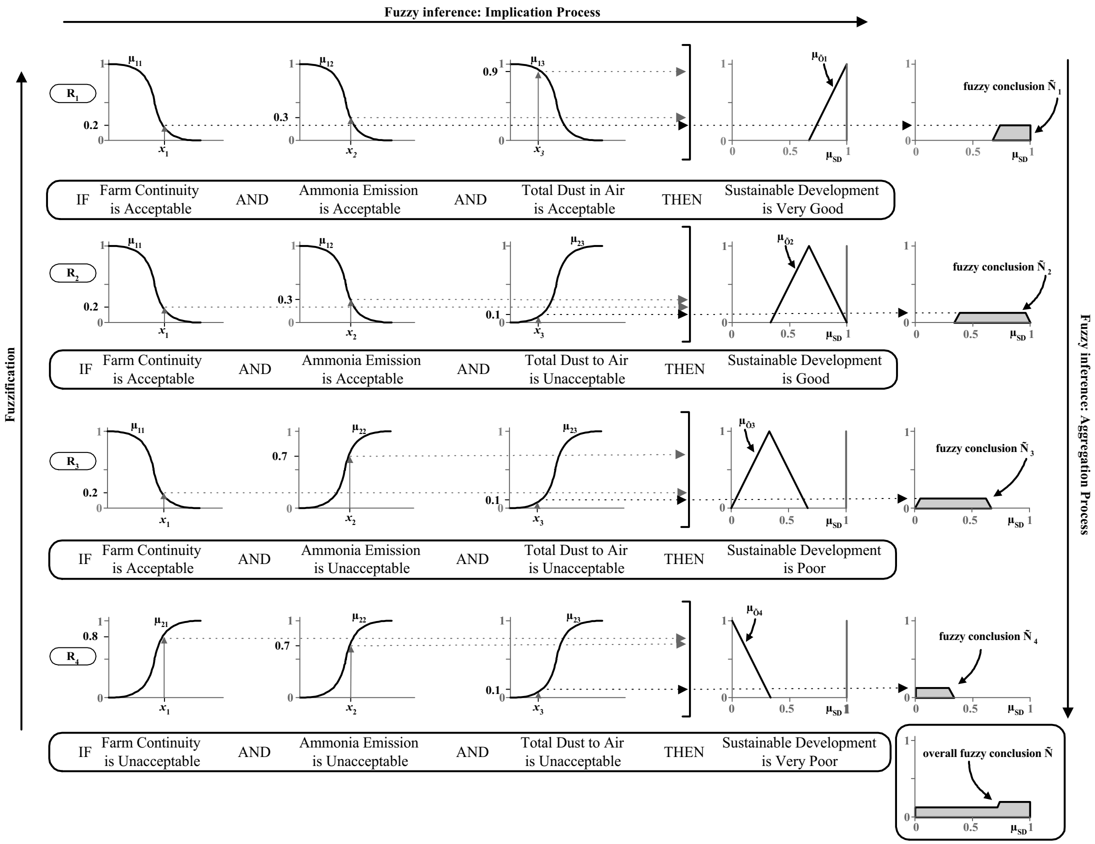

Figure 3.5: ***Approximate reasoning.*** Graphical illustration of a fuzzy model applying approximate reasoning to assess the sustainable development of housing systems for laying hens. A fuzzy rule base comprising four fuzzy *if-then* rules presents the contribution of three sustainability indicators (Farm Continuity, Ammonia Emission, and Total Dust in Air) to sustainable development. Approximate reasoning starts with fuzzification of model input x_1 (costs per hen), x_2 (kg NH_3 per hen), and x_3 (mg per m^3). Next, fuzzy inference, a two-step process comprising the implication process and the aggregation process, determines an overall fuzzy conclusion Ñ based on fuzzy conclusions $\tilde{N}_1$ through $\tilde{N}_4$ for each rule (based on Anonymous, 1998)

The implication process first defines a truth value τ_j for the premise of the proposition in R_j. If the premise contains a single fact ‹SI_k is $\tilde{A}_i$›, then τ_j is defined by the degree of membership $\mu_{ik}(x_k)$. If the premise contains more than one fact, however, then τ_j is defined by a logical connective (Zadeh, 1975b; Boixader and Godo, 1998).

Consider the example that assesses the SD of housing systems for laying hens. For R_j, the logical connective ‹AND› defines a fuzzy intersection operator to compute τ_j based on degrees of memberships. Applying the *min*-operator for R_1, for example, results in $\tau_1 = min[0.2, 0.3, 0.9] = 0.2$ (Figure 3.5).

The implication process then defines how τ_j implies a fuzzy conclusion $\tilde{N}_j$ based on the fact ‹SD is $\tilde{O}_p$›. The operator defined to implement the implication process in R_j modifies membership function $\mu_{\tilde{O}p}$, constructed in Step 3, to the degree specified by τ_j. Applying the *min*-operator for R_1, for example, modifies the membership function $\mu_{\tilde{O}1}$ by truncation at $\tau_1 = 0.2$. The fuzzy conclusion $\tilde{N}_1$ is the *area* under the truncated membership function (Figure 3.5).

The aggregation process defines an overall fuzzy conclusion $\tilde{N}$ by selecting an operator to aggregate the $\tilde{N}_j$. In a fuzzy rule base, rules are connected by the logical connective ‹ELSE› (Watanabe et al., 1992). In the example, the fuzzy rule base then reads

R_1	*if* SI_1 is $\tilde{A}_1$ AND SI_2 is $\tilde{A}_1$ AND SI_3 is $\tilde{A}_1$ *then* SD is $\tilde{O}_1$, ELSE
R_2	*if* SI_1 is $\tilde{A}_1$ AND SI_2 is $\tilde{A}_1$ AND SI_3 is $\tilde{A}_2$ *then* SD is $\tilde{O}_2$, ELSE
R_3	*if* SI_1 is $\tilde{A}_1$ AND SI_2 is $\tilde{A}_2$ AND SI_3 is $\tilde{A}_2$ *then* SD is $\tilde{O}_3$, ELSE
R_4	*if* SI_1 is $\tilde{A}_2$ AND SI_2 is $\tilde{A}_2$ AND SI_3 is $\tilde{A}_2$ *then* SD is $\tilde{O}_4$.

Each fuzzy rule above expresses a situation regarding the contribution of three SI to SD. In approximate reasoning, rules R_1 through R_4 are true to a certain degree, as expressed by τ_1 through τ_4, which means that all rules contribute partly to the overall fuzzy conclusion $\tilde{N}$. If one rule is completely true (e.g., $\tau_1 = 1$), then all other rules must be completely false (i.e., τ_2 through $\tau_4 = 0$) and should not contribute to $\tilde{N}$. The logical connective ‹ELSE› is defined, therefore, by the *max*-operator to enable a fuzzy union of $\tilde{N}_j$ (Yager, 1994; Türksen, 1999). The fuzzy conclusion $\tilde{N}$ is the area under the curve (Figure 3.5).

3.3.3.5 DEFUZZIFICATION

Defuzzification converts the fuzzy conclusion Ñ from an area under the curve to a numerical assessment μ_{SD}. Various methods of defuzzification are available (e.g., Filev and Yager, 1991; Yager and Filev, 1993; Bárdossy and Duckstein, 1995; Klir and Yuan, 1995; Dubois and Prade, 1998; Leekwijck and Kerre, 1999). The method used most often is the ‹center of gravity method›, which defines μ_{SD} as a value that divides the area under the curve into two equal subareas. In the example that assesses SD of housing systems for laying hens, the center of gravity is computed as $\mu_{SD} = 0.6$ (Figure 3.6).

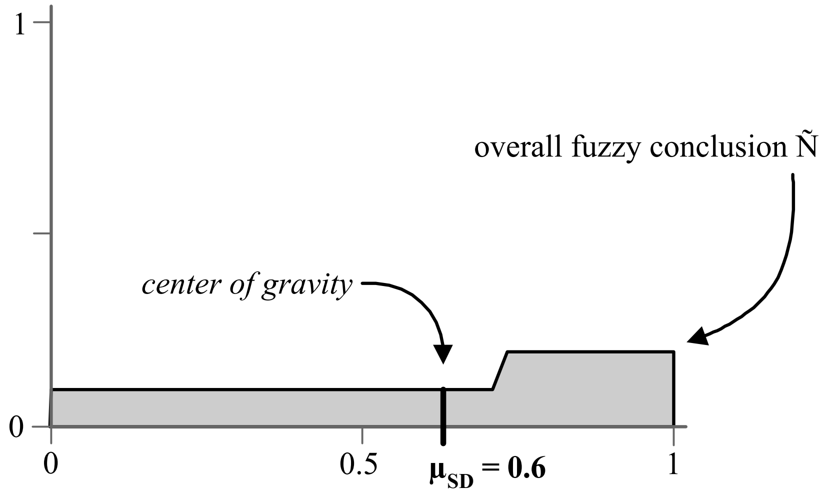

Figure 3.6: ***Defuzzification.*** Graphical illustration of defuzzification of the overall fuzzy conclusion Ñ in a fuzzy model applying approximate reasoning to assess the sustainable development of housing systems for laying hens. The center of gravity method divides the area under the curve Ñ into two equal subareas and thus determines μ_{SD}.

3.4 DISCUSSION

3.4.1 FUZZY MODELS TO ASSESS SUSTAINABLE DEVELOPMENT

The impact of sustainability on agricultural production systems emphasizes the need for a standardized framework to initiate and monitor sustainable development (Shearman, 1990; Hansen, 1996; Becker, 1997). A numerical assessment of SD in such a framework is based on context-dependent economic, ecological, and societal sustainability indicators. The objective of this paper was to introduce fuzzy set theory as a mathematical basis to enable a numerical assessment of SD. For this reason, we developed two fuzzy models: one model that applies fuzzy set aggregation operations and another that applies approximate reasoning. Each fuzzy model was explored using a hypothetical example of housing systems for laying hens. The hypothetical example is based on a currently important issue in Dutch agriculture (de Boer and Cornelissen, 2002).

The first fuzzy model constitutes a robust application of fuzzy set theory and enables a general approach to human reasoning. Fuzzy set aggregation operations allow a continuum of (political) attitudes toward SD, ranging from conservative to liberal.

The second fuzzy model constitutes a refined application of fuzzy set theory and enables a specific approach to human reasoning. Fuzzy *if-then* rules allow human expectations about SD to be expressed in linguistic propositions that present the contribution of SI to SD. A numerical assessment μ_{SD} can then be ‹fine-tuned› by selected fuzzy operators used in the approximate reasoning process to draw a conclusion regarding SD. Various fuzzy operators are available to implement fine-tuning of the reasoning process (Klir and Yuan, 1995; Rojas et al., 1999). The choice of operators, therefore, needs careful consideration.

3.4.2 Practical Implementation of Fuzzy Models

Membership functions are at the core of fuzzy models. The membership function is considered to be both the strongest and the weakest point of fuzzy set theory (Munda et al., 1992). It is the strongest, because a membership function defines a soft threshold, which allows a smooth and practical assessment of the contribution of SI to SD, in contrast with a characteristic function, which defines a hard threshold in classical set theory (Bosserman and Ragade, 1982; George et al., 1997; Silvert, 1997). It is the weakest, because the membership function is regarded as too subjective in relation to its construction. In industrial engineering applications of fuzzy set theory, construction of membership functions is realized mostly by trial and error (McNeill and Freiberger, 1993; Bárdossy and Duckstein, 1995; Klir and Yuan, 1995; Zimmerman, 1996). Trial-and-error methods to construct membership functions to assess SD, however, are not possible and are considered unacceptable.

Several studies discuss empirical methods to construct a membership function based on expert knowledge (e.g., Norwich and Türksen, 1984; Chameau and Santamarina, 1987; Santamarina and Chameau, 1987; Türksen, 1991; Bárdossy and

Duckstein, 1995; Ruspini et al., 1998; Türksen, 1999). Although in this paper the membership functions shown are of a hypothetical nature, three aspects regarding use of expert knowledge must be considered in future practical implementation of fuzzy models to assess SD: (1) criteria that determine necessary qualifications of experts, (2) proper elicitation of expert knowledge to construct a membership function, and (3) methods to test reliability of a membership function. Reliability of a membership function is also important with regard to verification and validation of the fuzzy model (Chang and Hall, 1992).

A potential problem in the practical application of the fuzzy model applying approximate reasoning concerns the combinatorial nature of the fuzzy rules. For example, the assessment of the contribution of n SI to SD using two linguistic values (e.g., acceptable and unacceptable) results in a fuzzy rule base of 2^n rules. Therefore, with increasing number of SI the number of fuzzy rules in the fuzzy rule base increases exponentially. In other words, because of the exponentially increasing number of fuzzy rules, the fuzzy rule base soon becomes nontransparent and difficult to apply. A possible way to overcome this problem is to consider as few SI as possible by choosing them mutually independently. For example, if two SI show high correlation, then both SI should be replaced by one new SI. The fuzzy model applying fuzzy set aggregation operations avoids problems concerning the combinatorial nature of a fuzzy rule base.

3.5 CONCLUSIONS

A decision-making process regarding SD is first and foremost a political and, therefore, a subjective issue (Bockstaller et al., 1997; Silvert, 1997; de Graaf and Musters, 1998). Although the attitude toward SD might be a subjective one, fuzzy set theory enables a formal mathematical framework to link human expectations about SD, expressed in linguistic propositions, to numerical data, expressed in measurements of SI. The fuzzy models developed in this paper, therefore, provide a novel approach to support decision-making regarding sustainable development. Current research applies both fuzzy models in practice.

CHAPTER 4

ELICITATION OF EXPERT KNOWLEDGE FOR FUZZY EVALUATION OF AGRICULTURAL PRODUCTION SYSTEMS

This chapter is in press.
A.M.G. Cornelissen, J. van den Berg, W.J. Koops, U. Kaymak, 2002. Elicitation of expert knowledge for fuzzy evaluation of agricultural production systems. *Agriculture, Ecosystems and Environment*.

4.1 Introduction

Public concern about, for example, food security and food safety, environmental degradation, and human and animal welfare nowadays is an important frame of reference for the development of agricultural production systems (e.g. Ruttan, 1997; Pinstrup-Andersen and Pandya-Lorch, 1998; Safley, 1998; Frouws and van Broekhuizen, 2000; Kunkel, 2000; OECD, 2000a). Such public concern emphasizes that agriculture is a human activity which takes its shape from being at the meeting point of natural systems and the rest of society (Thompson, 1986; Marsh, 1997; Bland, 1999). The development of agricultural production systems, therefore, involves two system levels (cf. Zoeteman, 2001). At society level, public concern is a perception of the impact of present agricultural production practices on society. At production system level, public concern finds a response in corrective measures to production practices (Figure 4.1A). For example, public concern for welfare of laying hens stimulated development of animal-friendly production practices like aviary and deep-litter production systems (de Jonge and Goewie, 2000).

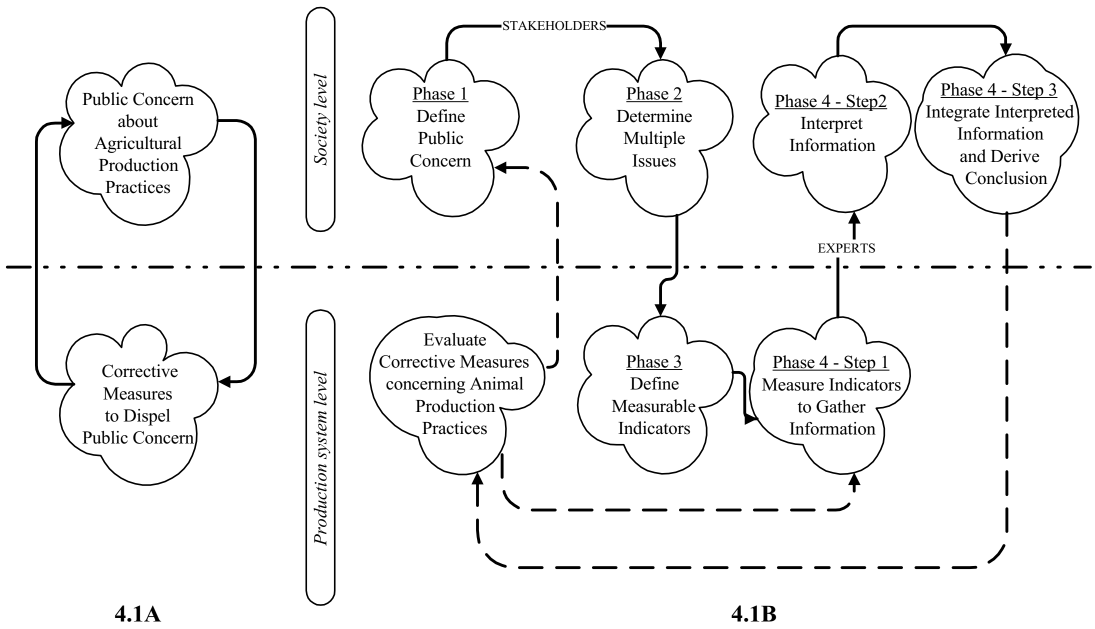

Figure 4.1: ***An evaluative framework.*** In Figure 4.1A, development of agricultural production systems builds on public concern about the impact of current agricultural activities on society. Figure 4.1A is elaborated in Figure 4.1B to introduce a four-phased framework to evaluate the development of agricultural production systems.

Public concern is a linguistic expression of a complex problem which generally can be characterized through multiple issues. Public concern regarding animal welfare, for example, comprises issues regarding animal behavior, physiology, health and production (de Jonge and Goewie, 2000). In an earlier paper (Cornelissen et al., 2001), we proposed a four-phased framework which acknowledges that evaluating development of agricultural production systems involves both society level and production system level (Figure 4.1B). In Phase 1, the public concern is defined in its specific context and relevant stakeholders of the problem are identified. For example, welfare of laying hens is defined as a public concern in the Netherlands and farmers, consumers, veterinarians and scientists might be identified as relevant stakeholders. In Phase 2, context-dependent issues which characterize the public concern are determined by the stakeholders. For example, space allowance and the resultant possibility for hens to move is a relevant issue regarding welfare of laying hens. In Phase 3, issues are translated into measurable, context-dependent indicators. For example, the issue ‹possibility to move› is translated into the indicator ‹stocking density› which at production system level is measured as the number of hens per m^2. Phase 4 of the framework consists of three steps. In Step 1, indicators are measured to gather information: e.g. ‹stocking density is x hens per m^2›. In Step 2, information gathered is interpreted: e.g. ‹stocking density is acceptable›. In Step 3, interpreted information is integrated to derive a conclusion: e.g. ‹*if* stocking density is acceptable, *then* the possibility for hens to move is good›.

Following Zadeh's «principle of incompatibility» (Zadeh, 1973) - which is based on how humans understand and manage complexity - information obtained at production system level through measuring indicators (stocking density is x hens per m^2) typically is interpreted at society level in imprecise, linguistic terms (stocking density is acceptable). In other words, according to Zadeh's principle there exists a trade-off between the complexity of a problem and the precision in formulating conclusions on the problem (Ruspini and Mamdani, 1998).

To make Phase 4 operational, we suggested the use of fuzzy models to link measurable information and its linguistic interpretation (Cornelissen et al., 2001). Membership functions (MFs) are at the core of fuzzy models, and proper use of such models, therefore, depends on proper construction of MFs (Krishnapuram, 1998). A number of elicitation methods are available to construct MFs using expert knowledge. Such MFs, however, are considered to be both the strongest and the weakest point of fuzzy models. They are the strongest, because MFs provide an understandable linguistic, context-dependent interpretation of information. They are the weakest, because MFs, paradoxically, are often regarded as too subjective with regard to their construction (Munda et al., 1992).

We propose that criticism regarding the inherent subjectivity in the construction of MFs mainly builds on two reasons. First, if expert knowledge is used to construct MFs, then *proper* selection of experts must ensure the use of *appropriate* expert knowledge. However, a justification for the selection of experts generally is absent in studies applying fuzzy models. Second, studies which apply expert knowledge to construct MFs either emphasize theoretical rather than practical aspects of elicitation methods (e.g. Norwich and Türksen, 1984; Giles, 1988; Blishun, 1989), or do not discuss the construction of MFs at all (e.g. Bosserman and Ragade, 1982; Angel et al., 1998; van der Werf and Zimmer, 1998). Therefore, as fuzzy models promise to be a valuable tool in evaluating development of agricultural production systems, a practical procedure to warrant proper selection of both experts and methods to elicit expert knowledge is needed.

The objective of this paper is to outline such a procedure and, thus, deal with criticism regarding the inherent subjectivity in the construction of MFs using expert knowledge. The procedure must constitute (i) criteria which qualify a person as an expert, and (ii) a selection of methods to elicit expert knowledge and construct MFs in a variety of practical situations. To realize (i), a foundation which can be used to define selection criteria is needed (section 4.2.1). In addition, it is meaningful to distinguish between the role of stakeholders and the role of experts in the evaluative framework (section 4.2.2). To realize (ii), first the essence of fuzzy modeling is briefly discussed (section 4.3.1) to provide the reader with an adequate background to consider a list of suitable elicitation methods (section 4.3.2) which enables a comparison of these methods to support their practical application (section 4.3.3). Next, the full procedure to elicit expert knowledge (section 4.4) is demonstrated using an illustrative example on the welfare of laying hens (section 4.5).

4.2 CRITERIA TO SELECT EXPERTS

4.2.1 FOUNDATION TO DEFINE SELECTION CRITERIA

Criteria to select experts guarantee elicitation of appropriate expert knowledge, i.e. they guarantee the quality of the expert knowledge required (Ram and Ram, 1996). Three aspects are important: how is expert knowledge obtained, which expert knowledge is available, and which combination of expert knowledge is preferred?

An expert is a person whose knowledge in a specific domain (e.g. welfare of laying hens) is obtained gradually through a period of learning and experience (Bromme, 1992; Turban, 1995). Learning and experience influence a person's cognitive, judgmental, social, creative, analytical, and procedural behavior (Greenwell, 1988). According to Greenwell, especially a person's judgmental and analytical behavior provide tangible points of departure to define criteria identifying experts.

A person's judgmental behavior relates to making decisions, weighting evidence and assessing consequences; a person's analytical behavior relates to examining a complex problem through dealing with it in terms of mutually related parts (Greenwell, 1988). Within the evaluation framework in Figure 4.1B, an expert's judgmental and analytical experience typically is used at the boundary of both system levels. An expert, therefore, is familiar with an analysis of the public concern in terms of multiple issues (e.g. an analysis of the welfare of laying hens in terms of behavioral, physiological, health and production issues), and is able to judge measurements of indicators corresponding to these issues in linguistic terms (e.g. judge ‹stocking density› in terms of ‹acceptable› and ‹unacceptable›). A person's experience can be theoretical (e.g. experience obtained from scientific research), practical (e.g. experience obtained from farming practice) or a combination of both (e.g. experience obtained in the extension service or at experimental farms) (Bromme, 1992; Schreiber et al., 2000).

Expert knowledge is influenced by individual perspectives and goals (Ford and Sterman, 1998). Complete impartiality of expert knowledge, therefore, is difficult to achieve. An important consideration in the selection of experts is whether to use a heterogenous group of experts (e.g. both scientists and farmers) or a homogenous group of experts (e.g. only scientists). The effect of differences in personal experience on an expert's judgment is assumed to be smaller in a homogenous group compared to a heterogenous group. Scientists, therefore, might come to a different evaluation of production systems in terms of animal welfare than farmers (Kunkel, 2000). Such differences, however, are not necessarily disadvantageous. A heterogenous group of experts can have an advantage over a homogenous group through considering all opinions and, thus, compensating for dissenting points of view by more liberal ones (cf. Reuzel, 2001).

In summary, criteria to identify experts are based on (I) a person's period of learning and experience in a specific domain of knowledge, thus influencing his or her judgmental and analytical behavior, and are based on (II) the specific circumstances in which experience is gained, e.g., in theoretical or practical circumstances. Criteria based on (I) to identify experts regarding welfare of laying hens among a group of scientists, for example, can be the number of projects on welfare of laying hens a person has been working on, the number of scientific publications a person has published on the subject, a person's involvement in public debates on the subject, or the length of a person's period of learning and experience (cf. Ram and Ram, 1996). Criteria based on (II) consider whether a heterogenous or a homogenous group of experts is preferred. Criteria can be assessed by both the person who is a candidate-expert, and by his or her peers. Although there exists no definite list of criteria, and even if criteria at best are formulated qualitatively, the important contribution is that the basis on which experts are to be selected is transparent and public.

4.2.2 Distinguishing between Stakeholders and Experts

Regarding the use of expert knowledge within the evaluation framework in Figure 4.1B, it is important to distinguish between the role of «experts» in Phase 4 and the role of «stakeholders» in Phases 1 and 2. That is, experts are not necessarily stakeholders and stakeholders are not necessarily experts. Stakeholders can be any group or individual who can affect or is affected by the behavior of the system (Mitchell et al, 1997; Greenwood, 2001). The role of stakeholders and experts in the evaluation framework is different, and so are the criteria for selection. Mitchell et al. (1997), for example, present a comprehensive discussion of possible criteria to define stakeholders. The difference between experts and stakeholders can be demonstrated by considering the role of expert and non-expert witnesses in law (Lectric Law Library, 2002). An expert witness is allowed to give an opinion on the meaning of facts observed. Non-expert witnesses, however, only are allowed to affirm the facts observed but cannot give an opinion on the meaning of these facts. Experts, on the one hand, are allowed to give an opinion on the meaning of information gathered. Stakeholders, on the other hand, are allowed to formulate the relevant issues but cannot give an opinion on the meaning of information.

Thus, a person who qualifies as a stakeholder not necessarily qualifies as an expert, as stakeholders and experts are selected on the basis of different criteria. For example, although consumers are considered stakeholders regarding the welfare of laying hens in Dutch egg production systems (de Jonge and Goewie, 2000), they are not necessarily experts qualified to judge whether specific stocking densities are acceptable with respect to a hen's possibility to move.

4.3 ELICITATION OF EXPERT KNOWLEDGE

4.3.1 ESSENCE OF FUZZY MODELING

Fuzzy models are based on the theory of fuzzy sets (Zadeh, 1965) and, as discussed in Cornelissen et al. (2001), use MFs to operate «linguistic variables» and interpret indicator information using expert knowledge. In Figure 4.2, a linguistic variable $\tilde{A}$ is characterized by: (i) *name* of $\tilde{A}$, (ii) *base variable* x of $\tilde{A}$, (iii) *linguistic value* $\tilde{A}_i$ of $\tilde{A}$ (i = 1…N), and (iv) *membership function* $\mu_{\tilde{A}i}$ of $\tilde{A}_i$ (adapted from Zadeh, 1975a,b; Klir and Yuan, 1995). At society level, if ‹stocking density› is the *name* of $\tilde{A}$, then ‹acceptable› ($\tilde{A}_1$) and ‹unacceptable› ($\tilde{A}_2$) are *linguistic values* $\tilde{A}_i$ of $\tilde{A}$ (N = 2). At production system level, indicator ‹stocking density› is measured as x hens per m^2 which is the *base variable* of $\tilde{A}$. A *membership function* $\mu_{\tilde{A}i}$ defines linguistic value $\tilde{A}_i$ by determining the degree $\mu_{\tilde{A}i}(x)$ to which stocking density x is ‹acceptable›, $\mu_{\tilde{A}1}(x)$, or ‹unacceptable›, $\mu_{\tilde{A}2}(x)$, by assigning to each x a value $\mu_{\tilde{A}i}(x)$ between 0 and 1. In Figure 4.2, the degree $\mu_{\tilde{A}1}(x)$ to which stocking density x is ‹acceptable› decreases with increasing stocking density. Thus, if $\mu_{\tilde{A}1}(x) = 1$, then linguistic statement ‹stocking density is acceptable› is true; if $\mu_{\tilde{A}1}(x) = 0$, then linguistic statement ‹stocking density is acceptable› is not true; and if $0 < \mu_{\tilde{A}1}(x) < 1$, then $\mu_{\tilde{A}1}(x)$ defines the degree to which linguistic statement ‹stocking density is acceptable› is true. In Figure 4.2, $\tilde{A}_2$ is the standard fuzzy complement of $\tilde{A}_1$, so that $\mu_{\tilde{A}2}(x) = 1 - \mu_{\tilde{A}1}(x)$ (Klir and Yuan, 1995).

Table 4.1 illustrates linguistic variables in three practical examples. The example ‹sustainable development› is based on de Boer and Cornelissen (2002); the example ‹animal welfare› is based on the illustrative example used in this paper. The example ‹height of men› is a common illustration in the literature on fuzzy set theory (Türksen, 1991). The construction of $\mu_{\tilde{A}i}$, i.e. the interpretation of base variable x in terms of linguistic value $\tilde{A}_i$, is realized by eliciting expert knowledge.

Different methods are available to elicit expert knowledge for the construction of membership functions. Different methods are based on different assumptions regarding the way an expert determines the degree $\mu_{\tilde{A}i}(x)$ to which x has property $\tilde{A}_i$ (Giles, 1988). Four elicitation methods are presented. «Point estimation» (or polling), «interval estimation», and «direct rating» originate from the literature (Hersch and Caramazza, 1976; Norwich and Türksen, 1984; Chameau and Santamarina, 1987; Türksen, 1991; Kaymak, 1998; Krishnapuram, 1998); «transition interval estimation» is developed in this paper as an alternative to the other elicitation methods.

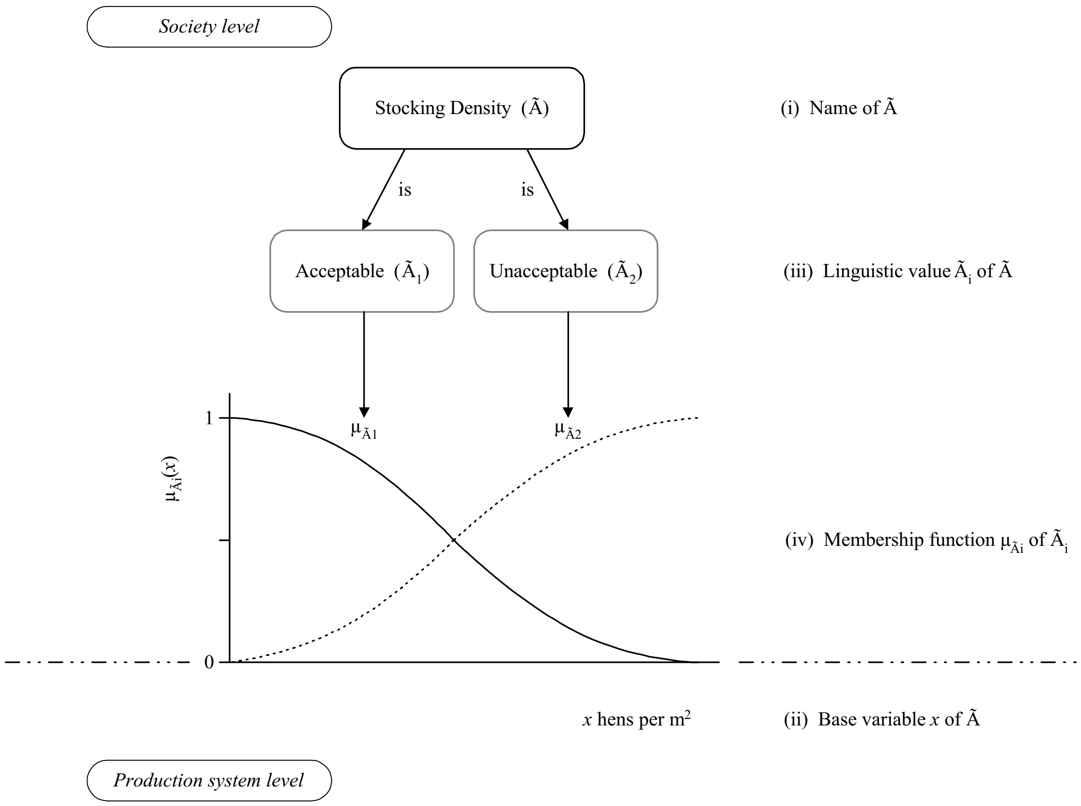

Figure 4.2: ***Essence of fuzzy modeling.*** At society level, linguistic variable Ã is characterized by (i) name of Ã, (iii) linguistic value $\tilde{A}_i$ of Ã, and (iv) membership function $\mu_{\tilde{A}i}$ of $\tilde{A}_i$. At production system level, Ã is characterized by (ii) base variable x of Ã (based on Zadeh, 1975a,b; Klir and Yuan, 1995).

For each elicitation method, the expert evaluation mode (i.e. the way an expert evaluates the degree to which x has property $\tilde{A}_i$), the way an overall assessment of $\mu_{\tilde{A}i}(x)$ is computed from individual expert assessments, the meaning of overall assessment $\mu_{\tilde{A}i}(x)$, the number of experts needed to obtain a proper MF, and the characteristics of the MF constructed are discussed and illustrated. Further, advantages and disadvantages of elicitation methods are considered and, on this basis, elicitation methods are compared in section 4.3.3 to support their practical application.

4.3.2.1 POINT ESTIMATION

In point estimation (PE), an expert p (p = 1…P) determines unambiguously whether each x does or does not have property $\tilde{A}_i$, i.e., an expert's response is crisp. Expert p, therefore, assesses if $\mu_{\tilde{A}i}(x)_p$ has value 1 or 0. An overall assessment $\mu_{\tilde{A}i}(x)$ is computed as

$$\mu_{\tilde{A}i}(x) = \frac{1}{P}\sum_{p=1}^{P}\mu_{\tilde{A}i}(x)_p \qquad [\ 4.1\ ]$$

where $\mu_{\tilde{A}i}(x) = 0.6$ means that 60% of P experts determine that x has property $\tilde{A}_i$. To obtain a proper MF, therefore, more than one expert is needed (Klir and Yuan, 1995). The MF constructed is characterized by data points $\mu_{\tilde{A}i}(x)$.

Recall from Figure 4.2 that stocking density is measured as x hens per m^2 and an expert evaluates stocking density in terms of ‹acceptable› ($\tilde{A}_1$) and ‹unacceptable› ($\tilde{A}_2$). In Figure 4.3A, expert p determines if stocking density x is ‹acceptable› ($\mu_{\tilde{A}1}(x)_p = 1$) or if stocking density x is ‹unacceptable› ($\mu_{\tilde{A}1}(x)_p = 0$). Expert p, therefore, determines an unambiguous distinction $x_{Tp} = 12$ hens per m^2 between acceptable stocking densities ($x \leq 12$ hens per m^2) and unacceptable stocking densities ($x > 12$ hens per m^2). An overall assessment $\mu_{\tilde{A}1}(x) = 0.6$ means that 60% of P experts determines that stocking density x is acceptable.

The main advantage of PE is the simple processing of elicited expert knowledge. Also, PE can be applied to nominal, discrete and continuous base variables. The main disadvantage of PE is the contradiction between the crispness of the expert response mode (i.e. x does or does not have property $\tilde{A}_i$) and the fuzziness inherent in human interpretation of information (i.e. x has property $\tilde{A}_i$ to a degree) (Zadeh, 1973). Also, experts need to evaluate a number of individual x within the relevant range U of the base variable. Therefore, if a large number of x needs to be evaluated, then practical application of PE can be laborious and time-consuming for an expert, and influence the reliability of expert evaluations (Nunnally, 1978; Chameau and Santamarina, 1987).

Table 4.1: ***Practical examples.*** Characteristics (i) through (iv) of a linguistic variable illustrated using examples regarding ‹sustainable development›, ‹animal welfare› and ‹height of men›.*

	Sustainable Development (de Boer and Cornelissen, 2002)	Animal Welfare (this study)	Height of Men (Türksen, 1991)
issues ∈ *public concern***	**economic, ecological and societal issues** ∈ *sustainable development* **secure farm continuity** ∈ *sustainable development of egg production systems*	**behavioral, physiological, health and production issues** ∈ *animal welfare* **possibility to move** ∈ *welfare of laying hens*	**man** ∈ *men*
context of *public concern*	**the Netherlands**	**the Netherlands**	**North America**
(i) linguistic variable $\tilde{\mathbf{A}}$	**labor profit**	**stocking density**	**height**
(ii) base variable $\boldsymbol{x}$ of $\tilde{\mathbf{A}}$ and its relevant range **U**	$\boldsymbol{x}$ **NLG** (× 1000) U = **[0, 100]**	$\boldsymbol{x}$ **hens per m**$^{\mathbf{2}}$ U = **[0, 30]**	$\boldsymbol{x}$ **meters** U = **[0, 2.20]**
(iii) linguistic value $\tilde{\mathbf{A}}_{\mathbf{i}}$ of $\tilde{A}$, i.e., property $\tilde{A}_i$ of x	**high**	**acceptable**	**tall**
(iv) membership function $\boldsymbol{\mu}_{\tilde{\mathbf{A}}\mathbf{i}}$ of $\tilde{\mathbf{A}}_{\mathbf{i}}$	• evaluation of labor profit of egg production systems by an expert who uses property **high** according to his/her understanding of the term within the context of labor profit of egg production systems in the Netherlands	• evaluation of stocking density of laying hens by an expert who uses property **acceptable** according to his/her understanding of the term within the context of stocking density of laying hens in egg production systems in the Netherlands	• evaluation of the height of a man by an expert who uses property **tall** according to his/her understanding of the term within the context of the height of a man in North America

* The example on ‹height of men› is an example often used in the literature to illustrate fuzzy set theory in general.
** The symbol ∈ denotes that multiple issues are ‹an element of› a public concern, i.e. that a public concern comprises multiple issues.

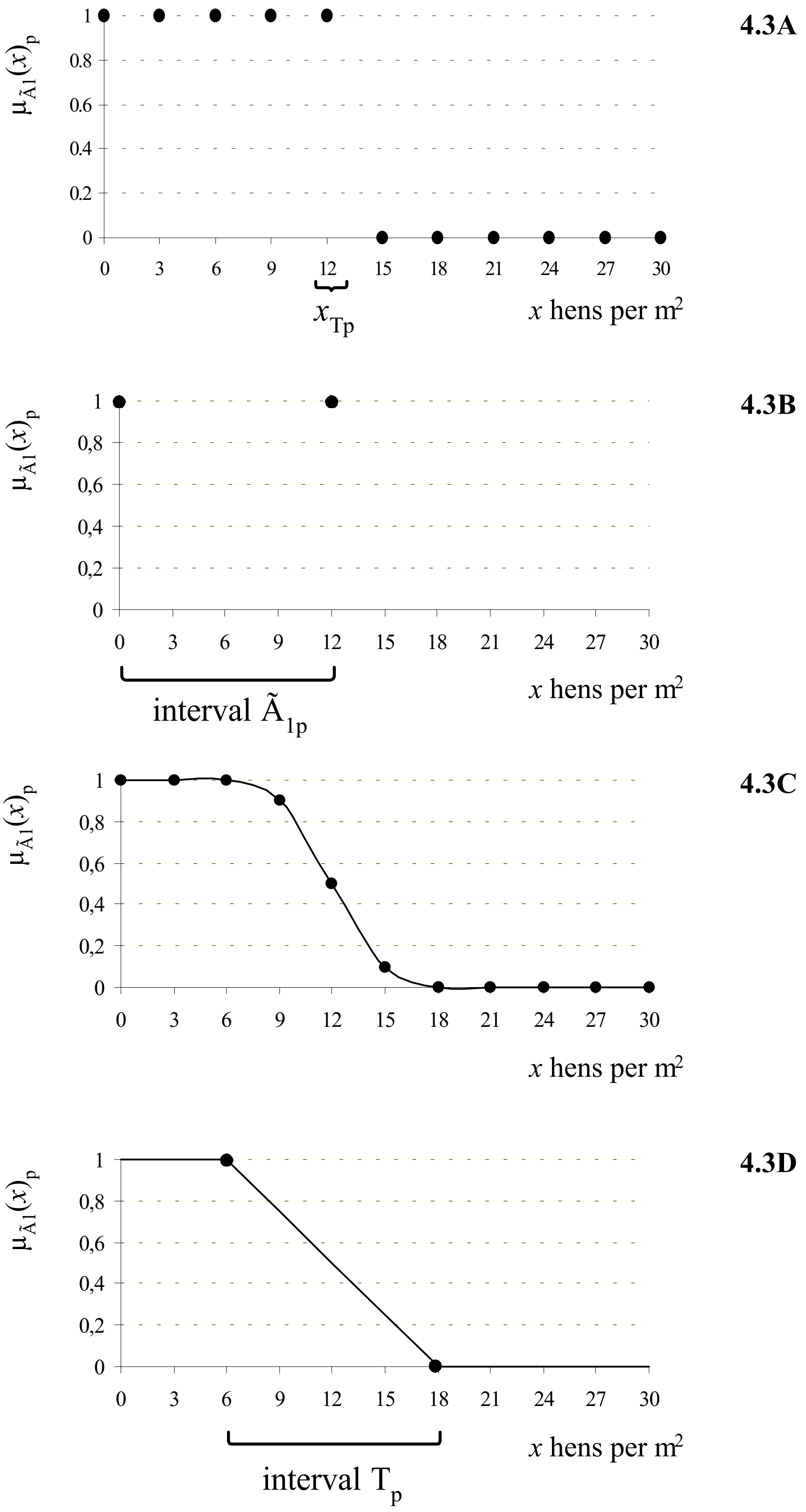

Figure 4.3: ***Elicitation methods.*** Four methods to elicit expert knowledge: point estimation (4.3A), interval estimation (4.3B), direct rating (4.3C), and transition interval estimation (4.3D). Expert p determines the degree $\mu_{\tilde{A}1}(x)$ to which base variable x (hens per m^2) is $\tilde{A}_1$ ‹Acceptable› by determining x_{Tp} (4.3A), by determining interval $\tilde{A}_{1p}$ (4.3B), by determining $\mu_{\tilde{A}1}(x)_p$ (4.3C), or by determining interval T_p (4.3D).

4.3.2.2 Interval Estimation

In interval estimation (IE), an expert p determines a sharply defined interval (over the relevant range U of the base variable) containing values of x for which property $\tilde{A}_i$ applies, i.e., an expert's response is crisp. Expert p, therefore, determines interval $\tilde{A}_{ip}$ on U for which $\mu_{\tilde{A}i}(x)_p$ has value 1. An overall assessment $\mu_{\tilde{A}i}(x)$ is computed using Equation 4.1 where $\mu_{\tilde{A}i}(x) = 0.6$ means that 60% of P experts determines that x is in the interval $\tilde{A}_i$. As in PE, more than one expert is needed to obtain a proper MF (Klir and Yuan, 1995). The MF constructed is characterized by data points $\mu_{\tilde{A}i}(x)$.

In Figure 4.3B, expert p determines an interval $\tilde{A}_{1p}$ that contains all stocking densities x which the expert considers ‹acceptable›. Expert p, thus, determines an unambiguous distinction $x_{Tp} = 12$ hens per m^2 between acceptable and unacceptable stocking densities as in PE. An overall assessment $\mu_{\tilde{A}1}(x) = 0.6$ means that 60% of P experts determines that stocking density x is acceptable.

The main advantage of IE is the simple processing of elicited knowledge. Also, by defining an interval over U practical application of IE is less laborious and time-consuming for an expert compared to evaluating individual x of U. As in PE, the main disadvantage of IE is the crispness of the response mode required from experts. Also, the range of application of IE is limited because the elicitation method cannot be applied to nominal base variables.

4.3.2.3 Direct Rating

In direct rating (DR), an expert p directly determines the degree $\mu_{\tilde{A}i}(x)$ to which each x has property $\tilde{A}_i$, i.e., fuzziness is allowed in an expert's response. Expert p, therefore, assigns to each x a value $\mu_{\tilde{A}i}(x)_p$ from the interval [0,1]. An overall assessment $\mu_{\tilde{A}i}(x)$ is computed using Equation 4.1 where $\mu_{\tilde{A}i}(x) = 0.6$ means that on average x resembles a typical value x_t, which truly has property $\tilde{A}_i$ (i.e. $\mu_{\tilde{A}i}(x_t) = 1$), to a degree of 0.6. One expert can be sufficient to obtain a proper MF (Klir and Yuan, 1995). The MF constructed is characterized by data points $\mu_{\tilde{A}i}(x)$.

In Figure 4.3C, expert p determines the degree to which stocking densities are ‹acceptable› by assigning a value from the interval [0,1] to stocking density x. For example, expert p evaluates $x = 9$ hens per m^2 as $\mu_{\tilde{A}1}(9)_p = 0.9$, i.e., expert p considers a stocking density of 9 hens per m^2 to be acceptable to a degree of 0.9. An overall assessment $\mu_{\tilde{A}1}(x) = 0.6$ means that, on average, P experts determine that stocking density x resembles a truly acceptable stocking density to a degree of 0.6.

The main advantage of DR is that it allows fuzziness in an expert's response mode, i.e., DR does not force experts to determine whether x does or does not have property $\tilde{A}_i$. Also, DR can be applied to nominal, discrete and continuous base variables. A disadvantage of DR, however, can be the low reproducibility of $\mu_{\tilde{A}i}(x)_p$ due to the assignment of precise numerical grades and because small differences in numerical values for $\mu_{\tilde{A}i}(x)_p$ may not seem to matter to an expert (Leung, 1981). As in PE, if a large number of x needs to be evaluated, then practical application of DR can be laborious and time-consuming for an expert, and influence the reliability of expert evaluations (Nunnally, 1978; Chameau and Santamarina, 1987).

4.3.2.4 Transition Interval Estimation

Table 4.2 summarizes expert evaluation modes and expert response modes regarding PE, IE and DR. In the literature, no distinct elicitation method was found that allowed the expert evaluation mode to use intervals rather than judging individual x of U and, at the same time, allowing an expert's response mode to be fuzzy rather than crisp. Based on a crude concept described in Macvicar-Whelan (1978), transition interval estimation (TIE) was developed to fill this gap.

Table 4.2: ***Expert assessment in relation to expert response mode.*** Elicitation methods* originating from the literature categorized based on expert assessment and expert response.

		expert response*** ***crisp***	 ***fuzzy***
expert assessment**	***individual x of U***	PE	DR
	interval on U	IE	…

* PE = point estimation; IE = interval estimation; DR = direct rating.
** Expert assessment can be done by judging individual x of U, or by defining an interval on U.
*** Expert response can be unambiguous, i.e., crisp, or allow fuzziness.

In TIE, expert p determines an interval (over the relevant range U of the base variable) containing values of x for which expert p can make no unambiguous distinction whether property $\tilde{A}_i$ does or does not apply, i.e., TIE allows a fuzzy response. Expert p, therefore, determines transition interval T_p on U bounded by $[x_{min-p}, x_{max-p}]$ for which $x_{min-p} < x < x_{max-p}$ and $0 < \mu_{\tilde{A}i}(x)_p < 1$. The minimum value and maximum value in itself, however, are not meaningful: they can be characterized by the center point of and the range between both values. An overall assessment $\mu_{\tilde{A}i}(x)$ in transition interval T, therefore, can be based on a linear transition characterized by center point x_{mp} and range d_p of T_p

$$x_m = \frac{1}{P}\sum_{p=1}^{P} x_{mp} \qquad [\ 4.2a\ ]$$

and

$$d = \frac{1}{P}\sum_{p=1}^{P} d_p \qquad \text{and } d_p = x_{max\text{-}p} - x_{min\text{-}p} \qquad [\ 4.2b\ ]$$

where x_m is the mean center point of T based on P assessments x_{mp} (Equation 4.2a), and d is the mean range of T based on P assessments d_p (Equation 4.2b). One expert, therefore, is sufficient to obtain a proper MF. Transition interval T is bounded by $[x_{min}, x_{max}]$ where x_{min} and x_{max} are defined as

$$x_{min} = x_m - \frac{d}{2} \qquad [\ 4.3a\ ]$$

and

$$x_{max} = x_m + \frac{d}{2} \qquad [\ 4.3b\ ]$$

Next, $\mu_{\tilde{A}i}(x)$ is computed as

$$\mu_{\tilde{A}i}(x) = \begin{cases} 0 \text{ or } 1 & \text{when } x < x_{min} \\ 0.5 \pm \dfrac{(x - x_m)}{d} & \text{when } x_{min} \le x \le x_{max} \\ 0 \text{ or } 1 & \text{when } x > x_{max} \end{cases} \qquad [\ 4.4\ ]$$

where $\mu_{\tilde{A}i}(x) = 0$ for $x < x_{min}$ and $\mu_{\tilde{A}i}(x) = 1$ for $x > x_{max}$ if the ±-sign is positive, i.e., $\mu_{\tilde{A}i}(x)$ is linearly increasing with increasing x. If the ±-sign is negative, then the assessment of $\mu_{\tilde{A}i}(x)$ in Equation 4.4 for $x < x_{min}$ and $x > x_{max}$ is reversed, i.e., $\mu_{\tilde{A}i}(x)$ is linearly decreasing with increasing x. As we consider this a first exploration in the possibilities of TIE, we have used the most elementary shape, i.e. a linear transition, to express the change in $\mu_{\tilde{A}i}(x)$ over transition interval T. The transition of $\mu_{\tilde{A}i}(x)$ over T, for example, also could be non-linear. The MF constructed is characterized by Equation 4.4. Additionally, on condition that only linear transitions are used in

Equation 4.4, parameter *d* can be interpreted as a measure of fuzziness to express the uncertainty among experts regarding the change-over between x is $\tilde{A}_i$ and x is not-$\tilde{A}_i$.

In Figure 4.3D, expert p determines transition interval T_p bounded by $x_{min\text{-}p} = 6$ hens per m^2 and $x_{max\text{-}p} = 18$ hens per m^2. Thus, expert p considers stocking densities smaller than 6 hens per m^2 to be acceptable, stocking densities greater than 18 hens per m^2 to be unacceptable, and stocking densities between 6 and 18 hens per m^2 to be intermediate between completely acceptable and completely unacceptable. An overall assessment $\mu_{\tilde{A}1}(x) = 0.6$ means that, on average, P experts determine that x is in the interval T, i.e. P experts cannot determine unambiguously that x is either $\tilde{A}_1$ or not $\tilde{A}_1$.

The main advantage of TIE is that experts do not have to determine precise numerical assignments $\mu_{\tilde{A}i}(x)$. Expert response mode can be fuzzy through defining an interval for which $0 < \mu_{\tilde{A}i}(x) < 1$ without precisely having to specify $\mu_{\tilde{A}i}(x)$. In addition, TIE is less laborious and time-consuming for an expert. A main disadvantage of TIE can be that the expert evaluation mode is less straightforward through the assignment of boundary values $x_{min\text{-}p}$ and $x_{max\text{-}p}$ of T_p compared to PE and IE. Also, the range of application of TIE is limited because the elicitation method cannot be applied to nominal base variables.

4.3.3 Comparison of Elicitation Methods

In Table 4.3, a qualitative comparison based on a practical application of elicitation methods is presented. The comparison considers (I) the range of application, (II) the ease of the response mode for experts, and (III) the ease of constructing and interpreting MFs.

Regarding (I), both PE and DR can be applied to nominal, discrete and continuous base variables, whereas both IE and TIE cannot be applied in case the base variable is nominal. Regarding (I), PE and DR in Table 4.3 are the most appropriate elicitation methods.

Regarding (II), the response mode of an expert in PE or IE is straightforward: the expert determines whether base variable x does or does not have property $\tilde{A}_i$. Both elicitation methods, however, do not allow fuzziness in the response mode of an expert and require a potentially difficult to define unambiguous threshold (Silvert, 1997). DR, in contrast, does allow fuzziness in an expert's response, but requires a potentially difficult to define precise numerical value (Leung, 1981). TIE provides a method that does allow fuzziness in expert response mode, and does not require a precise numerical evaluation as in DR. In contrast to PE and IE, however, the expert evaluation mode for TIE might be less straightforward. Regarding (II), TIE in Table 4.3 is the most appropriate elicitation method.

Table 4.3: ***Qualitative comparison of elicitation methods.*** Comparison of four methods* to elicit expert knowledge to support their practical application.

criteria	elicitation method**			
	PE	IE	DR	TIE
(1) range of application				
applicable to all types of base variables (nominal, discrete and continuous)	+	–	+	–
one expert is sufficient to obtain a proper MF	–	–	+	+
(2) ease of response mode for experts				
response mode is straightforward	+	+	–	–
response mode is consistent	+	+	–	+
response mode allows fuzziness	–	–	+	+
response mode is not time-consuming	–	+	–	+
(3) ease of constructing and interpreting MFs				
construction of MFs is uncomplicated	+	+	+	+
interpretation of MFs is straightforward	–	–	–	+

* Point estimation (PE), interval estimation (IE), direct rating (DR), and transition interval estimation (TIE).
** For (+) the method fulfills the criterion; for (–) the method does not fulfill the criterion.

Regarding (III), all four elicitation methods use rather uncomplicated procedures to construct MFs, i.e., Equations (4.1) through (4.4). MFs constructed from elicited knowledge applying PE, IE, and DR, however, are characterized only by data points $\mu_{\tilde{A}i}(x)$, whereas the MF constructed from elicited knowledge applying TIE provides an additional uncertainty measure d which defines the degree of fuzziness in expert evaluation. A similar numerical measure is available for results from PE, IE or DR only after characterizing available data points using, for example, logistic functions (cf. Brown and Rothery, 1993). Further, PE and IE need more than one expert to obtain a proper MF which can lead to problems if experts in a certain domain of knowledge are hard to find. Regarding (III), TIE in Table 4.3 is the most appropriate elicitation method.

Table 4.3 can be used in practical situations to support decisions regarding the choice of elicitation method to apply.

4.4 PROCEDURE TO ELICIT EXPERT KNOWLEDGE

A six-step procedure to elicit expert knowledge is developed based on criteria to select experts, and on the choice of a method to elicit expert knowledge.

Step 1 Domain of Knowledge:
define the domain(s) of knowledge represented in the issues and corresponding indicators selected.

Step 2 Candidate-Experts:
identify candidate-experts within each domain of knowledge: candidate-experts can originate from various parts of society, e.g., universities, extension services, farming communities, or pressure groups.

Step 3 Selection Criteria:
criteria are based on (I) a person's period of learning and experience in a specific domain of knowledge, and (II) the specific circumstances in which experience is gained.

Step 4 Selection of Experts:
criteria can be assessed by the person who is a candidate-expert, and by his or her peers.

Step 5 Elicitation Method:
determine the elicitation method(s) to be applied considering (I) the range of application, (II) the ease of the response mode for experts, and (III) the ease of constructing and interpreting MFs.

Step 6 Knowledge Elicitation:
prepare written questionnaires or oral interviews to elicit expert knowledge.

A body of literature is available to properly prepare and apply Step 6 in the procedure (e.g. Welbank, 1983). An in-depth study of step 6, however, is beyond the objectives of this paper.

4.5 ILLUSTRATIVE EXAMPLE

4.5.1 APPLYING THE SIX-STEP PROCEDURE

4.5.1.1 SELECTION OF EXPERTS

An increasing number of Dutch consumers objects to battery housing systems that interfere with the natural behavior of laying hens (de Jong and Goewie, 2000). Battery housing systems, for example, provide less possibilities for hens to move freely compared to animal-friendly housing systems like aviary systems or deep-litter systems. Providing a possibility for hens to move, therefore, is considered an important issue in relation to welfare (Appleby and Hughes, 1991; Blokhuis and Metz, 1992; Bokkers, 1995a). Two animal welfare indicators which determine a hens possibility to move have been selected in this illustrative example (Bokkers, 1995b): stocking density (AWI_1) and presence of perches (AWI_2). Table 4.4 defines characteristics of selected linguistic variables. The domain of knowledge, therefore, is the welfare of laying hens in Dutch egg production systems and, specifically, the influence of stocking density and presence of perches on a hen's possibility to move (Step 1).

Eighteen candidate-experts were identified with the assistance of an ethologist of Wageningen University. The group of candidate-experts consisted of animal scientists, ethologists and researchers at experimental farms employed at Wageningen University and Research Center, and professionals from two societal institutions: the Dutch Society for the Protection of Animals and the Agricultural Extension Service (Step 2).

Selection criteria used were the number of projects a person was involved in regarding the domain of knowledge defined, a person's involvement in public debate, and the length of time of a person's experience in the domain of knowledge. Because of widely varying points of view within the domain of knowledge, a heterogenous group of experts was preferred (Step 3). After being approached to participate in this study, five candidate-experts declined participation because they were no longer working and, therefore, were no longer up-to-date in the domain of knowledge. Finally, 13 experts contributed to this study (Step 4).

Table 4.4: ***Characteristics of selected linguistic variables.*** Two animal welfare indicators (AWI_1 and AWI_2) which influence a hens possibility to move: selected linguistic variables and corresponding characteristics.

Indicator	Linguistic Variable	Linguistic Values ($\tilde{A}_i$)	Base Variable	Type of Base Variable	Relevant Range of Base Variable
AWI_1	stocking density	acceptable ($\tilde{A}_1$) unacceptable ($\tilde{A}_2$)	hens per m^2	continuous	[0, 30]
AWI_2	presence of perches	acceptable ($\tilde{A}_1$) unacceptable ($\tilde{A}_2$)	level 1: present level 2: not present	nominal	–

4.5.1.2 Elicitation of Expert Knowledge

Regarding Step 5, transition interval estimation was applied for AWI_1, whose base variable is continuous. Results obtained from TIE are used to also illustrate PE and IE. To illustrate PE, center point x_{mp} in TIE is considered to be equal to x_{Tp} in PE (Figure 4.3). To illustrate IE, the interval $[0, x_{mp}]$ on U is considered to be equal to the interval $\tilde{A}_{1p}$ on U in IE (Figure 4.3).

Direct rating was applied for AWI_2, whose base variable is nominal. DR, however, was modified (DR_{mod}) to further align the expert response mode with TIE. Rather than defining a precise numerical assignment $\mu_{\tilde{A}1}(x)$, experts in DR_{mod} defined an interval on [0,1], i.e., a μ-interval bounded by $[\mu_{min\text{-}p}, \mu_{max\text{-}p}]$ in which x has property $\tilde{A}_1$ to a degree $\mu_{\tilde{A}1}(x)$ and $\mu_{min\text{-}p} \leq \mu_{\tilde{A}1}(x)_p \leq \mu_{max\text{-}p}$. Next, $\mu_{\tilde{A}i}(x)_p$ is defined as the center point of the μ-interval.

Experts contributed by way of written questionnaires which consisted of an introduction to this study, an example illustrating the evaluation mode and the response mode required, and the actual evaluation of AWI_1 and AWI_2 (Step 6).

4.5.2 Results

Table 4.5 and Figure 4.4 show results of applying TIE for AWI_1. The resulting MFs $\mu_{\tilde{A}1}$ and $\mu_{\tilde{A}2}$ which define linguistic values ‹Acceptable› ($\tilde{A}_1$) and ‹Unacceptable› ($\tilde{A}_2$) are

$$\mu_{\tilde{A}1} \begin{cases} 1 \\ 0.5 - \dfrac{(x - 8.9)}{5.4} \\ 0 \end{cases} \qquad \mu_{\tilde{A}2} \begin{cases} 0 & x < 6.2 \\ 0.5 + \dfrac{(x - 8.9)}{5.4} & 6.2 \leq x \leq 11.6 \\ 1 & x > 11.6 \end{cases} \qquad [\,4.5\,]$$

where $\tilde{A}_2$ is the standard fuzzy complement of $\tilde{A}_1$ (Klir and Yuan, 1995). Experts, therefore, consider stocking densities to change from acceptable to unacceptable at approximately 9 hens per m^2 regarding a hen's possibility to move.

Table 4.5: ***Expert elicitation results (I).*** Results of applying transition interval estimation for AWI_1 (Stocking Density).

expert p	transition interval T_p*			
	$x_{min\text{-}p}$	$x_{max\text{-}p}$	x_{mp}**	d_p**
1	3	8	5.5	5
2	7	17	12	10
3	1	4	2.5	3
4	2	8	5	6
5	6	12	9	6
6	6	12	9	6
7	2	4	3	2
8	5	8	6.5	3
9	6	9	7.5	3
10	10	14	12	4
11	7	10	8.5	3
12	6	20	13	14
13	20	25	22.5	5
			$\boldsymbol{x_m}$	***d***
			8.9 (sd*** 5.3)	**5.4** (sd*** 3.3)

* Expert p (p = 1…P, P = 13) determines transition interval T_p bounded by $x_{min\text{-}p}$ and $x_{max\text{-}p}$ between acceptable and unacceptabel stocking densities over a relevant range of [0, 30] hens per m^2.
** Mean centre point x_m and mean range d to construct MF are computed on the basis of P assessments x_{mp} and d_p.
*** sd = standard deviation

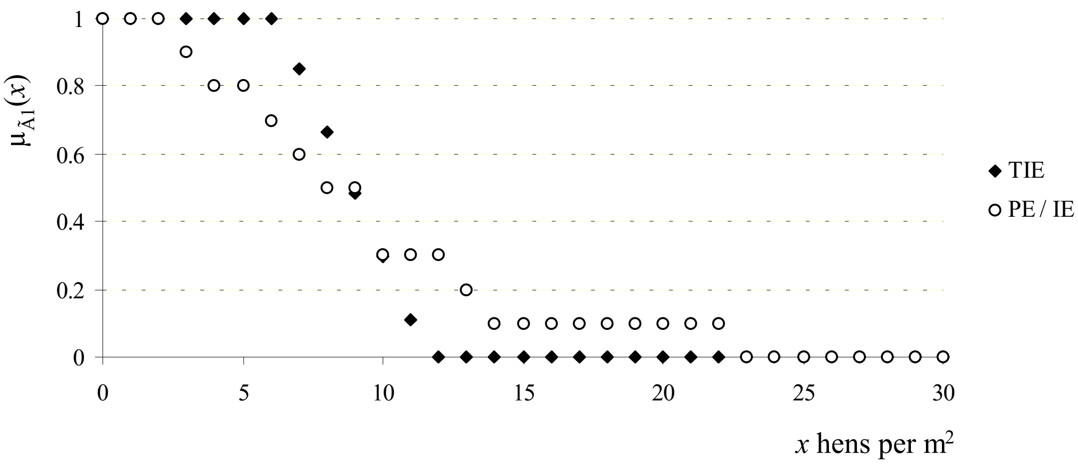

Figure 4.4: ***Membership functions (I).*** Membership function $\mu_{\tilde{A}1}$ constructed for AWI_1 (Stocking Density) using transition interval estimation (TIE), and point estimation/interval estimation (PE/IE).

Table 4.6 shows practical results when implementing Step 2 of Phase 4 in the evaluation framework of Figure 4.1. Based on MF $\mu_{\tilde{A}1}$ in Equation 4.5, minimum standards - according to European Union legislation – concerning stocking densities in different egg production systems are examined for their degree of truth $\mu_{\tilde{A}1}(x)_{TIE}$ regarding the linguistic statement ‹Stocking Density is Acceptable›. Experts consider biological egg production systems to provide the most acceptable stocking densities in relation to a hen's possibility to move ($\mu_{\tilde{A}1}(x)_{TIE}$ = 0.9), they are inconclusive where the acceptability of stocking densities for deep-litter and aviary systems is concerned ($\mu_{\tilde{A}1}(x)_{TIE}$ = 0.5), but they consider stocking densities in systems with enriched cages and battery cages as completely unacceptable ($\mu_{\tilde{A}1}(x)_{TIE}$ = 0).

Table 4.6: ***Expert evaluation of stocking density.*** Minimum standards for stocking densities in different egg production systems according to European Union legislation, and expert evaluation of their acceptability $\tilde{A}_1$ applying transition interval estimation ($\mu_{\tilde{A}1}(x)_{TIE}$).

egg production system	**stocking density** (x hens per m^2)	$\mu_{\tilde{A}1}(x)_{TIE}$
biological	6	0.9
deep-litter	9	0.5
aviary	9	0.5
enriched cage	13	0
battery cage	18	0

Table 4.7 and Figure 4.4 show results for both PE and IE, based on the set of data in Table 4.5 obtained from applying TIE. In Figure 4.4, the MF from TIE shows a smaller degree of fuzziness compared to the MF from PE/IE, because of lower sensitivity of TIE to outliers (i.e. the response of expert 13 in Table 4.5). Considering that both MFs are based on the same set of data, the difference seems to be systematic (cf. Santamarina and Chameau, 1987).

Table 4.8 and Figure 4.5 show the results of applying DR_{mod} for AWI_2. One expert did not respond, and one expert did not correctly respond to the questionnaire regarding AWI_2, so P = 11. The degree $\mu_{\tilde{A}1}(x)$ to which level 1 (perches present) is ‹Acceptable› is 0.9; the degree $\mu_{\tilde{A}1}(x)$ to which level 2 (perches not present) is ‹Acceptable› is 0.2. Experts, therefore, consider the presence of perches an important contribution to a hen's possibility to move.

Table 4.7: ***Expert elicitation results (II).*** Results of both point estimation and interval estimation for AWI_1 (Stocking Density) over a relevant range of [0, 30] hens per m^2.

x	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14…22	23…30
$\Sigma(\mu_{\tilde{A}1}(x)_p = 1)$	13	13	13	12	11	11	9	8	7	6	4	4	4	2	1	0
$\mu_{\tilde{A}1}(x)$	1	1	1	0.9	0.8	0.8	0.7	0.6	0.5	0.5	0.3	0.3	0.3	0.2	0.1	0

Note: results are derived from applying transition interval estimation assuming $x_{mp} = x_{Tp}$ for point estimation, and assuming interval $[0, x_{Tp}]$ = interval $\tilde{A}_{1p}$ for interval estimation.

Table 4.8: ***Expert elicitation results (III).*** Results of applying modified direct rating for AWI_2 (Presence of Perches) which has two levels: perches present (level 1) and perches not present (level 2).

	μ_p-interval for level 1 (perches present)*			
expert p	μ_{min-p}	μ_{max-p}	range	$\mu_{\tilde{A}1}$(level 1)$_p$
1	0.8	1	0.2	0.9
2	0.5	0.8	0.3	0.7
3	1	1	0	1
4	0.8	1	0.2	0.9
5	0.6	0.9	0.3	0.8
6	1	1	0	1
7	0.9	1	0.1	1
8	0.8	1	0.2	0.9
9	0.7	0.9	0.2	0.8
10	0.75	1	0.25	0.9
11	1	1	0	1
		mean range	0.2 (sd** 0.1)	
		$\mu_{\tilde{A}1}$(level 1)		**0.9** (sd** 0.1)

	μ_p-interval for level 2 (perches not present)*			
expert p	μ_{min-p}	μ_{max-p}	range	$\mu_{\tilde{A}1}$(level 2)$_p$
1	0	0.2	0.2	0.1
2	0.1	0.4	0.3	0.25
3	0	0	0	0
4	0	0.2	0.2	0.1
5	0.1	0.6	0.5	0.35
6	0.5	1	0.5	0.75
7	0	0.1	0.1	0.05
8	0.2	0.4	0.2	0.3
9	0.1	0.3	0.2	0.2
10	0.25	0.5	0.25	0.38
11	0	0.5	0.5	0.25
		mean range	0.3 (sd** 0.2)	
		$\mu_{\tilde{A}1}$(level 2)		**0.2** (sd** 0.2)

* Expert p (p = 1…P, P = 11) defines the μ_p-interval bounded by μ_{min-p} and μ_{max-p} on a scale of 0 to 1 which determines the degree to which levels of AWI_2 are acceptable ($\tilde{A}_1$).
** sd = standard deviation

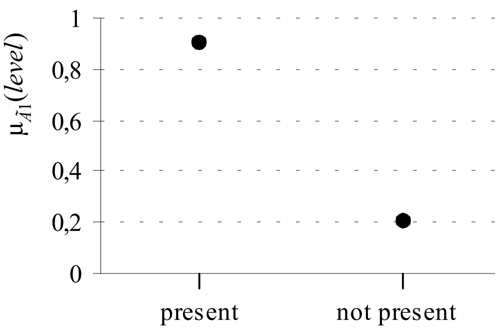

Figure 4.5: ***Membership functions (II).*** Membership function $\mu_{\tilde{A}1}$ constructed for AWI_2 (Presence of Perches) using modified direct rating.

4.6 DISCUSSION

Fuzzy models promise to be a valuable tool in evaluating the development of agricultural production systems, as such development nowadays is directed by public concern about the impact of current agricultural practices. Membership functions (MFs) are at the core of such fuzzy models. The objective of this study was to outline a procedure which dealt with criticism regarding the inherent subjectivity in the construction of MFs when using expert knowledge. We suggested that such a procedure should consider (i) selection of appropriate expert knowledge, and (ii) selection of methods to elicit expert knowledge and construct MFs.

4.6.1 SELECTION OF EXPERT KNOWLEDGE

The criteria defined in this study to determine whether a person qualifies as an expert are expressed in qualitative terms. Qualitative criteria increase the transparency in selecting experts and, at least, prevent ad hoc choices. It is, however, possible to quantify such criteria (Ram and Ram, 1996) using rating scales as described by Nunnally (1978). The procedure to elicit expert knowledge, however, already is a time-consuming activity. To fully quantify Steps 3 and 4 in order to establish a person's degree of expert knowledge will occupy more of an expert's time and might well diminish an expert's willingness to participate (Welbank, 1983). If, however, a quantitative degree of expert knowledge for experts is determined, then Equations 4.1, 4.2a and 4.2b can be further adapted to include weighting of the contribution of individual experts based on their degree of expert knowledge.

Considering public recognition of final evaluation results, credibility can play an important role in selecting experts. Experts reflect trustworthiness because they act both in the public interest and with regard to actual technical standards and practice (Kontic, 2000). In Figure 4.1B, experts typically have to empathize with situations at both society and production system level. Although farmers have considerable practical experience regarding the daily care of their animals, it remains to be seen whether farmers are qualified to actually judge the welfare of their animals. Credibility of evaluation in the eyes of the public or the authorities, however, may well increase when farmers are included as experts (Kontic, 2000). Nevertheless, farmers if not included as experts can still play an important role as a stakeholder in the evaluation framework presented in this paper.

4.6.2 Selection of Elicitation Methods

Qualitative comparison regarding practical application of four elicitation methods showed that the appropriateness of an elicitation method and, therefore, the choice of an elicitation method depends on the starting point for comparison: (1) the range of application, (2) the ease of the response mode for experts, or (3) the ease of constructing and interpreting MFs. Regarding (1), using PE and DR are appropriate methods. Regarding (2) and (3), TIE is an appropriate method. The actual choice, therefore, can depend on practical aspects like the type of base variables providing the input for the fuzzy model. Also, the choice to use just one elicitation method can be a rational one, thus requiring only a single response mode from the experts for all base variables involved. According to Nunnally (1978) a single response mode can increase the reliability of expert assessments. The choice for applying just one elicitation method can also be preferred considering that different elicitation methods result in different MFs for the same base variable, an effect that can be systematic (Santamarina and Chameau, 1987).

Results of the illustrative example show that experts are able to assess a measurable indicator in linguistic terms, which information can be used to construct MFs as shown in Figure 4.4 and Figure 4.5. The procedure could be further improved by using the supplementary information provided by standard deviations in Table 4.5, and mean ranges and standard deviations in Table 4.8, to allow an expression of the uncertainty regarding the reliability of a particular MF. This uncertainty can be expressed through computing type-2 fuzzy sets (Klir and Yuan, 1995). However, these authors also state that computational demands in defining type-2 fuzzy sets generally outweigh the advantage of including the supplementary information.

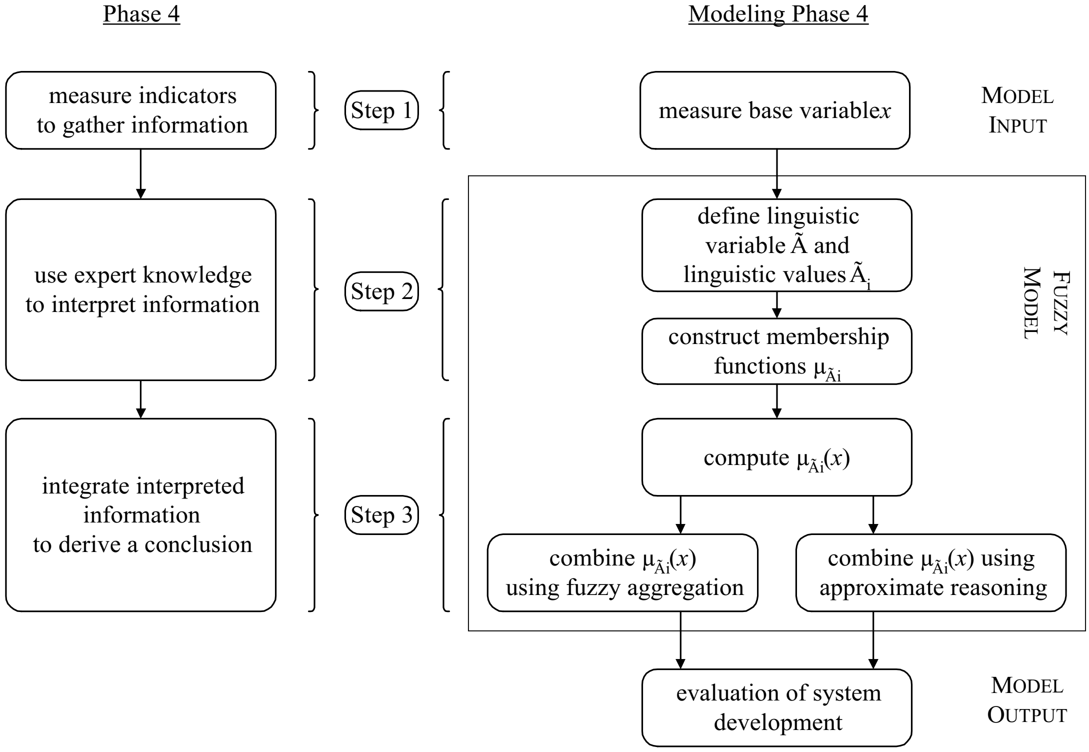

Figure 4.6: ***Fuzzy models to evaluate development of agricultural production systems***. Operationalization of Steps 1 through 3 of Phase 4 in a fuzzy model (Cornelissen et al., 2001).

4.6.3 APPLICATION OF MEMBERSHIP FUNCTIONS IN FUZZY MODELS

Cornelissen et al. (2001) developed two fuzzy models to evaluate development of agricultural production systems. In Figure 4.6, the results of Step 2 in Phase 4, i.e. the emphasis of the study in this paper, are integrated in Step 3 using fuzzy aggregation or approximate reasoning to derive a conclusion about the problem at hand.

Integrating of all interpreted information provided by different indicators will enable a more accurate conclusion. In Table 4.6, for example, experts were inconclusive where the acceptability of stocking density in relation to a hen's possibility to move in deep-litter and aviary systems was concerned. Integrating the results on stocking density with additional results about the contribution of the presence of perches to a hen's possibility to move will provide a more complete understanding.

4.7 CONCLUSION

Public concern nowadays is an important frame of reference for the development of agricultural production systems. Fuzzy models promise to be a valuable tool in evaluating such development, if a suitable response to criticism regarding the inherent subjectivity in the construction of membership functions is outlined. Also on the basis of the results in the illustrative example, the procedure outlined in this study suitably deals with such inherent subjectivity and enables practical implementation of a fuzzy evaluation of agricultural production systems. Current research implements the procedure to build a fuzzy model which evaluates egg production systems in relation to public concern about the welfare of laying hens.

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CHAPTER 5

FUZZY EVALUATION OF EGG PRODUCTION SYSTEMS FOR A LAYING HEN'S POSSIBILITY TO MOVE

This paper has been submitted.
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5.1 INTRODUCTION

Public concern about, for example, food security and food safety, environmental degradation, and human and animal welfare nowadays is an important frame of reference for the development of animal production systems (Kunkel, 2000). Public concern for the welfare of laying hens, for example, has initiated development of animal-friendly egg production systems (EPS) as an alternative to conventional battery cage systems (Blokhuis and Metz, 1992; de Jonge and Goewie, 2000). Development of EPS, therefore, involves two system levels (Figure 5.1). At society level, public concern is a perception of the impact of present production practices on animal welfare, whereas at production system level public concern finds a response in corrective measures to production practices. Thus, evaluation of EPS for their contribution to animal welfare is needed to inform society and to dispel public concern (cf. Bracke et al., 1999; de Jonge and Goewie, 2000).

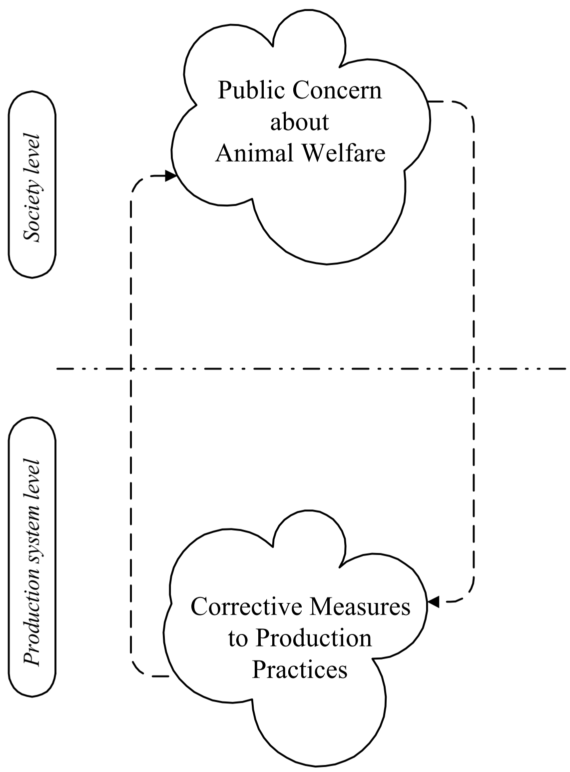

Figure 5.1: ***Two system levels.*** Development of egg production systems involves two system levels. At society level, public concern is a perception of the impact of production practices on animal welfare. At production system level, corrective measures to production practices aim to dispel public concern.

Evaluation is a reasoning process based on appropriate information to determine the welfare of animals in a particular EPS, and to derive a conclusion about the contribution of a particular EPS to animal welfare (cf. Fournier, 1995). Animal welfare complicates such an evaluation in two ways. At production system level, animal welfare is the *complex* resultant of an animal's behavior, physiology, health and production (e.g., Fraser, 1995). In the literature, a large number of variables have been suggested as relevant indicators of animal welfare at production system level (e.g., Duncan and Dawkins, 1983; Appleby and Hughes, 1991; Blokhuis and Metz, 1992; Striezel, 1994; Broom, 1997). A large number of indicators, however, typically results in a myriad of data where society asks for concise and comprehensible evaluation of animal welfare (de Jonge and Goewie, 2000). Policy makers and the general public can hardly be expected to take a decision or to form an opinion about animal welfare on the basis of a diffuse collection of data (Bracke, 2001). A model to evaluate animal welfare, therefore, must interpret and integrate information to derive a concise and comprehensible conclusion.

At society level, animal welfare is a *normative* concept: interpretation and integration of information inherently involves value judgments. A model to evaluate animal welfare must make such value judgments explicit (Sandøe and Simonsen, 1992; Fraser, 1995). Value judgments generally are expressed in linguistic terms: e.g., Fraser and Broom (1990) perceive animal welfare to be on a continuum from ‹very poor› to ‹very good›. So, if a particular animal welfare indicator is measured at production system level as ‹stocking density is x hens per m^2›, then this information can be interpreted at society level as, for example, ‹stocking density is low›. A model to evaluate animal welfare, therefore, can make value judgments explicit by using linguistic terms. The uncertainty involved in the linguistic statement ‹stocking density is low› can be expressed by the degree to which different people perceive ‹x hens per m^2› to be ‹low› in a specific context (cf. Ruspini et al., 1998). This type of uncertainty was formalized by Zadeh in his theory of fuzzy sets (Zadeh, 1965). Fuzzy set theory, therefore, offers a mathematical framework for developing a fuzzy model to evaluate animal welfare (cf. Cornelissen et al., 2001).

A laying hen's possibility to move (PM) is an important characteristic of the welfare of a laying hen, next to a hen's possibility to forage, to rest, and to nest, a hen's possibility for social and explorative behavior, and a hen's health (Bokkers, 1995b). The objective of this study is to develop and validate a fuzzy model to evaluate a laying hen's possibility to move. Development and validation of the fuzzy model is supported by evaluating the contribution of conventional and animal-friendly EPS to PM. To provide the reader with adequate background, first the basics of fuzzy modeling are presented in the next section. Next, the actual scheme of fuzzy modeling is introduced and its results are discussed.

5.2 MATERIALS AND METHODS

5.2.1 BASICS OF FUZZY MODELING

5.2.1.1 LINGUISTIC VARIABLES

Fuzzy models are based on the theory of fuzzy sets (Zadeh, 1965) and use linguistic variables to interpret and integrate information obtained by measuring indicators (Zadeh, 1975a,b). In Figure 5.2, a linguistic variable $\tilde{A}_i$ (i = 1,..,n) is characterized by: (1) *name* of $\tilde{A}_i$, (2) *base variable* x_i of $\tilde{A}_i$, (3) *linguistic value* $\tilde{A}_{ij}$ of $\tilde{A}_i$ (j = 1,..,m), and (4) *membership function* μ_{ij} of $\tilde{A}_{ij}$ (adapted from Zadeh, 1975a,b; Klir and Yuan, 1995). If ‹stocking density› is the *name* of $\tilde{A}_1$, then ‹low› ($\tilde{A}_{11}$), ‹moderate› ($\tilde{A}_{12}$), and ‹high› ($\tilde{A}_{13}$) are *linguistic values* $\tilde{A}_{1j}$ of $\tilde{A}_1$ (m = 3). Animal welfare indicator ‹stocking density› (AWI_1), for example, is measured as x_1 hens per m^2 which is the *base variable* x_1 of $\tilde{A}_1$. A *membership function* μ_{1j} defines linguistic value $\tilde{A}_{1j}$ by determining the degree $\mu_{1j}(x_1)$ to which stocking density x_1 is ‹low›, $\mu_{11}(x_1)$, ‹moderate›, $\mu_{12}(x_1)$, or ‹high›, $\mu_{13}(x_1)$, by assigning to each x_1 a value $\mu_{1j}(x_1)$ between 0 and 1. In Figure 5.2, the degree $\mu_{11}(x_1)$ to which stocking density x_1 is considered ‹low› decreases with increasing stocking density. Thus, if $\mu_{11}(x_1) = 1$, then linguistic statement ‹stocking density is low› is true; if $\mu_{11}(x_1) = 0$, then linguistic statement ‹stocking density is low› is not true; and if $0 < \mu_{11}(x_1) < 1$, then $\mu_{11}(x_1)$ defines the *degree* to which linguistic statement ‹stocking density is low› is true (cf. Klir and Yuan, 1995).

5.2.1.2 FUZZY RULE BASE

A fuzzy model to evaluate animal welfare can use approximate reasoning to integrate information obtained from measuring AWI (Cornelissen et al., 2001). Approximate reasoning is based on a series of q fuzzy rules R_p (p = 1,..,q) that together is referred to as the model's fuzzy rule base (FRB). R_p makes normative reasoning explicit by way of linguistic IF-THEN propositions. A proposition contains a premise, the IF-part, and a conclusion, the THEN-part (Boixader and Godo, 1998). In this study, a premise contains multiple linguistic statements ‹$\tilde{A}_i$ is $\tilde{A}_{ij}$› that are combined using the logical connective ‹AND›; and a conclusion contains a single linguistic statement ‹Õ is $\tilde{O}_c$› (c = 1,..,d).

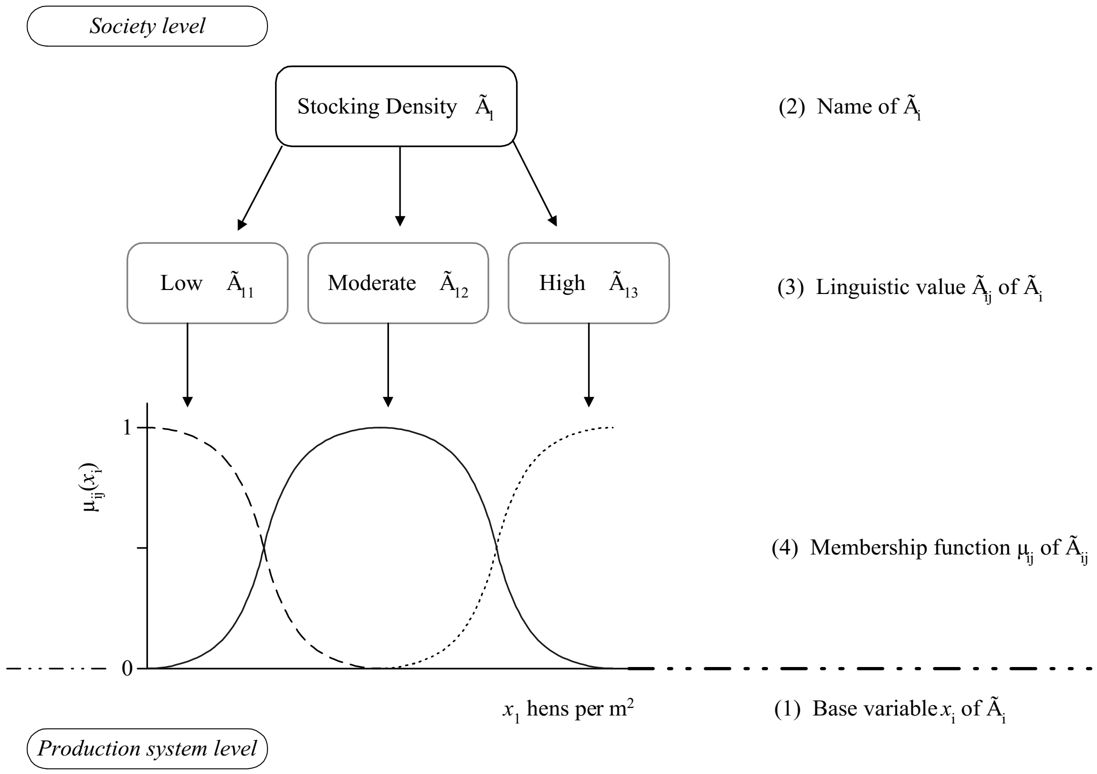

Figure 5.2: ***Linguistic variables.*** Use of a linguistic variable $\tilde{A}_i$ to interpret information at society level obtained by measuring indicators at production system level.

For example, if information obtained from two AWI is combined to derive a conclusion about a laying hen's possibility to move, then R_p reads as follows:

[R_p] IF ‹$\tilde{A}_1$ is $\tilde{A}_{1j}$› AND ‹$\tilde{A}_2$ is $\tilde{A}_{2j}$› THEN ‹Õ is $\tilde{O}_c$›.

If $\tilde{A}_1$ is the linguistic variable ‹stocking density›, and $\tilde{A}_{1j}$ its linguistic value ‹low›; if $\tilde{A}_2$ is the linguistic variable ‹use of outlet›, and $\tilde{A}_{2j}$ its linguistic value ‹good›; and if Õ is the linguistic variable ‹possibility to move›, and $\tilde{O}_c$ its linguistic value ‹good›; then a specific R_p reads:

[R_p] IF ‹stocking density is low› AND ‹use of outlet is good›
THEN ‹possibility to move is good›.

An essential characteristic of a fuzzy rule is, that the truth of its conclusion - and, therefore, the truth of R_p - is graded. The degree of truth $\mu_{\tilde{O}c,p}$ of conclusion ‹Õ is $\tilde{O}_c$› in R_p is defined by the degree $\mu_{ij}(x_i)$ to which linguistic statements ‹$\tilde{A}_i$ is $\tilde{A}_{ij}$› in the premise of R_p are true. A fuzzy implication operator defines how single $\mu_{ij}(x_i)$ in the premise of R_p are combined to infer $\mu_{\tilde{O}c,p}$. For example, if the logical connective ‹AND› defines the minimum-operator, and if $\mu_{1j}(x_1) = 0.2$ and $\mu_{2j}(x_2) = 0.7$, then $\mu_{\tilde{O}c,p}$ is inferred as $\mu_{\tilde{O}c,p} = min(0.2, 0.7) = 0.2$.

Next, if the logical connective ‹ELSE› combines fuzzy rules R_p in FRB, then an overall conclusion $\mu_{\tilde{O}c}$ can be inferred using the maximum-operator (Yager, 1994). For example, if q = 2, and if $\mu_{\tilde{O}c,1} = 0.2$ and $\mu_{\tilde{O}c,2} = 0.9$, then $\mu_{\tilde{O}c}$ is inferred as $\mu_{\tilde{O}c} = max(0.2, 0.9) = 0.9$ (cf. Cornelissen et al., 2001).

5.2.2 Scheme of Fuzzy Modeling

5.2.2.1 Notation

Input for the fuzzy model to evaluate a laying hen's possibility to move are n animal welfare indicators AWI_i (i = 1,..,n) and related base variables x_i, where x_i denote actual measurements of AWI_i. Associated with each AWI_i is linguistic variable $\tilde{A}_i$ and membership function μ_{ij} which defines linguistic value $\tilde{A}_{ij}$ (j = 1,..,m) by mapping x_i into the interval [0, 1]. Associating x_i with μ_{ij} results in n degrees of membership $\mu_{ij}(x_i)$ for each alternative EPS that is evaluated. An evaluative conclusion regarding PM is associated with linguistic variable Õ and linguistic values $\tilde{O}_c$ (c = 1,..,d). To integrate information obtained from measuring AWI_i, single linguistic statements ‹$\tilde{A}_i$ is $\tilde{A}_{ij}$› are combined in q fuzzy rules R_p (p = 1,..,q) to derive fuzzy conclusion ‹Õ is $\tilde{O}_c$›.

5.2.2.2 Scheme

Fuzzy modeling involves six steps (Figure 5.3). Step 1 defines relevant AWI_i and corresponding base variables x_i, i.e., model input. Step 2 defines linguistic variables $\tilde{A}_i$ and Õ, and linguistic values $\tilde{A}_{ij}$ and $\tilde{O}_c$, i.e., linguistic terms in which measurements of AWI_i are interpreted and conclusions with respect to PM are

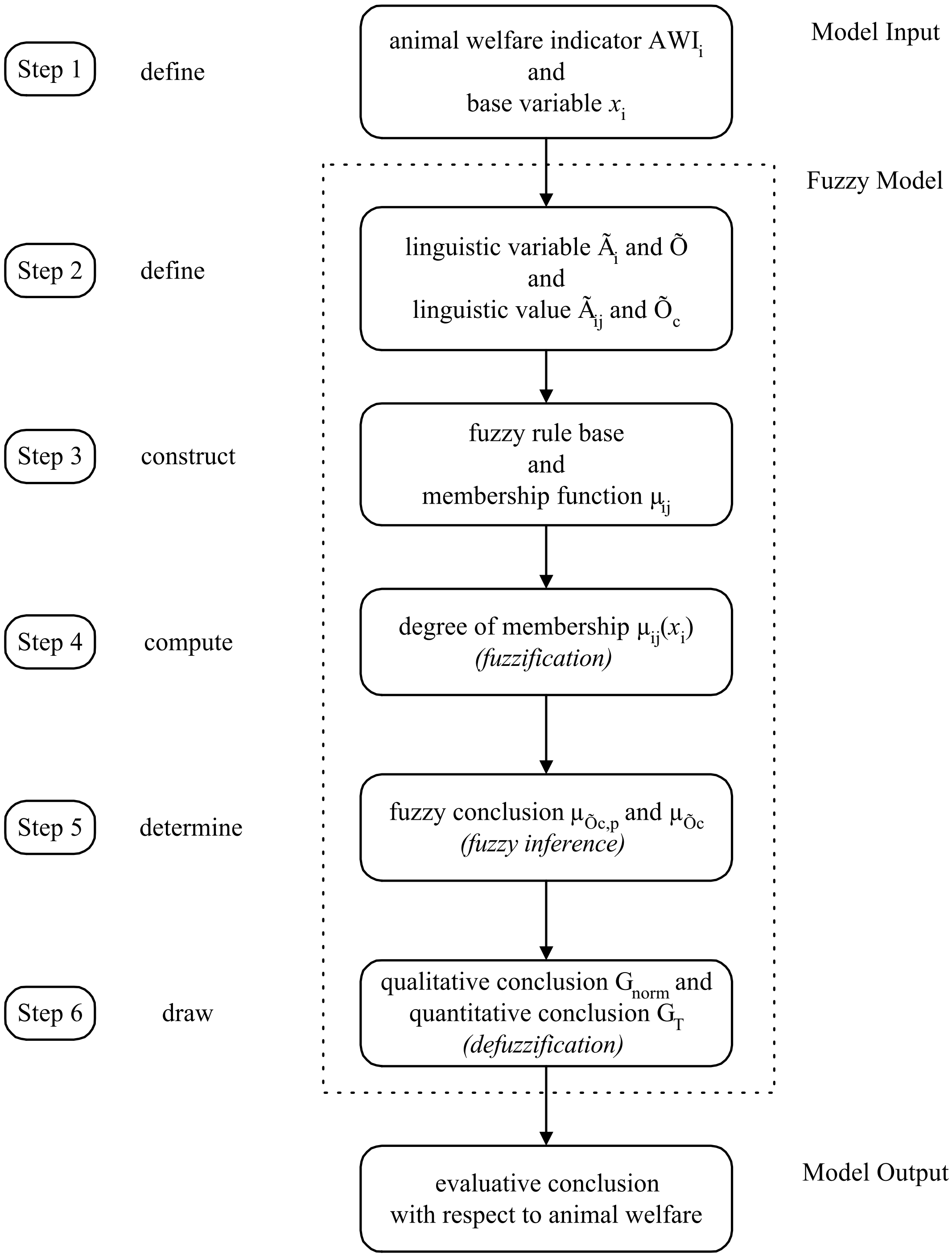

Figure 5.3: ***Six steps of fuzzy modeling.*** Scheme of fuzzy modeling to evaluate a laying hen's possibility to move.

formulated. Step 3 combines linguistic statements and constructs FRB, and constructs membership functions μ_{ij}. Step 4 computes degree of membership $\mu_{ij}(x_i)$ using actual measurements x_i for each alternative EPS. Step 5 determines fuzzy conclusions $\mu_{\tilde{O}c,p}$ and $\mu_{\tilde{O}c}$. Step 6, finally, defines a quantitative conclusion G_T, and a qualitative conclusion G_{norm} based on fuzzy conclusion $\mu_{\tilde{O}c}$. In fuzzy modeling, Step 4 is known as *fuzzification*, Step 5 is known as *fuzzy inference*, and Step 6 is known as *defuzzification* (adapted from Cornelissen et al., 2001). The fuzzy model was programmed using MATLAB 6.0® (® The Mathworks, Inc., Natick, MA).

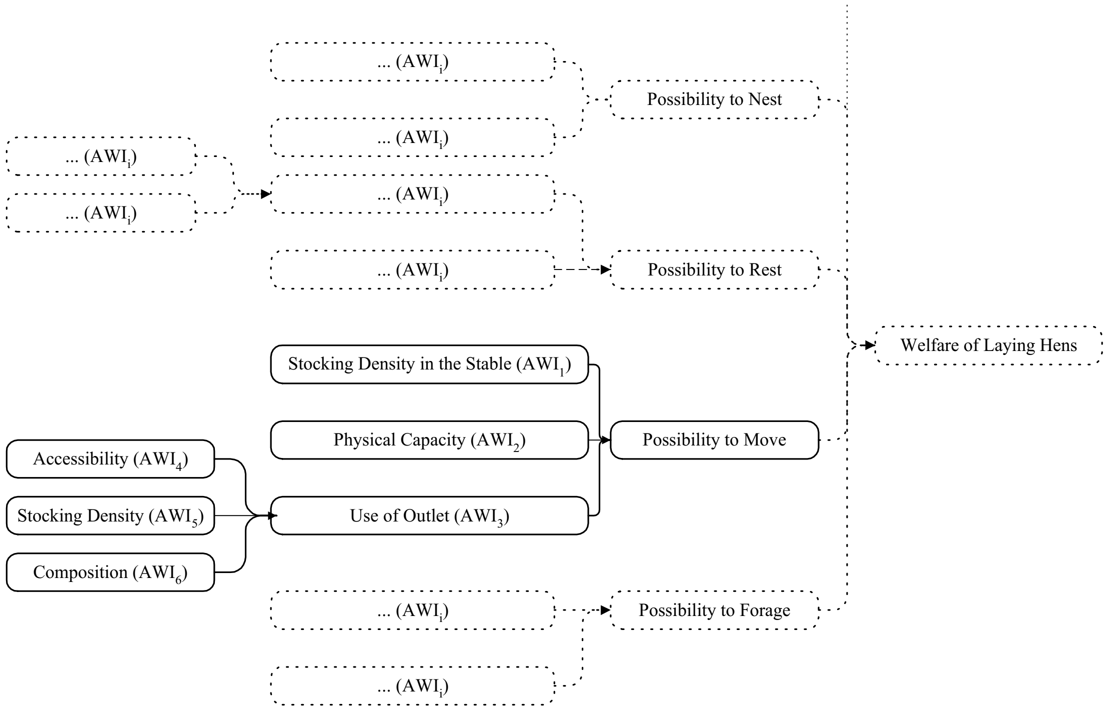

Figure 5.4: ***A hierarchical structure to evaluate the welfare of the laying hen.*** Continuous lines delineate the fuzzy model developed in this study.

STEP 1 AND 2

Relevant model input regarding PM was determined on the basis of (i) literature on the welfare of laying hens (Striezel, 1994; Sundrum and Andersson, 1994; Bokkers, 1995b), (ii) consultation with an expert (Ethology Group, Department of Animal Sciences, Wageningen University and Research Center), and (iii) European Union legislation concerning housing conditions in EPS (Council Directive 1999/74/EC). Figure 5.4 defines PM in relation to overall welfare of the laying hen in a hierarchical structure, and the fuzzy model developed in this study is delineated by continuous lines. PM is characterized by Stocking Density in the Stable (AWI_1), Physical Capacity (AWI_2), and Use of Outlet (AWI_3). Use of Outlet is characterized by its Accessibility (AWI_4), its spatial Composition (AWI_5), and its Stocking Density (AWI_6) (n = 6). Table 5.1 presents selected AWI, associated linguistic variables and values, and associated base variables. Model output is associated to linguistic variable $\tilde{O}$ ‹possibility to move› and linguistic values $\tilde{O}_1$ = ‹bad›, $\tilde{O}_2$ = ‹insufficient›, $\tilde{O}_3$ = ‹moderate›, $\tilde{O}_4$ = ‹sufficient›, and $\tilde{O}_5$ = ‹good› (d = 5).

STEP 3

Two FRB were constructed: FRB-1 using AWI_4 to AWI_6 to determine Use of Outlet (AWI_3), and FRB-2 using AWI_1 to AWI_3 to draw a conclusion for PM. Construction of an FRB involved two steps. First, the premises of the fuzzy rules were formulated through combining linguistic statements ‹$\tilde{A}_i$ is $\tilde{A}_{ij}$›. Second, an expert (Ethology Group, Department of Animal Sciences, Wageningen University and Research Center) formulated conclusions ‹$\tilde{O}$ is $\tilde{O}_c$› for each fuzzy rule by choosing appropriate linguistic value $\tilde{O}_c$. The second step was repeated three times with one-month intervals. If formulated conclusions ‹$\tilde{O}$ is $\tilde{O}_c$› for fuzzy rule R_p were not consistent in all three repetitions, then the most frequent formulation (if two out of three of the $\tilde{O}_c$ chosen were identical) or the intermediate formulation (if none of the $\tilde{O}_c$ chosen were identical) was selected. FRB-1 and FRB-2 are in Tables 5.2 and 5.3 respectively.

Membership functions were constructed following the procedure outlined in Cornelissen et al. (2002). Nineteen candidate-experts initially were selected based on (i) a person's involvement in projects related to the welfare of laying hens, (ii) a person's involvement in public and scientific debate, and (iii) the length of time of a person's experience. Five candidate-experts declined participation or did not respond, fourteen experts participated. Experts were animal scientists and ethologists, and professionals from the Dutch Society for the Protection of Animals and the Agricultural Extension Service.

A written questionnaire was used to elicit expert knowledge. Point estimation was selected as an appropriate method to elicit expert knowledge: this elicitation method allows a single response mode from the expert for continuous, discrete and nominal type base variables and, therefore, would provide highest confidence in consistency of expert responses (Cornelissen et al., 2002).

Table 5.1: ***Characteristics of selected indicators.*** Input for the fuzzy model to evaluate a laying hen's possibility to move (animal welfare indicators AWI_i and base variables x_i) and corresponding linguistic terms (linguistic variables $\tilde{A}_i$ and linguistic values $\tilde{A}_{ij}$)

AWI_i (i = 1,..,n)	*Linguistic Variable* $\tilde{A}_i$	Linguistic Values $\tilde{A}_{ij}$ (j = 1,..,m)	*Base Variable* x_i	Type of Base Variable	Relevant Range of Base Variable
AWI_1	stocking density ($\tilde{A}_1$)	low ($\tilde{A}_{11}$) moderate ($\tilde{A}_{12}$) high ($\tilde{A}_{13}$)	x_1 hens per m^2	continuous	[0, 30]
AWI_2	physical capacity ($\tilde{A}_2$)	good ($\tilde{A}_{21}$) poor ($\tilde{A}_{22}$)	x_2 presence of perches	nominal	{0, 1}[2]
AWI_3	Use of Outlet ($\tilde{A}_3$)	good ($\tilde{A}_{31}$) moderate ($\tilde{A}_{32}$) poor ($\tilde{A}_{33}$)	–	–	–
AWI_4	Accessibility of Outlet ($\tilde{A}_4$)	good ($\tilde{A}_{41}$) moderate ($\tilde{A}_{42}$) poor ($\tilde{A}_{43}$)	x_4 hours per day	continuous	[0, 12]
AWI_5	Composition of Outlet ($\tilde{A}_5$)	attractive ($\tilde{A}_{51}$) moderately attractive ($\tilde{A}_{52}$) unattractive ($\tilde{A}_{53}$)	x_5 number of stimuli[1]	discrete	{0, 4}
AWI_6	Stocking Density of Outlet ($\tilde{A}_6$)	low ($\tilde{A}_{61}$) moderate ($\tilde{A}_{62}$) high ($\tilde{A}_{63}$)	x_6 m^2 per hen	continuous	[0, 15]

[1]A stimulans refers to something in the outlet that stimulates laying hens to go outside and actually use the outlet. Stimuli can be feed, water, shelter, and overgrowth. ‹Overgrowth› means ‹covered with vegetation which is edible for laying hens›. No stimulus means that the outlet is barren.
[2] $x_2 = 0$ denotes ‹perches not present›, and $x_2 = 1$ denotes ‹perches present›.

Table 5.2: ***Construction of fuzzy rule base (I).*** Fuzzy rule base to determine Use of Outlet (FRB-1)

Rule R_p (q = 27)	IF Accesibility is	AND	Composition is	AND	Stocking Density is	THEN	Use of Outlet is
1	good		attractive		low		good
2	good		attractive		moderate		good
3	good		attractive		high		good
4	good		moderately attractive		low		good
5	good		moderately attractive		moderate		good
6	good		moderately attractive		high		moderate
7	good		unattractive		low		moderate
8	good		unattractive		moderate		poor
9	good		unattractive		high		poor
10	moderate		attractive		low		good
11	moderate		attractive		moderate		good
12	moderate		attractive		high		good
13	moderate		moderately attractive		low		moderate
14	moderate		moderately attractive		moderate		moderate
15	moderate		moderately attractive		high		moderate

Table 5.2: ***Construction of fuzzy rule base (I).*** (cont.)

Rule R_p	IF Accesibility is	AND	Composition is	AND	Stocking Density is	THEN	Use of Outlet is
16	moderate		unattractive		low		poor
17	moderate		unattractive		moderate		poor
18	moderate		unattractive		high		poor
19	poor		attractive		low		moderate
20	poor		attractive		moderate		moderate
21	poor		attractive		high		moderate
22	poor		moderately attractive		low		poor
23	poor		moderately attractive		moderate		poor
24	poor		moderately attractive		high		poor
25	poor		unattractive		low		poor
26	poor		unattractive		moderate		poor
27	poor		unattractive		high		poor

Table 5.3: ***Construction of fuzzy rule base (II).*** Fuzzy rule base to determine Possibility to Move (FRB-2)

Rule R_p (q = 24)	IF Stocking Density is	AND	Use of Outlet is	AND	Physical Capacity is	THEN	Use of Outlet is
1	low		good		good		good
2	low		good		poor		moderate
3	low		moderate		good		good
4	low		moderate		poor		moderate
5	low		poor		good		moderate
6	low		poor		poor		insufficient
7	low		none		good		sufficient
8	low		none		poor		moderate
9	moderate		good		good		good
10	moderate		good		poor		moderate
11	moderate		moderate		good		sufficient
12	moderate		moderate		poor		insufficient
13	moderate		poor		good		moderate
14	moderate		poor		poor		insufficient
15	moderate		none		good		sufficient
16	moderate		none		poor		insufficient

Table 5.3: ***Construction of fuzzy rule base (II).*** (cont.)

Rule R_p (q = 24)	IF Stocking Density is	AND	Use of Outlet is	AND	Physical Capacity is	THEN	Use of Outlet is
17	high		good		good		sufficient
18	high		good		poor		insufficient
19	high		moderate		good		moderate
20	high		moderate		poor		insufficient
21	high		poor		good		moderate
22	high		poor		poor		bad
23	high		none		good		insufficient
24	high		none		poor		bad

Five EPS were selected to obtain measurements x_1 to x_6: battery cage system, enriched cage system, deep-litter system, aviary system, and organic system. Four different situations were distinguished with respect to availability and spatial composition of the outlet in deep-litter and aviary systems: no outlet, barren outlet, feed-and-water outlet (i.e., outlet providing feed and water), and a complete outlet (i.e., outlet providing feed, water, overgrowth, and shelter). Table 5.4 shows input patterns for selected EPS, obtained using expert consultation (Ethology Group, Department of Animal Sciences, Wageningen University and Research Center) and European Union legislation concerning housing conditions in EPS (Council Directive 1999/74/EC).

Table 5.4: ***Input patterns for the fuzzy model.*** Input patterns of 11 egg production systems (EPS) based on five animal welfare indicators

	Animal Welfare Indicators AWI_i (i = 1,..,n)[1]				
EPS[2]	AWI_1	AWI_2	AWI_4	AWI_5	AWI_6
1	18	0	–	–	–
2	13	1	–	–	–
3	9	1	–	–	–
4	9	1	12	0	4
5	9	1	12	2	4
6	9	1	12	4	4
7	9	1	–	–	–
8	9	1	12	0	4
9	9	1	12	2	4
10	9	1	12	4	4
11	6	1	12	4	4

[1]AWI_1 = stocking density in the stable (x_1 hens per m^2); AWI_2 = physical capacity (x_2 = 0 denotes «no perches present»; x_2 = 1 denotes «perches present»); AWI_4 = accessibility of outlet (x_4 hours per day); AWI_5 = composition of outlet (x_5 number of stimuli); AWI_6 = stocking density of outlet (x_6 m^2 per hen).
[2]EPS 1 = battery cage; EPS 2 = enriched cage; EPS 3 = deep-litter - no outlet; EPS 4 = deep-litter - barren outlet; EPS 5 = deep-litter - feed-and-water outlet (i.e., outlet providing feed and water); EPS 6 = deep-litter - complete outlet (i.e., outlet providing feed, water, overgrowth, and shelter); EPS 7 = aviary - no outlet; EPS 8 = aviary - barren outlet; EPS 9 = aviary - feed-and-water outlet; EPS 10 = aviary - complete outlet; EPS 11 = organic system.

STEP 5

Fuzzy inference is a two-step process. First, a fuzzy implication operator infers a conclusion for individual R_p in a FRB; second, a fuzzy aggregation operator infers a conclusion for the complete FRB. In this study, Mamdani max-min composition was selected to achieve fuzzy inference. In Mamdani max-min composition, the minimum-operator is used as a fuzzy implication operator, and the maximum-operator is used as a fuzzy aggregation operator (Boixader and Godo, 1998; Cornelissen et al., 2001).

The result of FRB-1 was directly applied in FRB-2. Fuzzy conclusion $\mu_{\tilde{O}c}$ drawn from FRB-2 was defined on a discrete space $y_c \in \{1, 2, 3, 4, 5\}$ where y_c is associated with $\mu_{\tilde{O}c}$: i.e., $y_1 = 1$, which is associated with $\mu_{\tilde{O}1}$.

STEP 6

Defuzzification used the *cogus*-operator (Kaymak, 1998):

$$G = \left(\frac{\sum_{c=1}^{5} w_c \mu_{\tilde{O}_c}^{\alpha} y_c^{\beta}}{\sum_{c=1}^{5} w_c \mu_{\tilde{O}_c}^{\alpha}} \right)^{1/\beta} \qquad [5.1]$$

where G denotes a defuzzified value that provides a quantitative conclusion with respect to PM ($G \in [1, 5]$), G = 1 defines the worst possible conclusion, and G = 5 defines the best possible conclusion; $y_c \in \{1, 2, 3, 4, 5\}$ denotes domain elements in a discrete space associated with fuzzy conclusions $\mu_{\tilde{O}c}$; and $\mu_{\tilde{O}c}$ denotes the degree to which the fuzzy conclusion $\tilde{O}_c$ is true for a specific EPS. In addition, Equation 5.1 includes three parameters that introduce unequal sensitivity to domain elements. Parameter w_c denotes the relative importance of domain elements y_c ($w_c > 0$). Parameter α denotes a «degree of compromise» that defines the degree to which unfavorable assessments of $\mu_{\tilde{O}c}$ can be compensated for by possible favorable assessments. If α increases, then the influence of favorable assessments $\mu_{\tilde{O}c}$ on G will increase. Parameter β, finally, denotes unequal sensitivity to domain elements and can be interpreted to indicate ‹welfare awareness›. If β increases, then the influence of the more favorable conclusions with respect to PM (e.g., domain elements 4 and 5) on G will increase. In this study, all parameters were set at neutral values (i.e., $w_c = 1$, $\alpha = 1$, $\beta = 1$), as no empirical evidence was available to conclude otherwise.

5.2.2.3 Model Validation

To support qualitative model validation, defuzzified values G for each EPS were associated with linguistic terms {bad, insufficient, moderate, sufficient, good} to define G_{norm} as follows: if $G \in [1, 1.5>$, then G_{norm} = ‹bad›; if $G \in [1.5, 2.5>$, then G_{norm} = ‹insufficient›; *et cetera*. To support quantitative model validation, defuzzified values G were transformed to a continuous scale [0, 10] using linear equation:

$$G_T = 2.5(G - 1) \qquad [5.2]$$

where $G_T \in [0, 10]$, $G_T = 0$ defines the worst possible conclusion, and $G_T = 10$ denotes the best possible conclusion.

Empirical validation of the fuzzy model involved experts as a standard (Nunnally, 1978; McDowell and Newell, 1987). A written questionnaire was sent to the same group of experts as in Step 3: eight experts contributed. In the questionnaire, EPS were described in like manner on separate cards. Experts were asked to assess EPS in relation to PM exclusively, not considering any other characteristics regarding the welfare of laying hens (e.g., social and explorative behavior), nor considering economic, environmental and ergonomic aspects of EPS. Uniform conditions were emphasized: EPS were managed by well-experienced farmers, and suitable soil conditions in the outlet as well as the use of appropriate building materials according to current guidelines and legislation were to be assumed. After reading and initial ranking of cards, experts were asked to give a quantitative evaluation of PM for selected EPS, by assigning a number from the interval [0, 10] to each EPS (EE_{num}); and experts were asked to give a qualitative evaluation of PM for selected EPS by assigning the most appropriate term {bad, insufficient, moderate, sufficient, good} to each EPS (EE_{norm}).

Aggregation of validation results obtained from individual experts is considered acceptable if subjective perceptions of individual experts are not too different (Norwich and Türksen, 1984). The Kendall Coefficient of Concordance (W), defined in the interval [0, 1], was computed to analyze the agreement among experts with respect to their evaluation of EPS, where W = 1 denotes complete agreement among experts, and W = 0 denotes complete disagreement (Siegel and Castellan, 1988). If experts are used as a validation standard, results for W typically lie in the range 0.65 < W < 0.95, and are considered satisfactory if W > 0.85 (McDowell and Newell, 1987).

Quantitative expert evaluations EE_{num} were aggregated by computing the median. Qualitative expert evaluations EE_{norm} were aggregated by computing the relative frequency with which experts selected $\tilde{O}_c$ as an appropriate linguistic term for a specific EPS. EE_{norm}, further, is set in quantitative terms as $EE_{norm\text{-}T}$ using Equations 5.1 and 5.2.

The Spearman Rank Correlation Coefficient (r_s), defined in the interval [-1, 1], was computed to analyze the correlation between modeling result G_T, and validation results EE_{num} and $EE_{norm\text{-}T}$, where $r_s = -1$ denotes complete discordance between modeling results and validation results, $r_s = 0$ denotes complete independence, and $r_s = 1$ denotes complete concordance (Snedecor and Cochran, 1978). Non-parametric statistics were computed using Statistix 7© (© Analytical Software, Tallahassee, FL).

5.3 RESULTS

Table 5.5 shows the statistic W for EE_{norm} and EE_{num}. W for $EE_{norm} = 0.69$ ($P < 0.001$) and W for $EE_{num} = 0.87$ ($P < 0.001$): both values lie within the typical range given by McDowell and Newell (1987), and W for EE_{num} can be considered satisfactory ($EE_{num} > 0.85$). Table 5.6 shows results for EE_{num}, $EE_{norm\text{-}T}$, G_T, G_{norm} and EE_{norm} and for the statistic r_s. Figure 5.5 compares quantitative modeling result G_T and validation result EE_{num}. Figure 5.6 compares qualitative modeling result G_{norm} and validation result EE_{norm}. Triangles in Figure 5.6 denote final evaluative conclusions in qualitative terms.

Table 5.5: ***Agreement among experts.*** Kendall Coefficient of Concordance (W)[1] for quantitative (EE_{num}) and qualitative (EE_{norm}) expert evaluations of a hen's possibility to move with respect to 11 egg production systems

Expert assessment	W[2]
EE_{num}	0.87
EE_{norm}	0.69

[1]W is defined in the interval [0, 1] where W = 1 denotes complete agreement among experts, and W = 0 denotes complete disagreement.
[2] $P < 0.001$.

Table 5.6: *Modeling and validation results.* Modeling results (G_T and G_{norm}), validation results (EE_{num}, $EE_{norm\text{-}T}$ and EE_{norm}) and associated Spearman Rank Correlation Coefficients

EPS[1]	1 EE_{num}	2 $EE_{norm\text{-}T}$	3 G_T	EE_{norm}	G_{norm}	Spearman (r_s)[2]
1	1.0	0.3	0.0	bad	bad	
2	4.0	2.5	0.2	insufficient	bad	$r_{s\text{-}13} = 0.99$
3	6.8	5.9	1.6	moderate	insufficient	$r_{s\text{-}23} = 0.96$
4	7.1	7.2	4.9	sufficient	moderate	$r_{s\text{-}12} = 0.93$
5	7.5	7.5	5.2	sufficient	moderate	
6	8.0	9.7	6.6	good	sufficient	
7	6.5	7.2	1.6	sufficient	insufficient	
8	7.0	7.8	4.9	sufficient	moderate	
9	7.5	7.8	5.2	sufficient	moderate	
10	8.8	9.7	6.6	good	sufficient	
11	9.0	10.0	8.4	good	sufficient	

[1]For explanation of EPS see Table 5.4
[2] $P < 0.01$

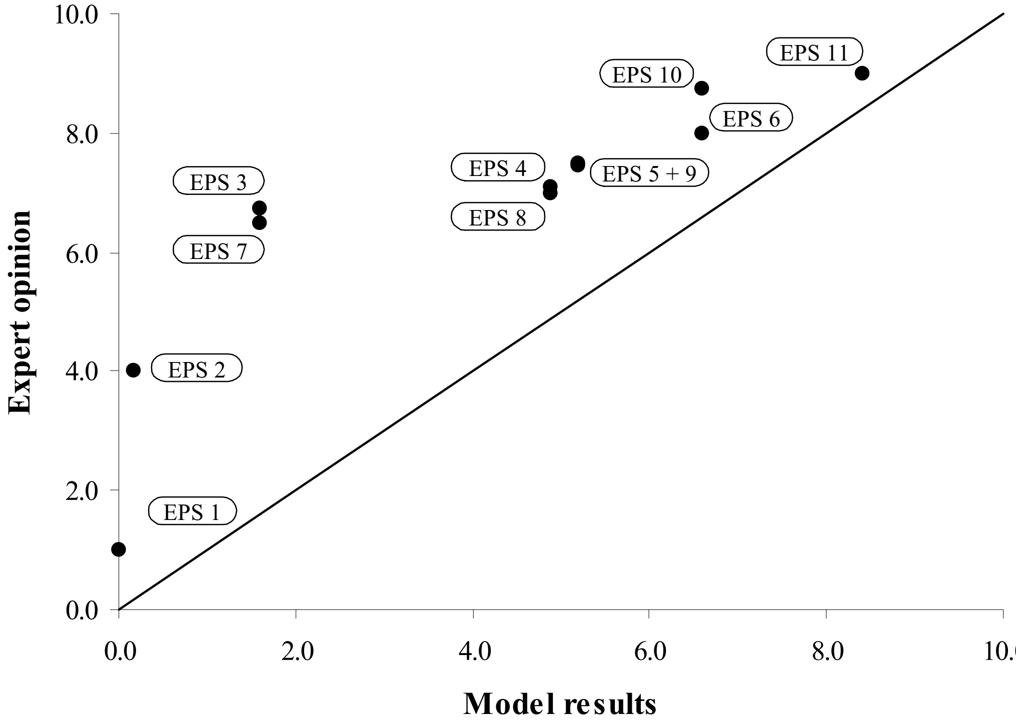

Figure 5.5: *Quantitative validation.* Comparison of quantitative modeling results and quantitative validation results for evaluative conclusions of a fuzzy model for a laying hen's possibility to move (for description of EPS 1 through 11 see Table 5.4).

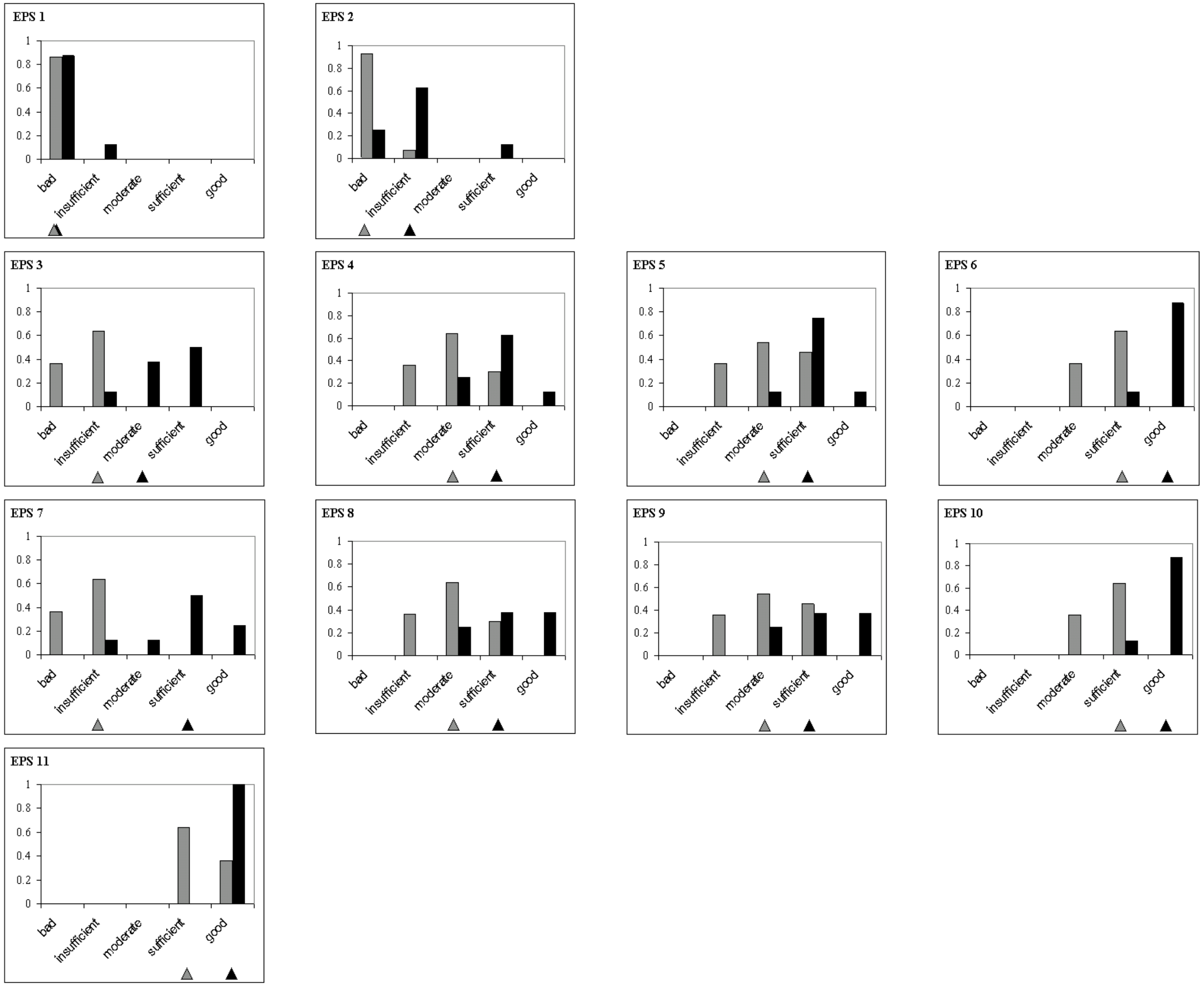

Figure 5.6: ***Qualitative validation.*** Graphical comparison of qualitative validation results (EE_{norm}: black bars) and modeling results (G_{norm}: grey bars). Triangles indicate final evaluative conclusions for specific EPS (for description of EPS see Table 5.4).

In relative terms, i.e. in terms of ranking, modeling results G_T and G_{norm} and validation results EE_{num} and EE_{norm} are comparable (Figures 5.5 and 5.6). These findings are supported by high r_s-values (Table 5.6): $r_{s-13} = 0.99$ ($P < 0.01$) for G_T and EE_{num}, and $r_{s-23} = 0.96$ ($P < 0.01$) for G_T and G_{norm-T} respectively. In absolute terms, however, modeling results consistently underrate a laying hen's possibility to move for different EPS in comparison to validation results. In Figure 5.5, this difference is illustrated by validation results lying consistently above the continuous line ‹$y = x$›. In Figure 5.6, absolute differences between final evaluative conclusions EE_{norm} and G_{norm} (denoted by triangles) are illustrated by a consistent shift to the right for EE_{norm}, except for the Battery Cage System (EPS 1).

Additionally, Figure 5.5 shows an interval between, on the one hand, EPS 1-3 and 7, and, on the other hand, EPS 4-6 and 8-11 for modeling results. This suggests that according to the fuzzy model PM especially improves in EPS that provide laying hens with a possibility to use an outlet. Regarding validation results, however, an interval occurs between, on the one hand, EPS 1 and 2, and, on the other hand, EPS 3-11. This suggests that according to experts PM especially improves in EPS that do not use cages and allow laying hens to roam freely, with enriched cages (EPS 2) being intermediate between battery cages and other EPS.

5.4 DISCUSSION

5.4.1 FUZZY MODELING

The objective of this paper was to develop and validate a fuzzy model to evaluate a laying hen's possibility to move. Development and validation of the fuzzy model was supported by evaluating the contribution of conventional and animal-friendly egg production systems to PM. Model validation, in general, compares modeling results against a real-world standard to test the success of the model at its task. However, such a validation procedure is not possible with respect to models that draw an evaluative conclusion of animal welfare, as no real-world standard is available. Empirical validation, therefore, involved experts as a standard.

The Kendall Coefficient of Concordance (W) was used to decide whether aggregating validation results of individual experts, to serve as a validation standard, was meaningful. High and significant values of W show that experts, essentially, apply the same criteria for ranking EPS with respect to PM (Siegel and Castellan, 1988). According to McDowell and Newell (1987), values of W greater than 0.85 are considered satisfactory. Although the statistic W for EE_{norm} was smaller than 0.85 (W = 0.69, Table 5.5), the Spearman Rank Correlation Coefficient between EE_{norm} and EE_{num} (r_{s-12} = 0.93 and P < 0.01, Table 5.6), however, proved sufficiently high to also use EE_{norm} as a validation standard.

A possible reason for W being lower for EE_{norm} than for EE_{num} could be that not enough linguistic terms were available for experts to provide an accurate qualitative evaluation (McDowell and Newell, 1987): this was supported by additional remarks made by some of the experts. Application of linguistic hedges is one possibility to increase the number of linguistic terms. The hedge ‹very›, for example, can be used in connection with the existing term ‹good› to create an additional linguistic term ‹very good› (Zadeh, 1975a,b; Klir and Yuan, 1995; Schwartz, 1998).

Validation results were compared to modeling results in relative terms, and in absolute terms. In relative terms, the Spearman Rank Correlation Coefficient (r_s) was used as a crude measure for the success of the fuzzy model at its task (Snedecor and Cochran, 1978). Results showed that modeling results and validation results correlated very well (r_{s-13} and r_{s-23} in Table 5.6), i.e., the fuzzy model and experts both ranked EPS in a similar way. If the success of the fuzzy model is considered only to depend on whether EPS are correctly ranked in terms of PM, because unequivocal evaluative conclusions with respect to animal welfare do not exist (cf. Sandøe and Simonsen, 1992), then the fuzzy model has been successfully validated.

In absolute terms, modeling results consistently underrated PM in comparison to validation results. Figures 5.5 and 5.6 suggest two possible causes. First, the fact that the fuzzy model consistently underrates PM suggests that linguistic statements in the conclusion of the fuzzy rules need to be reconsidered. Second, the fact that modeling results show a different emphasis with respect to which EPS improve PM, suggests that experts and the fuzzy model emphasize different characteristics in their line of reasoning: where the fuzzy model seems to emphasize the actual area available to laying hens, the experts seem to emphasize spatial perception of the laying hen. This suggests that an additional animal welfare indicator expressing spatial perception of laying hens would be a useful addition in the premises of the fuzzy rules in FRB-2. Research work with respect to spatial perception, however, has only just started (E.A.M. Bokkers, 2002, Ethology Group, Wageningen Institute of Animal Sciences, Wageningen UR, the Netherlands, personal communication). Hence, for the fuzzy model to be successfully validated in absolute terms, the results suggest reconsideration and reformulation of the models FRB. In addition, results also emphasize that validity of fuzzy models largely depends on correct construction of the model's FRB when expert knowledge plays an important role. Further research with respect to procedures to support construction of a fuzzy rule base, therefore, would be beneficial.

5.4.2 Fuzzy Modeling of Animal Welfare

Animal welfare complicates evaluation because it is a complex concept, and because it is a normative concept. Complexity is reflected in inevitable choice regarding which information to consider in the model so as to properly describe animal welfare. Part of what has been won in making a vague, common-sense concept like animal welfare concrete through in-depth research concerning behavioral, physiological, health and production aspects, at the same time has been lost in this diversity (Stafleu et al., 1996). In this study, selection of AWI to describe PM was based on characteristics of EPS rather than, for example, using physiology-based indicators. Additional indicators, however, can easily be inserted without having to modify the complete model. In Figure 5.3, only Steps 2 and 3 would have to be adjusted.

Normativity is reflected in interpretation of information, and in integration of information to draw an evaluative conclusion. Interpretation of information concerns defining thresholds, for example, with respect to which levels of stocking density are to be considered ‹low›. Use of hard thresholds - e.g., a distinct number of hens allowed per m^2 with respect to ‹low› stocking densities - have been criticized for being arbitrary and subjective (Mendl, 1991). Fuzzy models acknowledge the subjectivity involved by using membership functions that define soft thresholds (Cornelissen et al., 2001). Additionally, application of soft thresholds in fuzzy modeling also prevents that only technical facts dictate how animal welfare is conceived (cf. Sandøe and Simonsen, 1992).

Integration of information concerns making explicit the normative reasoning which is involved in formulating a concise evaluative conclusion. Fuzzy models acknowledge the subjectivity involved through the construction of a FRB that contains transparent linguistic statements in the terms of reference of policy makers and the general public (cf. Stafleu et al., 1996). Therefore, even though science cannot provide answers for value judgments implicit to animal welfare (Fraser, 1995), science can contribute by developing modeling procedures that help making such value judgments explicit.

In conclusion, this study shows that fuzzy modeling can be a useful tool to bridge the communication-gap between the production system level and the society level, as it helps to make explicit how humans manage and understand public concern. Although the procedure to construct the model's fuzzy rule base needs to be further refined, the prospects of fuzzy modeling with respect to drawing concise and easy-to-understand evaluative conclusions look promising. This also opens up perspectives for applying fuzzy evaluation to human issues in agriculture other than animal welfare that take place at the interface of production system level and society level: e.g., with respect to public concern for sustainability. It, therefore, seems to be worthwhile to broaden the experience with fuzzy modeling.

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CHAPTER 6

GENERAL DISCUSSION

6.1 RESEARCH OBJECTIVES

This thesis aimed at developing an evaluative framework to draw justifiable conclusions about the contribution of an agricultural production system to society's sustainable development. Using Fournier's general logic of evaluation, such conclusions should be based on methods that set criteria and standards for the evaluand, measure performance of the evaluand in terms of these criteria and standards, and integrate information in a final assessment of merit or worth of the evaluand (Fournier, 1995)[1]. Figure 6.1 presents the evaluative framework of sustainable development that served as a common thread in this thesis. The evaluative framework constitutes a complete cycle to monitor sustainable development: Phases 1 through 4 establish evaluative conclusions along the lines of Fournier, and Phase 5 closes the monitoring cycle by acting upon the conclusions.

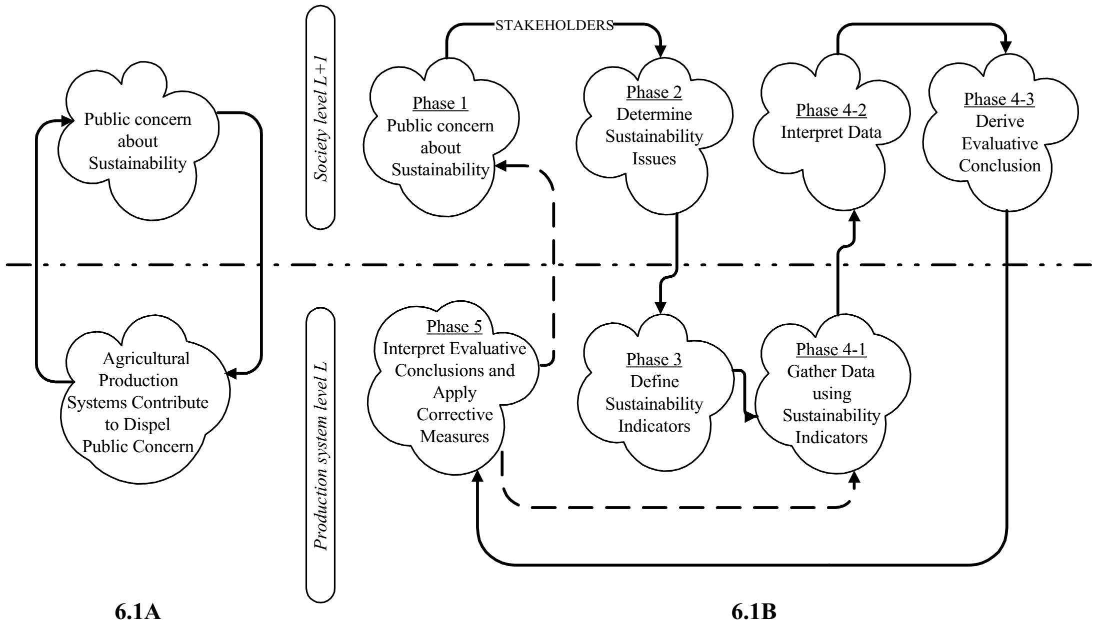

Figure 6.1: ***An evaluative framework of sustainable development.*** In Figure 6.1A, sustainable development is considered a social construct that, with respect to agriculture, builds on public concern about the impact of current agricultural activities on society. Figure 6.1A is elaborated in Figure 6.1B, which introduces a five-phased evaluative framework to monitor sustainable development. Phases 1 to 4 evaluate the contribution of agricultural production systems to society's sustainable development, and Phase 5 acts upon the conclusions drawn from the evaluation.

Emphasis in this thesis was on methodological aspects to identify (Phases 1 through 3) and interpret sustainability criteria (Phase 4). The objectives of the study, therefore, were as follows:

1. construct a support to identify appropriate sustainability criteria, and to obtain relevant information with respect to sustainable development;
2. construct a method to interpret this information, and to draw evaluative conclusions about sustainable development.

Figure 6.1, further, demonstrates that an evaluative framework of sustainable development operates at both the production system level and the society level: objective information gathered at the production system level is given subjective meaning at the society level. In the 1960's, fuzzy set theory was introduced to manage subjective human communication and interpretation of objective information (Zadeh, 1965). In this thesis, fuzzy set theory was suggested as a formal mathematical basis to support Phase 4 in the evaluative framework of sustainable development. The following research questions, therefore, were addressed:

1. What constitutes an appropriate support to identify relevant sustainability criteria?
2. Can use of fuzzy set theory combine objective information, obtained at the production system level, and subjective interpretation of information, obtained at the society level?
3. Can use of fuzzy set theory establish standards that allow subjective interpretation of information?
4. Can use of fuzzy set theory draw valid evaluative conclusions through integration of information?
5. Does the evaluative framework of sustainable development provide a valuable contribution to the sustainability debate?

6.2 RESEARCH RESULTS

6.2.1 IDENTIFYING SUSTAINABILITY CRITERIA

Sustainability criteria lie at the basis of drawing evaluative conclusions about sustainable development. In Figure 6.1, sustainability criteria are defined in Phases 1 through 3, and explicitly express public concern for sustainability (Phase 1) by identifying context-dependent issues of concern at the society level (Phase 2), and by translating such issues into measurable sustainability indicators at the production system level, to provide tangible, objective information (Phase 3). However, because of the implicit nature of rationales underlying concern for sustainability in Phase 1, Phase 2 lacks a solid basis, and the link between selected sustainability indicators in Phase 3 and concern for sustainability in Phase 1 remains obscure. This suggests that concern for sustainability can be characterized at will which, consequently, hampers implementation of local initiatives that aim at contributing to sustainable development (cf. Chatterton and Style, 2001)[2].

Chapter 2 identifies a «common ground» to provide an explicit point of departure for sustainable development, and prevent concern for sustainability from being characterized at will. Common ground for sustainable development was identified using Koestler's metaphor of the Janus-faced holon. The «Two Faces of Sustainability» provide a two-way perspective by integrating ecocentric and anthropocentric rationales in two imperatives of sustainability: a system imperative and a societal imperative. These imperatives define, on the one hand, system issues that refer to concern for the existence of society, and, on the other hand, societal issues that refer to concern for the acceptability of society. System and societal issues, ultimately, identify the common ground for sustainable development.

The association between both imperatives of sustainability emphasizes the need for an integrated approach, and refutes the supposed dichotomy between ecocentric and anthropocentric rationales (Thompson, 1992: 12). The system and societal imperatives, therefore, can be considered proper equivalents of the Kantian «categorical imperative» as their legitimacy hinges on acceptance of both system and societal issues by society as a whole (cf. Russel, 1996)[3]. Acceptance of a common ground for sustainable development, however, does not prevent existence of trade-offs between ecological integrity and quality-of-life. Common ground rather emphasizes that such trade-offs can only be avoided by society itself through choosing a lifestyle that represents a compromise solution with respect to both imperatives of sustainability[4]. As it is not realistic to force people to choose more sustainable lifestyles (Beekman, 2001), it is the more important for local initiatives that aim at contributing to sustainable development to make explicit their point of departure.

Chapter 2, therefore, introduces a simple graphical model that visualizes the «sustainability scope» of local initiatives by delineating the common ground covered using the selected sustainability indicators. The model uses an overall impression of grey tones that depends on the emphasis given to the various system and societal issues. If the sustainability scope is broad (i.e., system and societal issues have been given equal emphasis), then the impression will be evenly gray; if the sustainability scope is narrow (i.e., only a limited number of issues have been given emphasis), then the impression will tend to a black-and-white contrast.

The graphical model, however, should be applied with some restraint as it assumes all sustainability indicators to be of equal importance, i.e., it assumes that all indicators are necessary to appropriately reflect identified issues of concern. This condition can be met by selecting sustainability indicators in accordance with the criteria referred to in Chapter 2 (cf. Table 2.1). An additional criterion was provided by van der Werf and Petit (2002), who distinguish between means-based indicators, that express the degree of adherence to technologies, practices and policies implemented and, therefore, provide information about success or failure of measures taken; and effect-based indicators, that express the actual effect of the means implemented and, therefore, provide information about progress or regress with respect to dispelling an issue of concern. Because means-based indicators generally are easier to construct and cheaper to apply, the sustainability scope should be cautiously applied.

Sustainability indicators, rather than issues of concern, are used to delineate a sustainability scope, because not all issues of concern necessarily are considered in the evaluative framework. Relevant indicators may be omitted if they do not meet selection criteria (de Boer and Cornelissen, 2002). Sustainability indicators, therefore, best reflect the actual effort put into a contribution to sustainable development.

6.2.2. GIVING MEANING TO SUSTAINABILITY CRITERIA

If appropriate sustainability criteria have been identified, then giving meaning to the information obtained from sustainability criteria is the next phase in drawing evaluative conclusions about sustainable development. In Figure 6.1, objective information, gathered at the production system level (Phase 4-1), is given subjective meaning at the society level (Phases 4-2 and 4-3). Fuzzy set theory was suggested as a formal mathematical basis to support Phases 4-2 and 4-3 in the evaluative framework of sustainable development. The main body of research presented in this thesis, therefore, deals with the feasibility of fuzzy set theory to interpret and integrate available information.

6.2.2.1 INTERPRETATION OF INFORMATION

Interpreting information requires thresholds that serve as reference points to assess performance achieved (e.g., Bell and Morse, 1999). If, for example, a sustainability indicator provides information with respect to ammonia emission, then classical set theory defines a hard threshold value to identify an unambiguous distinction between acceptable and unacceptable levels of ammonia emission (cf. Chapter 3). If fuzzy set theory is applied, then a membership function defines a soft threshold that allows a smooth and gradual transition from unacceptable to acceptable levels of ammonia emission. The smooth interpretation of information by a membership function presents two important advantages over using hard thresholds. First, a membership function acknowledges the subjectivity involved when interpreting information and, second, by acknowledging the subjectivity involved, a membership function may help to prevent that technical detail (e.g., with respect to defining a hard threshold value) dictates the sustainability debate (cf. Chapter 5).

Chapter 3 applied fuzzy set theory to explore the feasibility of two fuzzy models that support decision-making with respect to sustainable development. Membership functions were found to be fundamental to fuzzy models, and Chapter 3 concluded that the reliability of such functions is essential to guarantee the validity of fuzzy models. First, reliability of membership functions depends on the appropriateness of elicited expert knowledge. This involves selection of expert knowledge and selection of methods to elicit expert knowledge. In Chapter 4, a six-step procedure was developed to improve this aspect of reliability and deal with criticism on the inherent subjectivity in the construction of membership functions based on expert knowledge.

Second, reliability of membership functions depends on the consistency of expert knowledge. Consistency, in this context, can refer to variation in repeated responses when knowledge is elicited from a single expert, or to the variation in responses when knowledge is elicited from multiple experts (Klir and Yuan, 1995). Including such variability in the construction of membership functions is possible by using so-called Type-2 fuzzy set techniques (Türksen, 2002). These techniques express the uncertainty embedded in the representation of meaning by fuzzy sets and, as such, can be considered analogous to confidence intervals in statistical methods. Although the potential of Type-2 fuzzy set representation was already discussed by Zadeh (1975b), the computational demand seems to be the main reason that such techniques hardly have been used in practical applications (Klir and Yuan, 1995). Türksen (2002), however, is convinced that current research that aims at reducing this computational demand will increase future applicability. Type-2 fuzzy set techniques, therefore, may improve this aspect of the reliability of membership functions.

Finally, the reliability of membership functions is not timeless, because human understanding is dynamic. Validity of fuzzy models with respect to their use of membership functions, therefore, neither is timeless and regular reconsideration of membership functions will be indispensable.

6.2.2.2 INTEGRATION OF INFORMATION

Chapter 3 explored two fuzzy models that apply different techniques to integrate information from individual sustainability indicators: one model applies fuzzy set aggregation operations, and another applies approximate reasoning. Fuzzy set aggregation techniques directly use evaluative conclusions on individual sustainability indicators to compute an overall evaluative conclusion with respect to sustainable development. Societal opinion with respect to sustainable development can then be incorporated in two ways. First, an evaluative conclusion can be adjusted by modifying the relative importance of individual indicators using a weighting procedure. Second, an evaluative conclusion can be adjusted by modifying the degree to which unfavorable evaluations of specific individual indicators can be compensated for by favorable ones using the degree of compromise (cf. Chapter 3, Subsection 3.3.2.2.).

In contrast to fuzzy set aggregation techniques, approximate reasoning techniques use evaluative conclusions on individual sustainability indicators to support a reasoning process that draws an overall evaluative conclusion with respect to sustainable development on the basis of available knowledge about possible relationships among indicators. In Chapter 5, a full fuzzy model applying approximate reasoning was made operational[5]. Such a model is valid only if the credibility of its conclusion can be guaranteed (Fournier, 1995). Model validation, in general, compares modeling results against a real-world standard to test the success of the model in ‹recreating› a recognizable reality. However, such a validation procedure is not possible with respect to fuzzy models that draw an evaluative conclusion on sustainable development, as no real-world standard is available. In Chapter 5, validation of the fuzzy model was performed by using expert opinion as a standard. Whether expert evaluation provides an appropriate validation standard, however, is contestable, as an expert's line of reasoning is not necessarily similar to the line of reasoning used in the fuzzy rule base of the fuzzy model. The validity of fuzzy modeling in the context of sustainable development, therefore, mainly has to be guaranteed by ensuring the correct use of expert knowledge to construct both membership functions and fuzzy rule bases. Thus, where Chapter 4 presents a procedure to guarantee the reliability of membership functions, a comparable procedure to support the construction of a fuzzy rule base would be beneficial. Such a support also could consider the use of multiple experts in developing a fuzzy rule base, to further improve the model's description of available knowledge.

Whether information obtained from sustainability indicators should be integrated into a single-value evaluative conclusion at all, is a contested topic in the sustainability debate (e.g., Bell and Morse, 1999; Gallopín, 1997; IISD, 2002; Neumayer, 2001; Niemeijer, 2002; von Wirén-Lehr, 2001; WRR, 2002). Arguments in favor of integrating information generally revolve around the undesirable situation where large numbers of sustainability indicators will inevitably result in a myriad of data. Society in general, and policy makers in particular, will be unable to take a decision or to form an opinion on the basis of a diffuse collection of data. Integration of information, thus, allows expression of the contribution to sustainable development in a comprehensive way, and increase awareness with respect to sustainable development.

Arguments against integration of information generally revolve around two issues. First, integration obscures insight in the information that has been included and, therefore, will lead to inevitable loss of valuable information. Information on individual sustainability indicators, however, is essential in order to identify the issues that are in need of further action. Moreover, single-value evaluative conclusions may come to dominate the political debate, rather than the information underlying such a conclusion and, consequently, may lead to ill-founded decision-making. Second, integration obscures underlying relations, and involves mathematical operations that reduce the transparency with respect to how evaluative conclusions are arrived at.

In this thesis, arguments against integration are addressed by considering a single-value conclusion about sustainable development as an integral part of a complete monitoring cycle. In this evaluative framework of sustainable development, information on individual sustainability indicators must be available to all participants at all times. Further, underlying mathematical equations and relations among indicators are made transparent by «computing with words», i.e., by use of linguistic variables, and by expressing relations as linguistic statements.

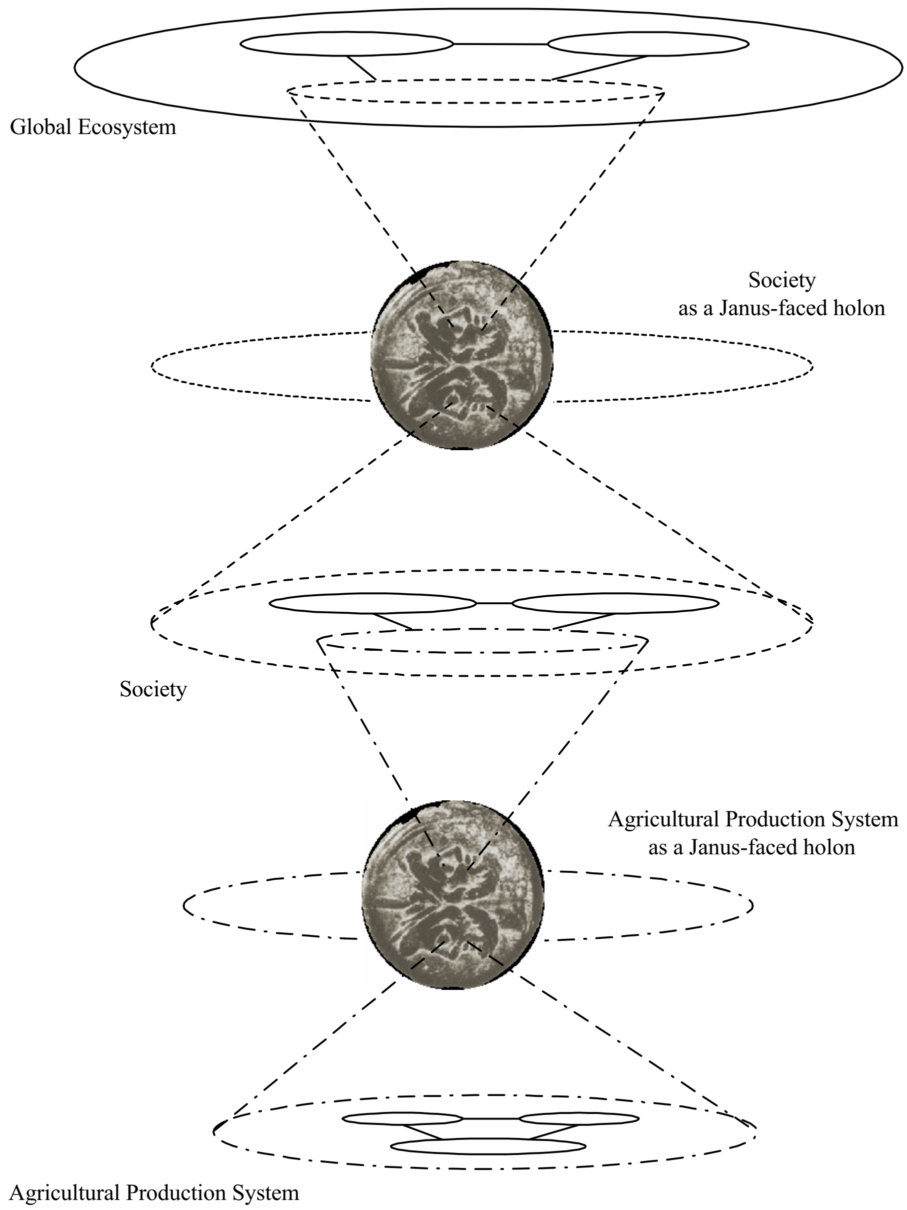

Figure 6.2: ***The Two Faces of Sustainability.*** Society and agricultural production systems as Janus-faced holons.

6.3 RESEARCH CONTRIBUTION TO THE SUSTAINABILITY DEBATE

The «Two Faces of Sustainability» provide a novel contribution to the sustainability debate in two ways (Figure 6.2). First, the metaphor applied to society identifies a common ground for sustainable development. Recent contributions to support the Dutch position with respect to the UN conference on *Sustainable Development* (in Johannesburg 2002) once again emphasize that such a common ground is considered essential (e.g., Bil and Peters, 2002; Rotmans et al., 2001; WRR, 2002). These contributions, in general, state that continuation of the sustainability debate without a common point of departure inevitably will only generate more debate and more controversy, but will not stimulate initiation of local contributions to set sustainable development in motion.

Second, the metaphor applied to agricultural production systems identifies an evaluative framework of sustainable development that operates at both the production system level and the society level. Sustainable development, in other words, involves a group that expresses a concern for sustainability and has an opinion about sustainable development (e.g., citizens and policy makers at the society level), and a group that deal with sustainable development in practice and can contribute to dispel concern for sustainability (e.g., farmers at the production system level). Fuzzy modeling provides a means to bridge the communication-gap between the society level and the production system level by contributing to the insights in how humans understand and manage complexity[6]. Where most studies using sustainability indicators stop at the ‹hard› data, fuzzy modeling attaches ‹soft› meaning to ‹hard› data, thus allowing implementation of a complete monitoring cycle. Moreover, as currently sustainable development essentially manifests itself at the policy level, policy makers will need a tool that provides them with information with respect to the state of sustainable development, as well as with information regarding specific interventions needed. Fuzzy models, therefore, can interface information between society and agricultural production systems (or any other part of society) to support platforms of all relevant stakeholders to learn their way to more sustainable futures (cf. Röling, 1994).

In conclusion, it appears worthwhile to broaden the experience with fuzzy modeling in the context of an evaluative framework of sustainable development and, in this way, support a learning process toward a more sustainable future. After all, the best validation of a fuzzy evaluation of sustainable development is its adoption in the unruly environment of the real world.

6.4 RESEARCH CONCLUSIONS

Final conclusion are formulated on the basis of the research questions addressed in this thesis.

1. The system and societal imperatives of sustainability identify system and societal issues that, in combination, define the «common ground for sustainable development». This common ground provides an explicit point of departure for local initiatives that aim at contributing to sustainable development.

2. Fuzzy models can interface information between the society level and the production systems level, because linguistic variables provide a bridge between subjective (soft) interpretation of objective (hard) measurements.

3. Membership functions are at the core of fuzzy models and provide a standard for drawing evaluative conclusions by defining a soft threshold that allows a smooth interpretation of information, and that acknowledges the subjectivity involved when interpreting information at the society level.

4. If expert knowledge is thoughtfully applied to construct both membership functions and fuzzy rule bases, then fuzzy models can draw valid evaluative conclusions with respect to sustainable development.

5. The evaluative framework of sustainable development that identifies sustainability criteria on the basis of the common ground, and that gives meaning to sustainability criteria on the basis of a fuzzy evaluation, provides a novel and valuable contribution to the sustainability debate.

NOTES

[1] Fournier's general logic of evaluation was introduced in Chapter 1 (Subsection 1.3.1). An «evaluand» denotes «that what is (to be) evaluated» (cf. Scriven, 1980). In this thesis, the evaluand is an agricultural production system.

[2] Consider Alice's theorem: ‹If you don't know where you want to go, it doesn't matter which road you take› (from: *Alice in Wonderland* by Lewis Carol).

[3] Immanuel Kant (1724-1804) deduces the «categorical imperative» in his book *Metaphysics of Morals* which states: ‹act only according to a maxim by which you can at the same time will that it shall become a general law› (Russel, 1996).

[4] Beekman (2001) provides a valuable philosophical reflection on possible non-directive government intervention in non-sustainable lifestyles.

[5] In Chapter 5, public concern for animal welfare was used to illustrate an operational fuzzy model. The decision to choose an illustrative example with respect to «animal welfare», rather than with respect to «sustainable development» was made on the following grounds. First, «animal welfare» and «sustainable development» both are entities that, as such, are not directly measurable. Both animal welfare and sustainable development can be considered as manifestations of public concern, i.e., they are a linguistic expression of a complex problem that is characterized by a variety of issues (cf. Table 4.1). Drawing evaluative conclusions with respect to animal welfare, therefore, also involves subjective interpretation at the society

level, of objective information gathered at the production system level. Second, emphasis in this chapter was on methodology, i.e., on development and validation of a full fuzzy model. Third, within the time-span available for this research project, information with respect to «animal welfare» was more readily available.

[6] Recall Zadeh's «principle of incompatibility» which states that a trade-off exists between the complexity of a problem, and the precision in formulating conclusions on the problem (Zadeh, 1973).

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SUMMARY

RESEARCH OBJECTIVES

This thesis aimed at developing an evaluative framework to draw justifiable conclusions about the contribution of an agricultural production system to society's sustainable development. Such conclusions should be based on methods that set criteria and standards for the evaluand (i.e., agricultural production systems), measure performance of the evaluand in terms of these criteria and standards, and integrate information in a final assessment of merit or worth of the evaluand. The evaluative framework, that served as a common thread in this thesis, constitutes a complete cycle to monitor sustainable development: Phases 1 through 4 establish evaluative conclusions, and Phase 5 closes the monitoring cycle by acting upon the conclusions.

Emphasis in this thesis was on methodological aspects to identify (Phases 1 through 3) and interpret sustainability criteria (Phase 4). The objectives of the study, therefore, were as follows:

1. construct a support to identify appropriate sustainability criteria, and to obtain relevant information with respect to sustainable development;
2. construct a method to interpret this information, and to draw evaluative conclusions about sustainable development.

An evaluative framework of sustainable development operates at both the production system level and the society level: objective information gathered at the production system level is given subjective meaning at the society level. In the 1960's, fuzzy set theory was introduced to manage subjective human communication and interpretation of objective information. In this thesis, fuzzy set theory was suggested as a formal mathematical basis to support Phase 4 in the evaluative framework of sustainable development. The following research questions, therefore, were addressed:

1. What constitutes an appropriate support to identify relevant sustainability criteria?
2. Can use of fuzzy set theory combine objective information, obtained at the production system level, and subjective interpretation of information, obtained at the society level?
3. Can use of fuzzy set theory establish standards that allow subjective interpretation of information?
4. Can use of fuzzy set theory draw valid evaluative conclusions through integration of information?

5. Does the evaluative framework of sustainable development provide a valuable contribution to the sustainability debate?

IDENTIFYING SUSTAINABILITY CRITERIA

Concern for sustainability currently is an important frame of reference for development of society, and numerous local initiatives claim to contribute to sustainable development. Although sustainable development inherently holds subjective aspects, expressing concern for sustainability needs an explicit point of departure to prevent sustainable development from being characterized at will.

Chapter 2 identifies a «common ground for sustainable development» to provide an explicit point of departure. Common ground was identified using Koestler's metaphor of the Janus-faced holon. The «Two Faces of Sustainability» provide a two-way perspective by integrating ecocentric and anthropocentric rationales in two imperatives of sustainability: a system imperative and a societal imperative. These imperatives define, on the one hand, system issues that refer to concern for the existence of society, and, on the other hand, societal issues that refer to concern for the acceptability of society. System and societal issues, ultimately, identify the common ground for sustainable development.

Chapter 2, additionally, introduces a simple graphical model that visualizes the «sustainability scope» of local initiatives by delineating the common ground covered using the selected sustainability indicators. The model uses an overall impression of grey tones that depends on the emphasis given to the various system and societal issues. If the sustainability scope is broad (i.e., system and societal issues have been given equal emphasis), then the impression will be evenly gray; if the sustainability scope is narrow (i.e., only a limited number of issues have been given emphasis), then the impression will tend to a black-and-white contrast. A case study in a region of the Province of Overijssel, the Netherlands, illustrates how the sustainability scope reflects the common ground covered based on sustainability indicators selected by local initiatives. Chapter 2 concludes that common ground for sustainable development allows proper identification of sustainability criteria, and that the sustainability scope provide a useful means for local initiatives to justify their specific contribution to sustainable development.

GIVING MEANING TO SUSTAINABILITY CRITERIA

If appropriate sustainability criteria have been identified, then giving meaning to the information obtained from sustainability criteria is the next phase in drawing evaluative conclusions about sustainable development. Fuzzy set theory was suggested as a formal mathematical basis to support Phases 4-2 and 4-3 in the evaluative framework of sustainable development. The main body of research presented in this thesis, therefore, deals with the feasibility of fuzzy set theory to interpret and integrate available information.

Chapter 3 introduces fuzzy set theory and develops two fuzzy models to assess sustainable development based on selected sustainability indicators: one model applies fuzzy set aggregation operations, and another applies approximate reasoning. Membership functions are at the core of fuzzy models, and define the degree to which sustainability indicators contribute to sustainable development. Implementation of fuzzy models with respect to sustainable development is based on elicitation of expert knowledge to construct a membership function. The membership function, therefore, often is considered to be both the strongest and the weakest point of a fuzzy model. It is the strongest, because a membership function defines a soft threshold, which allows a smooth and practical assessment of the contribution of sustainability indicators to sustainable development. It is the weakest, because the membership function is regarded as too subjective in relation to its construction. Chapter 3, therefore, concludes that the reliability of membership functions is essential to guarantee the validity of fuzzy models.

Chapter 4 outlines a procedure which deals with criticism regarding the inherent subjectivity in the construction of membership functions, when such construction is based on the use of expert knowledge. The procedure guarantees the selection of appropriate expert knowledge, and provides a guideline supporting the selection of methods to elicit expert knowledge and construct membership functions. Selection of appropriate expert knowledge is based on criteria to identify experts, and consider a person's period of learning and experience in a specific domain of knowledge, as well as the specific circumstances in which experience is gained

Next, qualitative comparison with respect to practical application of four elicitation methods (point estimation, interval estimation, direct rating, and transition interval estimation) showed that the actual choice of an elicitation method depends on the range of application, the ease of the response mode for experts, and the ease of constructing and interpreting membership functions. Also on the basis of the results in an illustrative example, Chapter 4 concludes that the procedure outlined suitably deals with criticism regarding membership functions and, therefore, enables a practical implementation of fuzzy models.

Chapter 5 develops and validates an operational fuzzy model to evaluate egg production systems for a laying hen's possibility to move. A laying hen's possibility to move is chosen as it provides a concise characteristic of the welfare of a laying hen. The decision to choose an illustrative example with respect to animal welfare, rather than with respect to sustainable development is made on the following grounds. First, animal welfare and sustainable development both are entities that, as such, are not directly measurable. Both animal welfare and sustainable development can be considered as manifestations of public concern, i.e., they are a linguistic expression of a complex problem that is characterized by a variety of issues. Drawing evaluative conclusions with respect to animal welfare, therefore, also involves subjective interpretation at the society level, of objective information gathered at the production system level. Second, emphasis in this chapter is on methodology, i.e., on development and validation of a full fuzzy model. Third, within the time-span available for this research project, information with respect to animal welfare was more readily available.

Empirical validation of the fuzzy model in Chapter 5 involves experts as a standard. Validation results are compared to modeling results in relative and in absolute terms. In relative terms, modeling results and validation results correlate very well, i.e., the fuzzy model and experts both ranked egg production systems with respect to a laying hen's possibility to move in a similar way. If the success of the fuzzy model is considered only to depend on whether egg production systems are correctly ranked in terms of possibility to move, then the fuzzy model is considered successfully validated. In absolute terms, modeling results consistently underrate a laying hen's possibility to move in comparison to validation results. For the fuzzy model to be successfully validated in absolute terms, the results suggest reconsideration of the model's fuzzy rule base. In addition, results emphasize that validity of fuzzy models largely depends on correct construction of a fuzzy rule base when expert knowledge plays an important role. Further research with respect to procedures to support construction of a fuzzy rule base, therefore, will be beneficial. Chapter 5 concludes that, even though the procedure to construct the model's fuzzy rule base needs to be further refined, the prospects of fuzzy modeling with respect to drawing concise and easy-to-understand evaluative conclusions look promising.

RESEARCH CONCLUSIONS

The «Two Faces of Sustainability», based on Koestler's metaphor of the Janus-faced holon, provide a novel contribution to the sustainability debate in two ways. First, the metaphor applied to society identifies a common ground for sustainable development. Second, the metaphor applied to agricultural production systems identifies an evaluative framework of sustainable development that operates at both the production system level and the society level.

Fuzzy modeling provides a means to bridge the communication-gap between the society level and the production system level by acknowledging how humans understand and manage complexity. As currently sustainable development essentially manifests itself at the policy level, policy makers will need a tool that provides them with information on the state of sustainable development, as well as with information with respect to specific interventions needed. Fuzzy models can interface information between society and agricultural production systems (or any other part of society) to support platforms of all relevant stakeholders, including policy makers, to learn their way to more sustainable futures.

Specific research conclusion are formulated on the basis of the research questions addressed in this thesis:

1. The system and societal imperatives of sustainability identify system and societal issues that, in combination, define the common ground for sustainable development. This common ground provides an explicit point of departure for local initiatives that aim at contributing to sustainable development.

2. Fuzzy models can interface information between the society level and the production systems level, because linguistic variables provide a bridge between subjective (soft) interpretation of objective (hard) measurements.

3. Membership functions are at the core of fuzzy models and provide a standard for drawing evaluative conclusions by defining a soft threshold that allows a smooth interpretation of information, and that acknowledges the subjectivity involved when interpreting information at the society level.

4. If expert knowledge is thoughtfully applied to construct both membership functions and fuzzy rule bases, then fuzzy models can draw valid evaluative conclusions with respect to sustainable development.

5. The evaluative framework of sustainable development that identifies sustainability criteria on the basis of the common ground, and that gives meaning to sustainability criteria on the basis of a fuzzy evaluation, provides a novel and valuable contribution to the sustainability debate.

SAMENVATTING (SUMMARY IN DUTCH)

DOELSTELLINGEN VAN DIT ONDERZOEK

Het onderzoek beschreven in dit proefschrift beoogde een evaluatief raamwerk te ontwikkelen om verantwoorde conclusies te kunnen trekken over de bijdrage van landbouwproductiesystemen aan een duurzame ontwikkeling van de maatschappij. Evaluatieve conclusies zijn het resultaat van methoden met behulp waarvan duurzaamheidscriteria worden vastgesteld, en van methoden waarmee vervolgens op basis van deze criteria de mate van succes wordt bepaald waarmee landbouwproductiesystemen bijdragen aan een duurzame ontwikkeling. De mate van succes wordt bepaald door de verkregen informatie te integreren in een uiteindelijke beoordeling. Het evaluatieve raamwerk, dat als een rode draad door dit proefschrift loopt, omvat een complete cyclus bedoeld om een duurzame ontwikkeling te monitoren: de Fasen 1 tot en met 4 in deze cyclus resulteren in evaluatieve conclusies, en Fase 5 sluit de monitoring-cyclus door te handelen naar de aard van de getrokken conclusies.

De nadruk in dit proefschrift ligt op de methodologische aspecten van het identificeren (Fasen 1 tot en met 3) en het interpreteren van duurzaamheidscriteria (Fase 4). De doelstellingen van dit onderzoek waren als volgt:

1. het bepalen van een grondslag, op basis waarvan geschikte duurzaamheidscriteria kunnen worden geïdentificeerd, en relevante informatie over duurzame ontwikkeling kan worden verkregen;
2. het bepalen van een methode om deze informatie op een zinvolle manier te kunnen interpreteren, en vervolgens evaluatieve conclusies over duurzame ontwikkeling te kunnen trekken.

Een evaluatief raamwerk voor duurzame ontwikkeling opereert zowel op het productiesysteem-niveau als op het maatschappij-niveau: objectieve informatie wordt verzameld op productiesysteem-niveau – door middel van meten of observeren van duurzaamheidsindicatoren – en krijgt subjectieve betekenis op maatschappij-niveau. In de jaren zestig werd *fuzzy set theory* (vaagverzamelingenleer) geïntroduceerd om subjectieve, menselijke communicatie te relateren aan de eraan ten grondslag liggende objectieve informatie. In dit proefschrift wordt onderzocht of *fuzzy set theory* kan worden gebruikt als een mogelijke formele wiskundige basis ter ondersteuning van Fase 4 in het evaluatief raamwerk voor duurzame ontwikkeling.

De volgende onderzoeksvragen kwamen in dit proefschrift aan de orde:

1. Op welke basis kunnen relevante duurzaamheidscriteria worden vastgesteld?
2. Kan door gebruik van *fuzzy set theory* objectieve informatie, verkregen op productiesysteem-niveau, gekoppeld worden aan subjectieve interpretatie van deze informatie op maatschappij-niveau?
3. Kunnen door gebruik van *fuzzy set theory* standaarden worden vastgesteld die deze inherente subjectiviteit ondersteunen?
4. Kunnen door het gebruik van *fuzzy set theory* verantwoorde evaluatieve conclusies worden getrokken middels het integreren van informatie?
5. Levert het «evaluatief raamwerk voor duurzame ontwikkeling» een waardevolle bijdrage aan het duurzaamheidsdebat?

IDENTIFICEREN VAN DUURZAAMHEIDSCRITERIA

De publieke zorg over duurzaamheid vormt tegenwoordig een belangrijk referentiekader waar het de (toekomstige) ontwikkeling van onze maatschappij betreft. Vele lokale initiatieven claimen bij te dragen aan een duurzame ontwikkeling van de maatschappij. Ondanks het inherente subjectieve karakter van duurzame ontwikkeling is een expliciet uitgangspunt echter noodzakelijk om te voorkomen dat duurzame ontwikkeling naar een ieders eigen inzicht wordt ingevuld.

Hoofdstuk 2 bepaalt een «algemeen uitgangspunt voor duurzame ontwikkeling» op basis waarvan context-specifieke duurzaamheidscriteria kunnen worden vastgesteld. Een dergelijke grondslag wordt ontwikkeld met behulp van Koestler's holon-theorie. Een «holon» is een abstracte benadering van de werkelijkheid waarin de maatschappij wordt voorgesteld als een systeem met twee gezichten. Het ene gezicht is gericht op het maatschappelijk systeem zelf en benadrukt een antropocentrische opstelling ten opzichte van duurzame ontwikkeling; het andere gezicht is gericht op de omgeving waarin (en de omgeving waarvan) dat maatschappelijk systeem moet bestaan, en benadrukt een ecocentrische opstelling. De «Twee Gezichten van Duurzaamheid» – twee gezichten van hetzelfde hoofd: een Janus-hoofd – leveren op die manier een tweeledig perspectief op duurzaamheid door antropocentrische en ecocentrische opstellingen te verenigen in twee duurzaamheidsimperatieven: een maatschappij-imperatief en een systeem-imperatief. Deze imperatieven formuleren enerzijds «systeemkwesties», die refereren aan zorg over de bestaanswijze van de maatschappij, en anderzijds «maatschappijkwesties», die refereren aan zorg over de redelijkheid van de maatschappij. Systeem- en maatschappijkwesties bepalen samen een expliciet algemeen uitgangspunt voor duurzame ontwikkeling.

Hoofdstuk 2 introduceert vervolgens een eenvoudig grafisch model om het «duurzaamheidsbereik» van lokale initiatieven te visualiseren met behulp van de door deze initiatieven geselecteerde duurzaamheidsindicatoren. Het model gebruikt een impressie van grijstinten welke afhankelijk is van de nadruk die door de geselecteerde duurzaamheidsindicatoren wordt gegeven aan de verschillende systeem- en maatschappijkwesties. Een breed duurzaamheidsbereik (gelijke nadruk wordt gegeven aan zowel systeem- als maatschappijkwesties) levert een regelmatige grijs-impressie op; een smal duurzaamheidsbereik (slechts een klein aantal kwesties krijgt aandacht) zal leiden tot meer zwart-wit contrasten. Een casestudy in de noordwestelijke regio van de provincie Overijssel illustreert hoe dit duurzaamheidsbereik visualiseert in welke mate de algemene uitgangspunten voor duurzame ontwikkeling worden meegenomen door de ontwikkelde lokale initiatieven. Hoofdstuk 2 concludeert dat het algemene uitgangspunt voor duurzame ontwikkeling, vastgesteld op basis van de twee duurzaamheidsimperatieven, het mogelijk maakt relevante duurzaamheidscriteria vast te stellen. Het visualiseren van het duurzaamheidsbereik kan voor lokale initiatieven een praktisch middel zijn om hun bijdrage aan een duurzame ontwikkeling van onze maatschappij te illustreren en te rechtvaardigen.

BETEKENIS GEVEN AAN DUURZAAMHEIDSCRITERIA

Na het vaststellen van relevante duurzaamheidscriteria moet betekenis worden gegeven aan de informatie verkregen op basis van deze criteria, om zodoende tot een evaluatieve conclusie te kunnen komen met betrekking tot duurzame ontwikkeling. *Fuzzy set theory* werd voorgesteld als een formele wiskundige basis om Fase 4 te operationaliseren. Het belangrijkste deel van het onderzoek beschreven in dit proefschrift richt zich op de mogelijke geschiktheid van deze wiskundige basis om de informatie, verkregen uit vastgestelde duurzaamheidscriteria, te interpreteren en te integreren.

Hoofdstuk 3 introduceert de basisprincipes van *fuzzy set theory* en ontwikkelt twee fuzzy modellen die de voortgang van een duurzame ontwikkeling vast kunnen stellen op basis van geselecteerde duurzaamheidsindicatoren. Eén model realiseert een evaluatieve conclusie door zogenaamde *fuzzy set* aggregatie operatoren toe te passen om informatie te integreren, het andere model maakt gebruik van *approximate reasoning*. Membershipfuncties (of lidmaatschapfuncties) liggen aan de basis van ieder fuzzy model en definiëren in principe de mate waarin duurzaamheidsindicatoren bijdragen aan duurzame ontwikkeling. Toepassing van fuzzy modellen in de praktijk moet gebruik maken van expertkennis om de noodzakelijke membershipfuncties te kunnen bepalen.

De membershipfunctie wordt vaak beschouwd als zowel het sterkste als het zwakste punt van een fuzzy model. De functie wordt beschouwd als het sterkste punt, omdat het de bijdrage van duurzaamheidsindicatoren aan duurzame ontwikkeling op een evenwichtige en realistische manier bepaalt. De functie wordt beschouwd als het zwakste punt, omdat de ontwikkeling van de functie zelf vaak als te subjectief wordt gezien. Hoofdstuk 3 concludeert dat het verzekeren van de betrouwbaarheid van membershipfuncties een essentieel aspect van de validiteit van fuzzy modellen vormt.

Hoofdstuk 4 zet vervolgens een procedure uiteen waarin een weerwoord wordt geformuleerd op de eerder geuite kritiek wat betreft de inherente subjectiviteit van membershipfuncties als deze worden ontwikkeld op basis van expertkennis. De procedure voorziet in een richtlijn voor de selectie van relevante expertkennis, alsook in een richtlijn voor de selectie van methoden om de benodigde expertkennis te vergaren en de membershipfuncties te ontwikkelen. De selectie van expertkennis is gebaseerd op criteria om die personen te identificeren die als expert op kunnen treden. Dergelijke criteria hebben bijvoorbeeld betrekking op de lengte van de periode waarin een persoon kennis en ervaring heeft opgedaan in een bepaald kennisgebied.

Een kwalitatieve vergelijking van vier mogelijke methoden die kunnen worden gebruikt om in de praktijk expertkennis te vergaren laat zien dat de keuze uiteindelijk afhangt van de diversiteit aan informatie die beschikbaar is, van het gemak waarmee experts de beschikbare informatie kunnen interpreteren en vervolgens hun oordeel kunnen formuleren, en van het gemak waarmee tenslotte de membershipfuncties uit de verkregen expertise kunnen worden bepaald. Mede op basis van een voorbeeld wordt in hoofdstuk 4 geconcludeerd dat de procedure, zoals die in dit hoofdstuk uiteengezet wordt, op een geschikte manier weerwoord biedt aan de geuite kritiek met betrekking tot de bepaling van membershipfuncties, en dat een praktische toepassing van fuzzy modellen daardoor mogelijk wordt.

Hoofdstuk 5 ontwikkeld en valideert een operationeel fuzzy model dat eiproductiesystemen evalueert in relatie tot de bewegingmogelijkheden van de leghennen die erin gehouden worden. De beweeglijkheid van leghennen is gekozen, omdat het een wezenlijk aspect van het welzijn van een leghen vormt. De keuze om een fuzzy model uit te werken aan de hand van een voorbeeld dat betrekking heeft op dierenwelzijn in plaats van op duurzame ontwikkeling is drieledig.

Ten eerste komt, mijns inziens, de problematiek met betrekking tot dierenwelzijn, net als waar het de problematiek omtrent het vaststellen van de bijdrage van landbouwproductiesystemen aan een duurzame ontwikkeling van onze maatschappij betreft, voort uit uitingen van publieke zorg. Met andere woorden, publieke zorg over zowel dierenwelzijn als duurzame ontwikkeling wordt geuit in linguïstische termen op maatschappij-niveau, en is als zodanig een weergave van een complex probleem dat is gekarakteriseerd door de samenkomst van een veelheid aan uiteenlopende kwesties. Ook in geval van dierenwelzijn worden uiteindelijk evaluatieve conclusies getrokken middels subjectieve interpretatie op maatschappij-niveau van objectieve informatie verkregen op productiesysteem-niveau. Ten tweede ligt de nadruk in dit hoofdstuk op de methodologische aspecten van het ontwikkelen en valideren van een operationeel fuzzy model. Het onderwerp van evaluatie is daarom in principe van minder belang. Ten derde was, gezien de beschikbare tijd om dit onderzoek af te ronden, betrouwbare informatie met betrekking tot dierenwelzijn eerder voorhanden dan informatie met betrekking tot duurzame ontwikkeling.

Empirische validatie van het fuzzy model in hoofdstuk 5 werd mogelijk gemaakt met behulp van experts. Validatieresultaten werden zowel in relatieve zin als in absolute zin vergeleken met de resultaten gegenereerd door het model. In relatieve zin correleerden modelresultaten en validatieresultaten uitstekend: het fuzzy model en de experts rangschikten de verschillende eiproductiesystemen in relatie tot de bewegingsmogelijkheden van leghennen op eenzelfde manier. Als het succes van het model uitsluitend zou worden bepaald door een relatieve validatie procedure, dan zou de validatie als geslaagd mogen worden beschouwd. In absolute zin echter lagen de modelresultaten systematisch lager als de validatieresultaten. Om in absolute zin van een geslaagde validatie te kunnen spreken zou daarom opnieuw moeten worden gekeken naar de *fuzzy rule base* die ten grondslag ligt aan het model. In deze *fuzzy rule base* liggen de regels opgeslagen die de verschillende bronnen van informatie integreren tot een uiteindelijke evaluatieve conclusie. De resultaten van dit onderzoek benadrukken dan ook dat de validatie van een fuzzy model, naast het correct opstellen van de relevante membershipfuncties, ook sterk afhankelijk is van het juist modeleren van de aan de conclusie ten grondslag liggende redeneerregels. Verder onderzoek naar procedures die het ontwikkelen van een correcte *fuzzy rule base* zouden ondersteunen is noodzakelijk. Hoofdstuk 5 concludeert dat de vooruitzichten wat betreft de toepassing van fuzzy modellen om tot bondige en gemakkelijk te begrijpen conclusies te komen veelbelovend lijken, maar dat de procedure tot het opzetten van een juiste *fuzzy rule base* nog worden verbeterd.

CONCLUSIES VAN DIT ONDERZOEK

De «Twee Gezichten van Duurzaamheid», gebaseerd op Koestler's holon-metafoor, leveren op twee manieren een nieuwe en waardevolle bijdrage aan het duurzaamheidsdebat. Als de metafoor wordt toegepast op maatschappij-niveau, dan maakt Koestler's metafoor het mogelijk om een algemeen en expliciet uitgangspunt voor een duurzame ontwikkeling van die maatschappij vast te stellen. Als de metafoor wordt toegepast op productiesysteem-niveau, dan illustreert Koestler's metafoor een communicatiekloof die door de keuze van de juiste methode in een evaluatief raamwerk voor duurzame ontwikkeling overbrugt kan worden. Fuzzy modellen helpen deze communicatiekloof tussen maatschappij-niveau en productiesysteem-niveau te dichten door informatie tussen beide niveaus te koppelen, en zodoende tegemoet te komen aan de manier waarop mensen om kunnen gaan met complexe problemen.

Duurzame ontwikkeling speelt tegenwoordig een grote rol op bestuurlijk gebied. Beleidsmakers hebben dan ook een instrument nodig waarmee ze de veelheid aan informatie – die op hen afkomt als het over duurzame ontwikkeling gaat – op een transparante manier kunnen doorvertalen in termen van verworvenheden, alsook in termen van de geschiktheid van mogelijk noodzakelijke interventies. Fuzzy modellen kunnen dan ook een zinvolle bijdrage leveren aan overlegplatformen waarin alle belangrijke maatschappelijke belangengroepen samenkomen om al lerende hun weg naar een duurzame toekomst te zoeken.

Specifieke conclusies van het onderzoek beschreven in dit proefschrift zijn:

1. De beide duurzaamheidsimperatieven bepalen samen een expliciet uitgangspunt op basis waarvan lokale initiatieven een relevante bijdrage aan een duurzame ontwikkeling van onze maatschappij kunnen bewerkstelligen.

2. Fuzzy modellen verbinden de informatiestroom tussen maatschappij-niveau en productiesysteem-niveau door met behulp van membershipfuncties de communicatiekloof tussen objectieve informatie en subjectieve interpretatie te overbruggen.

3. Membershipfuncties bepalen de bijdrage van duurzaamheidsindicatoren aan duurzame ontwikkeling op een evenwichtige en begrijpelijke manier.

4. Fuzzy modellen resulteren in valide evaluatieve conclusies met betrekking tot duurzame ontwikkeling als expertkennis op een juiste manier wordt ingezet.

5. Het evaluatieve raamwerk voor duurzame ontwikkeling, dat enerzijds context-specifieke duurzaamheidscriteria vaststelt uitgaande van het perspectief van de twee gezichten van duurzaamheid, en anderzijds een zinvolle betekenis kan geven aan informatie verkregen op basis van deze duurzaamheidscriteria door middel van een fuzzy evaluatie, levert een waardevolle nieuwe bijdrage aan het duurzaamheidsdebat.

CHEERS !

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Dit is 'm dan, mijn proefschrift! Toen ik in januari 1997 begon aan een onderzoek dat betrekking zou hebben op «duurzame ontwikkeling», liet een oud-collega me uit zijn eigen ervaring weten dat ik op dit onderwerp aardig wat tanden stuk zou kunnen bijten. Achteraf gezien heeft het me ook aardig wat ‹tanden› gekost, maar uiteindelijk is er voldoende gebit overgebleven om in de toekomst nog eens stevig op dit onderwerp door te kauwen…

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Wageningen, december 2002.

About the Author

CURRICULUM VITAE

Antonius Maria Gertrudis (Ton) Cornelissen was born in Venlo, the Netherlands, on 11 June 1969, as the first of three sons of Jos en Nel Cornelissen. He grew up in the nearby village of Maasbree, together with his brothers Berry and Tino. After attending the Blariacum College in Venlo-Blerick (VWO-atheneum), he moved to Wageningen in 1987 to study Animal Sciences at Wageningen Agricultural University.

During his studies, he spent six months in Indonesia at the Interdisciplinary Research Training Project ‹INRES› located at Brawijaya University in Malang, East Java. Subsequently, he stayed for six months in Malaysia to do a master's thesis in Grassland Science at MARDI Research Station in Kluang, Johor DT. This thesis work studied feed intake by grazing sheep, and was supervised in Malaysia by Dr. Liang Juan Boo, and in Wageningen by Professor Len 't Mannetje. Back in Wageningen, he started a second master's thesis in Tropical Animal Production. In this study, he validated a computer simulation program with respect to animal draught power, and was supervised by Dr. Henk Udo and Ing. Fokje Steenstra. For this thesis work, he won the ‹C.T. de Wit Thesis Award› in 1994 for ‹writing an excellent thesis›. Ton graduated ‹cum laude› in August 1993.

Since November 1993, the author was a member of the Animal Production Systems Group. He contributed, as a researcher and as a lecturer, to realize the Group's principal objective that aimed at developing a ‹systems approach› to make ‹sustainability› in agricultural production systems operational. In 1997, his work almost logically proceeded in a research project, of which the results are presented in this doctoral thesis. Since October 2002, the author is ‹putting his money where his mouth is›, and is now contributing to identify and implement policy objectives that aim at realizing a transition towards a sustainable agriculture in the Province of Noord-Brabant.

Ton lives with Susan Peelen in Wageningen.