Evaluating and Communicating Impact Significance in EIA: A Fuzzy Set Approach to Articulating Stakeholder Perspectives

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ABSTRACT. *Decisions which surround the evaluation of the significance of environmental impacts are a critical component of EIA, with implications for all stages in the process. Despite this, significance evaluation arguably remains one of the most complex and least understood of EIA activities, involving a combination of technical "scientific" approaches to appraisal situated within a political decision making arena, characterised by value judgements and case specific interpretations. EIAs typically use natural language terms such as "slight", "moderate", or "substantial" to communicate impact significance. Whilst pragmatic, this does raise the problem of lexical uncertainty and such terms in themselves may be contested – one persons "slight" impact is another's "substantial". Secondly, ES authors could manipulate the definitions of impact significance to their advantage. Thirdly, sharp 'black and white' boundaries between impact categories are often used that do not reflect the actual 'shades of grey' e.g. 100 traffic movements is considered a "slight" impact but 101 movements is classed as "moderate". Focussing on noise and visual effects for a live windfarm EIA, this paper explores the use of fuzzy set theory for establishing and communicating impact significance across different stakeholder groups. Research participants were exposed to a series of (i) computer-animated photomontages and (ii) various sound recordings of actual similar wind-turbines in operation, and were asked to grade the extent to which the impact matched their assessment of a "slight" impact, a "moderate" impact etc. Fuzzy sets representing these linguistic terms were subsequently calibrated against relevant corresponding continuous variables (e.g. dB(A) for noise) to 'map' the boundaries of impact significance. Differences in stakeholder assessments of impact significance are outlined, before considering how individual stakeholder fuzzy sets may be used to define fuzzy significance thresholds to guide the EIA process. Finally a critical evaluation of the approach is provided and its potential wider applicability considered.*

INTRODUCTION

EIA has been characterised as both a "science" and an "art" (Kennedy, 1984) in recognition that it attempts to adopt a technical approach to appraisal, whilst operating within a political decision-making arena where value judgements and interpretations of the significance of environmental effects are performed (Weston, 2000). Evaluating the significance of environmental effects has long been identified as the most critical component of EIA (Duinker & Beanlands, 1986; Sadler, 1996), and indeed impact assessment legislation, guidelines and Environmental Impact Statements (EISs) themselves make liberal, if rather nebulous use of the term "significant".

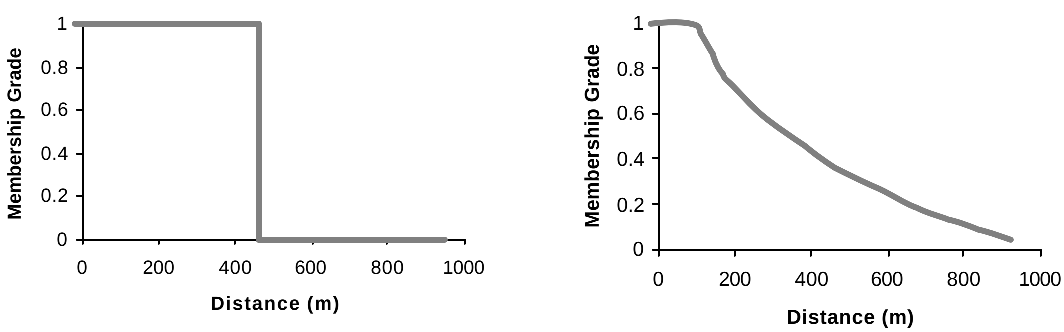
Despite the apparent importance of significance evaluation, it remains one of the most complex and least understood EIA activities, involving the consideration of a diverse mix of potentially well-defined characteristics (e.g. project type, size, location) and less readily defined judgemental criteria (e.g. environmental sensitivity, impact magnitude, duration, and importance). The intrinsic complexity of significance evaluation is further exacerbated in that the nature of the term 'significance' in decision-making evolves conceptually as a development proposal progresses through the EIA process, and as the nature and availability of environmental information changes (Hilden, 1995). For instance, the specific characteristics of significance evaluation during the early decision stages in the EIA process, including screening (deciding whether a project should be subject to EIA) and scoping (determining which environmental effects an EIA should focus upon) will differ markedly from the conceptualisation of significance during impact prediction and evaluation (Sadler, 1996).

The complex and contentious construction of 'significance' in EIA therefore warrants further research, being contingent upon value judgements and interpretations of qualitative and quantitative data that are typically characterised by uncertainty, vagueness and inexactitude. Using a live windfarm EIA case study, this paper reports upon the use of fuzzy set theory as a potential methodological paradigm to structure and delineate evaluations of significance made by a range of stakeholders that may be involved in EIA decision-making.

FUZZY SETS – AN OVERVIEW

In mathematics, a set refers to a class or collection of objects or elements that share common properties or confirm to a rule e.g. the set of statutory consultees in the EIA process. These sets may be referred to as classical or 'crisp' sets in the sense that membership is unequivocal – an element either belongs to the set or not. In contrast, a fuzzy set is one in which classes do not have sharply defined boundaries, and the transition from membership to non-membership of the set is gradual e.g. the fuzzy sets 'near', 'heavy' traffic, or 'loud' noise (Figure 1.)

Figure 1. Hypothetical Membership Function for the Concept "NEAR"



'Crisp' set **'Fuzzy' set**

In EIA, terms such as 'loud' noise, 'heavy' traffic or 'moderate' impact are essentially linguistic variables that cannot be sharply defined. For example, the concept 'short-term' (which may be used to describe the duration of a potential impact in an EIA) is in essence a fuzzy variable – there is no sharp transition from membership to non-membership in this class of time. The progression from 'short' to 'medium' through to 'long-term' is gradual, indicating that a given time interval belongs to the concept 'short-term' only to a certain degree. "Fuzziness in this context implies that there maybe instances where grades of membership exist intermediate between full membership and non-membership in a given class of objects or relations" (Lein, 1992). Excluding such fuzziness leads to a less realistic characterisation of the underlying concepts under consideration – for instance an infinitesimal change in time should not lead to an abrupt change in the classification of the duration of an impact from 'short-term' to 'medium-term'.

In essence, therefore, fuzzy sets are capable of capturing gradients of change based around natural language concepts, and are characterised by an ability to translate a wide variety of information – quantitative data, qualitative information and subjective opinions – into "a common language for characterising environmental effects" (Silvert, 2000), whilst preserving and expressing in an explicit way the imprecision inherent to definition.

The intuitive appeal of fuzzy sets as an aid for environmental decision-making has not gone unnoticed in the literature (e.g. Lein, 1992, Xiang *et al*, 1992, Smith, 1994, Parashar *et al* 1997, Angel *et al* 1998). However, the emphasis has largely been upon the use of pre-defined fuzzy sets for multi-criteria analysis, or more recently for the creation of abstract mathematical indices of impact significance (Bojorquez-Tapia *et al*, 2002) that circumvent the appeal of the methodology for exploring the more judgmental and linguistic aspects of environmental of decision-making.

The usefulness of fuzzy set theory "…depends critically on our capability to construct appropriate membership functions for various given concepts in various contexts" (Klir & Yuan, 1995), and it is from this perspective that the emphasis of the research is placed. Based upon a live EIA case study of a wind farm proposal at Thorney, near Peterborough in the UK, fuzzy set theory is used as an approach for exploring the evaluation and communication of impact significance by a range of stakeholders including the developer, environmental consultants, NGOs and local residents. In all cases the individuals concerned are the *actual* individuals or groups that held a genuine stake in the proposal and the EIA. The data collected therefore present a rich and valuable test bed for the approach. In essence the research seeks to:

- apply fuzzy set theory to determine membership functions associated with linguistic variables used to evaluate and communicate the significance of environmental effects in EIA; and

- construct membership functions for expert and community definitions of significance, and to draw comparisons.

To determine the fuzzy set memberships, experimental methods that follow an empirical semantic approach (Turksen, 1991) were employed. The empirical semantic approach "...may be regarded as an application of a pragmatic method in that it insists that all conclusions be firmly based in the practical meaning of the concepts involved. No axiom or law or syntax is laid down in advance" (Turksen, 1991). In this way the fuzzy set membership functions will relate explicitly to evaluations of impact significance that are specific to this development proposal and the context of the receiving environment.

CASE STUDY METHDOLOGY

Selection of Impacts for Consideration

The range of impacts that are typically addressed in EIA is broad, and for pragmatic reasons it was necessary to focus on a limited selection. Given the type of development project proposed and the environmental setting, it was anticipated that noise and landscape / visual effects would be issues of central concern, and this was confirmed by the responses made by local residents at an 'open day' hosted by the developer in the nearby village of Thorney. These two impacts also presented a useful test-bed for the broader applicability of the fuzzy set research approach in the sense that orthodox approaches to noise assessment are typically highly quantitative in nature, whilst landscape and visual assessments are underpinned by more qualitative methods of appraisal.

Noise Assessment Approach

In order to derive the fuzzy set memberships related to the evaluation of noise impact significance, a series of sound recordings of similar capacity wind turbines actually in operation were carried out using specialist equipment. Sound recordings were made at increasing distances from the turbines until the noise emitted became indistinguishable from the background, and at each recording location the sound pressure level (in dB (A) L_{eq}) was simultaneously measured. A random sequence of 30 noise samples each of 20 seconds duration was then selected. In a series of workshops, the noise levels were played to participants, making sure that the sound levels emitted were calibrated to match the levels originally noted. For each recording participants were asked to grade the extent to which the significance of the impact matched their personal assessment of what would constitute a "negligible", slight", "moderate", "substantial" and "very substantial" effect. Where respondents were individuals (e.g. the developer or noise consultant) the direct estimation approach was employed to extract the set membership. In contrast, the polling approach was used for workshops involving members of the public, previous research having found that this method is useful for unravelling a representative membership function for a group (Leung, 1988).

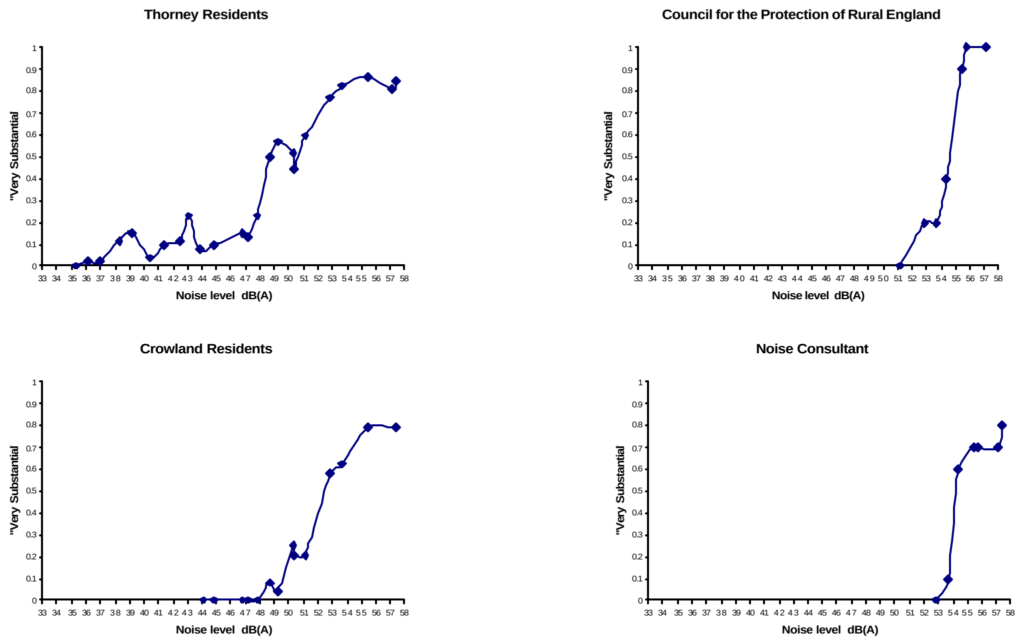
Landscape / Visual Impact Assessment Approach

A series of seven, publicly accessible, viewpoint locations were selected, all located in a 'landscape corridor' running south from a point adjacent to the proposed site and up to a distance of around 9km. Digital panoramic photographs were made of the landscape outlook using a focal length to match the magnification of the scene to the perspective of the viewer. Photomontages were then prepared, involving a series of images for each view containing different numbers / configurations of wind turbines (ranging from 2 through to 20 turbines – the maximum the development site could realistically contain). To enhance the realism of the photomontages, animated images were created to capture the visual effects caused by movement of the turbine blades. As with noise, a workshop approach was employed to determine the set membership using direct estimation or a polling approach as appropriate.

PRELIMINARY FINDINGS AND DISCUSSION

Examples of the membership functions derived for the fuzzy set "very substantial" noise impact are shown in Figure 2 (the developer did not consider any noise levels to be very substantial). In each case, the degree to which the noise experienced was considered by participants to be "very substantial" is indicated on the vertical axis, plotted against the actual noise level in dB (A) L_{eq}.

Figure 2. Membership Functions for "Very Substantial" Noise Impact

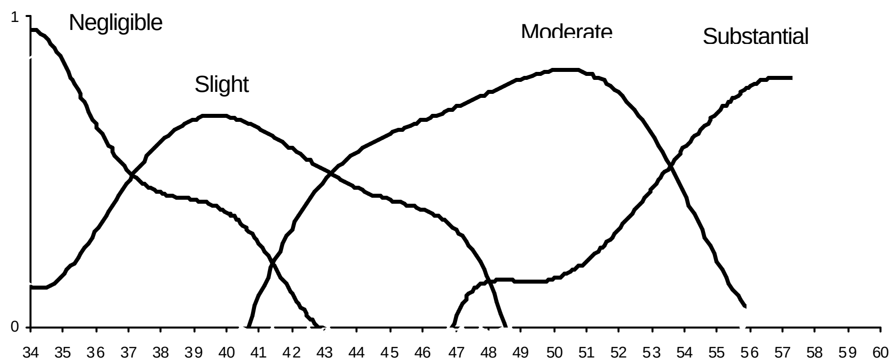


It is noticeable that the noise consultant and the respondent for the Council for the Protection of Rural England (CPRE), both produced membership functions that have a steep gradient, with membership of the set "very substantial" increasing rapidly between the range 53-56 dB i.e. these parties appear to have a tightly defined notion of the range of noise levels above which the impact is very substantial. In contrast the membership function for Thorney residents (the village closest to the proposal) covers a broader range, with lower noise levels (e.g. in the range 36-48 dB) exhibiting a partial membership of 0.1-0.2 in the set 'very substantial'. The particular sensitivity of these residents to wind turbine noise is evident when compared to the membership function for the residents of Crowland village, 5km from the site.

The illustrative fuzzy sets in Figure 2 clearly demonstrate the diversity of understandings and conceptualisation of the significance of noise impacts when related to the kind of natural language terms that are used to articulate impact significance in Environmental Impact Statements (EIS), and serve to exemplify the existence of lexical uncertainty in EIA – something that has to date received very little attention, either in practice or research circles.

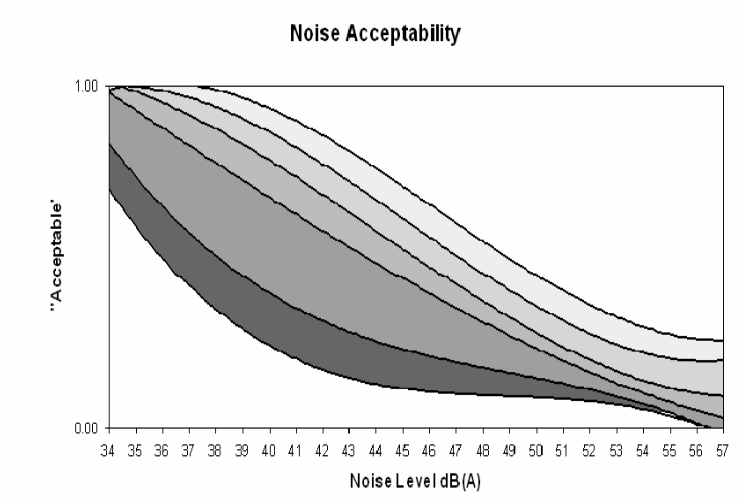
In defining impact significance in noise assessment for EIA, practitioners have a strong tendency to develop criteria that employ tightly defined, exclusive or 'crisp', bands of noise linked to natural language terms, e.g. 3-5 dB may be defined as a "minor" impact, 6-10 dB as "moderate", and 11-15 dB as a "major" impact. In reality, the boundaries between these levels or degrees of impact are not clear cut, and fuzzy set analysis provides a methodology well placed to capture the nature the 'shades of grey' that present a more realistic characterisation. Figure 3 provides an example that illustrates the cross-over that actually exists between terms used to describe the significance of noise impacts. For instance, in this case, the noise level 43 dB is considered by the windfarm developer to be a member of the set "Moderate" to degree 0.4, and the set "Slight" to degree 0.6– in other words, the impact might be considered to be "mostly slight but starting to move towards a moderately significant impact".

Figure 3. Significance of Noise Impact: Developer Membership Functions



In addition to providing a means for articulating perspectives on the significance of impacts, fuzzy set theory also provides a framework that enables the explicit identification of degrees of impact significance *across* the different stakeholder groups. In Figure 4, the uppermost curve defines the maximum degree of membership of the set "acceptable change" (also defined as the fuzzy set union, logic operator 'OR') for each and every noise level across the six different stakeholder groups investigated in the research. The next curve below this relates to the second highest degree of set membership for each noise level, and so on, until the lowest or 6th curve, representing the lowest degree of membership of the set "acceptable change" (also defined as the fuzzy set intersection, logic operator 'AND').

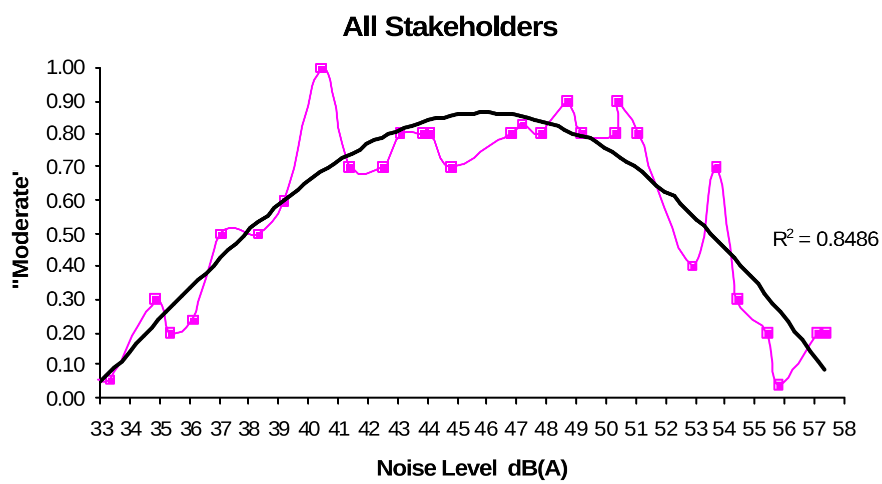
Figure 4. Noise Impact Acceptability



In Figure 4, the width of the difference between the maximum and minimum 'acceptability' curve is worthy of comment. For noise levels below around 37 dB the width of the graph is relatively narrow, as it is again for noise levels beyond 50 dB, indicating that there is less disagreement regarding the degree of membership of the set ‘acceptable’ for these noise levels. This contrasts to the region between 38-45 dB where the width of the graph is greater, indicative of more diversity in perceptions of acceptability. Interestingly these noise levels are those closest to the baseline conditions for the area.

Fuzzy logic operators also provide a means for generating membership functions for the EIA that might be considered more representative of the diversity of perspectives amongst stakeholders. In particular the union of sets (logic operator ‘OR’), defined in fuzzy set theory as the maximum membership value across the sets, serves to generate a ‘precautionary’ interpretation of impact significance across stakeholders. Figure 5 illustrates an example showing the output from determining the union of the individual stakeholder sets for “Moderate” noise impact significance.

Figure 5. Fuzzy Logic Operators: Union for “Moderate” Impact Significance



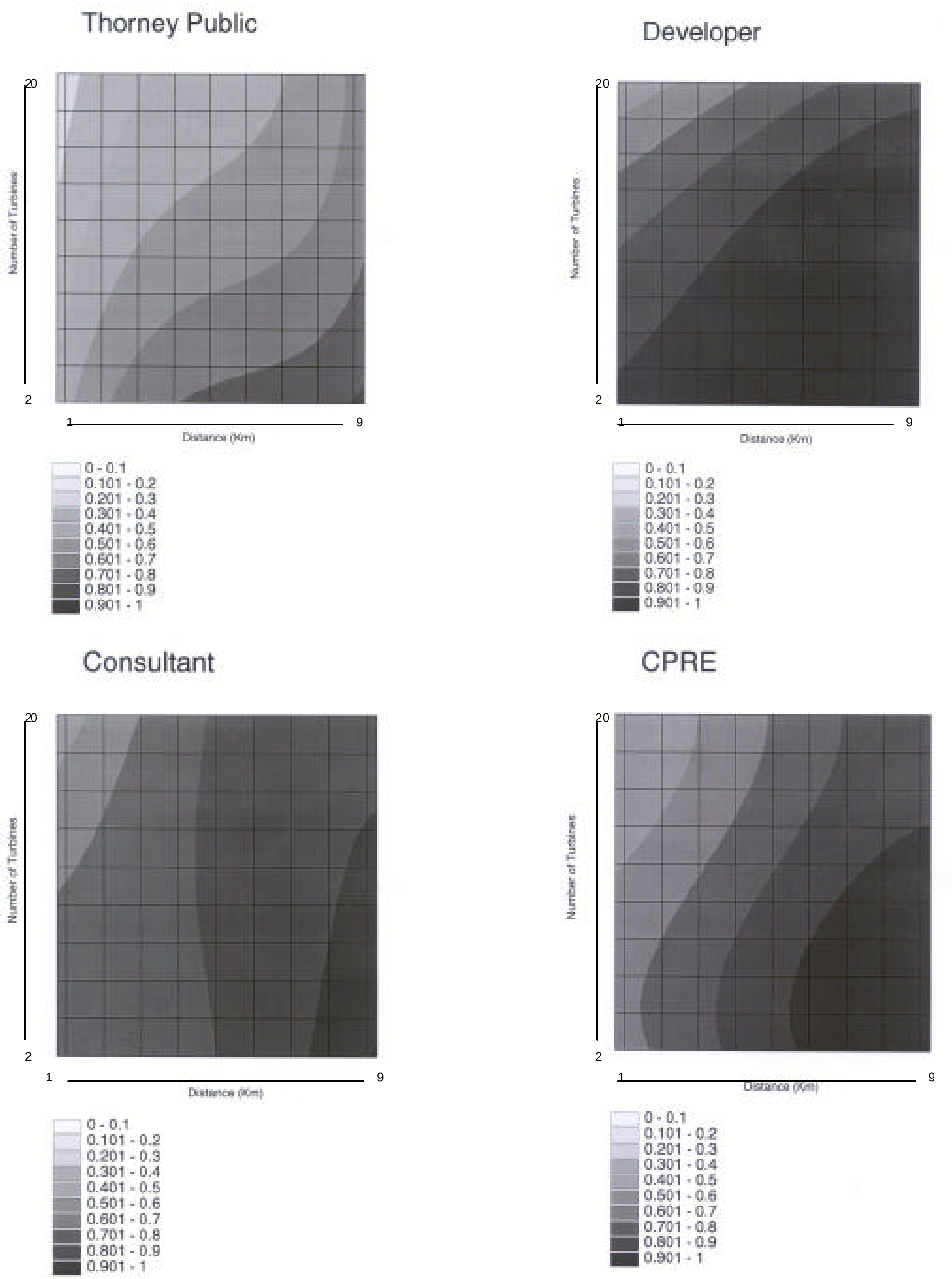
The preceding analysis has concerned noise impacts, and has focussed upon the identification of the nature of transition and equivalence between certain linguistic variables typically employed in EIA (‘substantial’, ‘moderate’, ‘slight’, ‘acceptable’ etc) and decibel level as the continuous variable underpinning the membership functions.

In the case of landscape and visual effects, the fuzzy set approach employed has sought to ‘map’ degrees of impact significance and impact acceptability by exploring the relationship of the linguistic variables with two variables acting in combination, namely:

- size of the development (as determined by the number of turbines); and
- magnitude of the impact (as determined by distance from the proposal).

Preliminary examples are given in Figure 6, which illustrates the membership functions for the fuzzy set ‘acceptable change’ for 4 different stakeholder groups.

Figure 6. Membership Functions for “Acceptable” Landscape / Visual Impact



As with the noise analysis, the approach serves to aid transparency for the EIA in the sense that the different perspectives can be explored for the same assessment terms. The approach also has potential for assisting with determining ‘Limits to Acceptable Change’ that could be used as an aid to determining project design and possibly with regards to assisting in development siting decision-making.

PRELIMINARY CONCLUSIONS

The nature of regulatory systems governing EIA has led to the evolution of institutional and administrative structures that enforce a highly reductionist conceptualisation of the environment, serving to treat environmental impacts in a compartmentalised, thematic, and predominantly technical or ‘instrumental’ manner. As a consequence, EIA regulatory systems can be seen to lend authority to the ‘knowledge claims’ fostered by experts and expert approaches, resulting in effect in an institutionalised dominance of instrumental rationality. However, as noted by Lawrence (1993) “As soon as the orientation shifts to interpretation, evaluation and prescription, impact assessment moves from the realm of science - to the value-laden realm of personal, social, and political preference and decision making”. The use of natural language terms regarding the significance of impacts is helpful in EIA, but is undoubtedly value laden and does raise the important issue of lexical uncertainty.

This paper has reported on preliminary findings relating to the exploration of fuzzy set theory for addressing lexical uncertainty, and as a means for identifying the gradients that exist in terms of different stakeholder perspectives on the relative degree of impacts. Using a simulation approach the research represents an attempt to bridge the gap that exists between instrumental experts and other ‘non-expert’ stakeholder groups, especially with respect to the issue of how to transfer information from the public and other stakeholders to the experts. In this sense the approach may be said to be moving towards a more communicative rationality, where EIA serves as a transactive planning tool, involving exchange of processed knowledge of experts with local knowledge of affected citizens.

Key advantages of the approach are identified as follows:

- it is empirically grounded and sensitive to the context specific nature of significance evaluation;
- it has the advantage of recognizing (rather than denying) the ‘shades of grey’ in boundaries between impact significance categories, and can serve to increase transparency of the assessment; and
- it also has potential to feed into more collaborative approaches to EIA, whereby the fuzzy set membership functions form the basis for negotiation and highlighting differences, even through to the use of fuzzy set analysis as a mean of defining significance terms across the stakeholder groups.

However, it should be recognised that noise and landscape effects are fundamentally “experiential” impacts, and through the simulation approach employed it was possible to bring the impacts to a level that was meaningful to a broader audience, and hence it was possible to derive the fuzzy set membership functions. Applying the approach to other impact areas to achieve the same broad degree of user engagement is challenging (e.g. grading changes in air quality). The approach is also resource intensive and arguably abstract, potentially reducing the appeal to EIA practitioners. Finally, and perhaps of most importance, by recognizing lexical uncertainty and engaging in a more open and inclusive approach to defining impact significance, the ability of a developer to control the analysis and conclusions contained in an EIS is dramatically eroded, and it is likely to be an unwillingness to relinquish this power that provides perhaps the greatest barrier to employing fuzzy set analysis in EIA.

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