# *Modular Evaluation Method for Subsurface Activities (MEMSA)A novel approach for integrating social acceptance in a permit decision-making process for subsurface activities*

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## Abstract

We investigate how the decision support system ‘Modular Evaluation Method Subsurface Activities’ (MEMSA) can help facilitate an informed decision-making process for permit applications of subsurface activities. To this end, we analyze the extent the MEMSA approach allows for a dialogue between stakeholders in a transparent manner. We use the exploration permit for the underground gas storage facility at the Pieterburen salt dome (Netherlands) as a case study. The results suggest that the MEMSA approach is flexible enough to adjust to changing conditions. Furthermore, MEMSA provides a novel way for identifying structural problems and possible solutions in permit decision-making processes for subsurface activities, on the basis of the sensitivity analysis of intermediate rankings. We suggest that the planned size of an activity should already be specified in the exploration phase, because this would allow for a more efficient use of the subsurface as a whole. We conclude that the host community should be involved to a greater extent and in an early phase of the permit decision-making process, for example, already during the initial analysis of the project area of a subsurface activity. We suggest that strategic national policy goals are to be re-evaluated on a regular basis, in the form of a strategic vision for the subsurface, to account for timing discrepancies between the realization of activities and policy deadlines, because this discrepancy can have a large impact on the necessity and therefore acceptance of a subsurface activity.

## 1 Introduction

Recent experiences with subsurface activities highlight the need to include strategic and social concerns in the permit decision-making process (DMP) for subsurface activities (van Os et al., 2014a, 2016). Several scholars have indicated possible approaches. Vanclay (2006) suggests using a social impact assessment to incorporate social concerns. Sánchez and Silva-Sánchez (2008) propose to facilitate the connection between the assessment of strategic drivers and project characteristics. However, they do not seem to address social and strategic as well as environmental and economic interests in a transparent and balanced way. As these attributes interact, the inclusion of all these concerns in the permit DMP seems highly important, turning the decision making into a dynamic process (van Os et al., 2014b).

In this study, we will present a novel approach that addresses the abovementioned concerns related to the permit DMP for a subsurface activity. Our approach consists of a single decision support system, which aims to increase the transparency and credibility of the DMP while improving the efficiency of subsurface utilization. Following van Os et al. (2016), we differentiate the DMP for subsurface activities according to the triangle of social acceptance by Wüstenhagen et al. (2007). This triangle categorizes the DMP on the basis of its stakeholders and their concerns and interest into three classes: sociopolitical, market, and community acceptance (see Wüstenhagen et al., 2007). This differentiation resulted in the Modular Evaluation Method Subsurface Activities (MEMSA) approach. We will apply this approach to the case of underground natural gas storage. To the best of our knowledge, this is the first time that a social acceptance motivated decision support system is used for subsurface activities. We will argue that MEMSA improves the current permit DMP because it structures the DMP in an orderly manner on the basis of the requirements and limitations set by the different classes of social acceptance and their interactions.

Our case study consists of the prematurely terminated exploration permit process for an underground gas storage (UGS) facility in the Pieterburen salt dome, in the north of the

Netherlands. We chose this case because of the pluriformity of its development options and the availability of information.

The basic setting of the case is as follows: On 13 January 2010, the French company Electricité de France applied for an exploration permit for the Pieterburen salt dome to assess the potential of an Underground Gas Storage (see Figure 1; EDF, 2010).

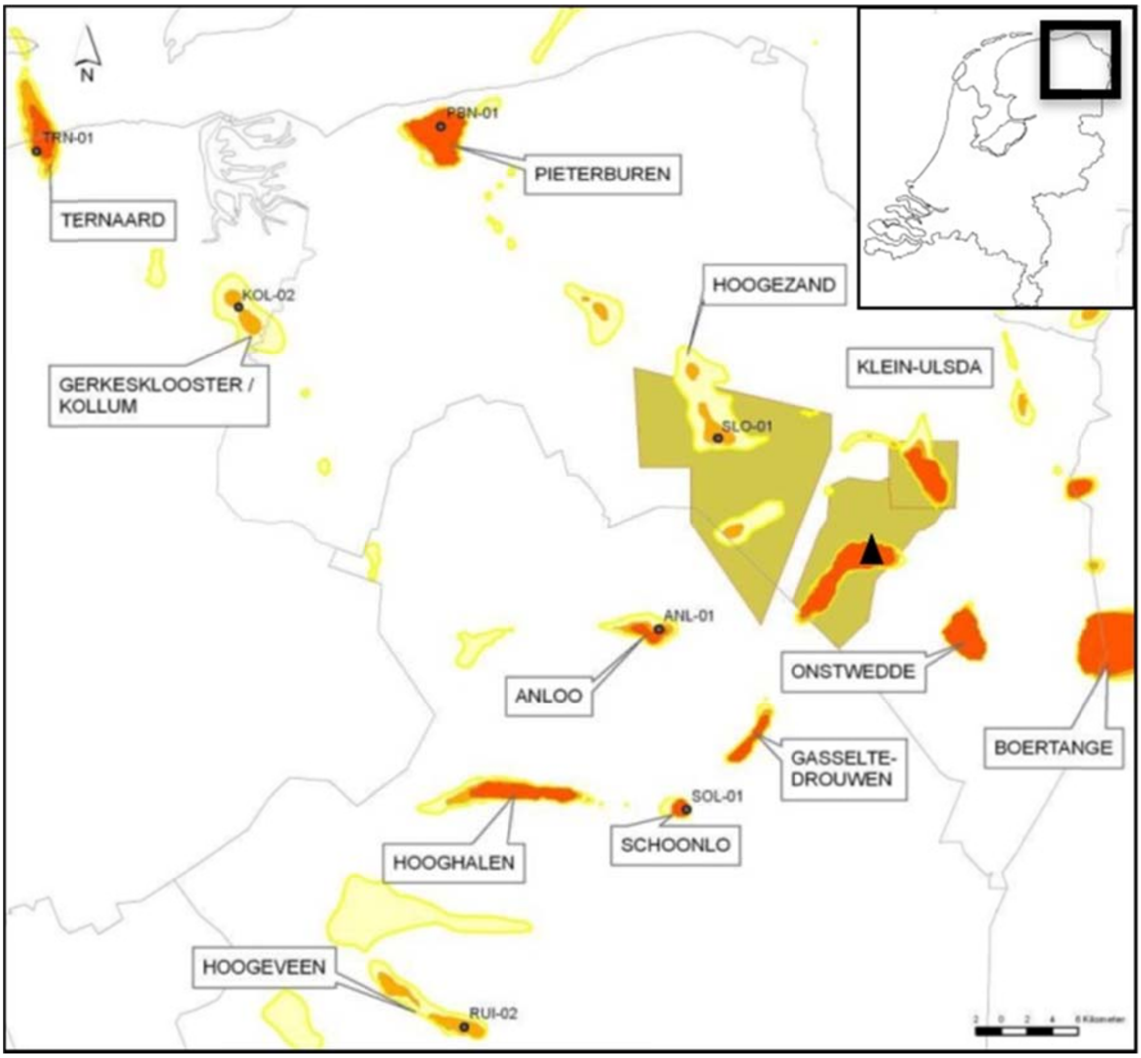

Figure 1. Salt domes in the northern Netherlands (Remmelts, 2011, TNO, 2012). The orange shapes represent the outlines of the salt domes at a depth of 1500 meters. The brown polygons show the existing salt production permits. The black dots indicate some of the existing exploration wells and the black triangle shows the location of the UGS in the Zuidwending salt dome.

The exploration permit was awarded to Electricité de France on 23 November 2010 (Minister of Economic Affairs, Agriculture and Innovations, 2012). However, very shortly after the announcement, the province of Groningen, a number of national and regional non-governmental organizations, and a local interest group, called Pieterburen

Tegengas, protested against the project. Subsequently, Electricité de France relinquished its permit on the 23 March 2012 (Ministry of Economic affairs, Agriculture and Innovation.2012a), citing a re-evaluation of its gas strategy as the official reason, as to why the UGS in Pieterburen was no longer required (EDF, 2012). In our view, as we will try to show in this paper, another important reason for Electricité de France to relinquish the exploration permit was the resistance of regional and local stakeholders, which was intensified by the permit DMP architecture itself. For example, the selection process for the Pieterburen salt dome was perceived as non-transparent and too narrowly defined and the need for an UGS was not made clear in light of the energy transition. Furthermore, there was no early involvement of the host community in the Pieterburen case. If this had been the case, it would have been clear from the onset that the host community had strong negative perceptions towards the proposed activity due to a perceived connection with a nuclear waste repository (NWR).

The Pieterburen case suggests that several aspects should be included early on in the permit DMP in order to increase the social acceptance level of the permit DMP and resulting decisions. That is not to say that we develop a model that will ‘automatically’ yield decisions that are favorable to project protagonists. However, we would argue that the inclusion of these aspects would allow for a more constructive dialogue between stakeholders, instead of the often-observed entrenched positions of the stakeholders. Therefore, in this paper we will investigate the potential for the systematic inclusion of these aspects in a decision support system.

## 2 The MEMSA process

The general aim of the MEMSA approach is to facilitate a dialog between the relevant stakeholders in the DMP, by mitigating the shortcomings of the current permit DMP, as observed in the Pieterburen case, as much as possible. We want to reiterate that it is not our intention to arrive at a model that results in project acceptance per se, but to account for key factors that have shown to be highly relevant and have been left unaccounted for. The DMP needs to be restructured in order to allow for the inclusion of a broader range of concerns and interests (van Os et al., 2016). The MEMSA approach structures the decision-making situation according to Wüstenhagen's (2007) classes of social acceptance. It consists of five connected modules: delineation steps, strategic module, operationalization module, socio-spatial impact module and political integration module. The result of the MEMSA approach is a ranking of alternative uses of the geological space under consideration on the basis of both objective and subjective information. A decision support system is selected for each class of social acceptance on the basis of the uncertainties, hazards and risks associated with the activities, as well as the requirements set by the DMP itself, including the relevant stakeholder concerns and interests (van Os et al., 2016). Therefore, for each module, a different set of stakeholders is involved, with the exception of the permit granting authority who is always involved as the process manager, which in the Netherlands is the ministry of Economic Affairs. Beside the requirements set by each class of social acceptance, the interactions between the three classes of social acceptance are an important aspect of the MEMSA approach, because a decision in one class will affect the design of the decision support system and ranking in the other classes (van Os et al., 2016).

The starting point of the MEMSA approach is the permit request by a (market) party for a proposed activity at a specified geological space. The order in which the different aspects of the permit DMP are addressed in MEMSA is governed by:

1. The dynamic nature of the evaluation subject, for example the properties of the targeted geological space are relatively static, as constrained by geotechnical conditions. Other aspects, like strategic national policy goals, are more dynamic in nature than the geology, because policy goals are affected by changing and diverse social and cultural views.
2. The required detailed information about the activities impact becomes available during the DMP, as a result of previous decisions, like type of activity and installation design.

The MEMSA approach starts with an evaluation of the alternatives on the basis of readily available information and knowledge. Although the quality of this information is usually low, it provides a first insight, which allows for a reduction of the number of alternatives. Throughout the process, the number of alternatives is stepwise reduced in each module, allowing for more detailed analysis, such as the social impact assessment which requires case and location specific information, usually not available in an early stage of the DMP. The MEMSA approach facilitates the selection of alternatives for each module by providing a ranking, including a sensitivity analysis of the underlying contributing subjective factors. Especially this sensitivity analysis provides a useful tool in the dialogue between stakeholders, because the effect of different views on the ranking can be quantified. This workflow increases the efficiency of the process, because if the initial evaluation indicates that the proposed activity is not viable according to the stakeholders, the permit DMP can be terminated and the remaining modules of MEMSA can be omitted. Figure 2 provides a schematic overview of the workflow of the MEMSA approach.

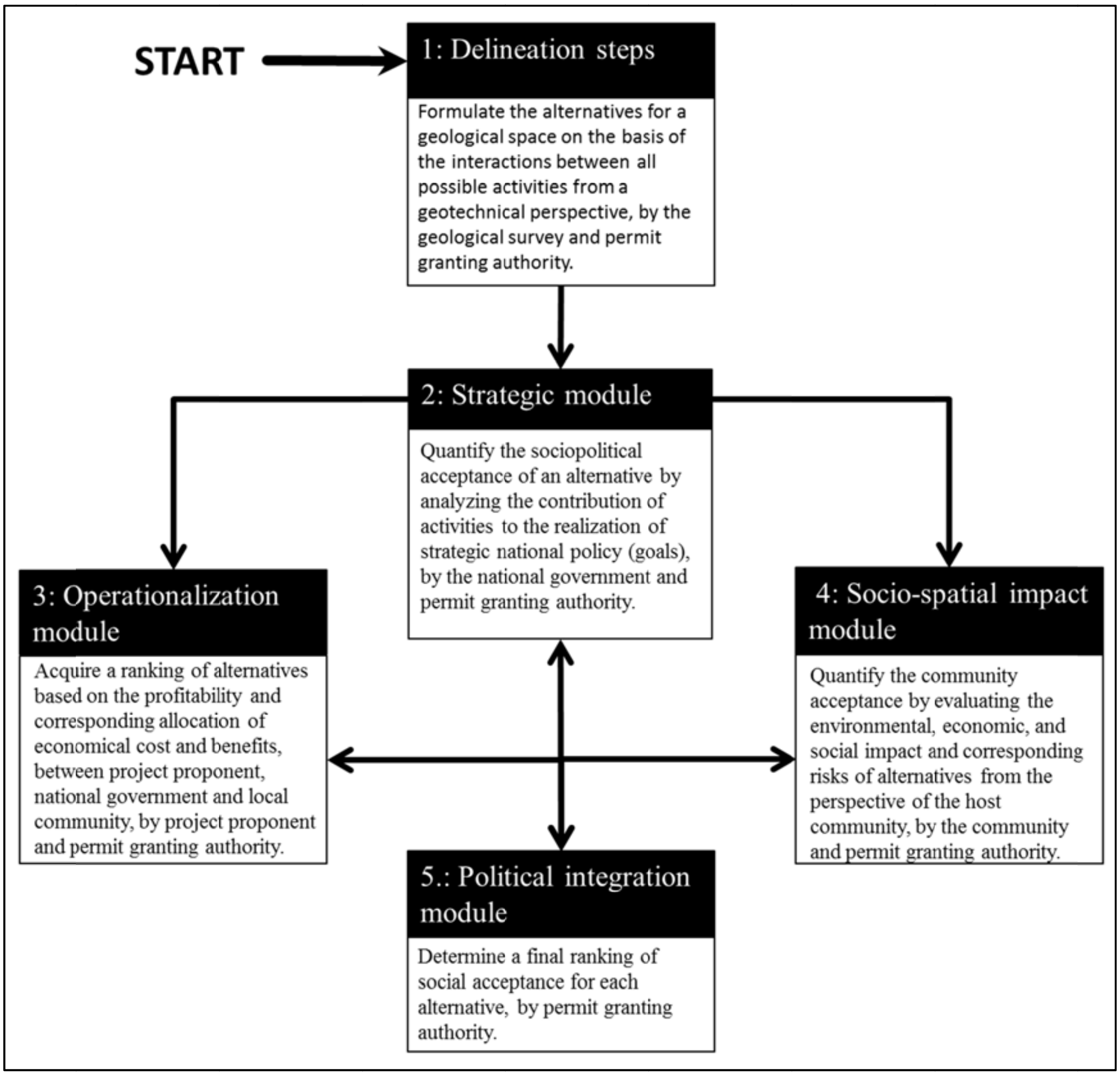


Figure 2. Schematic overview of MEMSA (based on: van Os et al., 2016). The solid black arrows indicate the flow direction within MEMSA. The iterative nature of the MEMSA workflow is indicated with

bidirectional arrows between modules 2 to 5. A detailed overview, including input, output and methods, for each module is presented in Appendix A.1.

After each module, there is the possibility of filtering out one or more alternatives, with the exception of the “do-nothing-now” and “do-nothing-forever” alternatives. These alternatives can be considered similar to the A0 alternative, which is common in environmental impact assessment practice (López, 2010). However, since it is hard to quantify the value of the “do-nothing-now” and “do-nothing-forever” alternatives, we assume that a geological space only has a strategic value if an activity contributes to the realization of strategic national policy goals, as indicated by the policy goal, activity products and geological space matrix. First, this implies that the value of the “do-nothing-now” option has the highest rank from a sociopolitical perspective, since all options are still possible in the future. However, not all activities can be realized at the same time due to competition between activities. Therefore, the strategic value of the “do-nothing-now” alternative is equivalent to the alternative with the highest rank in the sociopolitical acceptance class. Second, the “do-nothing-forever” alternative has a strategic score of zero if it does not contribute to the realization of strategic national policy (goals).

In the remaining sections, we discuss the MEMSA approach in greater detail, using the Pieterburen salt dome case. However, because of the premature termination of this project and the broad scope of the MEMSA approach, we have to make additional assumptions regarding the values and weight factors of some criteria. We will therefore base the scores for the criteria on other, analogous subsurface activities. Throughout this paper, we color-coded the assumed values (grey cells) and calculated values (white cells) in order to indicate the differences. Furthermore, we assume equal weight factors for subjective input information, unless otherwise indicated. Therefore, the scores and weight factors used in this study, are to be considered for illustrative purpose only.

## 3 The delineation steps

In order to put subsurface activities like the UGS case study in perspective of the MEMSA approach, we need to explain the formulation and delineation of the alternative options. In the delineation module, the alternatives for a geological space are defined on the basis of the interactions between all possible activities from a geotechnical perspective, by the geological survey, since they are the custodians of and experts on the subsurface. The result is a transparent selection process (van Os et al., 2016). It allows for a proactive procedure, because the MEMSA approach includes all alternatives upfront instead of broadening the list of alternatives after protest which, like in the Pieterburen case, can be seen as reactive.

### 3.1 Selecting activities

To identify the activities, we introduce the products, geological spaces, activities, and policy goals matrix, which provides a first insight, on the basis of current technology and practice, in the relations between

- The geological spaces, such as a cavern in a salt dome;
- The subsurface activities, such as compressed air energy storage (CAES), production water infiltration (PWI), Carbon Capture and Storage (CCS), Underground Nitrogen Storage (UNS) or Underground Hydrogen Storage (UHS);
- The products/services from subsurface activities, such as storage capacity
- The corresponding strategic national policy goals, such as energy reserve.

The products, geological spaces, activities, and policy goals matrix provides an initial understanding of the types of activities that can be exploited in geological space and thus allows for a holistic and objective assessment of all possible activities. Furthermore, it indicates which policy goals are related to the competing activities (for the complete products, geological spaces, activities, and policy goals matrix, see Appendix A.2). For a salt cavern, the following subsurface activities and possible policy goals are identified using the products, geological spaces, activities, and policy goals matrix, see Table 1.

| 1. Products/service | 2. Activities in salt dome | 3. Policy goal |
|---|---|---|
| a. Sodium chloride | a. Sodium/chloride production | a. Salt production |
| b. Magnesium | b. Magnesium production | a. Salt production |
| c. Natural gas | c. Underground Gas Storage | b. Energy reserve |
| d. Nitrogen | d. Underground Nitrogen Storage | c. Conversion reserve |
| e. Hydrogen | e. Underground Hydrogen Storage | d. Energy capacity |
| f. $CO_2$ | f. Carbon Capture and Storage | e. $CO_2$ emission reduction |
| g. Electricity | g. Compressed Air Energy Storage | d. Energy capacity |
| h. Oil | h. Underground Oil Storage | d. Energy reserve |
| i. Water | i. Production Water Infiltration | f. Waste management |
| j. Nuclear materials | j. Nuclear Waste Repository | g. Radioactive waste management |

Table 1. Products, geological spaces, activities, and policy goals matrix (TNO, 2012).

The products, geological spaces, activities, and policy goals matrix indicates that a typical salt cavern can host 10 different activities, contributing to the realization of 7 different policy goals. However, this is based on the current policy goals and state of technology. If these are changed, the products, geological spaces, activities, and policy goals matrix must be updated.

## 3.2 Proposing alternatives

In the second stage of the delineation module, the alternatives are proposed on the basis of the interaction between activities. The degree and nature of the interaction is determined by the extent to which an activity alters the properties of a geological space, the reversibility of that change, and the requirements set by a secondary activity. This can result in a differentiation between positive interactions, i.e. synergy, and negative interactions, i.e. interference, which can be used to formulate all the possible sequences of activities. Table 2 lists the sequential relations, between the activities for a salt cavern. The activities are here depicted twice, in rows (a till j) and columns (1 till 10), where the diagonal axis reflects the competition between activities on the basis of exclusivity, which is a part of the permit system in the Netherlands. The other cells in table describe the relation between activities on the basis of the geo-technical aspects, for example 1>c means that in order to have an underground gas storage (c) it is necessary to first created a cavern by mining salt (a, b).

| Salt dome | 1. Sodium/chloride production | 2. Magnesium production | 3. Underground Gas Storage | 4. Underground Nitrogen Storage | 5.Underground Hydrogen Storage | 6. Carbon Capture and Storage | 7. Compressed Air Energy Storage | 8. Underground Oil Storage | 9. Production Water Infiltration | 10. Nuclear Waste Repository |
|---|---|---|---|---|---|---|---|---|---|---|
| **a. Sodium/chloride production** | Only possible if same operator or agreement | Simultaneously if same operator or agreement | a > 3 | a> 4 | a > 5 | a > 6 | a > 7 | a > 8 | a > 9 | a > 10 |
| **b. Magnesium production** | Simultaneously if same operator or agreement | Only possible if same operator or agreement | b > 3 | b > 4 | b > 5 | b > 6 | b > 7 | b > 8 | b > 9 | b > 10 |
| **c. Underground Gas Storage** | 1 > c | 2 > c | Only possible if same operator or agreement | No sequence but mutually exclusive | No sequence but mutually exclusive | c > 6 | No sequence but mutually exclusive | No sequence but mutually exclusive | c > 9 | No sequence but mutually exclusive |
| **d. Underground Nitrogen Storage** | 1 > d | 2 > d | No sequence but mutually exclusive | Only possible if same operator or agreement | No sequence but mutually exclusive | d > 6 | No sequence but mutually exclusive | No sequence but mutually exclusive | d > 9 | No sequence but mutually exclusive |
| **e. Underground Hydrogen Storage** | 1 > e | 2 > e | No sequence but mutually exclusive | No sequence but mutually exclusive | Only possible if same operator or agreement | e > 6 | No sequence but mutually exclusive | No sequence but mutually exclusive | e > 9 | No sequence but mutually exclusive |
| **f. Carbon Capture and Storage** | 1 > f | 2 > f | 3 > f | 4 > f | 5 > f | Only possible if same operator or agreement | 7 > f | 8 > f | No sequence but mutually exclusive | No sequence but mutually exclusive |
| **g. Compressed Air Energy Storage** | 1 > g | 2 > g | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | g > 6 | Only possible if same operator or agreement | No sequence but mutually exclusive | g > 9 | No sequence but mutually exclusive |
| **h. Underground Oil Storage** | 1 > h | 2 > h | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | h > 6 | No sequence but mutually exclusive | Only possible if same operator or agreement | h > 9 | No sequence but mutually exclusive |
| **i. Production Water Infiltration** | 1 > i | 2 > i | 3 > j | 4 > j | 5 > j | No sequence but mutually exclusive | 7 > i | 8 > i | Only possible if same operator or agreement | No sequence but mutually exclusive |
| **j. Nuclear Waste Repository** | 1 > j | 2 > j | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | No sequence but mutually exclusive | Only possible if same operator or agreement |

Table 2. Sequence of activities in a salt dome (based on; TNO, 2012). The top row and first column show the different activities possible in a salt dome. The other cells show the different relations between the activities, where x > y means that activity x needs to be executed before activity y and so forth. On the diagonal axis, the legal exclusion grounds, based on permits, are depicted. This means that an additional activity can only be executed if the operator is the same, that is, the owner or operators of the existing and additional activity have an agreement about the exploitation of the salt dome.

On the basis of the sequences of the activities, it is possible to define all currently known and technically feasible alternatives, allowing for holistic and objective selection of alternatives. However, it should be noted that the sequential relations depicted in Table 2 could change, for example due to technological innovations or new activities. However, this does not require a change of the approach, because new or changing relationships can be incorporated by adjusting the sequential relationships in Table 2.

For practical reasons and illustrative purposes, we limit the alternatives for the Pieterburen case study to a maximum of three consecutive and unique activities, for example underground gas storage, compressed air energy storage and storage of nitrogen. Based on this we formulated 160 alternatives, including the "do-nothing-now" and "do-nothing-forever" alternatives for the case of the Pieterburen salt dome.

## 4 The sociopolitical acceptance module

In the sociopolitical acceptance module, the sociopolitical acceptance of an alternative is determined by analyzing the contribution of activities to the realization of strategic national policy (goals). This analysis is broad and abstract, due to the low quality of the available information (van Os et al., 2016). The sociopolitical acceptance module results in a ranking of alternatives that includes the following:

- The extent to which the selected geological space compares with competing geological spaces. The aim is to obtain a measure for the necessity of realizing the proposed activity in the targeted geological space, which is often disputed in the discussion, as was experienced in the Pieterburen case.
- The extent to which an activity is synergetic with the project area. The aim is to gain a first pass of in possible siting issues and concerns from the host community. From the Pieterburen case it was clear that this could have provided a valuable insight in the position of the community towards the project.

- The extent to which an activity contributes to the realization of strategic national policy goals over time. The aim is to obtain a measure of the sense of urgency of an activity according to the stakeholders in the sociopolitical acceptance class. This is important because, as is apparent in the Pieterburen case, the added strategic value of the proposed project for the Dutch society at large could not be made clear, resulting in a lack of social acceptance.

### 4.1 Comparison of geological spaces

For the comparative analysis of geological spaces, we introduce the situation index. The situation index is, following Remmelts (2011), based on geotechnical criteria such as pore volume, permeability, depth, and availability of reusable wells. The normalization of the score and the weight factors of these criteria are determined by the planned subsurface activity. For example, in the case of natural gas storage in a salt cavern, permeability should be low to prevent leakage. However, when comparing aquifers for geothermal development, permeability should be high to establish an economically viable flow rate. For the Pieterburen case, MEMSA uses well established geotechnical criteria (see figure B.1.1).

Each sub criterion is scored individually and multiplied by a weight factor. The weight factors are attributed on the basis of the characteristics and requirements of the activity and are based on existing information. For each alternative, the group criterion is summed and multiplied by a priority factor, resulting in a ranking of the alternative geological spaces. The priority factors of the group criteria are based on the input from the stakeholders. This allows the stakeholders to convey their view, while maintaining a relatively objective basis through the subcriteria scores. Table 3 shows the situation indexes for UGS applications in salt domes in the north of the Netherlands.

| Weight factor for group criteria | 1. Structure | 2. Safety | | 3. Infrastructure | | 4. Legal | Total weight factor |
|---|---|---|---|---|---|---|---|
| | 0.25 | 0.25 | | 0.25 | | 0.25 | 1 |
| **Situation index for UGS** | Available volume **(1 = sufficient)** | Faults **(1 = no faults)** | Homogeneity **(1 = no irregularities)** | Presence of re-usable infrastructure **(1 = yes)** | Exploration well **(1 = yes)** | Licensed **(1 = no)** | Situation index (weighted summation) |
| Weight factor for subcriteria | **1.00** | **0.50** | **0.50** | **0.50** | **0.50** | **.00** | |
| a. Pieterburen | 1 | 1 | 1 | 0 | 0.25 | 1 | **0.78** |
| b. Ternaard | 1 | 1 | 1 | 0 | 1 | 1 | **0.88** |
| c. Gerkesklooster | 0.5 | 0 | 0.5 | 0 | 0.5 | 1 | **0.50** |
| d. Klein-Ulsda | 0 | 1 | 1 | 0 | 0 | 1 | **0.50** |
| e. Hoogezand | 0.5 | 1 | 0.5 | 0 | 0.5 | 1 | **0.63** |
| f. Anloo | 0.5 | 1 | 1 | 0 | 1 | 1 | **0.75** |
| g. Onstwedde | 1 | 1 | 0.5 | 0 | 0 | 1 | **0.69** |
| h. Boertange | 1 | 1 | 1 | 0 | 0 | 1 | **0.75** |
| i. Hooghalen | 1 | 1 | 1 | 0 | 0 | 1 | **0.75** |
| j. Schoonloo | 0.5 | 1 | 0.5 | 0 | 0.25 | 1 | **0.59** |
| k. Gasselte-Drouwen | 0.5 | 1 | 0.5 | 0 | 0 | 1 | **0.56** |
| l. Hoogeveen | 0.5 | 1 | 0.5 | 0 | 1 | 1 | **0.69** |
| m. Winschoten | 0.25 | 1 | 1 | 1 | 1 | 0 | **0.56** |
| n. Zuidwending | 0.25 | 1 | 1 | 1 | 1 | 0 | **0.56** |

Table 3. Situation index for UGS in the relevant salt domes. The first column indicates the different salt domes in the region. The top four rows indicate the different criteria, subcriteria, and weight factors (see Figure B.1.1 for a description). The gray cells indicate the values for each criterion for each salt dome, based on Remmelts (2011). The scores are normalized on a scale 0 till 1 using a linear approach . The last column indicates the situation index for salt domes under evaluation, calculated using a weighted summation. The locations of the salt domes are depicted in Figure 1.

The range (from zero to one) of the values for the criteria in Table 4 is relatively low, because the available geological information is limited to regional geological surveys, which has a relatively low level of detail and high uncertainty margins. The scores are normalized on the basis of the discrepancy between the requirements set by the activity (e.g., depth range) and the available information, such as the presence and properties of wells, which are indicated in bold for each sub criterion. From Table 4, we find that the Pieterburen salt dome ranks second after the Ternaard salt dome as a possible location for an UGS[1].

### 4.2 Interactions with activity site

In order to analyze the extent to which the activity and the project area, including the host community, are synergetic or interfering, we introduce the site index. Since the actual location, design and scale of the activity are not known at this phase of the permit DMP, the site index is based on general information, for example, zoning maps and examples of similar activities. In this sense, the site index allows for early identification of previously unknown concerns and interests from the host community. For the Pieterburen case, the site index uses the criteria mentioned in Appendix B.1.2.

The site index also uses group criteria and subcriteria, and is normalized and calculated in a similar manner as the situation index. The site index uses different types of interaction between an activity and its surroundings (see Table B.1 for an overview). Where, synergy indicates a positive relation, interference indicates a negative relation, impact stands for the effect the activity will have on its surroundings, and hazards,

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[1] However, it should be noted that the Pieterburen salt dome is larger than the Ternaard salt dome and that the criterion ‘sufficient volume’ is based on an assumed size of the proposed underground gas storage, since permit applicants are not obligated to indicate the size of proposed activity at this stage of the permit DMP (Remmelts, 2011). Therefore, if the size of the proposed activity would be known at this stage of the permit DMP, it would be possible to discriminate more between the salt domes, allowing for more efficient utilization of the subsurface

which are an unwanted event that may result from an activity. By classifying the interactions, the decision-making becomes more structured, which, in turn, clarifies the permit DMP (van Os et al., 2016*)*. Furthermore, because the scores of the criteria are based on readily available information, characterized by a low level of detail, the resolving power of the site index is low. This is also reflected in the small scoring range (0 - 1). Furthermore, for some criteria, such as surface impact during operation, none of the activities score 1, because activities will always have some impact on their surroundings. For the Pieterburen case we arrive at the following site index values, see Table 4, on the basis of the assumed scores and equal weight factors for the criteria mentioned in Figure B.1.2.

| Weight factor group criteria | 1. Synergy | | 2. Interference | | | 3. Impact | | 4. Hazards | | | Total weight factor |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.25 | | 0.25 | | | 0.25 | | 0.25 | | | 1 |
| **Site index Pieterburen salt dome** | Local supply of production resources **(1=high)** | Local demand for production (waste) stream **(1=high)** | Conflicting policy **(1=no)** | Conflicting land use **(0=yes)** | Interference with other subsurface activities **(1=no interference)** | Surface impact of activity during operations **(0=high)** | Remaining surface impact after closure of activity **(1=low)** | Maturity of technology / activity **(1=high)** | Remaining risk level after abandonment of activity **(1=low)** | Mitigation potential during operation **(1=high)** | 5. Site index |
| Weight factor sub-criteria | 0.50 | 0.50 | 0.33 | 0.33 | 0.33 | 0.50 | 0.50 | 0.33 | 0.33 | 0.33 | |
| a. Sodium/Chloride production | 0.5 | 0 | 0.5 | 0.5 | 1 | 0.75 | 1 | 1 | 0.5 | 0.5 | **0.61** |
| b. Magnesium production | 0.5 | 0 | 0.5 | 0.5 | 1 | 0.75 | 1 | 1 | 0.5 | 0.5 | **0.61** |
| c. Underground Gas Storage | 0.5 | 0 | 0.25 | 0.75 | 1 | 0.25 | 1 | 1 | 0.5 | 0.25 | **0.53** |
| d. Underground Nitrogen Storage | 1 | 0 | 0.75 | 0.25 | 1 | 0.5 | 1 | 0.5 | 0.5 | 0.25 | **0.58** |
| e. Underground Hydrogen Storage | 0 | 0 | 0.5 | 0.25 | 1 | 0.5 | 1 | 0.25 | 0.5 | 0.25 | **0.42** |
| f. Carbon Capture and Storage | 0.25 | 0 | 0 | 0 | 1 | 0.5 | 1 | 0.5 | 0.75 | 0.25 | **0.43** |
| g. Compressed Air Energy Storage | 1 | 1 | 0.5 | 0 | 1 | 0.5 | 1 | 0.25 | 0.5 | 0.25 | **0.65** |
| h. Underground Oil Storage | 0 | 0 | 0.25 | 0.75 | 1 | 0.25 | 1 | 0.5 | 0.5 | 0.25 | **0.43** |
| i. Production water infiltration | 0.25 | 0 | 0.75 | 0.5 | 1 | 0.5 | 1 | 1 | 0.5 | 0.5 | **0.57** |
| j. Nuclear Waste Repository | 0 | 0 | 0 | 0 | 1 | 0 | 0.25 | 0 | 0.25 | 0.75 | **0.20** |

Table 4. Site index for activities in the Pieterburen salt dome. The top four rows depict the criteria, subcriteria, and their weight factors (see Figure B.1.2 for a description). The first column reports the activities that are possible in a salt dome (see also Table 1). The gray cells show the assumed values for a salt dome on the basis of the corresponding criterion, based on analogous examples in the Netherlands. The scores are normalized on a scale 0 till 1 using a linear approach. The site index is calculated using a weighted summation and is reported in the last column.

From Table 4, we derive that CAES has the highest site index score, 0.65. This is mainly due to the high score for the synergy options (Figure 6, column 1, row g), since only a connection to the already existing electricity grid is required. The proposed activity UGS has the fifth highest rank, with a site index score of 0.53. This mainly due to the absence of gas infrastructure (Figure 5, column 1, row c) and land use, which is conflicting with the local zoning plan (Table 6, column 2, row c).

### 4.3 Realization of strategic national policy goals

To assess the extent to which an activity contributes to the realization of one or more strategic national policy goals, we introduce the strategic score. This is a single measure which quantifies the contribution of an alternative to multiple policy goals in relation to the degree the policy goal is already realized. We will refer to the latter as the delta policy goal. In this way, we are able to obtain a measure for the added value of an additional activity. In this way, the sense of urgency of the strategic national policy goal is included in the strategic score. Furthermore, the strategic score allows for the inclusion of different views concerning the priority of strategic national policy goals, through the use of weight factors, while maintaining the same basic information for all stakeholders. Moreover, by aggregating these aspects in a single value, the complexity of the comparison is reduced. The strategic score is defined in a similar manner as the weighted goal interval programming method described by Tamiz and Romero (1998):

$$SS_i \equiv \left(\frac{\Delta PG_i}{PG_i} * \frac{CA_p}{\Delta PG_i}\right) * PW_x + \left(\frac{\Delta PG_j}{PG_j} * \frac{CA_s}{\Delta PG_j}\right) * PW_y + \cdots + \left(\frac{\Delta PG_n}{PG_n} * \frac{CA_t}{\Delta PG_n}\right) * PW_z \quad i=1,..,N \qquad (1)$$

where

$SS_i$ = Strategic score of alternative i
$PG_{i,}$ = Policy goals or desired market levels for alternative i
$\Delta PG_{i,}$ = Delta policy goal for alternative i
$CA_p$ = Contribution of primary activity
$PW_x$ = Policy priority weight factor for policy goal x (in our case considered equal in % for all activities that have a non-zero value
$N$ = Maximum number alternatives
$_p$ = Primary activity
$_s$ = Secondary activity
$_t$ = Tertiary activity

Equation (1) standardizes the scores of activities by eliminating the units and scale differences between the scores, allowing for a numerical comparison (van Os et al., 2016). Furthermore, negative and missing values are set to zero.

The strategic national policy goals are selected using the product, subsurface activity and policy goal matrix. However, for some activities only market-driven goals are available. Therefore, in our description of the Pieterburen case, we treat the market-driven goals in a similar fashion as the strategic national policy goals. This has a significant effect on the score of UGS, UNS, UHS, CAES and PWI, since the missing values (see column 4 of Table 5) would have resulted in a strategic score of zero (see Equation 1). Furthermore, to calculate the contribution of an activity, we used analogous activities to obtain realistic values. Column 9 of Table 5 lists the strategic score for all possible activities.

| 1. Activities in salt dome | 2. Policy goal | 3. Units | 4. Policy goal (level) | 5. Desired level (market-driven) | 6. Delta Policy goal | 7. Contribution of activity | 8. Strategic score without weight factor | 9. Strategic score base case | 10. Rank |
|---|---|---|---|---|---|---|---|---|---|
| a. Sodium/Chloride production | Salt production | Mton | x | 500 | 0 | 6,9 | 0 | 0 | x |
| b. Magnesium production | Salt production | Mton | x | 500 | 0 | 6,9 | 0 | 0 | x |
| c. Underground Gas Storage | Energy capacity | GWh | x | 30,7 | 30,7 | 7,6 | 0,24 | 0,062 | 2 |
| d. Underground Nitrogen Storage | Conversion capacity | m3/h | x | 541000 | 0 | 1900000 | 0 | 0 | x |
| e. Underground Hydrogen Storage | Energy capacity | GWh | x | 30,7 | 30,7 | 2,12 | 0,069 | 0,017 | 4 |
| f. Carbon Capture and Storage | CO2 emission reduction | Mton | 3600 | x | 3600 | 2,5 | 0,0007 | 0,0001 | 6 |
| g. Compressed Air Energy Storage | Energy capacity | GWh | x | 30,7 | 30,7 | 0,55 | 0,017 | 0,004 | 5 |
| h. Underground Oil Storage | Energy reserve | Kton | x | 3844000000 | 0 | 2124000000 | 0 | 0 | x |
| i. Production water infiltration | Waste management | Kton | x | 30000000 | 30000000 | 3200000 | 0,106 | 0,026 | 3 |
| j. Nuclear Waste Repository | Radioactive waste management | Mton | 0,473 | x | 0,473 | 0,473 | 1 | 0,25 | 1 |

Table 5. The strategic score for all activities in the Pieterburen salt dome. Column 1 indicates the different activities. The top row indicates the variables used to calculate the strategic scores. The other cells contain the values for each variable. Although great care went into determining accurate values for each variable, they are for illustration purpose only, since they are based on similar activities in the Netherlands. Table B.2 shows the scores and provides the sources used to arrive at these scores. Furthermore, we assume, when available, a market-driven level for activities for which a policy goal was lacking. The small x indicates that the corresponding value is missing.

For some activities, such as sodium chloride production, the strategic score is zero, since the delta policy goal is zero, indicating no need for additional sodium chloride production. Furthermore, Table 5 shows that an NWR has the highest strategic score; this is because a single NWR will already realize the entire strategic national policy goal for the Netherlands (Figure 5, column 8, row j). Underground gas storage comes second, due to the fact that a single facility would contributed a quarter (0.25) to the total energy capacity policy goal (Table 5, column 8, row c)

### 4.4 Timing discrepancy

Since the strategic score of an alternative is based on strategic national policy goals, it is important to include the possible discrepancy between the moment an activity is realized and the time frame or deadline included in the policy goal, because this could result in over- or under valuation. Therefore, the strategic scores of alternatives need to account for this possible discrepancy. MEMSA takes this discrepancy into account through the temporal coefficient. The temporal coefficient is a binary variable (0 - 1), set to one in cases of no discrepancy or no policy goal horizon and to zero in the case of a timing discrepancy due to premature or late completion. Depending on the nature of the policy goals, different time frames are used. To determine temporal coefficient values for the Pieterburen case, we assumed the duration and construction times for each activity listed in Table 6.

| 1. Activities | 2. Duration (years) | 3. Construction primary (years) | 4. Construction secondary/tertiary (years) |
|---|---|---|---|
| a. Sodium/chloride production | 20 | 0 | x |
| b. Magnesium production | 20 | 0 | x |
| c. UGS | 30 | 7 | 4 |
| d. UNS | 30 | 7 | 4 |
| e. UHS | 30 | 7 | 4 |
| f. CCS | 5 | 7 | 4 |
| g. CAES | 30 | 7 | 4 |
| h. UOS | 30 | 7 | 4 |
| i. PWI | 5 | 7 | 4 |
| j. NWR | 50 | 20 | 20 |
| k. Permit deadline | 3 | | |

Table 6. Durations of activities. Column 1 shows the activities. Column 2 indicate the duration i.e. expected life time of the activity. Column 3 shows the assumed construction time when the corresponding activity is the primary activity. Column 4 shows the assumed construction time when the corresponding activity is the secondary or tertiary activity. The values are based on assumptions based on analogue examples.

All the temporal coefficient values used in our Pieterburen case are obtained using the values mentioned in Table 6.

### 4.5 Aggregation into a single ranking

To arrive at a single ranking for the sociopolitical acceptance module, the situation index, site index, strategic score, and the temporal coefficient values need to be aggregated into one single score. We define this single score as the relative strategic factor, which is expressed as follows:

$$RSF_i \equiv \left(\left(SS_p * TC_p\right) + \left(SS_s * TC_s\right) + \left(SS_t * TC_t\right)\right) * \left(\frac{\left(SI_p * WF_p\right) + \left(SI_s * WF_s 2\right) + SI_t * WF_t}{\sum_{p,s.t} WF}\right) * SU \quad \text{i=1,…,N} \qquad (2)$$

where

| | |
|---|---|
| $RSF_i$ | = Relative strategic factor of alternative i |
| $SS_{p,}$ | = Strategic score of primary activity |
| $TC_p$ | = Temporal coefficient of primary activity |
| $SI_{p,s,t}$ | = Site index of primary activity |
| $SU$ | = Situation index of the geological space under evaluation |
| $WF_p$ | = Weight factor primary activity |
| $_p$ | = Primary activity |
| $_s$ | = Secondary activity |
| $_t$ | = Tertiary activity |
| N | = Maximum number of alternatives |

Equation (2) adjusts the strategic score of an alternative in order to include the limitations caused by the alternative's temporal coefficient, site index and situation index. In addition, Equation (2) makes it possible to include a weight factor for the different site indexes for each activity in an alternative. For the Pieterburen case we used a linear weight scenario, where the first activity has a higher weight factor then the second activity and so forth. Through this weight factor, it is possible to adjust the effect that the site index of activities has on the relative strategic factor of an alternative. In this sense, it is possible to include the effect of changing social and cultural considerations of future subsurface activities, in the relative strategic factor values.

Based on the previous step described in Section 4, the following relative strategic factor values are obtained for the Pieterburen case, see Table 7.

| 1. Rank | 2. Alternative | 3. Relative Strategic Factor | 4. Sequence of activities in alternative | | |
|---|---|---|---|---|---|
| 1 | A10 | 0.039 | Nuclear Waste Repository | | |
| 2 | A114 | 0.037 | Compressed Air Energy Storage | Underground Gas Storage | Underground Hydrogen Storage |
| 3 | A123 | 0.036 | Compressed Air Energy Storage | Underground Hydrogen Storage | Underground Gas Storage |
| 4 | A46 | 0.036 | Underground Gas Storage | Compressed Air Energy Storage | Underground Hydrogen Storage |
| 5 | A62 | 0.035 | Underground Nitrogen Storage | Underground Gas Storage | Underground Hydrogen Storage |
| 6 | A97 | 0.034 | Underground Hydrogen Storage | Compressed Air Energy Storage | Underground Gas Storage |
| 7 | A42 | 0.034 | Underground Gas Storage | Underground Hydrogen Storage | Compressed Air Energy Storage |
| 8 | A35 | 0.033 | Underground Gas Storage | Underground Nitrogen Storage | Underground Hydrogen Storage |
| 9 | A89 | 0.032 | Underground Hydrogen Storage | Underground Gas Storage | Compressed Air Energy Storage |
| 10 | A66 | 0.032 | Underground Nitrogen Storage | Underground Hydrogen Storage | Underground Gas Storage |

Table 7. Relative strategic factor for the top 10 alternatives. For simplicity, we show only the 10 highest scoring alternatives. Column 1 shows the rank of the corresponding alternative, which are numbered in column 2. Column 3 shows the relative strategic factor value of an alternative. Column 4 shows the sequences of activities for each alternative. The relative strategic factor values are calculated using the input from Table 5 in Equation (1). A complete overview of the relative strategic factor values of all 158 alternatives is not include here due to size limitations, but can be made available upon request.

From Table 7, it results that the highest scoring alternatives is A10 (NWR) with a relative strategic factor value of 0.039 Meaning that this is the most preferred alternative according to the stakeholders in the sociopolitical acceptance class, such as the national government The high relative strategic factor score is due to the high strategic score of the NWR, despite the low site index value. The other alternatives consist of a UGS, CEAS, UNS or UHS in different sequences. The difference in relative strategic factor value between these alternatives, results from the weighted site index, which reduces the relative strategic factor value for secondary and tertiary activities. Furthermore, the differences in relative strategic factor are also caused by the differences in strategic scores. From our sensitivity analysis of the relative strategic factor, we find a direct relationship between policy weight factor and the relative strategic factor value of an activity, see Appendix B.3. This is explained by the fact that in our example all the policy goals have a temporal coefficient value of 1. Furthermore, as mentioned in Section 3, the “do-nothing-now” alternative is considered equal to the alternative with the highest relative strategic factor value. In our case, this would be the A10 alternative.

On the basis of this ranking the permit granting authority or national government might call for a termination, continuation, or reassessment of the permit DMP. The sensitivity analysis of the relative strategic factor allows the permit granting authority to test the robustness of the ranking in order support their decision. In the case of termination, the remaining modules of the MEMSA approach are omitted. In the case of reassessment, the scores, criteria, and weights used in the sociopolitical acceptance module are adjusted to reflect new information, concerns, and policy reprioritization. However, in the case of continuation, the remaining alternatives are further evaluated in the market acceptance module. For now, we assume for practical reasons that this is the case for the top 10 alternatives (see Table 7), in order to assess the overall profitably and distribution of costs and benefits of alternatives.

## 5 The market acceptance module

The market acceptance module focuses on acquiring a ranking of alternatives based on the profitability and corresponding allocation of economic cost and benefits, between project proponent, national government and the local community. The distribution of cost and benefits is included because it provides a starting point for the discussion about (economic) fairness issues and compensation schemes. Although these matters where already present and discussed, for example in relation to windmill parks, their momentum increased after the increased occurrence and severity of the induced earthquakes emanating from the Groningen gas field. Following van Os et al. (2016), MEMSA uses a real option valuation (ROV) approach. The ranking in the market acceptance module is based on the following:

- The real option of an alternative, with the aim of incorporating the value of future activities and the effect of economic risks on expected profitability.
- The amount of revenue for the national government in the form of taxes or excises
- The amount of local expenditure by the operator, with the aim of assessing the economic benefits for the host community.

## 5.1 Input information

To compare the alternatives, the projected annual cash flows and investments need to be aggregated. Table C.1 in the Appendix and Figure 3 provide an overview of the assumed annual cash flows, annual investments, the activity lifetime, taxes, and other expenditures that are used in these calculations for each activity. The annual cash flow and investment of an alternative are discounted against a risk-free rate of 5% before tax, as follows:

$$SF_i \equiv {}_{\tau=T'}^{\;d}\sum C_{p,s,t} - \left({}_{\tau=T}^{\;T'}\sum CC_{\;p,s,t}\,(d) * GT_{p,s,t}\,(d)\right) - \left({}_{\tau=T}^{\;T'}\sum C_{p,s,t}\,(d) * CE_{p,s,t}(d)\right) \quad i=1,\ldots,N \qquad (3)$$

$$X_i \equiv {}_{\tau=T}^{\;T'}\sum I_{p,s,t} - \left({}_{\tau=T}^{\;T'}\sum I_{p,s,t}\,(d) * (GT_{p,s,t}(d) - GW_{p,s,t,}(d))\right) - \left({}_{\tau=T}^{\;T'}\sum I_{p,s,t}\,(d) * CE_{p,s,t,}\,(d)\right) - \left({}_{\tau=T}^{\;T'}\sum I_{p,s,t}\,(d) * RC_{p,s,t}(d)\right) \quad i=1,\ldots,N \qquad (4)$$

where

| | |
|---|---|
| $SF_i$ | = Discounted total cash flow of alternative i (millions of euro’s) |
| $X_i$ | = Discounted total investment of alternative i (millions of euro’s) |
| $C_p$, | = Annual net cash flow of primary activity (millions of euro’s) |
| $C_s$, | = Annual net cash flow of secondary activity (millions of euro’s |
| $C_t$, | = Annual net cash flow of tertiary activity (millions of euro’s |
| $I_p$ | = Annual investment of primary activity (millions of euro’s) |
| $I_s$ | = Annual investment of secondary activity (millions of euro’s) |
| $I_t$ | = Annual investment of tertiary activity (millions of euro’s) |
| $d$ | = Risk-free rate (5 %) |
| $T$ | = Start date of activity (years) |
| $T'$ | = End date of activity |
| $GT_p$ | = Government tax for primary activity (%, see Table C.1 for the percentage for each activity) |
| $GT_s$ | = Government tax for secondary activity (%, see Table C.1 for the percentage for each activity) |
| $GT_t$ | = Government tax for tertiary activity (%, see Table C.1 for the percentage for each activity) |
| $GW_p$ | = Government tax write-off for primary activity (%, see Table C.1 for the percentage for each activity) |
| $GW_s$ | = Government tax write-off for secondary activity (%, see Table C.1 for the percentage for each activity) |
| $GW_t$ | = Government tax write-off for tertiary activity (%, see Table C.1 for the percentage for each activity |
| $G_p$ | = Government tax write-off for primary activity (%, see Table C.1 for the percentage for each activity) |
| $G_s$ | = Government tax write-off for secondary activity (%, see Table C.1 for the percentage for each activity) |
| $G_t$ | = Government tax write-off for tertiary activity (%, see Table C.1 for the percentage for each activity) |

$CE_p$ = Community expenditures for primary activity (%, see Table C.1 for the percentage for each activity)
$CE_s$ = Community expenditures for secondary activity (%, see Table C.1 for the percentage for each activity)
$CE_t$ = Community expenditures for tertiary activity (%, see Table C.1 for the percentage for each activity)
$RC_p$ = Research cost for primary activity (%, see Table C.1 the for percentage for each activity)
$RC_s$ = Research cost for secondary activity (%, see Table C.1 the for percentage for each activity)
$RC_t$ = Research cost for tertiary activity (%, see Table C.1 the for percentage for each activity)
$\tau$ = time (in years)
N = Maximum number of alternatives

Equation 3 states the total cash flow of an activity on the basis of the annual cash flow, taxes and community expenditure over its entire duration. Equation 4 states the total investment of an activity on the basis of the annual investments, taxes, tax write offs and community expenditure. The scrap value and abandonment cost for each activity are included in the annual investments (I) for each alternative. We also exclude value added tax in our analysis, because this is the same for all activities. Furthermore, we do not use stochastic values for the different cash flows and investments in Equations (3) and (4) because this variability is already accounted for in the calculation of the real option value.

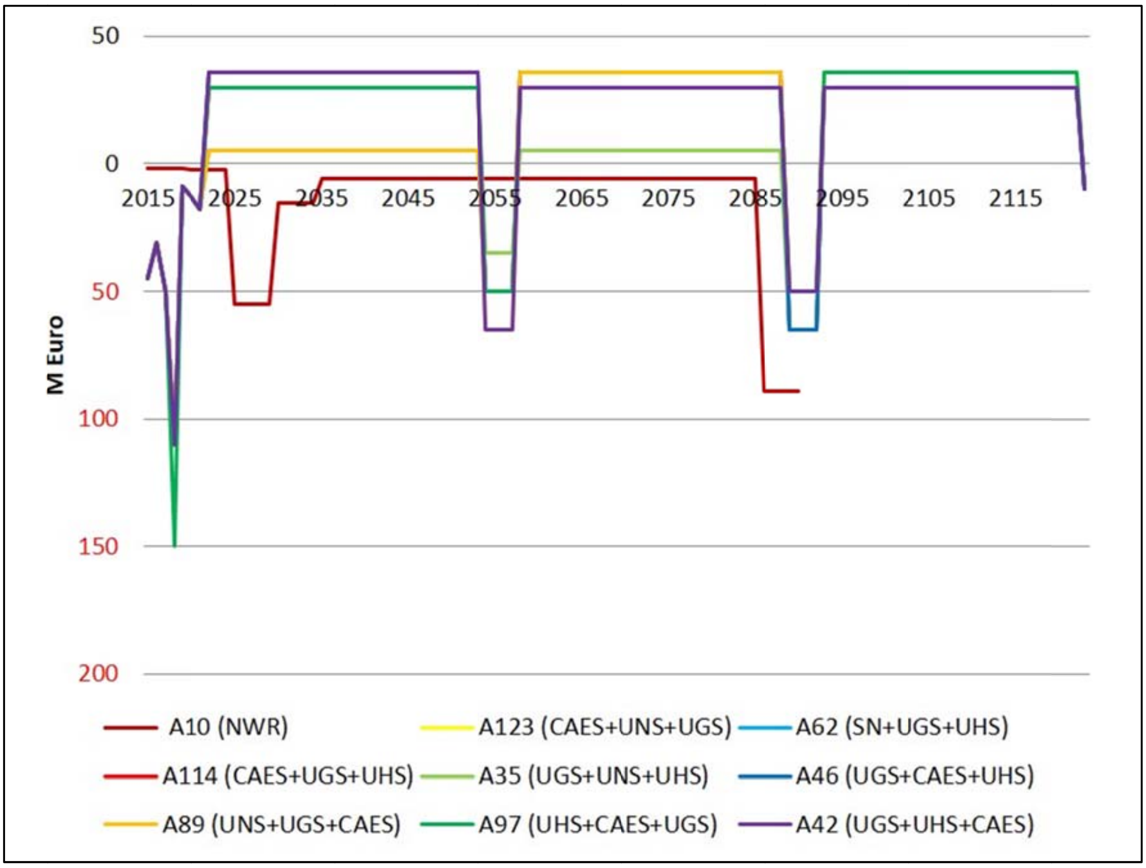


Figure 3. Annual cash flow and investments. The negative values indicate the investments and abandonment cost at the beginning and end of an alternative, respectively. For the A10 alternative, the annual cash flow is negative.

Following van Os et al. (2016), the MEMSA-approach distinguishes between technical, market, and non-technical risks to account for the different types of economic risk levels and their mitigation potential. The risk and mitigation levels are expressed as a percentage of the option value of an activity, in order to allow for a comparison between the different types of risk that may affect an activity. In the Pieterburen base case, we assume the following risk levels and risk reduction for secondary and tertiary activities, see Table 8.

| | 1. Primary activity risk level | | | | 2. Secondary activity risk level and reduction | | | | 3. Tertiary activity risk level and reduction | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| a. Mitigation potential | **0%** | **0%** | **0%** | | -20% | -10% | -5% | | -20% | -10% | -5% | |
| b. Activity | technical | market | non-technical | **4. Avg.** | technical | market | non-technical | **5. Avg.** | technical | market | non-technical | **6. Avg.** |
| c. NWR | 60% | 10% | 80% | **50%** | 48% | 9% | 76% | **44%** | 38% | 8% | 72% | **40%** |
| d. CAES | 30% | 60% | 20% | **37%** | 24% | 54% | 19% | **32%** | 19% | 49% | 18% | **29%** |
| e. UGS | 40% | 40% | 40% | **40%** | 32% | 36% | 38% | **35%** | 26% | 32% | 36% | **31%** |
| f. UNS | 20% | 60% | 20% | **33%** | 16% | 54% | 19% | **30%** | 13% | 49% | 18% | **26%** |
| g. UHS | 40% | 60% | 60% | **53%** | 32% | 54% | 57% | **48%** | 26% | 49% | 54% | **43%** |

Table 8. Economic risks and mitigation levels for the Pieterburen case. The values in the grey cells are based on analogue examples and should be considers for illustrative purpose only. The columns are grouped into primary, secondary, and tertiary activities respectively columns 1, 2 and 3. For each group, the assumed risk level (rows c – g) and risk reduction (row a) levels are shown in percentages. These percentages indicate the possible effect on the option value of an activity. The average risk level (in bold) is given for each primary, secondary and tertiary activity in columns 4, 5 and 6, respectively.

The three risk levels and risk reduction are averaged for the primary, secondary, and tertiary activities, from which the standard deviation is used to calculate the ROV of an alternative, see Equation 5 and 6.

## 5.2 Real Option Value (ROV)

To assess the expected economic value of an alternative, MEMSA uses a real option value (ROV) approach with European options, which means that the follow-up activities are seen as options, which can only be realized at certain time i.e. the deferral time. This approach allows the inclusion of the economic consequences that follow from the ranking in the sociopolitical acceptance class (van Os et al., 2016). Furthermore, since the secondary and tertiary activities are also seen as options, meaning the project proponent is not obligated to execute these activities, flexibility can be accounted for in the value of the alternative (van Os et al., 2016).

In the Pieterburen case, the deferral times are based on the strategic national policy goal deadline for NWR and the permit expiration deadline (3 years) for the other primary activities. For secondary and tertiary activities, the assumed construction and duration times of the activities depicted in Table 7 are used to define the deferral times, see Table 9.

| | | **3. Deferral time of activities in years** | | |
|---|---|---|---|---|
| **1. Alternatives** | **2. Activities** | **Primary activity** | **Secondary activity** | **Tertiary activity** |
| A10 | NWR | 65 | 0 | 0 |
| A123 | CAES+UNS+UGS | 3 | 37 | 71 |
| A62 | UNS+UGS+UHS | 3 | 37 | 71 |
| A114 | CAES+UGS+UHS | 3 | 37 | 71 |
| A35 | UGS+UNS+UHS | 3 | 37 | 71 |
| A49 | UGS+CAES+UHS | 3 | 37 | 71 |
| A89 | UNS+UGS+ CAES | 3 | 37 | 71 |
| A97 | UHS+CAES+UGS | 3 | 37 | 71 |
| A42 | UGS+UHS+CAES | 3 | 37 | 71 |
| A66 | UNS+UHS+UGS | 3 | 37 | 71 |

Table 9. Deferral times. The values in the grey cells are based on analogue examples and should be considered for illustrative purpose only. Column 1 depicts the alternatives. Column 2 shows the sequences of activities in an alternative. Column 3 depicts the deferral time for the primary, secondary and tertiary activities for each alternative. The deferral times are based on the values in Table 7 and the current deadline for a permit, that is, three years.

The MEMSA approach uses the Black–Scholes (1973) equation for European options to calculate the real option value:

$$d_1 = \frac{\ln\left(\frac{SF_p}{X_p}\right)+\left(r+\frac{sd^2}{2}\right)\tau_p}{sd\sqrt{t}} \qquad (5)$$

$$d_2 = d_1 - sd\sqrt{\tau_p} \qquad (6)$$

$$ROV_p = SF_p N(d_1) - N(d_2) X_p e^{-r\tau_p} \qquad (7)$$

$$ROV_i \equiv ROV_p \times \left(1 - PT_p\right) + ROV_s \times (1 - PT_s) + ROV_t \times (1 - PT_t) \quad i=1,\ldots,N \qquad (8)$$

where

$ROV_i$ = Real option value of alternative i (millions of euro's)
$ROV_p$ = Real option value of primary activity (millions of euro's)
$ROV_s$ = Real option value of secondary activity (millions of euro's)
$ROV_t$ = Real option value of tertiary activity (millions of euro's)
$d_1$ = Exercise price
$d_2$ = Stock price
$SF_p$ = Discounted total cash flow of primary activity
$X_p$ = Discounted total investment of primary activity
$\tau$ = Deferral time of activity (years)
$r$ = Risk-free rate (5 %)
$N(d_1)$ = Standard normal cumulative distribution function, ranging from zero to one (0.05% significance)
$N(d_2)$ = Probability density function
$sd$ = Standard deviation of risks
$PT_p$ = Profit tax of primary activity (%, only applies when *ROV* of activity is positive)
$_p$ = Primary activity
$_s$ = Secondary activity
$_t$ = Tertiary activity
N = Maximum number of alternatives

In our example of the Pieterburen salt dome, the ROV results in the expected net value of an alternative in millions of euro's at the 2016 price level. Based on the input variables described in Figure 3 and Tables 8, 9 and 11, the following real option values are obtained for the Pieterburen case, see Table 10.

| **1. Rank** | **2.Alternatives** | **3. Activities** | **4. ROV alternative** (mm euro) |
|---|---|---|---|
| 1 | A46 | UGS+CAES+UHS | 133.5 |
| 2 | A42 | UGS+UHS+CAES | 130.2 |
| 3 | A35 | UGS+UNS+UHS | 118.6 |
| 4 | A114 | CAES+UGS+UHS | 104.7 |
| 5 | A123 | CAES+UNS+UGS | 100.9 |
| 6 | A97 | UHS+CAES+UGS | 94.7 |
| 7 | A89 | UNS+UGS+CAES | 23.0 |
| 8 | A62 | UNS+UGS+UHS | 18.8 |
| 9 | A66 | UNS+UHS+UGS | 0.0 |
| 10 | A10 | NWR | -31.5 |

Table 10. Real option value for the top 10 alternatives. Column 1 shows the rank of the alternatives on the basis of the ROV. Column 2 depicts the alternatives. Column 3 shows the sequences of activities for each alternative. Column 4 shows the real option value for each alternative. The real option values are given in millions of euros at the 2016 price level and calculated using the input information provided in Tables 8, 9 and Figure 3 in Equations (3) to (8).

Table 10 shows that the A46 alternative, with the primary activity UGS, has the highest ROV value, 127.6 million euro's. The alternatives, with the primary activity CAES, have a lower ROV value (84.3 million euro's till 102.2 million euro's) and the remaining alternatives have a low or negative ROV value (-31.0 million euro's to 18.4 million euro's). The difference in ROV values is primarily related to the UGS activity, which is the most profitable activity (see Table C.2.1 to C.2.5). This means that alternatives that contain the UGS activity will have a higher ROV, making it the preferred activity for market parties. Second, the option value for a secondary and tertiary UGS activity is reduced due to the discounting of cash flows and lower economic risks levels (see Figure C.2.1 to C.2.5 and Table 8). Furthermore, the sensitivity analysis (see Appendix C) allows market parties to optimize the ROV by adjusting the deferral time and risk level. For example, the ROV approach will result in higher values than the net present value approach, especially in the case of relative high risk levels, see Figure C.2.1 to C.2.5. Such results are common for the ROV approach with European options, because it uses an asymmetrical manner to account for economic risks, meaning that the negative effects can be avoided, because secondary and tertiary activities are options (Lander and Pinches, 1998).

## 5.3 Distribution of cost and benefits

The next step is to determine the allocation of costs and benefits by including taxes and tariffs, as well as possible expenditures paid by the activity owner to the community, as part of a broader scheme for improving their wellbeing. In the Netherlands, the activity owner is not required to do so by law (Ministry of Economic affairs, Agriculture and Innovation.2012b). However, the added value of such a scheme has been argued by scholars (ter Mors et al., 2012). In the MEMSA approach, we therefore include the possibility of including such a community expenditure.

Both national government taxes and community expenditures are expressed in MEMSA in the form of the percentages of the different cash flows of an activity. Table C.1 gives the assumed percentages used to determine tax and community expenditures.

The total amount of national and/or regional taxes and tariffs are calculated using Equation 9.

$$GT_i \equiv (SF_p * RT_p) - (X_p * TW_p) + (ROV_p * PT_p) + (SF_s * RT_s) - (X_s * TW_s) + (ROV_s * PT_s) + (SF_t * t) - (X_t * TW_t) + (ROV_t * PT_t) \quad i=1,\dots,N \tag{9}$$

where

$GT_i$ = Government tax for activity i (millions of euro's)
$SF_p$ = Discounted total net cash flow of primary activity (millions of euro's)
$SF_s$ = Discounted total net cash flow of secondary activity (millions of euro's)
$SF_t$ = Discounted total net cash flow of tertiary activity (millions of euro's)
$X_p$ = Discounted total net investment of primary activity (millions of euro's)
$X_s$ = Discounted total net investment of secondary activity (millions of euro's)
$X_t$ = Discounted total net investment of tertiary activity (millions of euro's)
$RT_p$ = Revenue tax of primary activity (%)
$RT_s$ = Revenue tax of secondary activity (%)
$RT_t$ = Revenue tax of tertiary activity (%)
$TW_p$ = Tax write-off of primary activity (%)
$TW_s$ = Tax write-off of secondary activity (%)
$TW_t$ = Tax write-off of tertiary activity (%)
$PT_p$ = Profit tax of primary activity (%)
$PT_s$ = Profit tax of secondary activity (%)
$PT_t$ = Profit tax of tertiary activity (%)
$ROV_p$ = Real option value of primary activity (millions of euro's)
$ROV_s$ = Real option value of secondary activity (millions of euro's)
$ROV_t$ = Real option value of tertiary activity (millions of euro's)
N =Maximum number of alternatives

Furthermore, to determine the total amount of government tax, the corresponding values of the three activities that are part of an alternative are defined using

$$GT_i \equiv GT_p + GT_s + GT_t \quad i=1,\dots,N \tag{10}$$

where

$GT_i$ = Government tax for alternative I (millions of euro's)
$GT_p$ = Government tax for primary activity (millions of euro's)
$GT_s$ = Government tax for secondary activity (millions of euro's)
$GT_s$ = Government tax for tertiary activity (millions of euro's)
N = Maximum number of alternatives

The (optional) amount of community expenditure is defined as

$$CE_i \equiv (SF_p * GE_p) + (X_p * CE_p) + (SF_s * GE_s) + (X_s * CE_s) + (SF_t * GE_t) + (X_t * CE_t) \quad i = 1, \dots, N \tag{11}$$

where

$CE_i$ = Community expenditure for activity i (millions of euro's)
$SF_p$ = Discounted total net cash flow of primary activity (millions of euro's)
$SF_s$ = Discounted total net cash flow of secondary activity (millions of euro's)
$SF_t$ = Discounted total net cash flow of tertiary activity (millions of euro's)
$X_p$ = Discounted total investment of primary activity (millions of euro's)
$X_s$ = Discounted total investment of secondary activity (millions of euro's)
$X_t$ = Discounted total investment of tertiary activity (millions of euro's)
$CE_p$ = Community Expenditure for primary activity (%)
$CE_s$ = Community Expenditure for secondary activity (%)
$CE_t$ = Community Expenditure for tertiary activity (%)
$N$ = Maximum number of alternatives

Furthermore, to determine the total amount of community expenditure, the corresponding values of the three activities have to be summated:

$$CE_i \equiv CE_p + CE_s + CE_t \quad i=1,\dots,N \tag{12}$$

where

$CE_i$ = Community expenditure for alternative i (millions of euro's)
$CE_p$ = Community expenditure for primary activity (millions of euro's)
$CE_s$ = Community expenditure for secondary activity (millions of euro's)
$CE_t$ = Community expenditure for tertiary activity (millions of euro's)
$N$ = Maximum number of alternatives

## 5.4 Aggregation into a single ranking

Furthermore, to obtain a single ranking for the market acceptance class, which is required for the final ranking, the ROV of an alternative, the government tax, and the community expenditure, are aggregated into a single score, the market acceptance factor. This factor is the sum of the percentages of the ROV, government tax, and community expenditure of each alternative, as follows:

$$MAF_i \equiv \left(\sum_{j=1}^{N} ROV_i + \sum_{j=1}^{N} GT_i + \sum_{j=1}^{N} CE_i\right) \times 100\% \quad j=1,\dots,N$$

(13)

where

$MAF_i$ = Market acceptance factor of alternative i (%).
$ROV_i$ = Real option value of alternative i (millions of euro's).
$GT_i$ = Government tax of alternative i (millions of euro's).
$CE_i$ = Community expenditure of alternative (millions of euro's).
N = Maximum number of alternatives

Table 11 shows the ROV, government tax, and community expenditure for the Pieterburen case alternatives.

| 1. Rank | 2.Alternatives | 3. Activities | 4. ROV alternative | 5. ROV alternative (% of total) | 6. Government tax | 7. Government Tax (% of total) | 8. Community Expenditure | 9. Community Expenditure (% of total) | 10. Total value | 11. MAF |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | **A46** | UGS+CAES+UHS | **133.5** | 19.3% | **85** | 41% | **18** | **13%** | **237** | 22.5% |
| 2 | **A42** | UGS+UHS+CAES | **130.2** | 18.8% | **83** | 40% | **18** | **13%** | **231** | 22.0% |
| 3 | **A35** | UGS+UNS+UHS | **118.6** | 17.1% | **74** | 36% | **17** | **12%** | **210** | 20.0% |
| 4 | **A114** | CAES+UGS+UHS | **104.7** | 15.1% | **52** | 25% | **17** | **12%** | **174** | 16.5% |
| 5 | **A123** | CAES+UNS+UGS | **100.9** | 14.6% | **47** | 23% | **17** | **12%** | **164** | 15.6% |
| 6 | **A97** | UHS+CAES+UGS | **94.7** | 13.7% | **35** | 17% | **17** | **12%** | **147** | 13.9% |
| 7 | **A10** | NWR | **-31.5** | -4.6% | **0** | 0% | **20** | **14%** | **-12** | -1.1% |
| 8 | **A89** | UNS+UGS+CAES | **23.0** | 3.3% | **-52** | -26% | **10** | **7%** | **-19** | -1.8% |
| 9 | **A62** | UNS+UGS+UHS | **18.8** | 2.7% | **-53** | -26% | **10** | **7%** | **-24** | -2.3% |
| 10 | **A66** | UNS+UHS+UGS | **0.0** | 0.0% | **-66** | -32% | **10** | **7%** | **-56** | -5.3% |

Table 11. Market acceptance factor ranking for the Pieterburen salt dome alternatives. Column 1 indicates the rank of an alternative on the basis of the market acceptance factor Column 2 depicts the top 10 alternatives. Column 3 shows the sequences of activities in each alternative. Column 4 depicts the real option value for each alternative, see also Table 10. Column 5 shows the real option value for each alternative, expressed as a percentage of the total real option value of the top 10 alternatives for the Pieterburen salt dome. Column 6 depicts the amount of net government tax for each alternative on the basis of the percentages shown in Table C.1 and Equations 9 and 10. Column 7 shows amount of government tax for each alternative, expressed as a percentage of the total government tax of the top 10 alternatives for the Pieterburen salt dome. Column 8 depicts the amount of community expenditure for each alternative on the basis of the percentages shown in Table C.1 and Equations 11 and 12. Column 9 shows amount of community expenditure for each alternative, expressed as a percentage of the total government tax of the top 10 alternatives for the Pieterburen salt dome. Column 10 shows the total value of an alternative, which is a summation of the corresponding values in columns 3, 5 and 7. Column 11 shows the market acceptance Factor for each alternative, which is calculated using Equation 13.

Table 11 shows, for the Pieterburen case that the A46, consisting of UGS, CEAS, and UOS, has the highest market acceptance factor value, making it the preferred alternative. The negative percentages for some alternatives indicate that the market acceptance is very low. The market acceptance factor ranking and the subsequent sensitivity analysis can be used by the market parties and permit granting authority to determine the added economic value of an activity. In this sense, it provides a factual basis for a discussion about economic fairness and compensation with the host community.

On the basis of these market acceptance factor values, we assume that the following alternatives are further evaluated in the community acceptance class:

- The NWR alternative (A10), cannot be dropped as an alternative, because it doubles as the do-nothing-now alternative, see section 2.2.
- The UGS, CAES, and UHS alternative (A46), because it has the highest market acceptance factor value and UGS is the actually proposed activity in the Pieterburen case.
- The CAES, UGS, and UHS alternative (A114), because it has the highest market acceptance factor value of all other alternatives where UGS is not the primary activity, see Table 11.

# 6 The community acceptance module

The community acceptance module focuses on the impact of an activity on the host community, as perceived by the host community itself. In this sense the host community can have a say in the aspects that are closely related to them, which is an often-heard lacking attribute of the current practice (van Os et al., 2016). Therefore, following van Os et al. (2016), the MEMSA approach uses an analytical hierarchical process with a pairwise comparison, because this approach fulfills the requirements set by the community acceptance stakeholders to a high extent. In MEMSA, the impact of an activity is subdivided into the environmental, economic, and social impacts and risk that result from a subsurface activity. The priority for each of these aspects, following Al-Harbi (2001), is expressed on a nine-point scale for each pairwise comparison. This approach allows the formulation of a dominance matrix. This matrix contains the synthesized priorities for each criterion, on the basis of the pairwise comparisons. Furthermore, most alternatives have possible future secondary and tertiary subsurface activities. In this respect, it is important to consider that the view from the host community can vary over time, for example due to experience gained during the operation of the primary activity (van Os, et al., 2016). This may have a substantial impact on the perception of the host community of those future activities. In addition, the lack of accurate detailed information, such as the impact of a secondary activity that could take place in 30 years' time, reduces the comprehensibility of the comparison. Therefore, in the community acceptance module only the alternative's primary activity is evaluated.

## 6.1 Input information

To evaluate the environmental, economic, and social impact and corresponding hazards, the MEMSA approach uses the following (existing) assessments:

1. The field (resource) development plan (FDP), based on a local geological model and contains information such as production rates and the installation design, including the projected cash flows.

2. The environmental impact assessment (EIA) is used to obtain information about changes in surface conditions, such as ground subsidence or the risk of groundwater pollution.

3. The social impact assessment (SIA) contains information about changes in social conditions. Furthermore, SIA embodies a process in which the host community is involved in the DMP to a greater extent (Vanclay, 2006). This is operationalized in community acceptance module by including the community's views regarding the activity and the corresponding impacts and risks, in the assessment of community acceptance.

In the MEMSA approach, the FDP, EIA and SIA are integrated in a single evaluation, thus allowing a comprehensive evaluation of the desired and undesired impacts. However, in the permit DMP, the usefulness and perceived importance of the criteria in these assessments depend on the activity, the project area, the community, and other contextual matters, such as regulations. Therefore, these criteria should be defined and assessed in conjunction with the competent authority and the host community in an early phase of the permit DMP, preferably when assessing the site index. In the Pieterburen case, the permit DMP was terminated before the FDP, EIA and SIA where available. We therefore assume that the criteria used in the Pieterburen case description are sufficient. Furthermore, on the basis of similar cases, we assume the following hazards and impacts, see Table 12.

| 1.Group level criteria | 2. Sub-level Criteria | 3. A10 (NWR) | 4. A46 (UGS+CAES+UHS) | 5. A114 (CAES+UGS+UHS) | 6. “do-nothing-forever” |
|---|---|---|---|---|---|
| a. Economic | a.1. Compensation scheme | *€ 19,8 million* | *€ 18,0 million* | *€ 16,6 million* | *€ 0 million* |
| | a.2. Loss in property value | €1.000.000 | €60.000 | €50.000 | 0 |
| | a.3 Local economic benefits | €80.000 | €40.000 | €20.000 | 0 |
| b. Environmental | b.1. Subsidence/tremors | Low | Low | Low | None |
| | b.2. Water changes | Low | Low | Low | None |
| | b.3. Ecological changes | High | High | Medium | None |
| | b.4. Cultural/historical changes | Medium | Low | Low | None |
| | b.5. Technical-Environmental changes | High | Medium | Medium | None |
| | b.6. Environmental hazards | High | Medium | Medium | None |
| c. Social | c.1 Perception proponent | Very negative | Negative | Positive | Indifferent |
| | c.2. Influences on social-economic minorities | Low | Low | Low | None |
| | c.3. Strain on local emergency services | High | High | Low | None |
| | c.4. Safety hazards | High | Medium | Medium | None |
| | c.5. Spatial integration | Low | Low | Medium | None |

Table 12. Criteria in the community acceptance class for the Pieterburen case. Column 1 indicates the criteria for the group level. Column 2 depicts the sublevel criteria. Columns 3 - 6 (grey cells) indicate the assumed values, which are based on analogous examples, for all the alternatives for each criterion, on the basis of an assumed FDP, EIA, and SIA for the Pieterburen case. The values in row **a**.1. are derived from the market acceptance class (see Table 11).

## 6.2 Aggregation into a single ranking

To obtain a ranking of the alternatives under evaluation in the community acceptance module, the subcriteria and group criteria must be aggregated into a single number, which we define as the community acceptance priority factor. Following Al-Harbi (2001), the score for each initial activity of an alternative is calculated by determining the synthesized priorities of the alternatives and subcriteria. In Table 13, the synthesized priorities and resulting community acceptance priority factor values for the remaining alternatives in the community acceptance module in the Pieterburen case, are shown.

| | | Alternatives | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **1.NWR** | | **2.UGS** | | **3.CAES** | | **4."do-nothing-forever"** | |
| Group criteria | Sub-criteria | PVA | SPC | PVA | SPC | PVA | SPC | PVA | SPC |
| **a. Economic criteria** | Compensation scheme | 0.04 | 0.21 | 0.60 | 0.21 | 0.25 | 0.21 | 0.12 | 0.21 |
| | Loss in property value | 0.53 | 0.69 | 0.05 | 0.69 | 0.31 | 0.69 | 0.11 | 0.69 |
| | Local economic benefits | 0.46 | 0,1 | 0.13 | 0,1 | 0.11 | 0,1 | 0.30 | 0,1 |
| | GCP | *0,33* | | *0,33* | | *0,33* | | *0,33* | |
| | Score | 0.42 | | 0.17 | | 0.28 | | 0.13 | |
| | Group priority | 0.14 | | 0.06 | | 0.09 | | 0.04 | |
| **b. Environmental criteria** | Soil changes | 0.05 | 0.39 | 0.05 | 0,39 | 0.05 | 0,39 | 0.86 | 0,39 |
| | Water changes | 0.05 | 0.13 | 0.05 | 0,13 | 0.05 | 0,13 | 0.86 | 0,13 |
| | Ecological changes | 0.04 | 0.05 | 0.14 | 0,05 | 0.20 | 0,05 | 0.62 | 0,05 |
| | Cultural and historical changes | 0.05 | 0.07 | 0.14 | 0.0 7 | 0.14 | 0.07 | 0.68 | 0.07 |
| | Environmental changes | 0.08 | 0.12 | 0.16 | 0,12 | 0.16 | 0,12 | 0.61 | 0,12 |
| | Environmental hazards | 0.03 | 0.24 | 0.09 | 0,24 | 0.11 | 0,24 | 0.78 | 0,24 |
| | GCP | *0,33* | | *0,33* | | *0,33* | | *0,33* | |
| | Score | 0,04 | | 0,08 | | 0,09 | | 0,79 | |
| | Group priority | 0,01 | | 0,03 | | 0,03 | | 0,26 | |
| **c. Social criteria** | Perception proponent/activity | 0.05 | 0.08 | 0.10 | 0,08 | 0.24 | 0,08 | 0.60 | 0,08 |
| | Influences on Social-economic minorities | 0.07 | 0.04 | 0.07 | 0,04 | 0.07 | 0,04 | 0.78 | 0,04 |
| | Strain on local emergency services | 0.05 | 0.15 | 0.10 | 0,15 | 0.24 | 0,15 | 0.60 | 0,15 |
| | Safety hazards | 0.05 | 0.51 | 0.14 | 0,51 | 0.14 | 0,51 | 0.68 | 0,51 |
| | Spatial integration | 0.04 | 0.21 | 0.04 | 0,21 | 0.21 | 0,21 | 0.70 | 0,21 |
| | GCP | *0,33* | | *0.33* | | *0.33* | | *0,33* | |
| | Score | 0,05 | | 0,11 | | 0,17 | | 0,67 | |
| | Group priority | 0,02 | | 0,04 | | 0,06 | | 0,22 | |
| **d. Community Acceptance Priority Factor** | | **17%** | | **12%** | | **18%** | | **53%** | |

Table 13. Community acceptance priority factor. The columns 1-4 indicate the activities under evaluation. Rows a – c show the different criteria used for the community acceptance priority factor, respectively economical (a), environmental (b) and social (c). Row d shows the community acceptance priority factor scores for all activities under evaluation, calculated using the input information in Table 12 and Equations (14) to (16). The grey cells, labeled with GCP, are the assumed group criterion priority.

From Table 13, it results that the “do-nothing-forever" alternative has the highest community acceptance priority factor value of 53%. This result indicates that this alternative is the most preferred by the host community. The second highest-scoring alternative is A114 (CEAS), with a community acceptance priority factor value of 18%. Furthermore, the lowest-scoring alternative is the proposed A46 (UGS) alternative, with a community acceptance priority factor value of 12%. These results suggest that the host community would prefer not to utilize the Pieterburen salt dome at all. This insight can be used by the permit granting authority to decline the permit or to select a different location where community acceptance priority factor for the “do-nothing-forever" alternative is lower. In addition, the permit granting authority can use the sensitivity analysis of the community acceptance priority factor to improve it, by compensating or mitigating the key negative aspects of the proposed activity, as perceived by the host community.

However, it should be noted that the community acceptance priority factor ranking is based on the assumption that the priorities are linearly related to the assumed scores shown in Table 12.In a real-life application, this may not be the case, because the preference of criteria by community members may suffer from an inconsistency. Therefore, the extent to which the pairwise comparisons are internally consistent has to be investigated by determining the consistency ratio. The consistency ratio is a measure that indicates the internal consistency or rationality of the dominance between criteria (Al-Harbi, 2001).

# 7 Integration module

As indicated by van Os et al. (2016), a final ranking from a social acceptance perspective should be based on easily demonstrable principles to facilitate the discussion among the stakeholders in the permit decision-making process. In addition, the evaluation methods used in each acceptance module need to fulfill the requirements originating from each social acceptance class (van Os et al., 2016). Therefore, the MEMSA approach uses a weighted summation of relative strategic factor, market acceptance factor, and community acceptance priority factor, called the social acceptance factor. In this manner, the MEMSA approach complies with the two above mentioned requirements. Furthermore, the weight factor for the relative strategic factor, market acceptance factor and community acceptance priority factor allows stakeholders to include the priority of each social acceptance class in the overall ranking of the alternatives, according to their own view. However, because several alternatives were eliminated in the sociopolitical and market acceptance modules, the relative strategic factor and market acceptance factor values need to be adjusted to reflect the reduced number of alternatives after the community acceptance module. This adjustment takes place in the integration module, because the remaining alternatives can only be determined after the community acceptance module. We use the following equations to adjust the relative strategic factor and market acceptance factor values:

$$RSF'_i \equiv \frac{RSF_i}{\sum_{j=1}^{N} RSF_j} * 100\% \quad i=1,\ldots,N \tag{14}$$

$$MAF'_i \equiv \frac{MAF_i}{\sum_{j=1}^{N} MAF_j} * 100\% \quad i=1,\ldots,N \tag{15}$$

where

| | |
|---|---|
| $RSF_i$ | = Relative strategic factor of alternative i |
| $RSF'_i$ | = Adjusted Relative strategic factor for alternative i |
| $MAF_i$ | = Market acceptance factor for alternative i |
| $MAF'_i$ | = Adjusted Market acceptance factor for alternative i |
| $N$ | = Maximum number of alternatives |

Equations (17) and (18) normalize the relative strategic factor and market acceptance factor values to make them comparable with the community acceptance priority factor values and to reflect the reduced number of alternatives. Furthermore, to incorporate the relative importance of the social acceptance classes, we use a weight factor: in defining the social acceptance factor values

$$SAF_i \equiv RSF'_i * PW_{RSF} + MAF'_i * PW_{MAF} + CAPF_i * PW_{CAPF} \quad i=1,\ldots,N \tag{16}$$

where

| | |
|---|---|
| $SAF_i$ | = Social acceptance factor of alternative i |
| $RSF'_i$ | = Adjusted Relative strategic factor of alternative i |
| $MAF'_i$ | = Adjusted Market acceptance factor of alternative i |
| $CAPF_i$ | = Community acceptance priority factor of alternative i |
| $PW_{RSF}$ | = Priority weight factor for sociopolitical acceptance class |
| $PW_{MAF}$ | = Priority weight factor for market acceptance class |
| $PW_{CAPF}$ | = Priority weight factor for community acceptance class |
| $N$ | = Maximum number of alternatives |

Based on the results from the sociopolitical, market, and community acceptance modules, we obtain the social acceptance factor values for the four remaining alternatives, see Table 14.

| Priority Weight factor | | | | | *0,33* | | | *0,33* | | *0,33* | 1,00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Rank | 2. Alternatives | 3. Activity | 4. RSF | 5. RSF adjusted | 6. RSF weighted | 7. MAF | 8. MAF adjusted | 9. MAF weighted | 10. CAPF | 11. CAPF weighted | 12. SAF |
| 1 | A46 | UGS | 0.036 | 32% | 11% | 22% | 59% | 20% | 12% | 4% | 34% |
| 2 | A 114 | CAES | 0.037 | 33% | 11% | 20% | 43% | 14% | 18% | 6% | 32% |
| 3 | “do-nothing-forever” | | 0 | 0% | 0% | 0% | 0% | 0% | 53% | 18% | 18% |
| 4 | A 10 | NWR | 0.039 | 34% | 11% | -1% | -2% | -1% | 17% | 6% | 16% |

Table 14. Social acceptance factors for the Pieterburen case alternatives. From left to right, the columns indicate the rank of the alternative on the basis of the social acceptance factor, the alternatives (column 2), the relevant activities (column 3, the relative strategic factor (column 4) the adjusted relative strategic factor (column 5), the weighted relative strategic factor (column 6), market acceptance factor (column 7), the adjusted market acceptance factor (column 8), the weighted market acceptance factor (column 9), the community acceptance priority factor (column 10), the weighted community acceptance priority factor (column 11) and the social acceptance factor (column 12). The adjusted values of relative strategic factor and market acceptance factor are calculated using Equations (14) and (15), respectively. The social acceptance factor values for each alternative, are calculated using Equation (16). The priority weight factors, in italics, are considered equal for all three classes.

Table 14 shows that the A46 (UGS+CAES+UHS) alternative has the highest social acceptance factor value (34%). This is mainly due to the overall high score of this alternative in all modules. This means that the proposed activity by Electricité de France was the best option, using the assumptions made in this case study. Therefore, in order gain an insight in the robustness of our ranking we used different priority weight factors (see Appendix E.1). From this we find that the A46 is still the preferred alternative in the cases where the sociopolitical and community priority weight factors are low. However, when the priority weight factors for sociopolitical and community are high, then the highest-ranking alternatives are resp. A114 and A0 “do-noting forever”. By adjusting the priority weight factors, for example to reflect the view from a stakeholder, a better understanding is obtained about the values of the involved stakeholders, allowing for a more constructive dialogue.

Furthermore, it should be noted that the main contributing factor to the high score of the A46 alternative was the assumption that the reduced capacity of the Groningen gas field, due to the occurrence of earthquakes, resulted is an additional demand in energy reserve capacity. This was not an issue at the time that Electricité de France applied for an exploration permit, which would mean that at that time the relative strategic factor of an UGS would be substantially lower, while considering everything else the same. In this sense the MEMSA approach facilitates the evaluation of the interactions between subsurface activities.

In addition, the “do-nothing-forever” alternative has a higher social acceptance factor value then the A10, which doubles as the “do-nothing now” alternative, despite it only scored in the community acceptance class. These results reflect the decision made in the actual Pieterburen permit DMP. First, the local community was against any development of the salt dome, as reflected in the high social acceptance factor score of the “do-nothing-forever”. Second, the national government did not support an UGS to her fullest extent, by using its overriding power. Here, a possible explanation could be the low strategic value of UGS in comparison to a NWR and the reservation for a future use.

## 7.1 Interpreting the MEMSA results

Aggregation of the relative strategic factor, market acceptance factor and community acceptance priority factor values into a single ranking reduces the insight in the underlying relations between criteria applied. This reduces the potential to formulate possible solutions and to indicate an alternative’s structural shortcomings. We believe this insight can be provided by the sensitivity analysis of relative strategic factor, market acceptance factor, and community acceptance priority factor as included in Appendix B.3, C and D, when the sensitivities are transparent. For example, for the A10 NWR alternative, extending the deferral time improves ROV and, in turn, market acceptance factor. Furthermore, from the sensitivity analyses of the community acceptance priority factor values, it is clear that the NWR is sensitive to a change in the economic benefits for the host community. Furthermore, reducing the environmental impact, for example, by relocating or reducing some of the surface installations, will have a positive effect on the community acceptance priority factor of an NWR. However, it is doubtful, considering the low score of the NWR alternative for the environmental and social group criteria, that this strategy will be successful. It is also questionable if the low acceptance levels can be increased due to activity-specific constraints. For example, eliminating the need for a surface facility will probably decrease the social and environmental impact of an NWR and thereby increase the community acceptance priority factor. However, for all practical purposes, an actual NWR will always have a surface facility.

## 8 Conclusion

We investigate how the decision support system ‘Modular Evaluation Method Subsurface Activities’ (MEMSA) can help to overcome the shortcomings of the current practice in the Netherlands. In this respect, it appears that MEMSA facilitates a more informed decision-making process for permit applications of subsurface activities. It has not been our intention to arrive at a model that results in project acceptance per se, but to account for key factors that have shown to be highly relevant and have been left unaccounted for.

From our case study of the Pieterburen salt dome, we conclude the following with regard to the MEMSA approach: Firstly, it facilitates the formulation of alternatives in a more proactive procedure, which reduces potential bias in the selection procedure of alternatives, as often observed in practice. Secondly, it allows for the identification of additional concerns by the community, in an earlier phase of the permit decision-making process, then is possible now. Thirdly, it considers the consequences of a decision following from the path dependency of a subsurface activity for strategic national policy goals in more concrete terms. In addition, MEMSA makes the contribution of a subsurface activity explicit. Both are lacking in current practice, often resulting in unsupported claims in the DMP and corresponding discussion. Fourthly, it ranks alternatives on the basis of economic performance and the distribution of cost and benefits, providing a common factual basis for the discussion about compensation and economical justice. Fifthly, it allows the host community to become more involved in the permit decision-making, in a structural manner that corresponds to their knowledge level, concerns and interests. Finally, it facilitates the evaluation of the interaction between subsurface activities, which is lacking in the current practice in the Netherlands. Based on these conclusions, we argue that the applied tools and methods in the MEMSA approach seem to provide a more transparent and structured process that facilities a dialogue in which the stakeholders can express their concerns and interests in a more comprehensive fashion, than what is possible the current practice.

The results from our case study are based on a selection of criteria in each class of social acceptance and several assumptions regarding the relevance these criteria, such as policy goals weight factors. A lack of strategic national policy goals and their relative importance reduces the ability of the MEMSA approach to discriminate between alternatives.

Furthermore, due to a lack of information we used analogues to determine the scores for many of the criteria. Although the criteria, criteria scores and information are based on examples from the literature and analogous cases, they are perhaps not generally applicable and require case-specific adjustment, especially regarding the site index and community acceptance priority factor. However, this information is hard to obtain beforehand. This is why we structured the MEMSA approach in the described manner, going from abstract to detailed. This means that the criteria use in the MEMSA approach are selected on the basis the context of the specific case. In this sense the MEMSA approach should be seen more as a flexible evaluation process that facilitates the discussion between stakeholder, then a static evaluation method that provides normative results.

Furthermore, we limit our sensitivity analysis to the policy priority for the relative strategic factor, the assumed risk level, and the deferral time for the real option values and the group criterion priority for the community acceptance priority factor. However, in some cases, a more extensive sensitivity analysis may be required. In addition, a geological space could have an intrinsic value that cannot be quantified. We therefore use an indirect approach to determine the value of the “do-nothing-now” and “do-nothing-forever” alternatives that assumes that a geological space only has strategic value when an activity contributes to the realization of strategic national policy goals. However, this indirect approach may omit in some cases a part of the intrinsic value. Such a situation effectively acts as an ex post evaluation of policy and policy goals. If a stakeholder argues that some important policy goals or fields are not accounted for in MEMSA, these can be easily incorporated, for example, in the products, geological spaces, activities, and policy goals matrix without changing the approach itself.

Furthermore, by analyzing the concerns, interests, and resulting interactions, it is possible to indicate the order and extent to which these aspects should be addressed in the permit decision-making process. We argue that this is very useful for decision-makers working on subsurface activities, because in this sense the MEMSA approach is more concrete in the “when and how” regarding community involvement than the popular claim that the community should be involved to a greater extent in an early phase.

Despite the assumptions regarding the selection and scores of criteria, used in our study of the Pieterburen salt dome, we identify the potential of the MEMSA approach for including strategic and social concerns as well as economic and environmental concerns in the permit DMP for subsurface activities in a single transparent approach. The benefit of the MEMSA approach is that it can systematically address the interactions resulting from the inclusion of strategic, environmental, economic, and social concerns. Furthermore, the MEMSA approach structures the permit DMP for subsurface activities and it allows for the inclusion of stakeholder's view, thereby improving the DMP. The MEMSA approach may be also useful in other research or policy fields, where there is a need for a systematic comprehensive project evaluation of a wide variety of alternatives that includes both strategic and social aspects.

Finally, the MEMSA approach includes the top down interaction between the strategic level and project level. However, the bottom-up interactions between project level and strategic national policy for the subsurface, are not included in the MEMSA approach. We would like to argue that the bottom up interactions should be included in a decision support system, because the subsurface activities that are realized will determine the extent to which strategic national policies will be achieved. By understanding the bottom up interaction, it would possible to better adjust strategic policies for subsurface in order to mitigate unwanted strategic outcomes. Therefore, we will investigate in future research the potential of identifying and analyzing key parameters which describe the interactions between strategic policies for the subsurface and the associated activities.

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**Appendix A.**

## A.1 Detailed schematic overview

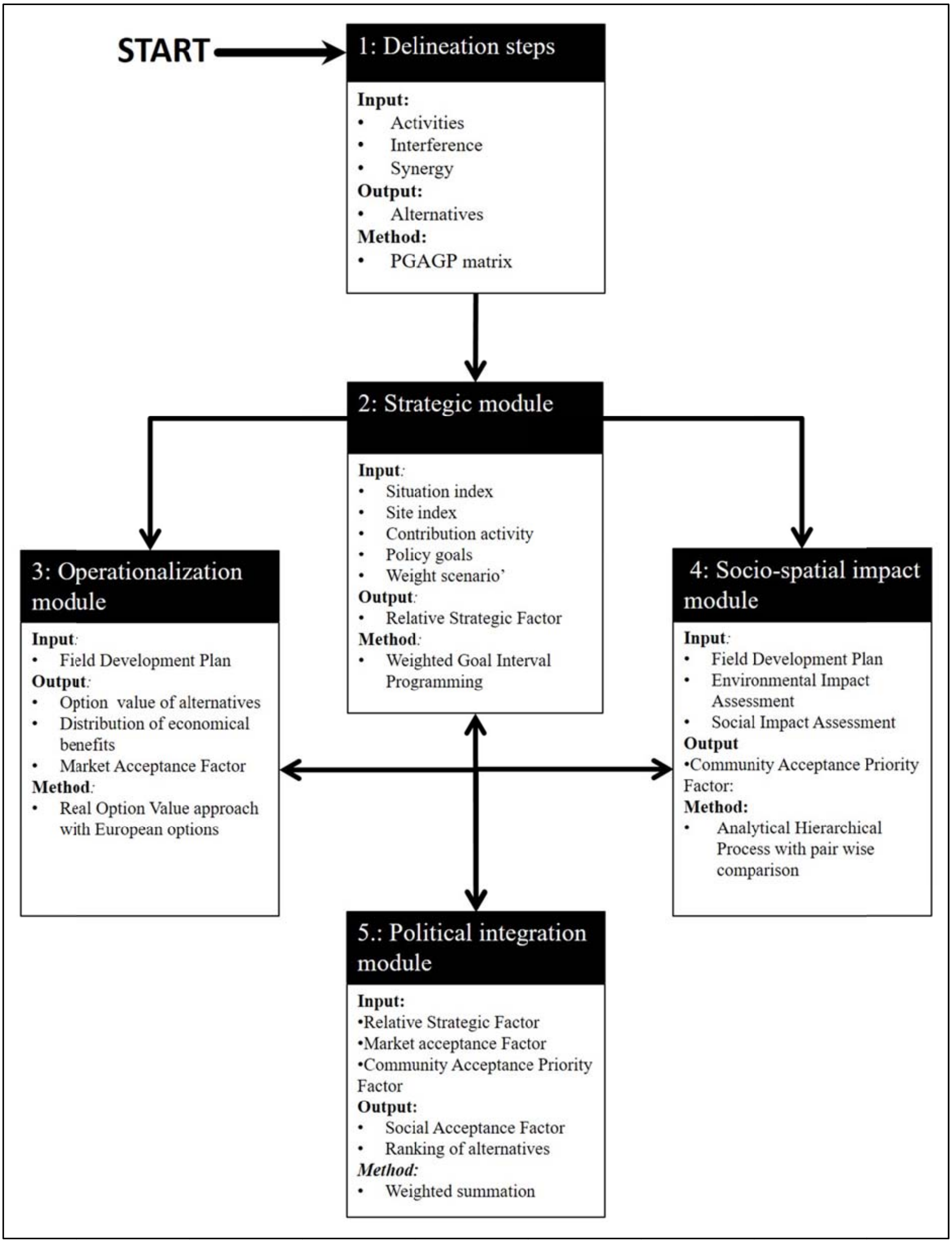
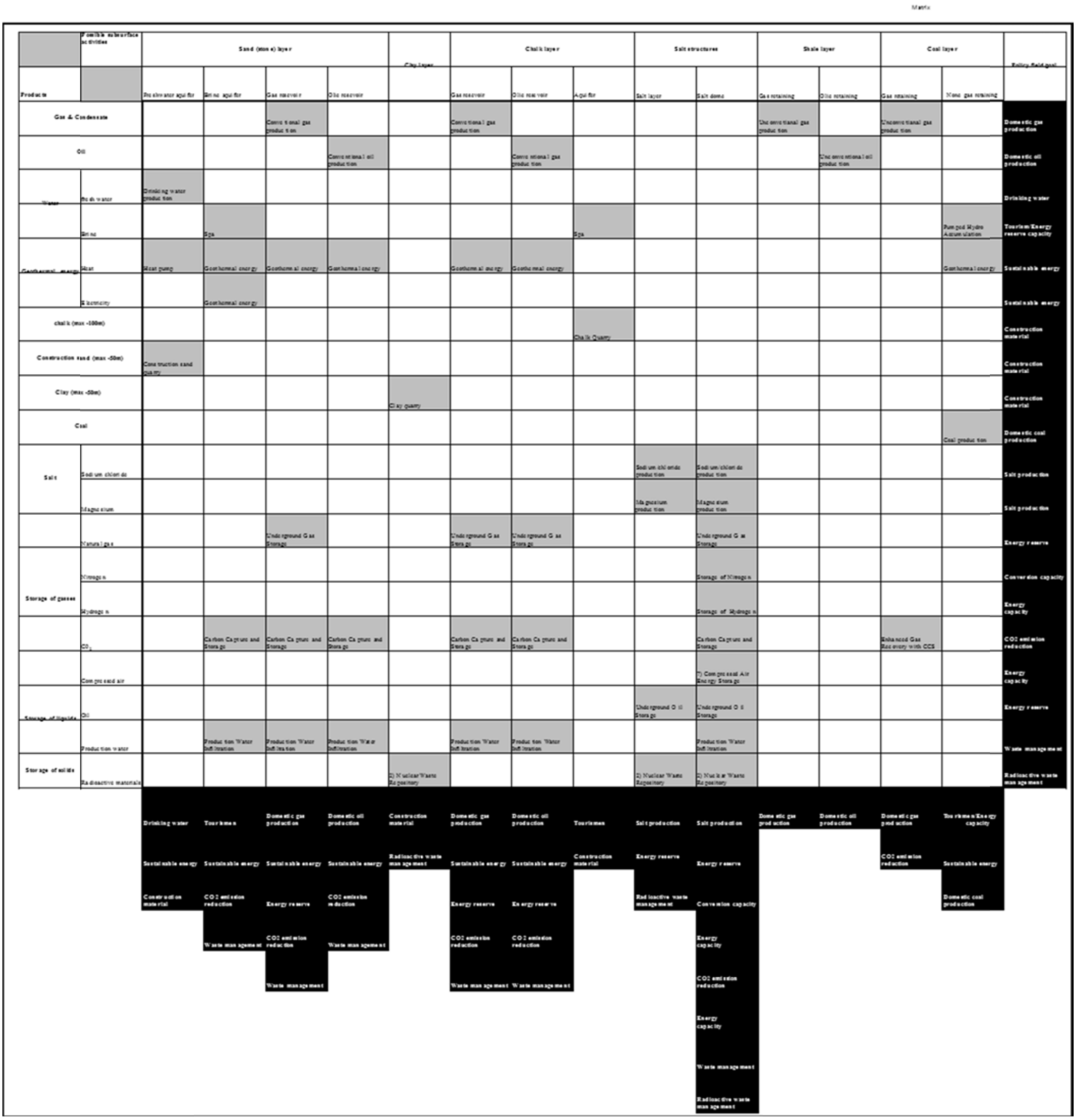



Figure A.1: Schematic detailed overview. The solid black arrows indicate the flow direction within MEMSA. The iterative nature of the MEMSA workflow is indicated with bidirectional arrows between modules 2 to 5. The dotted black arrows indicate the different feedback mechanisms.

1154 ## A.2 Products, geological spaces, activities, and policy goals matrix




1155
1156 Figure A.2: The complete products, geological spaces, activities, and policy goals matrix. The white cells
1157 indicate the products and the geological layers. The grey cells indicate the different subsurface activities. The
1158 black cells at the bottom of the policy goal, activity, products and geological space matrix show the conflicting
1159 strategic national policy goals for each geological space. The black cells at the bottom show the conflicting
1160 strategic national policy goals for each geological space.

## Appendix B.1

| B.1.1 Situation index criteria | |
|---|---|
| Criteria | Explanation |
| Structure | The structure is related to the shape and depth of the geological space, which affect the potential of subsurface activity. |
| Safety | Safety aspects that are affected by the geo-technical parameters. |
| Infrastructure | Infrastructure that may affect the profitability and risk level of a subsurface activity. |
| Legal | Legal aspects that may affect the opportunity to execute a subsurface activity. |
| Available volume (1=sufficient) | The criterion indicates if the geological spaces have the necessary volume to accommodate the proposed subsurface activity. A high factor e.g. 1 indicates that the volume is sufficient. A low factor e.g. 0 indicated that the volume is not sufficient. |
| Faults (1= no faults) | The criterion indicates the presence of faults and the extent in which they may negatively affect the safety of subsurface activities. A high factor e.g. 1 indicates no faults or no negative effect. A low factor indicates e.g. 0 indicates the presence of faults or the potential of a negative effect. |
| Homogeneity (1= no irregularities) | The criterion indicates the homogeneity of the geological space. A high factor e.g. 1 indicates a high level of homogeneity. A low factor e.g. 0 indicates a low homogeneity level or a lack of information. |
| Presence of re-usable infrastructure (1=yes) | The criterion indicates the presence of existing re-usable infrastructure, like wells. A high factor e.g. 1 indicates the presence of re-usable infrastructure. A low factor e.g. o indicates no presence of re-usable infrastructure. |
| Exploration well (1=yes) | The criterion indicates the extent in which there is an exploration well is present that provides the desired information, for example to the target depth. A high factor e.g. 1 indicates the presence of an exploration well that provides the desired information. A low factor e.g. 0 indicates that there is no exploration well. |
| Licensed (1=no) | The criterion indicates the extent in which the geological space is licensed to another licenses holder. A high factor e.g. 1 indicates that the geological spaces are not licensed. A low factor e.g. indicates that the geological space is licensed to another license holder. |

Table B.1.1: Situation index criteria.

| **B.1.2 Site index criteria** | |
|---|---|
| Criteria | Explanation |
| Synergy options | Potential beneficiary aspect between the subsurface activity and other local (economic) activities or processes. |
| Interference | Potential limiting factors that follow from interference with other human activities. |
| Impact | The physical impact of the surface installation of the subsurface activity. |
| Risk | The risk related to the technical and geological aspects of the subsurface activity. |
| Local supply of production resources (1=high) | The criterion indicates the local supply of locally sourced production resources, excluding labor, which are necessary for the subsurface activity. A high factor e.g. 1 indicates a high local supply of production resources. A low factor e.g. 0 indicated no local supply of production resources. |
| Local demand for production (waste) stream (1=high) | The criterion indicates the extent in which products that result from the activities can be used locally. A high factor e.g. 1 indicates a high potential use. A low factor e.g. 0 indicates a low potential local use of products that result from the subsurface activity. |
| Conflicting policy (1=no) | The criterion indicates the extent in which policy excludes the subsurface activity. A high factor e.g. 1 indicates that there is not conflicting policy. A low factor e.g. 0 indicates that there is conflicting policy. |
| Conflicting land use (0=yes) | The criterion indicates the extent in which there is a conflicting land use. A high factor e.g. 1 indicates no conflicting land use. A low factor e.g. indicates a conflicting land use. |
| Interference with other subsurface activities (1=no interference) | The criterion indicates the potential interference with other subsurface activities i.e. a negative relation between subsurface activities. A high factor e.g. 1 indicates no interference. A low factor e.g. 0 indicates a high level of interference. |
| Surface impact of activity during operations (0=high) | The criterion indicates the level of surface impact of the subsurface activity during operations. A high factor e.g. 1 indicates a low level of impact. A low factor e.g. o indicates a high impact. |
| Remaining surface impact after closure of activity (1=low) | The criterion indicates the surface impact after the production life of the subsurface activity. A high factor e.g. 1 indicates a low impact after cessation of the subsurface activity. A low factor e.g. 0 indicates a high impact after the cessation of the subsurface activity. |
| Maturity of technology / activity (1=high) | The criterion indicates the maturity of the technology used for subsurface activity in a certain geological setting. A high factor e.g. 1 indicates a very mature technology. A low factor e.g. 0 indicates an immature technology. |
| Remaining risk level after abandonment of activity (1=low) | The criterion indicates the combination of the likelihood and severity of potential hazards that are associated with the subsurface activity, used technology and geological setting. A high factor e.g. 1 indicates a low risk level. A low factor e.g. 0 indicates a high risk. |
| Mitigation potential during operation (1=high) | The criterion indicates the mitigation potential of the reducing the likelihood and severity of a hazard. A high factor e.g. 1 indicates a high mitigation potential. A low factor e.g. 0 indicates a low mitigation potential. |

Table B.1.2: Site index criteria

| **B.1.3 Community acceptance criteria** | |
|---|---|
| Criteria | Explanation |
| Expenditure scheme (Monetary scale) | The level of expenditure, the requirements for expenditure and the level of control of the host community in the formulation of the expenditure scheme. |
| Loss in property value (Monetary scale) | The expected loss in property value, including real estate, land and businesses. |
| Local economic benefits (Monetary scale) | The expected indirect benefits originating from the proposed subsurface activity, only includes monetary units. |
| Subsidence/tremors (3-point semantic scale) | The expected likelihood and severity of subsidence and tremors. |
| Water changes (3-point semantic scale) | The expected change in the quality and quantity of ground and surface water. |
| Ecological changes (3-point semantic scale) | The expected change in the quality and quantity of the local ecology. |
| Cultural/historical changes (3-point semantic scale) | The expected change in the quality and quantity of the cultural and historic protected sites |
| Technical-Environmental changes (3-point semantic scale) | The expected likelihood and severity of changes to technical environmental aspects, like sound levels and light pollution. |
| Environmental hazards (3-point semantic scale) | The expected likelihood and severity of risk that affect the environment, like a leakage from a well. |
| Perception proponent (5-point semantic scale) | The perception of the host community concerning the proponent. |
| Influences on social-economic minorities (3-point semantic scale) | The expected/ perceived effect that the activity will have on socio-economic minorities. |
| Strain on local emergency services (3-point semantic scale) | The expected/ perceived strain on local emergency services in the case of calamities. |
| Safety hazards (3-point semantic scale) | The expected/ perceived likelihood and severity of risk that affect the safety of the host community, like a blow out of a gas well. |
| Spatial integration (3-point semantic scale) | The judgment of the host community concerning the spatial integration of the surface installation of the subsurface activity. |

Table B.1.3: Community acceptance criteria.

## B.2 Strategic national policy goals and contribution of activity

| 1. Contribution of activity | 2. Amount | 3.. Unit | 4. Source | 5. Calculation | 6. Activity contribution | 7. Units |
|---|---|---|---|---|---|---|
| a. UGS | 1040001 | Kg/h | Hyunder, 2016 | Flow rate multiplied with a factor of 5 in order to get a similar size as Pieterburen, Kg converted to GWH using upper heating value of methane (14.72 KWh/kg) | 7.65 | GWh |
| b. UNS | 1900000 | M3/h | GTS,2013 | Based on the exiting UNS in the Netherlands in a salt caverne | 1900000 | M3/h |
| c. UHS | 10800 | Kg/h | Hyunder, 2016 | Flow rate multiplied with a factor of 5 in order to get a similar size as Pieterburen, Kg converted to GWH using upper heating value of hydrogen (39.39 KWh/kg) | 2.18 | GWh |
| d. CAES | 1.1 | GWh | Hyunder, 2016 | Based on the CAES in McIntosh, Alabama, USA multiplied with a factor of 5 to get a similar size as Pieterburen. | 5.5 | GWh |
| i. NWR | 0.473 | Mton | CORA, 2015 | Based on the inventory in CORA research which indicates the amount of radioactive waste and the square meters of the nuclear waste repository | 0.473 | Mton |

| 8. Policy Goals/desired level | 9. Explanation | 10. Level | 11. Unit | 12. Source |
|---|---|---|---|---|
| Cavern size | Based on the Zuidwending UGS | 3200000 | m3 | Energystock, 2015 |
| Salt production | Current production is 5 Mton/Y, which can be sustained for 100 years | 500 | Mton | Personal communication |
| Energy capacity | 20 % reduction in production rate of Groningen gas field | 387 | GWh | Assumption, Hyunder, 2016 |
| Conversion reserve | Expected shortages in kg | 0,00 | M3/h | GTS , 2013 |
| Energy reserve | 90 days of oil import converted in kton | 1,2E+12 | Kton | CORA, 2015 |
| CO2 emission reduction | Based on the green scenario, requiring 90Mton/y for the coming 40 years | 3600 | Mton | Mckinsey & Company, 2009 |
| Waste management | Oil production to water ratio, from Schoonebeek field, multiplied for remaining total oil reserve onshore, excluding Schoonebeek oil field. | 3E+07 | m3 | TNO, 2014 |
| Nuclear waste including containers | Number of radioactive waste per waste type multiplied with weight of container | 0,473 | Mton | Opera, 2014 |

Table B.2:Values for the activity contribution and strategic national policy goals. Columns 2 – 7 shows the different values that were used to obtain realistic, but not accurate, values for the contribution of an activity. Columns 8 – 12 provide the explanations behind the policy goals and their source. The policy goals are only for illustrative purposes (GTS, 2013, McKinsey & Company, 2009, Energystock, 2015,COVA, 2013,OPERA, 2014,Hyunder, 2016).

### B.3 *Sensitivity* of the *relative strategic factor*

We investigate the sensitivity of the relative strategic factor values to a change in policy weight factors. For this analysis, we use five different sets of weights scenario's that alternate the weight for each policy goal, as indicated in Table B.3.

| 1. Policy | 2. Base case scenario | 3. Energy reserve capacity scenario | 4. CO2 storage scenario | 5. Waste management scenario | 6. Radioactive waste management scenario |
|---|---|---|---|---|---|
| a. $CO_2$ storage | 0,25 | 0,17 | 0,50 | 0,17 | 0,17 |
| b. Energy reserve capacity | 0,25 | 0,50 | 0,17 | 0,17 | 0,17 |
| c. Waste management | 0,25 | 0,17 | 0,17 | 0,50 | 0,17 |
| c. Radioactive waste management | 0,25 | 0,17 | 0,17 | 0,17 | 0,50 |

Table B.3: Weight scenarios for the Pieterburen case. Column 1 depicts the relevant policy goals for a salt dome. Columns 2-6 indicate the different weight factors for each policy goal for the corresponding weight scenario.

On the basis of the different weight scenarios for the policy priority weight factors (see Equation (1)), the differences between the base case and weight scenarios found for each alternative are shown in Figure B.3.

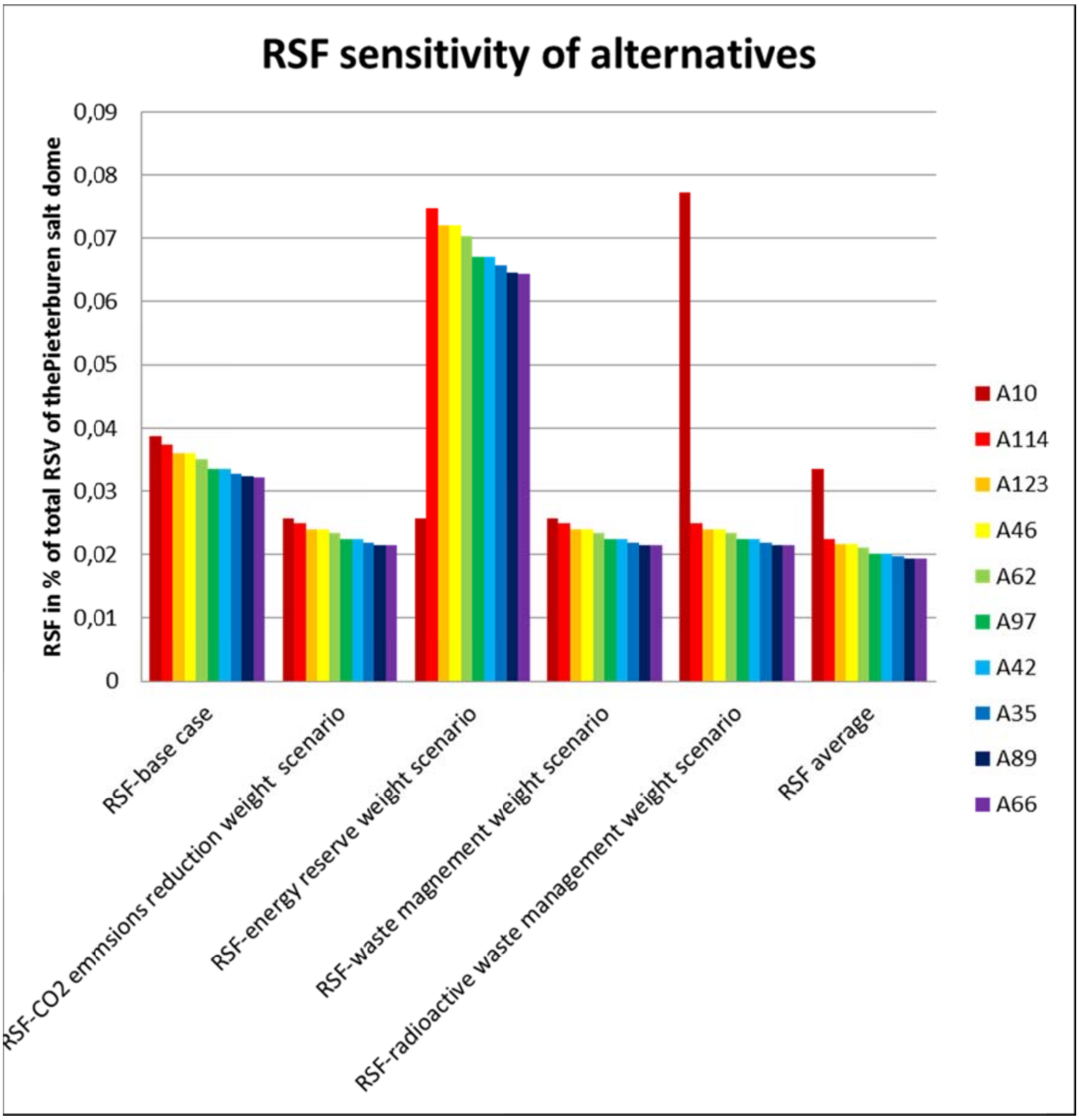



Figure B.3: Sensitivity analysis of the relative strategic factor. The first column indicates the alternatives. The other columns indicate the relative strategic factor values for each weight scenarios for each alternative. The relative strategic factor for each weight scenario is based in the input described in Table 1 while using the different priority weight sets depicted in Table 11 and the temporal coefficient parameter described in Table B.3 in Equations (2) and (3).

Figure B.3 shows that the A10 (NWR) alternative has the highest relative strategic factor value in all the weight scenarios except for the energy reserve capacity scenario. In this scenario, the A114 (CAES+UGS+UHS) scores higher than the A10 (NWR). This is the result of the direct relationship between the activities in the alternatives and the corresponding policy goals.

## Appendix C

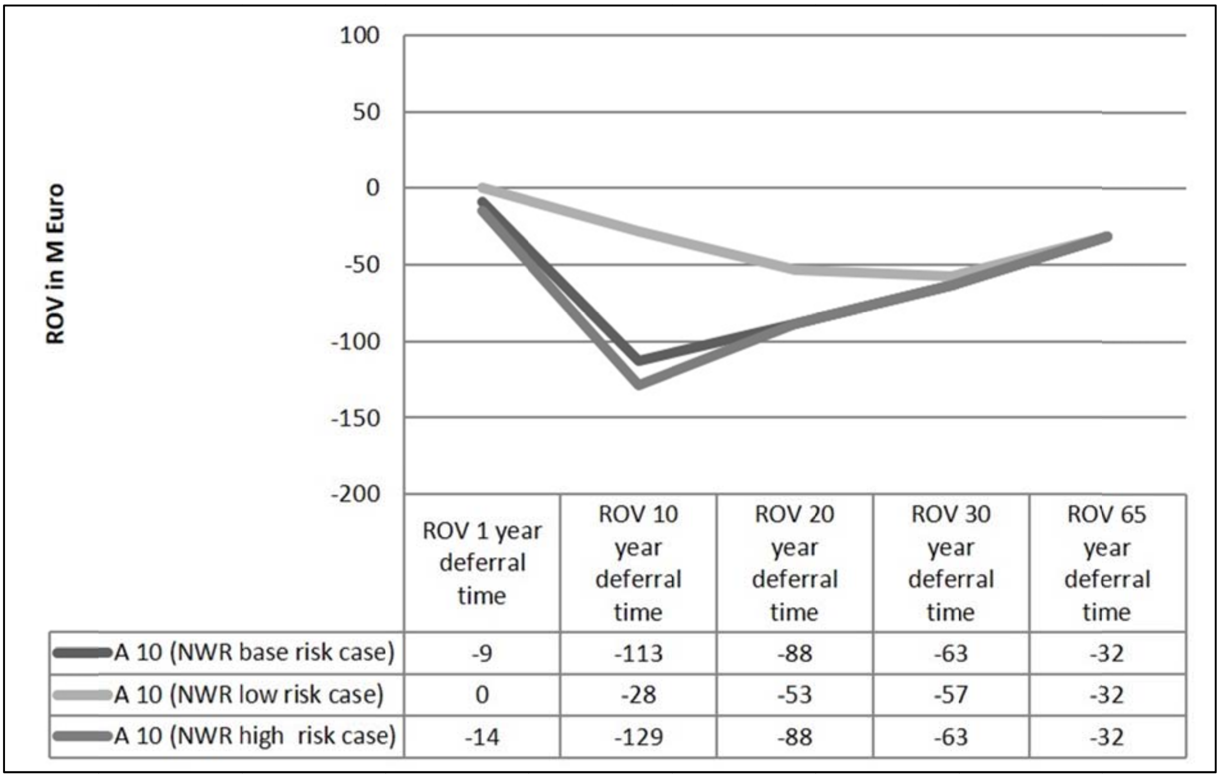
| 1. Activity | 2. Revenue tax rate (% of S) | 3. Investment tax write-off (% of X) | 4. Community expenditure (% of S and X) | 5. Profit tax (% of ROV) |
|---|---|---|---|---|
| a. NWR | 0 | 0 | 0.1 | 0.25 |
| b. CAES | 0.35 | 0.35 | 0.03 | 0.25 |
| c. UGS | 0.45 | 0.45 | 0.03 | 0.25 |
| d. UOS | 0.45 | 0.45 | 0.03 | 0.25 |
| e. UHS | 0.35 | 0.35 | 0.03 | 0.25 |

### Appendix C.1 Distribution of cost and benefits.

Figure C.1. Government tax and community expenditures in percentages. The values in the grey cells are based on analogue examples and should be considered for illustrative purposes only. Column 1 shows the relevant activities. Columns 2-5 show the different percentages used to determine the ROV, tax and community expenditure. The percentages are based on analogue examples.

### Appendix C.2 Real Options Sensitivity analysis

In the Pieterburen salt dome example, we assume specific technical, market, and non-technical risk levels in the market acceptance class (see Table 14). Therefore, in order to gain insight into the effect of these risks, we perform a sensitivity analysis. For the ROV, we analyze the effect of a wide range of risk levels (low, medium, and high at 10%, 45%, and 90%, respectively) for each of the selected alternatives. Furthermore, we investigate the effect on the ROV by applying different deferral times of one, 10, 20, 30, and 65 years for each first activity in an alternative.




| | ROV 1 year deferral time | ROV 10 year deferral time | ROV 20 year deferral time | ROV 30 year deferral time | ROV 65 year deferral time |
|---|---|---|---|---|---|
| A 10 (NWR base risk case) | -9 | -113 | -88 | -63 | -32 |
| A 10 (NWR low risk case) | 0 | -28 | -53 | -57 | -32 |
| A 10 (NWR high risk case) | -14 | -129 | -88 | -63 | -32 |

Figure C.2.1: Sensitivity analysis of the A10 alternative. The y-axis represents the ROV of the NWR alternative in millions of Euro (2016). The x-axis represents the different deferral times. The low and high risks levels are assumed to be respectively 10% and 90%). The risks levels for the base are indicated in table 14. The deferral times are 1, 10, 20, 30 and 65 years). Based on these inputs the sensitivity of the ROV is calculated while using the same value as in the base case for the other parameters mentioned in Equations 5, 6 and 7. For the NWR alternative we find that with a 1-year deferral time that the risk effect on the ROV is very minimal. However, if the deferral time is increased the risk effect becomes more important i.e. the difference between the risk cases increases (see Figure C.3.1). As deferral time increases to 10 years the risk level becomes dominant, whereas at larger deferral times up to 65 years the risk level has no influence anymore on the ROV.

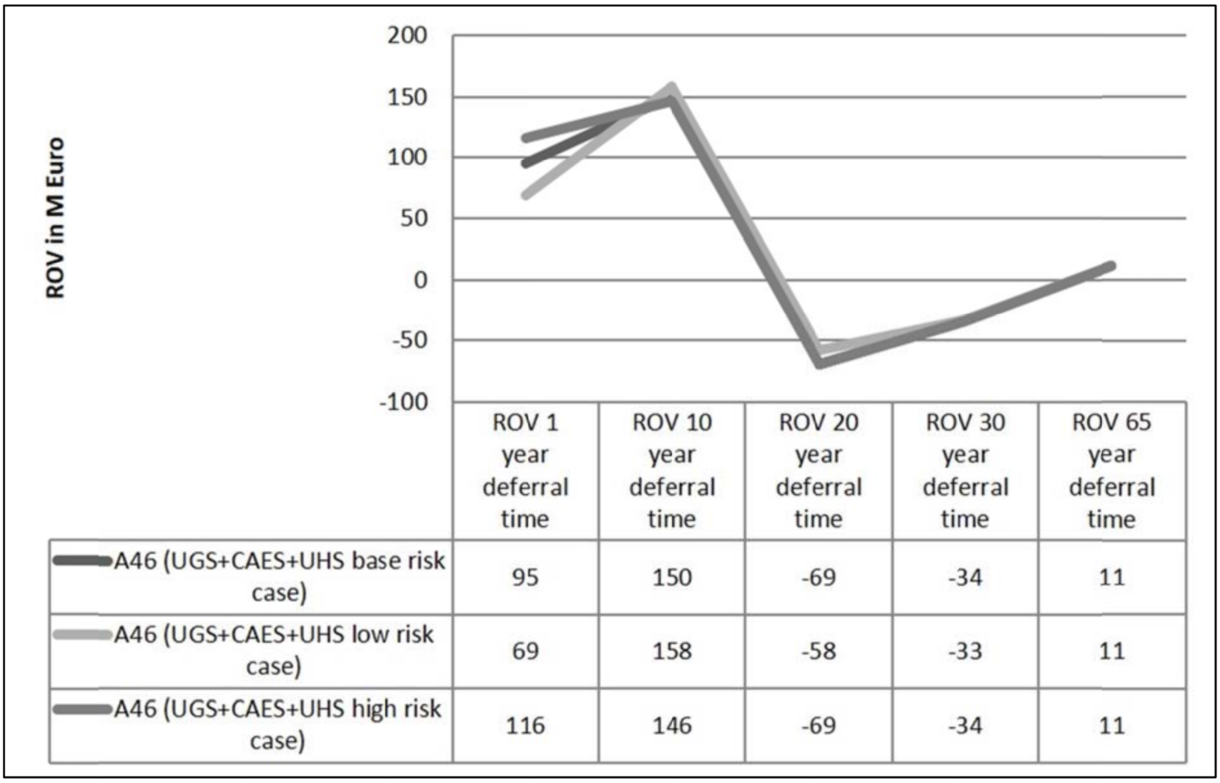



Figure C.2.2: Sensitivity of the A46 alternative. The y-axis represents the ROV of the NWR alternative in millions of Euro (2016). The x-axis represents the different deferral times. The low and high risks levels are assumed to be respectively 10% and 90%). The risks levels for the base are indicated in table 14. The deferral times are 1, 10, 20, 30 and 65 years). Based on these inputs the sensitivity of the ROV is calculated while using the same value as in the base case for the other parameters mentioned in Equations 5, 6 and 7.

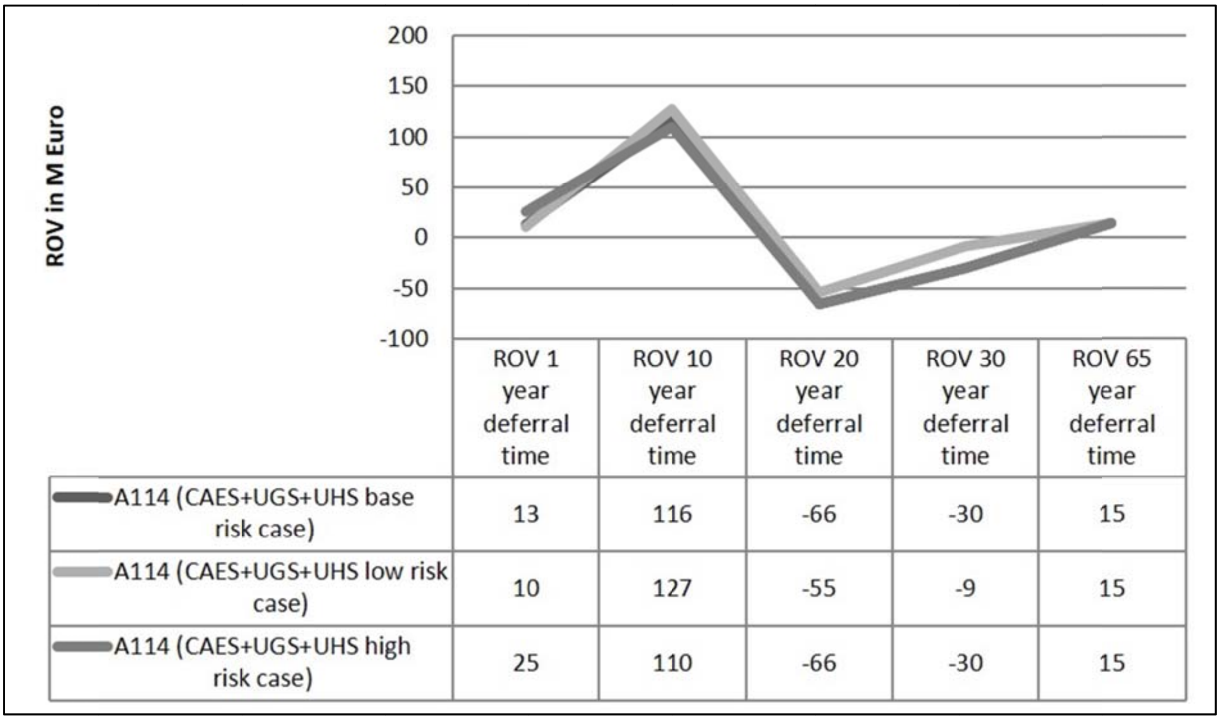



Figure C.2.3: Sensitivity of the A114 alternative. The y-axis represents the ROV of the NWR alternative in millions of Euro (2016). The x-axis represents the different deferral times. The low and high risks levels are assumed to be respectively 10% and 90%). The risks levels for the base are indicated in table 14. The deferral times are 1, 10, 20, 30 and 65 years). Based on these inputs the sensitivity of the ROV is calculated while using the same value as in the base case for the other parameters mentioned in Equations 5, 6 and 7.

On the basis of the results shown in Figures C.2.1 to C.2.3, we conclude that risk, mitigation and deferral times have an effect on the ROV of an activity. Furthermore, we see a difference in effect between activities with a positive and negative ROV. However, the ROV of the CAES alternative behaves similarly to the UGS alternative as a function of risk and deferral time (see Figure C.3.3).

## Appendix D Sensitivity of the community acceptance priority factor

To calculate the community acceptance priority factor, we assumed certain priority weight factors for the economic, environmental, and social group criteria, that is, the group criteria priority. In the base case, we consider the priority factors to be equal for each group criterion, namely, 33.3%. However, this could be an unrealistic assumption. Therefore, to analyze the sensitivity of the community acceptance priority factor values for each alternative, we use three priority weight scenarios, consisting of alternating priority weight factors of 66%, 16%, and 16% for each group criterion. It is possible to investigate the sensitivity of the ranking of the community acceptance priority factor on the basis of these scores.

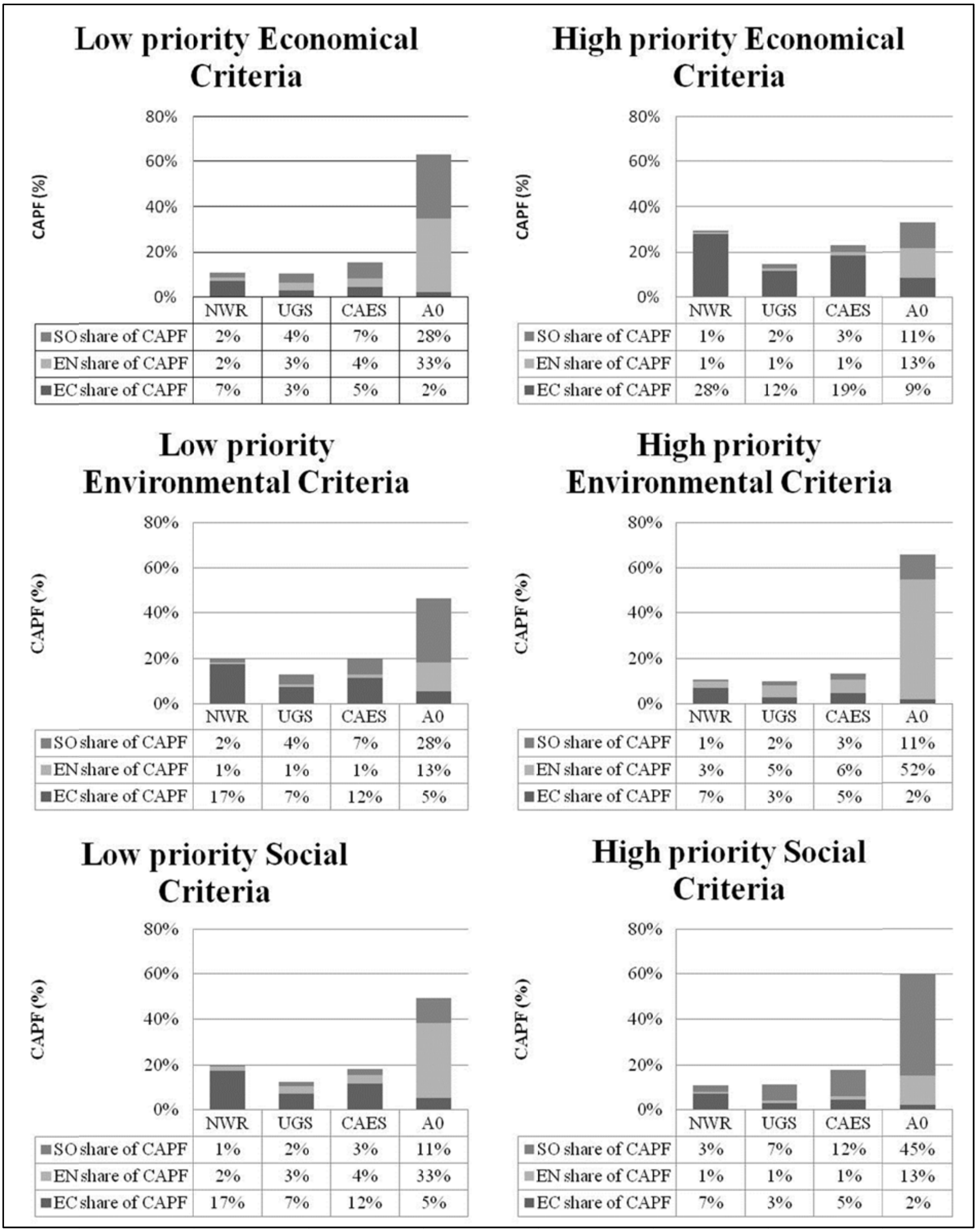
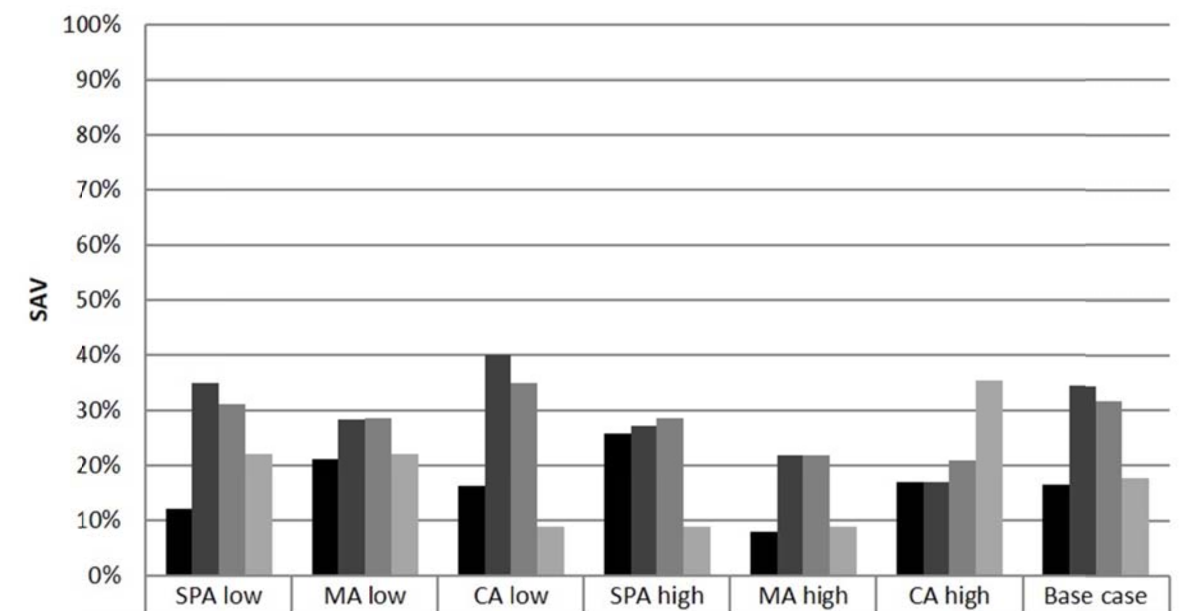



Figure D.2: Sensitivity of group criteria on the community acceptance priority factor values. The sensitivity of the community acceptance priority factor for each alternative is determined by changing the priority weight factor in Equation (15) to 0.16 for the low cases and to 0.66 for the high cases for each group criterion, while maintaining an overall weight factor of one. For each alternative, the share of the group criterion is indicated as a percentage of the total community acceptance priority factor. A0 represents the “doing-nothing-forever” alternative.

Figure D.2 shows that the “doing-nothing-forever” alternative has the highest community acceptance priority factor value in each of the priority weight scenarios, which would indicate a robust ranking. Furthermore, both the NWR and CAES score relatively well, depending on the applied weight scenario. The UGS scores the lowest. Furthermore, we can observe that the community acceptance priority factor score for the NWR is mainly determined by the economic criteria. This is, to a lesser extent, also applicable to UGS and CAES. The “do-nothing-forever” alternative is as expected, since the economic impact is minimal, almost indifferent to the scores related to the economic criteria. Furthermore, we can observe that the environmental and social criteria affect the community acceptance priority factor value to a great extent.

## Appendix E Sensitivity of the social acceptance factor

The ranking of alternatives on the basis of the social acceptance factor helps to indicate the most socially acceptable alternative under consideration. By varying the priority weight factors, insight can be obtained into the robustness of the ranking (see Figure E.1).




| | SPA low | MA low | CA low | SPA high | MA high | CA high | Base case |
|---|---|---|---|---|---|---|---|
| A 10 | 12% | 21% | 16% | 26% | 8% | 17% | 16% |
| A 46 | 35% | 28% | 40% | 27% | 22% | 17% | 34% |
| A 114 | 31% | 29% | 35% | 29% | 22% | 21% | 32% |
| A0 | 22% | 22% | 9% | 9% | 9% | 35% | 18% |

Figure E.1: Social acceptance factor sensitivity of alternatives. The sensitivity of the social acceptance factor values for each alternative is determined by changing the weight factor in Equation (17) to 0.16 for the low cases and to 0.66 for the high cases for each specified social acceptance module, while maintaining a total weight factor of one. The base case assumes equal weights, that is, 0.33, for relative strategic factor, market acceptance factor, and community acceptance priority factor. A0 represents the "doing-nothing-forever" alternative.

The A46 and A114 alternatives shows potential for a successful realization, especially in the low community acceptance case. Furthermore, A10 shows a small potential for a successful realization. However, this assumes that the stakeholders in the social political acceptance class are willing and able to compensate the two other classes to increase their respective acceptance levels. This is possible by adjusting the proposed activity to reflect the concerns and interest from the other classes of social acceptance to a greater extent. On the basis of the sensitivities for the different modules, we could conclude that, for the market acceptance class, the best course of action would be an extension of the deferral time or a reduction of the cost i.e. a subsidy in order to increase the market acceptance factor. On the basis of the sensitivities for the community acceptance class, we could conclude that the best course of action would be an increase in community compensation or a decrease in the environmental impact, in order to increase the community acceptance priority factor.