Subsurface activities and decision support systems: an analysis of the requirements for a social acceptance-motivated decision support system

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Abstract

In this paper, we present a novel perspective on evaluating subsurface activities by increasing the role of social acceptance in the decision-making process. We use the triangle of social acceptance to structure and analyze the decision-making problem in three classes: social–political, market, and community acceptance. This allows the inclusion of strategic and social concerns, beside economical and environmental aspects in the evaluation of subsurface activities. We analyze the requirements of a decision support system for each class according to three aspects: the requirements originating from the context, the requirements derived from the decision-making process, and the extent to which the decision support system can fulfill these requirements. Furthermore, we identify the mechanisms that shape and govern the interactions between the requirements and limitations that result from the context and decision-making process of subsurface activities. We conclude that the requirements of a decision support system for subsurface activities are very different for each class of social acceptance. In addition, we find that several aspects need to be included in an earlier phase of the decision-making process for subsurface activities.

Keywords: Decision making, subsurface activities decision support system, social acceptance.

1 Introduction

Decision makers are often confronted with a high degree of uncertainty when dealing with activities involving the deployment of subsurface resources, such as natural gas production (Ministerie van I&M, 2011). This uncertainty complicates the decision-making process, which is already affected by a number of recent trends. First, the increasing level of utilization of the subsurface by a growing variety of activities, such as shale gas production and the underground storage of CO_2, increases the chance of interference between subsurface activities (Weyer, 2013). Secondly, the distribution of costs and benefits, in the broadest sense of the word, is often perceived by several stakeholders as unfair (Franks, 2009). Third, society is becoming more concerned with the risks and socio-physical changes involved, such as an increase in safety risks or changes in land use associated with subsurface activities, which in many cases result in protests, delays, or project termination (Franks, 2009).

Recent experiences in the Netherlands show that the increasing utilization of the subsurface, the perceived distribution of cost and benefits, as well as increasing attention to risks and socio-physical changes have a negative influence on the quality and effectiveness of the decision-making process for subsurface activities (van Os et al., 2014a) We will therefore investigate the requirements for a decision support system in order to improve the current decision-making process. Hence, the challenge is to investigate whether policies, permit procedures, and associated instruments such as a decision support system (DSS) can be redefined. Furthermore, instead of focusing on siting issues of undesired activities ("not in my back yard"), it is important to maintain a broad perspective when analyzing policies or formulating a DSS (Wolsink, 2010). Therefore, following Koornneef et al. (2008), we argue that the decision-making process and subsequent DSS for the permit procedure for a subsurface activity have to be expanded by including strategic and social concerns, that is, competing alternatives and views from host community members. Furthermore, in relation to strategic concerns, the DSS should be able to provide insight about the impact of a strategic decision and the means to identify potential mitigating actions (Vicente and Partidário, 2006). However, how to incorporate all these aspects in a single DSS is still unclear (Koornneef et al., 2008). In this article, we propose a method which includes these aspects and to determine which methods are best suited for the task.

In our analysis, we determine the requirements of a DSS for subsurface activities by analyzing the uncertainties, risks, and decision-making processes associated with subsurface activities. In addition, following the recommendation of Dyer et al. (1992), we include the characteristics and preferences of stakeholders in our analysis of the requirements of a DSS. To the best of our knowledge, this kind of analysis has never been done before for subsurface activities. Several studies have addressed the different aspects affecting the design of a DSS (Al-Harbi, 2001,Dyer et al., 1992). However, in these studies the requirements and choices were analyzed in isolation, without including interactions between the context, the decision-making process, and stakeholder characteristics. A previous study by van Os et al. (2014b) concludes that the interaction of these aspects substantially affects the requirements of a DSS. Therefore, we believe that our analysis framework presented in this article will increase our knowledge of these interactions and allow us to formulate a DSS for subsurface activities from a social acceptance perspective. Furthermore, to the best of our knowledge, this is the first attempt to incorporate strategic and social concerns, besides economic and environmental concerns, in a single DSS for subsurface activities.

To analyze the decision-making situation for subsurface activities, we use the triangle of social acceptance (Wüstenhagen et al., 2007), because it allows for a comprehensive analysis of the different driving forces, stakeholders, and their concerns (van Os et al., 2014a). The triangle divides the decision-making situation into three classes: social–political, market, and community acceptance (Figure 1).

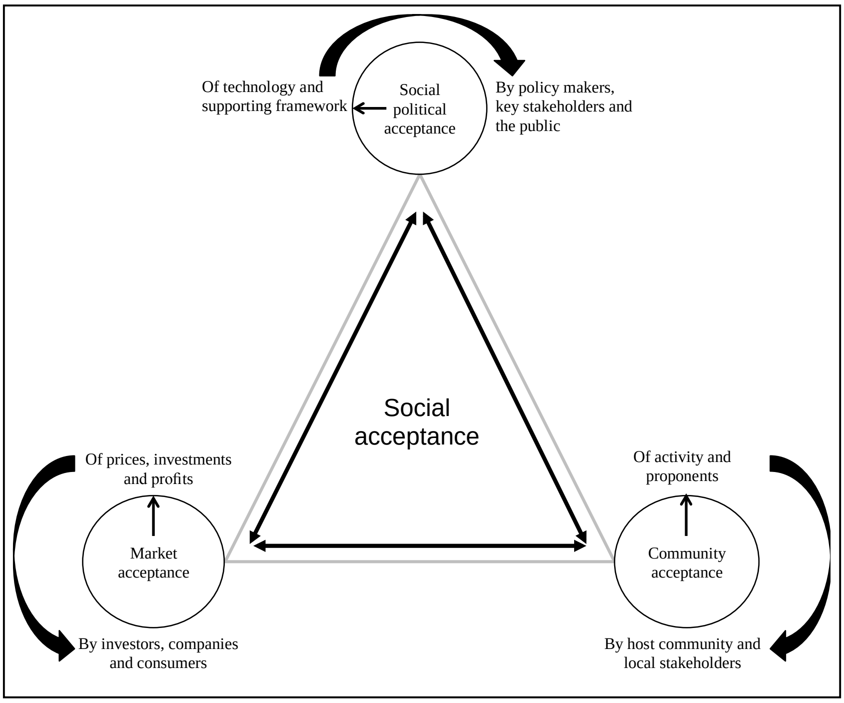

Figure 1: Triangle of social acceptance (Wüstenhagen et al., 2007). The three classes of social acceptance are depicted as circles. The small arrows indicate the concerns of the class and the curved arrows indicate the relevant stakeholders. The triangle in the middle indicates the interaction between the three classes of social acceptance. In the social–political acceptance class, the main goal of a decision support system is to gain better insight into the contribution of a subsurface activity to the realization of policy goals both now and in the future. These policy goals are usually formulated broadly and at a highly abstract level, such as for energy security and CO_2 emission reduction (Wüstenhagen et al., 2007). In the market acceptance class, the main goal of the decision-support system is to determine the allocation of costs benefits and risks among market participants, which consist of producers as well as consumers. For the community acceptance class, the main element of the decision support system is to facilitate the judgment of the host community concerning the locally endured risks and the social, physical and economic changes resulting from the proposed subsurface activity as well as the reputation of the project owner (van Os et al., 2014b)

In this triangle, social acceptance is viewed from a broad perspective (van Os et al., 2014a,Wüstenhagen et al., 2007). Furthermore, as indicated in Figure 1, the acceptance level for each class is determined by the stakeholder’s views and concerns. Hence the manner in which trust, procedural justice and empowerment e.g. the perceived fairness of the decision-making process, are addressed in the decision-making process and in the underlying decision support system directly affect the acceptance level (van Os et. al., 2014a, Marsden and Markusson, 2011). We want to point out that there may be a problem with unambiguously defining the stakeholders and their concerns and interests. Therefore, we will analyze the role of the stakeholders congruent with each category of social acceptance. (van Os et al., 2014a) . Furthermore, our interpretation of the triangle of social acceptance differs from the original interpretation of Wüstenhagen et. al., (2007), which focuses on institutional changes necessary for the implementation of renewable. However, following van Os et. al., (2014a) and van Os et. al., (2014b), we will use the triangle of social acceptance to indentify the relationship between the different driving forces affecting subsurface activities and the relevant stakeholder. Furthermore, we use the triangle to identify the interaction between different driving forces and between the different stakeholders. This allows the structuring of the decision-making process. Furthermore, we use the insight underlying the triangle of social acceptance, for example role of empowerment, procedural justice and trust building, as criteria for analyzing the requirements for a decision support system for subsurface activities.

In Section 2, we describe the context for subsurface activities for all three classes of social acceptance and we analyze the uncertainties, risks, and interactions between the classes. In Section 3, we describe the requirements and limitations of decision-making processes following from the conditions set by the context. In Section 4, we assess the suitability of several common DSS approaches for subsurface activities, based on analysis of the requirements and limitations. Section 5 comprises a discussion of the results in which we reflect on the universal applicability of our findings and the assumptions used in our analysis. Furthermore, we indicate possibilities for future research.

2 Context of subsurface activities

2.1 Context analysis criteria

We are predominantly interested in the methodology for addressing uncertainty and risk in a DSS and less so in an in-depth analysis of the uncertainties and risks themselves . To this end we identify uncertainty as an important factor shaping the context of subsurface activities, because it influences both the severity and likelihood of risk, as well as possibilities for mitigation. These aspects play a role in the acceptance of an activity (van Os et al., 2014b). Following Walker et al. (2005, p5), we define uncertainty as “any deviation from the unachievable ideal of complete deterministic knowledge.” However, uncertainty as a concept is too broad for our analysis. Therefore, we focus on three aspects, namely, the nature, level, and location of the uncertainty. The *nature* of uncertainty is not only caused by incomplete knowledge but is also induced by the variability of situations, in both time and space, to which the decision applies (Walker et al., 2005). The *level* of uncertainty can vary between deterministic knowledge and total ignorance (Walker et al., 2005). The *location* of uncertainty within the decision-making process can be related to the quality or completeness of the input information, results, or interactions between the elements of the process (LeRoy and Singell, 1987,Walker et al., 2005).

In addition, uncertainty affects risk, which has a large influence on the acceptance of subsurface activities (van Os et al., 2014b). Generally, risk can be defined as the combination of two basic dimensions: (a) possible consequences and (b) associated uncertainties (Aven et al., 2007). However, because we differentiate between risk and uncertainty, we define risk as (a) possible consequences and (b) likelihood. Furthermore, risks related to subsurface activities are generally characterized by large uncertainty margins (Zoback et al., 2010), although, depending on the maturity of the activity and the level of site-specific knowledge—for example, drilling data and seismic imaging—there is some variation between activities and regions. Despite the assumption that knowledge improvements could result in more accurate risk assessments, some uncertainty will always remain, which needs to be considered in the decision-making process.

2.2 Social–political acceptance context

2.2.1 Uncertainty in the social–political acceptance class

From a social–political perspective, the importance of an activity is determined by its contribution to policy goals. However, as described by van Os et al., (2014a), policy goals and subsurface activities can be framed in different ways. Although this is an important aspects, it is of lesser relevance when designing a DSS, since the main object is to evaluate the effect that a policy goal has on the extent that a subsurface activity is appreciated and how to include this in a decision support system van Os et al., (2014b). We therefore consider the framing of policy goals beyond the scope of our research.

Most subsurface activities cover a long time span, often several decades (Otto, 1998). This complicates the choice between competing subsurface activities, since their priorities are often disputed and time dependent, for instance, due to changing political and social preferences (Otto, 1998). An activity's actual contribution depends on a number of variables. For example, in the case of carbon capture and storage (CCS), some of these variables are unique to the activity, such as mineral dissolution, which affects storage integrity and capacity (Bolourinejad et al., 2014). Other variables, however, are used for comparison with competing activities. For instance, in the case of emissions reduction, CCS competes with renewable energy production, such as geothermal energy extraction. The activities may even compete for the same geological space, such as a depleted gas field, which technically could accommodate either activity (Bentham and Kirby, 2005). The relevant variables here are the interference, synergy, mutual exclusion, and/or sequences of the activities (Bentham and Kirby, 2005,Weyer, 2013). In all cases, alternative options would be to not exploit the geological space now, to preserve it for future exploitation, and to not exploit it at all. In other words, the "do nothing now" and "do nothing forever" alternatives need to be part of the assessment.

2.2.2 Risk in the social–political acceptance class

From a social–political acceptance perspective, one of the main risks of making a decision is that it could conflict with future social, economic, and cultural views. The impact of such a decision is determined, first, by the products provided by the selected subsurface activity and, second, by those that could be provided by a competing alternative activity. The irreversible nature of many activities limits the possibilities of mitigating their potential adverse effects. In addition, the finite character of the subsurface, that is, the scarcity of geological assets, increases the severity of making a decision that conflicts with future views.

2.2.3 Interactions with the other acceptance classes

Lack of a clear prioritization of the different policy goals could result in an unstable policy support framework for subsurface activities. This increases the uncertainty for stakeholders in the other acceptance classes. For market parties, it could affect the risks associated with a project, such as a lower profit margin or a delay in investment (Blyth and Yang, 2006). Miller and Lessard (2001), refer to this as sovereign risk, which results from a lack of trust on the part of market parties in the stability of the social-political institutions. Lack of prioritization of policy goals could also result in lower community acceptance, especially if an activity's necessity is uncertain or when the underlying values are contested, for example the manner in which policy goals are framed (van Os et al., 2014a,Voogd, 1983). We therefore argue that a clear prioritization of policy goals, preferably based on a strategic vision or logic, is essential (van Os et al., 2014a).

2.3 Market acceptance context

2.3.1 Uncertainty in the market acceptance class

Following Wüstenhagen and Menichetti (2012), we would argue that an ‘‘ambidextrous policy’’, is the preferred approach for market acceptance. This is a twofold policy strategy which firstly focuses on adjusting the investment behavior of incumbent stakeholders and secondly focuses on providing opportunities for new market stakeholders. However before such policies can be formulated and applied, it is necessary to have a good understanding of the different requirements, limitations and possibilities that affect these policies. Wüstenhagen and Menichetti (2012), indicate several important aspects that should be included in the assessment of market acceptance, such as the risk-return perceptions of market stakeholders and the path dependence that follows from the action or behavior of market parties. Subsurface activities often require substantial upfront investments, such as for drilling wells or constructing a pipeline infrastructure. Changes in terms and conditions—such as taxes, tariffs, subsidies, or regulatory burden—will affect a project's profitability and, therefore, its economic lifetime. Therefore, from a social acceptance perspective, uncertainty manifests itself predominantly in the project's duration. Moreover, reusing the same geological space for a different activity can prolong the project's duration. One such example is the reuse of a depleted gas field as an underground gas storage facility (Breunese, 2006). After the cessation of production, the costs of the (mandatory) abandonment of wells can be avoided by reusing them as injectors or producers in the underground gas storage phase, reducing the initial investment. At the same time, the probability of success is increased, because the primary activity already provided knowledge about the geological asset. This can be considered a synergetic effect between activities.

2.3.2 Risks in the market acceptance class

The risks associated with subsurface activities can be divided into three groups:

- Technical risks, such as the production performance of an oil well, which can be below expected levels due to poor reservoir permeability (Agarwal et al., 1999).
- Risks related to the market itself, such as the declining gas prices in the United States as a result of the shale gas boom (Wang et al., 2014).
- Non-technical risks resulting from sociocultural, socioeconomic or environmental changes over time (Franks, 2009,Krijnen, 2014).

In the following, we address each type of risk.

2.3.2.1 Technical risks

In the case of subsurface activities, following the definition and classification of risk of Miller and Lessard (2001, p439) we define technical risks as “risks related to the engineering difficulties, often inherent to the geological setting and technology applied, resulting in a deviation from the anticipated outcome.” In the case of a relatively mature subsurface activity, such as oil or gas development, the technical risks are usually well established via an exploration campaign prior to the start of the production phase. Common practice is to use a statistical approach consisting of a set of production forecasts with various likelihoods of occurrence (P90–P50–P10) based on expert judgment. For less well-developed activities, such as CCS, the lack of practical experience increases the uncertainty margin of the expected profitability (Bolourinejad et al., 2014). However, it can be assumed that improving the knowledge level, technology deployment, and practical experience will reduce the risk level and increase the understanding and effectiveness of mitigating measures associated with the technical risk.

2.3.2.2 Market risks

Market risks are associated with changes in market conditions, such as demand, supply, and price changes (Miller and Lessard, 2001). These risks are more difficult to predict than technical risks because of the diversity of the marketplace in which products from subsurface activities are competing not only with each other but also with those of other sources (Miller and Lessard, 2001). The scale of the different marketplaces is especially relevant when comparing alternative uses of a geological space. For example, the oil price is set in a global market, natural gas prices are set in regional markets, and prices for geothermal energy (direct heat) are set in local markets. These markets are characterized by different price and income developments and interact through exchange rates, substitution, and product complementarity, which affect market risk (Dowd, 2007,Giot and Laurent, 2003). Despite these difficulties, probabilistic forecasts can be used to assess market risks (Miller and Lessard, 2001).

2.3.2.3 Non-technical risks

Non-technical risks are becoming more widely recognized as problematic by the exploration and production (E&P) industry (Davis and Franks, 2011). Following Krijnen (2014) we define non-technical risks as: The unexpected change in the institutional constrains, as rooted in socio-cultural and socio-economic conditions, affecting the established normal practice. As indicated in a study by Franks (2009), one of the main causes of non-technical risk is the economic change related to an activity, such as a negative effect on the value of real estate. Non-technical risks, such as a change in the supporting policy framework or protests by the host community members, could restrict the lifetime and profitability of an activity. The E&P industry has therefore responded by increasing its efforts to identify and quantify these risks upfront in their business cases and investment decisions for subsurface activities (Franks, 2009,Laplante and Spears, 2008).

2.3.3 Interactions with the other acceptance classes

Although non-technical risks manifest themselves in the market acceptance class in the form of decreased revenues, delays, increased operational costs, or the complete abandonment of an activity, they are the result of the dynamics in the two other classes of social acceptance (Davis and Franks, 2011). However, the current permit procedure for subsurface activities, for example, in the Netherlands and in Germany, focuses only on the profitability for the company and the state and not on the impact regarding other stakeholders, such as the host community (Ministry of Economic affairs, Agriculture and Innovation, 2012,Weyer, 2013). A proactive approach, in collaboration with the host community, to address the economic impact of an activity for a wider range of stakeholders will provide the means for identifying and assessing non-technical risks for market parties as well as facilitating the discussion about what is a fair distribution of cost and benefits, in the most broadest sense of the word, as perceived by the host community(Laplante and Spears, 2008).

2.4 Community acceptance context

2.4.1 Uncertainty in the community acceptance class

The way in which the risks and socio-physical changes associated with subsurface activities are perceived and judged by society changes over time. Assuming an a priori uniformly defined perception trend level of the risks and socio-physical changes could result in faulty assessment (van Os et al., 2014a). It is possible to improve this situation by performing a social impact assessment. In the field of social impact assessments the principle of free prior and informed consent (FPIC) forms the basis for community involvement (Anderson et al., 2011,Carley et al., 2012,Vanclay, 2006). This implies that the community should be involved before the final decision by the competent authority is made. In subsurface projects, however, development is preceded by an exploration phase, which provides information for the appropriate risk assessment and design of the activity to mitigate the technical risks. Often, however, the exploration phase itself, which in most cases involves drilling, is already perceived as risky and uncertain. This complicates the assessment of community acceptance and the timing of community involvement.

2.4.2 Risks in the community acceptance class

In accordance with the FPIC principle, the community requires a comprehensive understanding of the subsurface activity, including the associated technical and geological risks as well as socio-physical changes. However, the FPIC principle does not define the scope of the community's mandate. Whatever the range of subjects of interest and related knowledge levels may be, some aspects are not covered by the mandate of the community and are therefore handled by other stakeholders. This may be due to legislation or other policies, which define the responsibilities for other stakeholders. Therefore, there is always an interaction consisting of decisions and knowledge exchange between the community, the competent authority and the proponent of a subsurface activity. This interaction constitutes a risk in itself (see section 2.3.2.3), because the success of the interaction is greatly affected by aspects such as trust and the perception of justice), especially if the communities involvement is framed as a higher level of participation than the actual level of participation (van Os et. al., 2014b , van Os et al., 2014b). Therefore, the degree to which host communities can influence the decision-making process, including the nature and extent of a mitigation or financial compensation scheme, will affect the way in which the decision-making process, the technical and geological risks and the socio-physical changes of an activity are perceived and judged (Laplante and Spears, 2008). This means that a DSS should, especially for the community acceptance class, allow for higher levels of transparency and participation .

2.4.3 Interactions with the other acceptance classes

As shown by van Os et al., (2014b) in order to get an insight in the community acceptance the aspects of the perceived level of fairness of the decision-making process need to be included, such as procedural justice and empowerment. Therefore, following van Os et al., (2014b) who included this aspect in the analysis of the design criteria of a DSS, we have incorporated this aspect in the requirement that a DSS should allow for higher levels of transparency and participation in the decision-making process. In the past, the way the interactions between stakeholders were executed has resulted in several conflicts. Some were related to the power of decision, that is, the level at which the host community can influence a decision and the scope of the community's involvement, as in the case of induced earthquakes in the Groningen gas field (van der Voort and Vanclay, 2015). To reduce the frequency and severity of the earthquakes, part of the community wants to lower the level of gas production, which is under the mandate of the national state, that is, part of the social–political acceptance class. This will not only affect the state's revenues but also the profitability of the gas field operator and is therefore related to market acceptance. In other cases, as in the Barendrecht CCS case, the selection process for the site, which did not include the community, was perceived as non-transparent and resulted in conflict (Kuijper, 2011). Furthermore, in the case of the Wellenberg (Switzerland) nuclear waste repository the selection and delineation of the host community resulted in grievances from a neighboring community that would be also affected by the nuclear waste repository. However, they did not have a similar level of influence in the decision-making process and compensation (Krütli et al., 2010). These aspects often form a barrier for a meaningful participation of the host community, because it requires the delegation of decision power to the community, which may conflict with the institutional framework. Therefore, it can be concluded that it is important that all stakeholders in an early phase of a project have a clear understanding of the required power of decision and the scope of the communities involvement, otherwise it will result in lower levels of community acceptance.

3 Decision-making process for subsurface activities

3.1 Decision-making process analysis criteria

In this section, we analyze the decision-making process to determine the design criteria for a DSS. We focus on the following three dimensions of the decision-making process and associated design criteria (van Os et al., 2014b).

- The *inter-subjective dimension,* which is related to who the relevant stakeholders are and their level of knowledge. The associated design criterion relates to the extent to which the DSS should accommodate stakeholder communications, information exchange, and problem structuring and depends on who the relevant stakeholders are and their knowledge level (van Os et al., 2014b).
- The *object dimension,* which relates to the kinds of concerns that should be included in the decision-making process. The associated design criterion

involves measuring the scale of the required input information (van Os et al., 2014b).

- The *subject dimension,* which deals with the rationality of the decision-making process. This is related to manner in which decisions are operationalized and substantiated in the decision-making process. Rationality can range between technical and communicative rationality and the most optimal form is based on the scope of the decisions and hierarchical nature of the decision-making process (van Os et al., 2014b, de Roo and Porter, 2007).

3.2 Decision-making process for social–political acceptance

3.2.1 Stakeholders and their responsibilities

The legal framework of a nation determines which stakeholders are responsible for realizing policy goals and underlying policy instruments, such as permits for subsurface activities. Generally, stakeholders have a base of knowledge that is strongly related to their responsibilities. The Dutch Geological Survey, for example, is the custodian of the geological knowledge base, which they deploy when advising the (Ministry of Economic affairs, Agriculture and Innovation, 2012), that is, the competent authority. However, other variables affected by the geological setting, such as the profitability of a subsurface activity, are not part of the knowledge base of the Dutch Geological Survey. It is therefore important that a DSS enable communications between the stakeholders who are responsible for different interlinked aspects of the subsurface activity.

3.2.2 Rationality of social–political acceptance

Otto (1997) observes that, in most countries, the decision-making process for subsurface activities has a top–down approach. Furthermore, in most cases, policy goals are formulated at a high abstract level, that is, referring only to “the what” and not to “the how.” Moreover, these policy goals are often formulated in isolation, resulting in single fixed targets, such as the Kyoto Protocol emission reduction goals (Babiker and Eckaus, 2002). Therefore, the rationality for social–political acceptance should be able to handle single fixed targets. Furthermore, the decision-making process should focus on goal maximization, in view of the finite number of geological assets, that is, scarcity.

3.3 Decision-making process for market acceptance

3.3.1 Stakeholders and their responsibilities

In most countries, the state is responsible for setting the conditions for a subsurface activity, including the tax rates, tariff levels, subsidy levels, policy framework, and regulations (Otto, 1997). These conditions affect the opportunities for a market party to execute a subsurface activity and determine the corresponding profitability, as well as the distribution of profits and costs between stakeholders. These conditions are usually formulated so that the effect on the distribution of benefits and costs can be quantified (Otto, 1998). When the primary activity is followed by a series of competing secondary activities, the quantification of the profitability becomes more difficult, because more information is needed (Linden and Voogd, 2004). In addition, the secondary activity may not be part of the core business of the operator of the primary activity.

Furthermore, to determine the impact of all the alternatives for a geological asset, additional input information is required that may not be available at this phase of the decision-making process. This knowledge gap can be filled through additional investigations, albeit incurring additional time and money. Furthermore, the number of alternatives depends on the number of competing activities and their interference, which can result in an excessive number of alternatives. Therefore, to keep the decision-making process manageable, the number of alternatives for which the economic value is evaluated should be minimized (Linden and Voogd, 2004). However, from a social acceptance perspective, this reduction of alternatives should be based on relatively objective input and a transparent process. Ranking in the social–political acceptance class could serve as a basis to reduce the number of alternatives evaluated in the market acceptance class. This approach has the added value that the results from the social–political acceptance class are incorporated into the market acceptance class. However, this requires that the evaluation in the social–

political acceptance class is performed in a transparent and holistic fashion in cooperation with the host community.

3.3.2 Assessing the assessment

The assessment and validation of non-technical risks are important in the decision-making process for market acceptance and are, in most cases, based on perceptions and lessons learned from other projects. This assessment is strongly affected by the supporting framework, the host community, and the nature and scale of the subsurface project (Banks, 2008,Franks, 2009). Meaning that there will be always uncertainty in assessing a priori the likelihood and impact of non-technical risks. Therefore, it is imperative that both the host communities and the responsible authority are consulted in the decision-making process to identify, quantify, and mitigate non-technical risks (Franks, 2009).

3.3.3 Rationality of market acceptance

In recent decades, the E&P industry has moved away from a single focus on profitability by including other targets, such as environmental performance (Davis and Franks, 2011). However, it still often uses single fixed targets for problem solving, in line with a technocratic approach (Bridge, 2004). In the past, two stakeholders dominated the decision-making process: the company in question and the state. However, when host communities and third parties, such as non-governmental organizations (NGOs), are involved, the hierarchical nature of the decision-making process needs to move from a top–down approach to a shared governance approach (de Roo and Porter, 2007). Therefore, to reduce non-technical risks, the market acceptance class must include broad objectives to a greater extent.

3.4 Decision-making process for community acceptance

3.4.1 Timing of community involvement

According to the FPIC principle, communities should be involved in the process as early as possible (Anderson et al., 2011,Carley et al., 2012,Vanclay, 2006). At such an early stage, however, the input information is usually characterized by a low level of detail and high levels of uncertainty. Furthermore, information concerning the risk and socio-physical changes, which is usually the community's main concern, only becomes available after the exploration and design phase (Franks, 2009,Weyer, 2013). The level of community involvement should hence correspond to the quality of the required input information available at that time. This implies that, when the information quality and trust levels are still low, the involvement should focus more on joint knowledge building rather than consultation. At this stage, the identification of possible concerns and the needs and ambitions of the host community could result in lower non-technical risk for the market. However, when the quality of information and trust is high, the decision support system should be able to facilitate the community in providing a judgment about the proposed activity, which could result in a more positive stance of the community towards the activity.

3.4.2 Scope of community involvement

The extent to which the host community can be effectively informed about the risks and socio-physical changes of a subsurface activity depends on their level of knowledge. In the fields of geology, engineering, and economy, this level is often low, especially in comparison with other stakeholders involved in the decision-making process. In that situation, the community usually acquires such knowledge through external experts and NGOs. On the other hand, the community may have a high level of local tacit knowledge related to a proposed project site, whereas this is usually very poorly developed among the other stakeholders. These differences in the nature and level of knowledge can determine the scope of the communities' involvement in addition to what is required by law. Furthermore, for the host community to express informed consent, there needs to be knowledge exchange. This can take different forms, depending on the nature of the concerns, which can be narrow, such as a dominant focus on the perceived risks, or broader, such as climate change and economic growth. If the concerns are narrow and/or trust in the experts is low, knowledge exchange is best accompanied by joint knowledge building. When concerns are broad and the experts are highly trusted, the exchange of knowledge could be limited to informing the host community.

Furthermore, the scope of the decision-making process could also reflect the needs and ambitions of the community (Franks, 2009). One is often entitled to, wants, or is offered a form of compensation for hosting a subsurface activity (ter Mors et al., 2012). In addition, the governance structure and level of compensation will affect the acceptance level of subsurface activity (Franks, 2009). However, the business case of an activity and the applicable supporting regulatory framework will determine the degree to which these needs and ambitions can be realized. For example, in the case of an economically marginal activity, the costs of the compensation scheme can be substantial in comparison with the revenues. This can result in the proponent considering the project non-economically viable, which in turn will affect the extent to which policy goals will be realized. This interaction between the acceptance classes needs be included in a DSS for subsurface activities by allowing for an iterative process in which the effect of a decision originating from one class is determined for the other classes.

4 DSS

4.1 DSS analysis criteria

In this section, we analyze the preferred evaluation methods for a DSS for each social acceptance class. To this end, we select three design criteria of evaluation methods from the fields of multi-criteria decision aid methods and investment evaluations (van Os et al., 2014b).

- The *elucidation mode* is related to the way in which preferences for different evaluation criteria are obtained. Two of the most common elucidation modes are direct rating, where a weight factor is assigned to each criterion, and pairwise comparison, where the dominant criterion for each pair of evaluation criteria is determined (Roy, 1990,Montis and Toro, 2005). The level to which the elucidation method reflects the cognitive choice process of the stakeholders will affect their understanding and acceptance of the evaluation results (Guitouni and Martel, 1998).
- The *aggregation optimization mode* is associated with the way in which the final score is aggregated, that is, based on performance or preference

(Guitouni and Martel, 1998). The level to which the aggregation mode reflects the goal of the decision-making process affects the acceptance and usefulness of the evaluation results. The preferred aggregation mode for goal maximization is based on performance. The preferred aggregation mode for process optimization is based on preference. However, in practice, most decision-making situations will consist of a combination of goal maximization and process optimization (de Roo and Rauws, 2012). This means that the preferred aggregation mode in practice will also be a combination of performance and preference optimization.

- The *measuring scale of the ranking*, ranging from quantitative to qualitative differences between the rank positions. For quantitative criterion scales, the numerical distance between alternative scores is known and fixed. However, for qualitative criterion scales, the numerical distance between alternative scores sometimes cannot be determined and is sometimes flexible (Schenkerman, 1994). The more quantitative this ranking, the stronger the basis for a decision and therefore the greater the acceptance of the evaluation results.

The requirements and limitations set by the context and decision-making process of subsurface activities determine the optimal values for these three criteria. Furthermore, because the requirements and limitations are different for each class of social acceptance, we analyze the optimal values for the design criteria for each class.

4.2 Social–political acceptance

4.2.1 Elucidation mode

In the case of social–political acceptance, the ranking of an activity should be based on the degree to which it contributes to the achievement of policy goals, because this allows for goal maximization (see Sections 2.2.1 and 3.2.2). However, to compare activities that contribute to different policy goals, the DSS needs to consider the preference for these goals. Separating the relative objective score of an activity and the relative subjective preference for a policy goal in the form of weight factors results in a more transparent ranking. This facilitates the discussion between the stakeholders about the need and necessity of subsurface activities under evaluation.

Therefore, the elucidation mode should resemble the degree to which stakeholders can and want to prioritize policy goals. When the stakeholders have a clear understanding of this prioritization, a direct weighting approach is more suitable. When prioritization is less clear, a pairwise comparison is better. However, as indicated in Section 2.2.3, the lack of clear prioritization can result in uncertainties for the two other classes. Hence the direct weighting approach is better suited, because it allows for a clearer distinction between the priorities of different policy goals.

4.2.2 Aggregation mode

As described in Section 3.2.2, the ranking in the social–political acceptance class needs to facilitate goal maximization in the decision-making process. This means that alternatives need to be evaluated on the basis of their performance in realizing policy goals. Furthermore, the diverse nature of the policy goals requires a DSS that is able to aggregate different criteria with different measuring scales. In addition, the computation of the scores should be based on relatively objective input variables (see Section 2.3.2.1) to obtain a quantitative ranking of the alternatives. The DSS for social–political acceptance should also enable an initial screening of a large group of competing alternatives. Weighted goal interval programming (WGIP), part of the multi-criteria decision method family, is a multi-objective optimization aggregation approach that meets all these requirements (Charnes and Cooper, 1977,Jones and Tamiz, 2002,Romero, 2014,Stewart, 1992). The WGIP uses a specific constraint, that is, a policy goal that should be satisfied as much as possible (Charnes and Cooper, 1977). In our case, the score of an activity is determined by the WGIP method, using the extent to which an activity contributes to the realization of policy goals as well as their priority (Tamiz et al., 1998). The weights serve a dual purpose:

1. To indicate the priority of the decision-maker.
2. To normalize the different scores to eliminate the bias of policy goals that have a higher order of magnitude and overcome incommensurability (Tamiz et al., 1998).

The WGIP method determines the score of an activity by using the policy goal—and not just the contribution in itself—as a baseline. Through the addition of the policy goal, the score is determined in a relative manner, which makes the assessment more robust, because a change in the policy goal at a higher or lower level can be incorporated without changing the assessment methodology (Charnes and Cooper, 1977). Generally, goal programming methods may suffer from Pareto efficiency, which in our case would mean that the extent to which one policy goal is realized can be increased without affecting the realization of another policy goal (Tamiz et al., 1998). It can, however, be argued that the likelihood of Pareto efficiency is low, due to interferences between subsurface activities. Furthermore, considering the facilitating function of the DSS in the discussion about the priority of policy goals, it can be argued that the interactive restoration approach is suitable in overcoming possible Pareto efficiency. In this iterative approach, stakeholders select a policy goal they want to improve, followed by the next policy goal, and so forth (Tamiz and Jones. 1996).

4.2.3 Measuring scale of the ranking

The extent to which the WGIP method is able to provide a quantitative ranking will depend on the elucidation mode and the way policy goals are formulated (van Os et al., 2014b). However, as described in Section 4.2.2, the most suitable elucidation mode in social–political acceptance is the direct weighting method, which can lead to a quantitative ranking of results. This means that the main limiting factor for the measuring scale of the ranking is the way in which policy goals are formulated. For example, more quantitatively defined policy goals, such as a reduction in the emission of X by an amount Y in the year Z, will result in a quantitative ranking of the alternatives. Policy goals, which are formulated more qualitatively, will result in a qualitative ranking of the alternatives. However, it is unlikely that all policy goals will be formulated similarly. Therefore, a DSS should be flexible enough to accommodate for such differences.

4.3 Market acceptance

4.3.1 Elucidation mode

For each risk group, it is possible to indicate the preferred elucidation mode for assessing the risk level. This is done on the basis of the nature as well as availability and quality of the input information (Blyth and Yang, 2006). For example, technical risks manifest themselves as a range of values for certain input parameters, such as daily production rates. This range can be assessed for individual parameters by applying simple statistical methods to acquired data and information. The interaction between parameters can, however, be quite complex. In the E&P industry, they are usually analyzed with Monte Carlo simulations (Suslick and Schiozer, 2004). Market risk manifests itself as changes in the demand and price of the products provided by the activity (see Section 2.3.2). This mechanism can be modeled using a simulation that explicitly makes assumptions about the likelihood and severity of events affecting demand and price (Blyth and Yang, 2006). Non-technical risks originating from the community acceptance class are highly volatile and diverse. To reduce these risks, a dialogue with the government and host community is required.

4.3.2 Aggregation mode

The expected profitability will determine the proponent's acceptance of a subsurface activity. The basic underlying assumption is that a project proponent is only willing to accept project risks if the expected return on investments is above a certain level, the so-called minimum attractive rate of return (Remer and Nieto, 1995).. A common approach in the E&P industry is to use a risk-adjusted discount rate to indicate the effect of risks on the profitability of an activity. However, the main challenge with risk-adjusted discount rates is the difficulty in determining the correct level, because too high a discount rate can result in unrealistic assessments of future costs and benefits for projects with a long lifespan (Smith and McCardle, 1999). In addition, Discounted cash flow (DCF) methods assume a single discount rate for an activity for its entire lifetime, which assumes the risk level is time invariant (Blyth and Yang, 2006). However, as indicated in Section 3.2.2, the risks that affect market acceptance change over time and the value of adjusting the original proposal to mitigate risks is not quantified. This makes DCF methods unsuitable for evaluating alternatives with a wide variety of technical, market, and non-technical risk levels that change over time (Fernandes et al., 2011).

The Real Option Valuation (ROV) approach overcomes these shortcomings of DCF methods and is gaining wide recognition in both academia and industry (Fernandes et al., 2011). The ROV approach is based on option pricing theory and enables the quantification of the risks associated with subsurface activities and the means to mitigate them (Fernandes et al., 2011). An option can be defined as "the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting or abandoning) at a predetermined cost, called exercise price, for a predetermined period of time – the life of the option" (Antikarov and Copeland, 2001). The ROV approach can explicitly incorporate the different risks of an activity into its cash flow through options, thereby reducing the need to add a single risk premium (Fernandes et al., 2011). With the ROV approach, it is possible to attribute a value for delaying an activity by incorporating the effect of risk mitigation measures (Fernandes et al., 2011).

Furthermore, there are two types of calls in the ROV approach: American calls and European calls. American calls require more advanced and complex methods than European calls (Trigeorgis, 1996). This may be problematic, especially when dealing with the host community. Another difference is that American calls can be exercised at any time and European calls can only be exercised on their expiration date (Luehrman, 1998,Trigeorgis, 1996). However, subsurface activities contribute to the realization of policy goals, which may have temporal dimensions, reducing the possibilities for exercising an option. The same applies to the timeframes of permits and field production/storage plans. This means that, in our case, options for subsurface activities can be considered European calls (Zhao and van Wijnbergen, 2014).

4.3.3 Measuring scale of the ranking

Within the market acceptance class, the goal is to maximize the return on investment by selecting the most profitable alternative. Under normal conditions, the ROV method results in a quantitative ranking of the alternatives, that is, an expected amount of profit for each alternative(Bierman Jr. and Smidt, 2012). The project proponent will therefore only proceed with a subsurface activity if the value is positive. In the case of mutually exclusive alternatives, the alternative with the highest value should be selected. However, the results of the ROV approach are sensitive to the assumed risk level and deferral time selected (Wu, 2004). Therefore, they should be viewed as an approximation.

4.4 Community acceptance

4.4.1 Elucidation mode

Several studies indicate that non-experts are more comfortable with an elucidation mode, which does not allow for compensation between the different evaluation criteria (Guitouni and Martel, 1998). However, such elucidation modes require a good understanding of these criteria and their priorities. This would indicate that partial compensation, which requires a lower level of knowledge, is more suited for the community acceptance class. Pairwise comparison allows for partial compensation and facilitates an intuitive way of assigning weights to different criteria, since it resembles the cognitive process (Montis and Toro, 2005). This can be seen as a positive attribute in this context, because the host community cannot be expected to know a priori the weights for all the evaluation criteria (Guitouni and Martel, 1998).

4.4.2 Aggregation mode

Due to the diverse nature of risk and the socio-physical changes of alternatives, an aggregation mode is needed that can address the range of criteria for different measuring scales to indicate the preferences of the community. In this respect, a multi-criteria analysis is often used (Aloysius et al., 2006). However, the downside of all multi-criteria analysis methods is their tendency to become complex due to the multitude of criteria and corresponding weights, which is especially problematic when the community is involved. Sorting the criteria and weights hierarchically can alleviate this problem. However, hierarchical methods such as the analytic hierarchy process (AHP), tend to have greater variance when assigning weights directly (Stillwell, 1987). The AHP involves a comparison matrix that shows the results from pairwise comparisons of criteria at multiple levels of the hierarchy, that is, criteria and sub-criteria (Ishizaka et al., 2011). Another disadvantage of this aggregation mode is the possibility of rank reversal. This is especially relevant when alternatives have a high degree of similarity (Triantaphyllou, 2001). However, the likelihood of rank reversal in our case is limited because the competing alternatives have different risk profiles and result in different socio-physical changes. Furthermore, the possibility of rank reversal is greater with criteria that are measured on a qualitative scale (Schenkerman, 1994). For quantitatively scaled criteria, the likelihood of rank reversal can be reduced by adjusting the normalization procedure (Schenkerman, 1994). Qualitative scales are flexible and the numerical distances between the weight factors for the criteria are not fixed, which means that the decision maker can, at best, obtain insight into the score of a particular criterion (Schenkerman, 1994). However, as noted by Schenkerman (1994, p413),

> This is not to say that decisions cannot be made with subjective data. It is to say that with subjective data the decision process cannot be wrapped in the mantle of 'scientific decision making'. The process should be revealed and respected for what it is – decision making based on instinct, experience, and intuition. Even the most analytic of us often make important decisions intuitively.

We therefore conclude that the AHP is a suitable method for the community acceptance class. However, the number of quantitative scales should be as low as possible (Schenkerman, 1994). In addition, it may be prudent to check the consistency of the scores by using, for example, the approach described by Al-Harbi (2001).

4.4.3 Measuring scale of the ranking

The AHP method in combination with a pairwise comparison elucidation mode could limit the measuring scale of the ranking to a qualitative ranking of the alternatives

(Belton and Gear, 1983,Murphy, 1993). In addition, through the use of the partial compensation strategy, some detailed and perhaps important information can be lost during aggregation (Sijtsma, 2006,Stewart, 1992). However, from the analysis of the decision-making process for the community acceptance class, it can be argued that it is important that the knowledge requirements of the DSS resemble the knowledge level of the host community. The characteristics of this aggregation and elucidation mode are the facilitation of problem structuration, knowledge building through a learning process, and an intuitive way of assigning priorities to evaluation criteria. These can be regarded as advantages of the AHP, especially in the case of community acceptance involving non-experts with limited a priori knowledge about the priorities (Reddy et al., 2014).

4.5 Social acceptance

To obtain a final ranking from all three classes, the ranking for each individual class needs to be aggregated into a single ranking. To this end, the different rankings need to be normalized to compensate for any bias due to the magnitude of each ranking. In addition, the final ranking may require an additional set of weight factors for the scores of an activity in all three classes to indicate the importance of each class of social acceptance and to compensate for incommensurability (Tamiz et al., 1998). Moreover, a sensitivity analysis of the effect the different criteria can have on the final ranking may be necessary. This would allow for better insight into the interaction between the different criteria and will give a insight in the robustness of the final ranking. Furthermore, to facilitate the dialog between stakeholders, a relatively simple and quick aggregation method is preferred for the final ranking (Voogd, 1983). Therefore, we propose using a weighted summation of the score of the three classes of social acceptance. Its advantage is that it is easy to convey to other stakeholders, since the underlying principle is relatively simple and easy to illustrate. In addition, the summation uses the score from the three classes of social acceptance, which were obtained using the best-suited approaches.

5 Discussion and conclusions

51Conclusions

From the analysis of the social–political acceptance class, we conclude that the DSS needs to include the do nothing now and do nothing forever alternatives, as well as feedback mechanisms that address changes in the realization of policy goals and the utilization of the subsurface. In addition, we find that a DSS for social–political acceptance needs to be flexible enough to account for policy goals with varying formulations. We find that the measuring scale of such policy goals has a large effect on the measuring scale of the ranking in the social–political acceptance class. Based on these aspects, we argue that the WGIP method fulfills the requirements. Considering the requirements of a DSS for market acceptance, we conclude that the elucidation mode for indicating risks should be based on the nature and levels of the technical, market, and non-technical risks. Hence, DCF methods are inadequate, since they apply a single discount rate for the entire duration of the project. Instead, an ROV approach, which uses European calls, is the preferred aggregation mode, because it explicitly incorporates the effect of changing risk levels into an activity's cash flow. The knowledge level of the host community has a large effect on the requirements of a DSS in the community acceptance class. We therefore argue that, in such a case, an AHP with a pairwise comparison is the preferred method. Furthermore, we conclude that a simple approach, based on the score of each acceptance class, is the preferred approach for obtaining a final ranking.

5.23 Discussion and future research

In our analysis, we make several assumptions and omit some aspects. For example, we assume on the basis of the triangle of social acceptance that the classes of social acceptance each have only one specific type of concern. In the case of social–political acceptance, these concerns are strategic. This may not be the case in all situations. In addition, we assume that the complexity associated with the increasing number of activities, the perception of unfair cost/benefit allocation, and the increasing attention of society on risks is a universal problem. However, in some regions of the world, this may apply to a lesser extent, which could affect the universal applicability and usefulness of our analysis and results.

We are optimistic and hope that, by applying the results of our analysis to a real case, we can gain better insight into these knowledge gaps. This would allow us to use case-specific information, which will make our assessment of a social acceptance-motivated DSS more concrete. Therefore, in future research, we will analyze whether the requirements resulting from the analysis presented in this article are sufficient to formulate a social acceptance-motivated DSS using a case study.

Despite these reservations and knowledge gaps, we believe that our analysis in itself could provide more in-depth insight for decision makers who deal with the complexity and uncertainty associated with subsurface activities. Furthermore, in response to the observation of Koornneef et al. (2008), we show that it is possible to expand the current decision-making process for subsurface activities to include strategic and social issues. Furthermore, our analysis is the first attempt, to the best of our knowledge at least, to integrate social acceptance in a DSS for a decision-making situation with high levels of complexity, uncertainty, and risk. Inclusion of the uncertainties, risks, dimensions of the decision-making process, and methodological aspects of DSSs in a single analysis framework seems a promising first step in the actual realization of social acceptance-motivated DSS for subsurface activities.

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