DELFT UNIVERSITY OF TECHNOLOGY

EPA1361 - MODEL-BASED DECISION MAKING

Robust Decision Making for Multi-Actor Governance: Policy Advice for Flood Risk Mitigation in the Municipality of Gorssel

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List of abbreviations

RfR	Room for River
DAPP	Dynamic Adaptive Policy Pathways
RDM	Robust Decision Making
MORDM	Multi-Objective Robust Decision Making
MSMORDM	Multi-Scenario Multi-Objective Robust Decision Making
EWS	Early Warning System
QS	Quantitative Storytelling

Executive Summary

Located on the banks of the IJssel River - a river with a history of flooding - a plan for flood risk management is crucial to Gorssel. When coming up with a plan to mitigate these dangers, multiple stakeholders have to be considered. These stakeholders make up a complex actor arena with different objectives, which results in conflict and no one preferred outcome. Paired with the uncertainties and the decision making processes on a local and provincial level, many uncertainties are involved when deciding on a strategy. Therefore, all decisions have to made under deep uncertainty.
In this report, we propose a policy strategy for Gorssel during the negotiations for flood risk mitigation in the Province of Overijssel. The research questions answered is

How can Gorssel (Dike Ring 4) affordably protect its citizens and businesses from flood risk to a similar level as neighbouring urban areas, while still preserving and protecting farmland from encroachment?

To accurately assess the effectiveness of Gorssel's policy choices, the possible policy support for other Deventer and Overijssel will also be considered to increase feasibility.

There are three ways Gorssel can minimise flood risk: Firstly, Gorssel and Deventer can heighten their dikes; secondly, Overijssel can utilise the Early Warning System as a flood warning system; and lastly, Gorssel and Deventer can implement Room for the River projects. When considering these options, Gorssel wants to minimise land encroachment to protect their farmers' livelihood while ensuring "fairness" in the measures taken across the entire IJssel river. Furthermore, there are three key performance indicators (KPIs) for Gorssel to consider while looking for a suitable strategy. The KPIs consist of expected damage, expected deaths, and the relevant actor's implemented strategy's total cost. We use Exploratory Modelling Analysis (EMA) with the associated workbench to deal with multiple objectives and deep uncertainty. EMA enables the modeller to understand the relation between uncertainties and policies better, resulting in a robust outcome. To start, we identified uncertainties followed by scenario discovery, where we identified possible futures. With this, we could analyse the effectiveness of policies and then or robustness, after which we can make a recommendation.

Robustness and uncertainty analysis from the perspective of Gorssel, Deventer and Overijssel revealed a selection of preferred policies for each actor:

- Gorssel: Preferences policies with extensive investment in Room for the River projects and dike heightening in Deventer only, with no or modest dike heightening in Gorssel and earlier warnings for evacuation.

- Deventer: Preferences policies with extensive investment in Room for the River projects in Gorssel, accompanied by either significant dike heightening in Gorssel or earlier warnings for evacuation.

- Overijssel: Supports low-moderate dike increases in both Gorssel and Deventer, with no investment in Room for the River projects, alongside earlier warnings for evacuations.

Based on these results, we recommend that the Municipality of Gorssel consider the following steps for flood risk mitigation:

1. Modest dike increases in both Gorssel and Deventer in the near future present a robust solution to minimise flood risk in Gorssel.

2. Gorssel should support the Overijssel regional government in lobbying for an increase of the Early Warning System to 3 days.

3. The current scoping of the problem suggests that Room for the River projects are not favourable due to relative costs (compared to dike increases). However, the sensitivity of proposed policies to uncertainty in the probability of a dike failure suggests that these options may warrant further exploration as a policy option.

4. We recommend that if Gorssel pursues dike heightening projects and EWS increases, that they complement these policies with other activities to improve their real-world robustness.

At the end of this document, we also include a political reflection, which considers how these recommendations feed into the real-world decision-making environment. The reflection assesses potential challenges to implementing the suggested policies and proposes possible solutions and their impacts.

Contents

1 Problem Framing

1.1 Introduction

Through the years, the river IJssel has been of incredible importance in Dutch history. In times of prosperity, the river was a trading route. In times of war, it made up a strategically defensible border. Situated along this river, between the two bigger cities of Deventer and Zutphen, one can find the smaller town of Gorssel. Located along the banks of the IJssel river, water management and flood prevention have both been interwoven with the town's existence since the first farmers situated themselves there. However, when in 1993 and 1995, the water rose to dangerous levels in the IJssel, the discussion on water management became a national interest. Thus, the Room for the River initiative was born (Rijke et al., 2012). However, the fight against water continues. With global warming added into the mix, the rivers currently face even greater pressure (Takken et al., 2009) and a flood risk mitigation plan is key for the future of Gorssel and its farmers. Besides the complexity such a plan inherently has, this particular problem requires a careful examination of the actor field, for there are many involved stakeholders. We can fairly assume that all parties want to prevent a life-threatening flood, but beneath that, all involved parties have their own objectives they aim to achieve.

This report uses innovative modelling and analysis techniques to analyse options for planning flood protection measures along the IJssel river. As explained, flood management in this region is complex due to significant uncertainties (i.e. flood wave shapes, dike failure probabilities, and breach widths) and conflicting priorities of different stakeholders in the region. This report uses exploratory modelling and analysis to support decision-making under the deep uncertainty this complexity causes. We perform this model-based decision making from the perspective of our problem owner, Gorssel, in addition to two key stakeholders of interest: Overijssel Regional Government and the city of Deventer. We do this to reveal necessary trade-offs and the outcomes of conflicting objectives to inform the policy-making process in the Overijssel region.

1.2 Research Question

Protecting the livelihoods of those that reside in Gorssel is Gorssel's primary objective. The population of Gorssel is mainly comprised of farmers, and their livelihood consists of the crops they organically grow. Gorssel wants to minimise flood risk and expected flood damage while also preventing land encroachment to preserve the amount of land available for farming. Both of these are not favourable but are currently in a trade-off with each other. However, there is a limit to how much land Gorssel wants encroached upon - too much, and the farmers are left without anything. Furthermore, it is also essential that any policy measure treats Gorssel equal to the surrounding cities and that other actors also receive fair treatment. The goal of this report is to find a strategy for Gorssel to navigate these difficult waters.

The research question that is in line with this goal is as follows:

> *How can Gorssel (Dike Ring 4) affordably protect its citizens and businesses from flood risk to a similar level as neighbouring urban areas while still preserving and protecting farmland from encroachment?*

This question was informed by the mandate for Gorssel provided as part of the EPA1361 Debate (see Section 6 for more information), in addition to formal documentation of the Room for the River project, conducted by Rijkswaterstaat between 2010 and 2019 (Rijke et al., 2012; Rijkswaterstaat, 2013).

To explore suitable policies for achieving these objectives, we devised a problem formulation in the EMA Workbench. The prioritised objectives for the Gorssel-perspective problem formulation are:

- *Minimise Expected Annual Damage for Gorssel*: This objective reflects Gorssel's desire to generally minimise flood risk while also reflecting the effects of damage to farms and other property
- *Minimise Expected Number of Deaths for Gorssel:* This objective reflects Gorssel's desire to minimise flood risk generally.
- *Minimise Total Costs:* This objective reflects the desire to reduce the cost impact of flood mitigation measures taken across the entire IJssel River system. Total costs for all actors were considered relevant given the requirement of cost-sharing for flood mitigation activities across the region.
- *Difference in Expected Annual Damage (EAD) between Gorssel and Deventer (information only - no objective set)*: This function returns results on the difference in Expected Annual Damages between Gorssel and Deventer, but we do not optimise over it. The results for this feature under different policies provide information on the relative 'fairness' in terms of rural-urban burden-sharing in terms of flood risk and as an additional feature for informing satisficing or regret-based robustness metrics.

- *Difference in Expected Number of Deaths between Gorssel and Deventer (information only - no objective set)*: rationale for the inclusion of this metric is as for the difference in EAD.

These five core objectives are a refinement of all available objectives. We prioritised these due to the computational limitations of the exploratory modelling and analysis approaches (as explained in Section 2) and due to limitations in stakeholder comprehension of multiple objectives. As we have chosen not to present the analysis in the format of dynamic adaptive policy pathways, we aggregated all objective outcomes to a single planning step. For Gorssel, the relevant levers were:

- Dike Heightening: Gorssel can elect for dike heightening in Gorssel and/or Deventer
- Early Warning System: Applied across the whole region
- Room for the River: Gorssel can elect for Room for the River projects to be implemented in Gorssel or Deventer.

All assumptions that were made to carry out this analysis are listed in Appendix A.

1.3 Actor Analysis

We interpreted the primary analysis of preferred options based on Gorssel's mandate, wherein its goals and preferred outcomes are known. But to conduct a complete analysis, it is essential to understand the goals and objectives of other actors involved, as that might reveal opportunities for coalition-forming or potential adversaries. For this analysis, we selected the city of Deventer and the provincial government of Overijssel as other actors for study. This section of the report motivates this choice through an actor analysis approach.

To determine which actors were of interest, we assessed the power and interest and the objective of each actor. These two assessments would tell us which actors are of influence on Gorssel's problem and what their interests are in the problem. Starting, we studied which actors could exert power over the discussion. We display these findings in a power-interest grid from Gorssel's point of view.

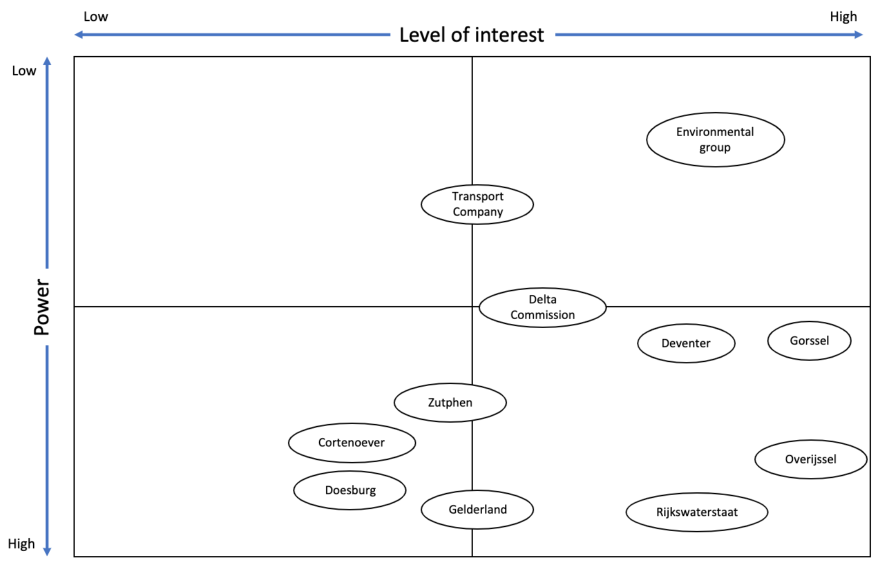

Figure 1: Initial Power Interest Grid

As can be deduced, the Room for the River Project is a complex multi-actor initiative, and therefore objectives between the stakeholders will not always align. Knowing that Rijkswaterstaat, Deventer and Overijssel are actors with high interest and high power in the issue means that they are the actors for whom Gorssel should be aware. Knowing this, we will study the actors' objectives as it is important to keep in mind potential rival actors and conceptualise possible arguments and framings they can/will use to counter Gorssel's aims. All involved actors and their objectives for the RfR decision arena are listed in Table 1.

Considering the power interest matrix as shown in Figure 1 as well as relations between actors, Deventer and Overijssel are chosen as rival actors to explore alternate problem formulations. Since the Overijssel provincial

Table 1: Interest and objectives in the policy arena.

Actor	Interest	Objective
Rijkswaterstaat	Flood risk mitigation, Maintenance of water infrastructure	designing flood protection with widespread support
Delta Commission	Long-term Flood Risk Mitigation	implementing effective and robust flood protection projects
Transport Company	Efficient Road Network	ensuring accessibility/connectivity between various cities
Env. Protec. Gr.	Environmental protection	minimising land use change in protected areas due to RfR
Gelderland	Flood risk mitigation, Approval of residents	ensuring equitable time/cost distribution among provinces and municipalities
Cortenoever/Doesburg	Livability for residents	minimising land use change
Overijssel	Flood risk mitigation, Approval of Residents	ensuring equitable time/cost distribution among provinces and municipalities
Deventer	Livability for residents, Aesthetic quality of the city	improving flood security to residents, minimising land use change
Gorssel	Livelihood of resident farmers	protecting farmland, minimising profit loss

government administers both Gorssel and Deventer, there is the greatest chance of having conflicting goals and objectives regarding land-use change, possibly resulting in adverse outcomes for the client. At the same time, these two actors also present the opportunity to find common ground and form coalitions, support one another at the negotiation table with other provinces, like Gelderland, and ensure that Rijkswaterstaat drafts a mutually beneficial proposal. We have converted the actions of other cities (those in Gelderland province) to uncertainties in the model.

Opposing stances from rival actors will be accompanied by an alternate framing of the problem. Rival actors can then use this framing to understand their actions. The city of Deventer, a much larger and older municipality of roughly 100 000 inhabitants, will be able to argue from a utilitarian point of view that it should carry greater weight in decision-making. Due to its cultural heritage, it can also argue that land encroachment would be far more invasive than relocating several farms from the community of Gorssel.

Overijssel, being the next level administrative body above Gorssel and Deventer, will significantly influence which flood mitigation measures Rijkswaterstaat implements in higher-level policy negotiations. Overijssel is required to find some balance of impacts between urban and rural communities as a provincial government. Due to Deventer's larger economic importance, they may use similar framing to legitimise claims for implementing specific measures over others. Regional policy-makers can also obscure discourse using ill-defined neologisms, for example, hybrid concepts such as "nature development" and "spatial quality" (Warner & Van Buuren, 2011). These empty signifiers combine environmental with economic values to appear holistic and fair. Yet, these frames do not address the social and economic concerns of Gorssel's population and fail to address the increasing divide between urban and rural populations. Gorssel may still refine and challenge these views to specifically address these problems.

The prioritised objectives for the Deventer-perspective problem formulation are:

- Minimise Expected Annual Damage for Deventer: This objective reflects Gorssel's desire to generally minimise flood risk while also reflecting effects of damage to farms and other property
- Minimise Expected Number of Deaths for Deventer: This objective reflects Deventer's desire to minimise flood risk generally.
- Minimise Total Costs: This objective reflects the desire to reduce the cost impact of flood mitigation measures taken across the entire IJssel River system. Total costs for all actors were considered relevant given the requirement of cost-sharing for flood mitigation activities across the region.

For Deventer, the policy lever for dike heightening in Deventer is switched off in the model to reflect Deventer's hard constraint around encroachment of sites of cultural and historical significance in the city centre.

The prioritised objectives for the Overijssel-perspective problem formulation are:

- Minimise Expected Annual Damage for Gorssel and Deventer: This objective reflects Gorssel's desire to generally minimise flood risk while also reflecting effects of damage to farms and other property
- Minimise Expected Number of Deaths for Gorssel and Deventer: This objective reflects Overijssel's desire to minimise flood risk generally for residents and businesses in the region.

- Minimise Total Costs: This objective reflects the desire to reduce the cost impact of flood mitigation measures taken across the entire IJssel River system. Total costs for all actors were considered relevant given the requirement of cost-sharing for flood mitigation activities across the region.

As is done for Gorssel, we treat the actions of other actors in Gelderland province as uncertainties in both Deventer's and Overijssel's problem formulations.

2 Approach

Multiple alternative techniques to analyse the explicated problem framings were considered, with the final result being a combination. Ultimately, we chose a multi-scenario multi-objective robust decision-making (MORDM) process to analyse and select policy approaches. This approach was chosen for its ability to achieve a balance between finding robust solutions that are optimal in specific scenarios while also being computationally efficient, given constraints in time and computing power (Bartholomew & Kwakkel, 2020). A visualisation of the workflow we adopted is shown in Figure 2. Below, we explain the deep uncertainty techniques applied in each step and selections of these approaches motivated in light of currently available literature. Because certain steps of the this approach were conducted prior to selecting policies and concerned the scenarios, they will be explained and their results will be discussed in this section, leaving the Results section to discuss the policies.

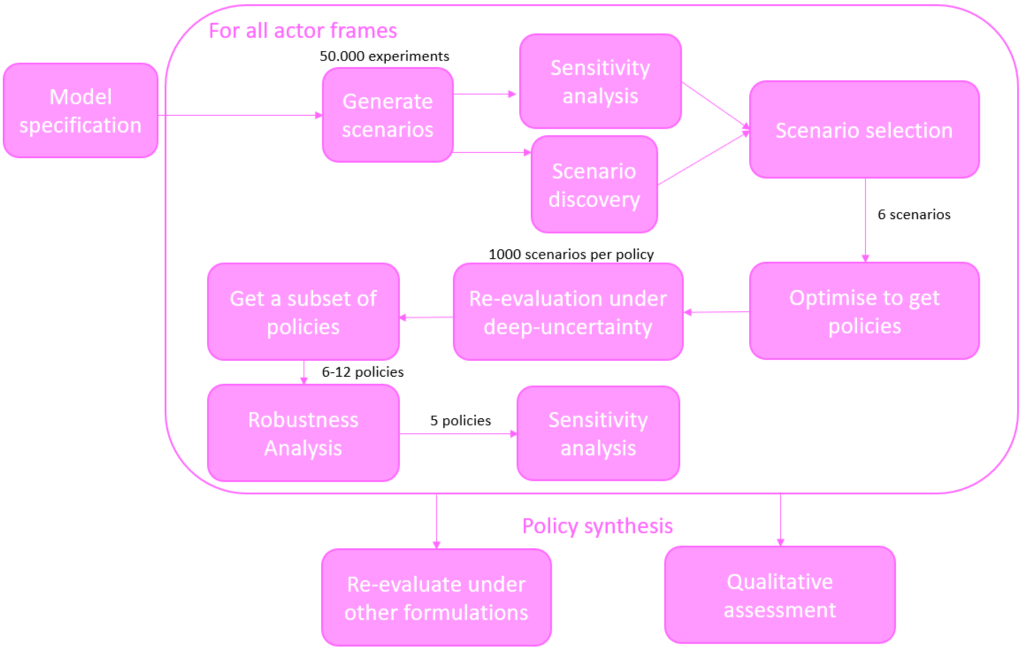

Figure 2: The MSMORDM Process, inspired by Bartholomew and Kwakkel.

We used the Exploratory Modelling Workbench (an open-source Python library) to implement this approach (J. H. Kwakkel, 2017). Readers can find Jupyter Notebooks and Python files for the reproduction of the analysis implementation in the repository in the Appendix C.

2.1 Problem Formulation

In the first step of this process, we defined the problem formulations for each of the three actors, as described in Section 1. For each actor, we defined multiple objectives to elicit relevant trade-offs (predominantly between cost and risk). We used these formulations to initialise the model to run experiments. We opted to look at results over three planning steps (each step equates to roughly 67 years) to observe the evolution of planning and risk and get more granularity in the potential policies and uncertainties.

2.2 Generation of Scenarios

To start off, the generation of scenarios is essential. A large number of scenarios is necessary as the chosen problem framing increased the number of uncertainties in the model. To achieve this, the Latin Hypercube Sampling method was chosen, which is a conceptually simple method that splits the uncertainty space into intervals of equal probability (cite Stein, Halton). The decision was made to run 50,000 scenarios without policies for each actor as to trade off the granularity/resolution of available scenarios against the computational intensity of generating and optimising over this large range.

It is also important to note that the provided model was modified to serve the selected problem formulation. Adjustments were made by disaggregating the cost factors of Room for the River Costs and the Evacuations Costs, such that costs for the actors of Gorssel and Deventer were individualised. The ranges of the uncertainties already present in the model were left as they were. We also used the population size for Deventer and Lochem to get the difference in damage in deaths per capita.

2.3 Sensitivity Analysis and Scenario Discovery

After having generated the scenarios, a sensitivity analysis and scenario discovery were conducted to identify the most dominant uncertainties and levers in the input space for each of the three actors (regarding damage). However, prior to this a data exploration is conducted. It was found that a high correlation between deaths and damages existed for all actors: 0.98 for Gorssel, 0.98 for Deventer, and 0.98 for Overijssel. Knowing this, for the remainder of this step of the analysis, the focus is primarily on on damages.

To fully understand the impact of the uncertainty of this problem on the potential policies, the Extra Trees algorithm was utilised. The outcome shows that for Gorssel, only the durability of their own dike was by far the most dominant (estimator instance of 0.56). For Deventer and Overijssel, Deventer's dike durability was the most dominant (estimator instances of 0.45 and 0.55, respectively). All other uncertainties and levers had an estimator instance < 0.081. All estimator instances with a more in-depth analysis can be seen in Appendix B.

As mentioned before, a scenario discovery has to be performed within the uncertainty surrounding the IJssel river. One of the ways to do this, is to use the scenario discovering technique Patient Rule Induction Algorithm (PRIM). PRIM allows the modeller to visualise and investigate the uncertainty space to identify suitable ranges of uncertainty for scenario selection in the multi-scenario MORDM process (Bryant & Lempert, 2010). In Gorssel's case, PRIM is used to identify the worst and best case scenarios, which are then used for optimisation. PRIM is not the only method that can be used, for other exist such as Dimensional Stacking and Logistic Regression. However, PRIM was chosen because it is highly interactive and the visualisations provide users a balance among the measures of scenario quality: interpretability, density and coverage (Bryant & Lempert, 2010).

For this report, the worst 10th percentile and the best 40th percentile of damages were selected and studied. Whenever a density ρ with $\rho > 0.8$ was reached, the range of uncertainties were considered. This showed that for Overijssel the durability of Gorssel's dike is dominant (even though it had an estimator instance of 0.06 during the sensitivity analysis).

This process thus revealed that the most dominant uncertainties for the three actors were the probability of dike failure at either Gorssel and/or Deventer. These factors were the strongest determinants of policy success across the broadest range of scenarios. These uncertainties and their influence on the worst 10th percentile and best 40th percentile are shown in Figure 3.

2.4 Scenario Selection

To select the appropriate scenarios to develop policies in, a process for selecting six scenarios was constructed. It was made sure that a good distribution of dike failure probability values across the selected scenarios. And thus, we opted for a mixture of good, 'middle', and worst-case scenarios to enable us to observe the performance of and preferences towards policies under the broadest range of scenarios. This also aided in generating stakeholder comprehension of policy outcomes. We selected this approach instead of a 'maximise diversity' approach due to time constraints in the computational intensity of such an approach over such a large number of scenarios and uncertainties (Eker & Kwakkel, 2018). The logic used to select the scenarios is shown in Table 2.

Table 2: A crude notation of the logic that we used to select scenarios. D_1 is Deaths, D_2 is Damages, and D is both. For low, middle and high scenarios, this means both outcomes had to be within those percentiles.

	Gorssel	Deventer	Overijssel
best	$D_1 = 0 \wedge D_2 = 0$	$D_1 = 0 \wedge D_2 = 0$	$D_1 = 0 \wedge D_2 = 0$
low	$23\% > D \leq 27\%$	$25\% > D \leq 35\%$	$23\% > D \leq 27\%$
middle	$48\% > D \leq 52\%$	$48\% > D \leq 52\%$	$48\% > D \leq 52\%$
high	$73\% > D \leq 77\%$	$73\% > D \leq 77\%$	$73\% > D \leq 77\%$
worst deaths	$max(D_1)$	x	x
worst damage	x	$max(D_2)$	$max(D_2)$
absolute worst	$max(\frac{norm(D_1)+norm(D_2)}{2})$	$max(\frac{norm(D_1)+norm(D_2)}{2})$	$max(\frac{norm(D_1)+norm(D_2)}{2})$

We applied these ranges to both Damage and Deaths for low, middle and high, and the scenario would have to be present in both. Deventer's low scenario range is bigger, as there is less overlap between the two outcomes than for the other actors. For the best scenario, a scenario with 0 deaths and 0 damages was selected and for the worst scenarios, the scenarios with the worst outcome was selected. For all actors, either worst damage or worst deaths was the same as the absolute worst scenario, hence why either one of these is excluded (as can be seen indicated with an *x*) from the set of scenarios. The absolute worst scenario was selected by normalising Damages and Deaths and dividing it by 2, meaning that if damages and deaths were highest in the same scenario, this value would equal 1. For all actors, this scenario was the same as either the worst damage (for Gorssel) or worst deaths (Overijssel and Deventer), in which we opted to continue with the "absolute worst" label for that scenario. This means that the scenario with most damage was always a different scenario than the scenario with the most deaths. We selected the remaining scenarios based on the union of the scenarios present in the ranges displayed in the table. Note that we needed to use a more extensive range for Deventer's low scenario, which means there is less correlation in the lower range of Deaths and Damages.

The two 'worst case' scenarios (one representing worst case for deaths or damages, and another across all outcomes) exist within the uncertainty range that result in the highest 10th percentile of damages and deaths as identified in the previous step. This is shown in Figure 3. Interestingly, The range for Gorssel's dike durability is larger and higher than Deventer's dike durability for the worst percentile for Overijssel, even though the sensitivity analysis showed it is more sensitive to Deventer's dike durability. This is because when Gorssel's dike is kept intact, water will not be released there. Instead it will go towards Deventer. The same is true for Overijssel: if Gorssel's dike remains intact, the IJssel can cause more damage in Deventer as it is downstream.

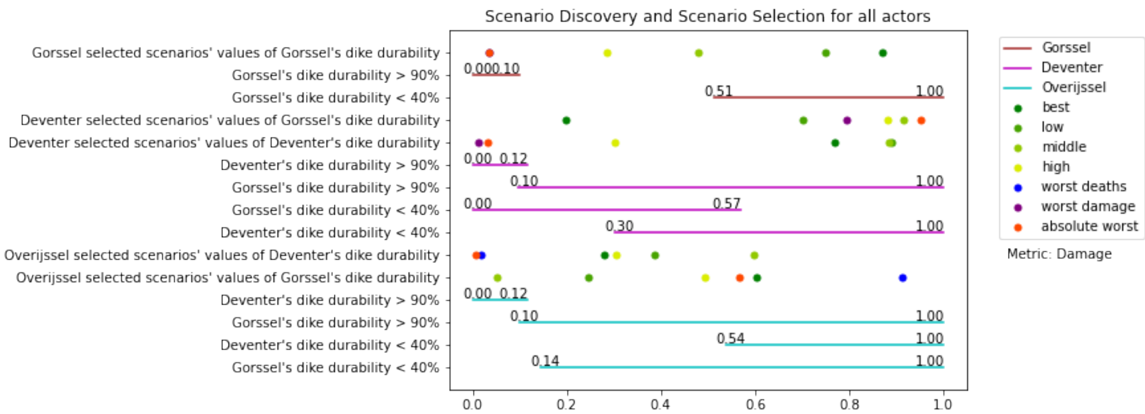

Figure 3: The results from the scenario discovery process and the selected scenarios. $< 40\%$ is all the scenarios with damage up to the 40th percentile, and > 90 are all the scenarios that have damage between the 90th and 100th percentile. All values of the dominant uncertainties of the "worst scenarios" correspond to the worst 10th percentile.

2.5 Identifying Policy Alternatives

Following scenario generation, policy alternatives were generated by optimising the policy objectives for the three actors to determine the Pareto-approximate set, using a many-objective evolutionary algorithm. The algorithm used was ϵ-NSGA2. We considered this algorithm appropriate for our formulations, as previous studies have shown that it performs well for six-objective problem formulations in related applications (Salazar et al., 2016). The epsilon values for these optimisations were selected through trial and error, informed by the range of values observed in the generated scenarios, with attention given to the number of potential policies generated from each iteration. We were ultimately satisfied that the chosen epsilon values represented an optimisation space that could trade-off between generating a sufficient number of interesting policy combinations without creating so much granularity that there was duplication or 'nonsense' policies being generated. The number of function evaluations for each optimisation were also selected based on trial and error, with the optimisations re-run until model results converged.

2.6 Re-evaluation of Policies under Deep Uncertainty and Policy Subset Selection

Having selected the six scenarios over which to optimise, the Many-Objective Evolutionary Algorithm (MOEA) was run to identify Pareto-approximate policies for each scenario for each actor. Duplicate policies were discarded and a more manageable subset was selected by clustering the remaining subset with k-means (with $K = 6$), resulting in 6 clusters. Within those clusters, we normalised the lever values and summed the values per policy. Then, the policies with the highest two sums were chosen to get the most "extreme" policies per cluster. This means that there were at most 12 different policies to be processed by the next step.

2.7 Robustness Analysis

We then examined the subsetted selection of policy alternatives according to two types of robustness metrics: one satisficing and one regret based (domain-criterion (Bartholomew & Kwakkel, 2020)). We considered the use of two metrics necessary to see where there might be disagreement between the two metrics and to identify if any policies could achieve good scores under both metrics (indicating policies that are more robust across different perspectives) (McPhail et al., 2018). The policies will be ranked by satisficing (highest value) and then re-ranked using the regret-based (lowest-value) metric. The outcome results in a final shortlist of five candidate policies per actor. To be able to compare this, the regret results were normalised using a min-max-normalisation. Then the mean of these results were used for the ranking. The satisficing results did not have to be normalised as this was done before.

Readers can find the threshold values for the satisficing analysis in Table 3. The threshold values for the total costs are the exact budgets of the institutions for water/traffic management so that it is a somewhat realistic representation. The expected annual damage was set as 10% of the Total costs available every year to the institutions. We calculated the values for expected annual deaths from the maximum risk of 1:100,000 people that can die from flooding multiplied (Slootjes & van der Most, 2016), which we then multiplied with the population of the area.

Table 3: This table shows the threshold values for the three actors. The values for the town of Gorssel come from its bigger municipality Lochem (Gemeente Lochem, 2021). Deventer's value is derived from (Gemeente Deventer, 2021). The value for Overijssel is obtained from (Overijssel, 2021).

	Robustness Threshold Values		
	Outcome	**Goal**	**Threshold**
Gorssel	Expected annual damage	Minimize	$5.4E+05$
	Expected annual casualties	Minimize	$1.0E-05$
	Total costs	Minimize	$5.4E+06$
Deventer	Expected annual damage	Minimize	$1.1E+06$
	Expected annual casualties	Minimize	$1.0E-05$
	Total costs	Minimize	$1.1E+07$
Overijssel	Expected annual damage	Minimize	$1.53E+06$
	Expected annual casualties	Minimize	$1.0E-05$
	Total costs	Minimize	$1.53E+07$

2.8 Uncertainty Analysis

Then the candidate policies for each actor are analysed for their sensitivity to uncertainties. The chosen method for global uncertainty analysis was the Extra Trees algorithm. We chose this approach as it is known to be an effective means of replicating the insights of global uncertainty analysis with much lower computational requirements (Jaxa-Rozen & Kwakkel, 2018).

2.9 Policy Synthesis

Finally, we ran Gorssel's policies for Overijssel's to see how receptive Overijssel is to Gorssel's optimal policies, and we used the approaches from Deventer and Overijssel and ran them for Gorssel's objective to see how good/bad they are for our client. Additionally, we identified where there are policies that are consistent (or at least similar) between actors to support coalition forming (in the case of consistent policies) or informing policy negotiations (in the case of inconsistent policies). We compared the five candidate policies from each actor to find potential similarities in lever choices, informing opportunities for coalition-building or areas for negotiation in future formulations and iterations over the multi-scenario MORDM process.

3 Results

This section summarises the key results from applying this approach, first identifying the most robust policies for Gorssel, Deventer and Overijssel, and subsequently discussing options for synthesising policy choices between the three actors.

3.1 Robust Decision Making

We used two metrics for the robust decision-making process: Satisficing (the domain-criterion) and maximum regret.

3.1.1 Gorssel

The results for Gorssel's satisficing analysis with the domain criterion are shown in Figure 4. We analysed the twelve policies selected during policy subset selection for trade-offs and the extent to which the results satisfy Gorssel's threshold values.
Figure 4 shows that every policy is satisficing for "Gorssel Expected Number of Deaths". This means that all potential policy recommendations ensure that the legal standards for citizen safety are met in all tested scenarios. We can also observe that Gorssel's G_1 policy performs best for the domain-criterion results, reaching the highest domain-criterion scores on average. However, this policy comes with a significant trade-off with the expected annual damage as the policy often goes over the annual damage budget and thus reaches a low domain-criterion value for 'expected annual damage'. This would make the policy less robust in terms of damage and more in terms of costs. For the other policies, it is the other way around. Most policies except for G_1 score 0 on 'total costs', and these policies are thus not robust when considering these satisficing results.

In Figure 5, the results for Gorssel's regret analysis are shown. The least regret for Gorssel appears with policy G_2. This is because the expected number of Deaths and the Damage for Gorssel have 0 regret in this policy; this comes at a high total cost. This is a clear example of the trade-offs that we must make within the policies. A trade-off like this is also shown with policy G_8, where there is little regret for the damage, but the number of deaths and the costs leads to high regret.

Another noteworthy result is that some of the high regret policies have a low satisficing score and vice-versa.

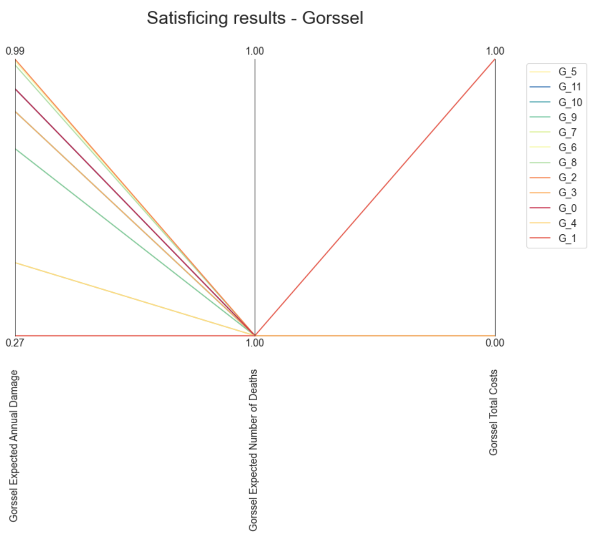

Figure 4: Results for Gorssel's domain criterion.

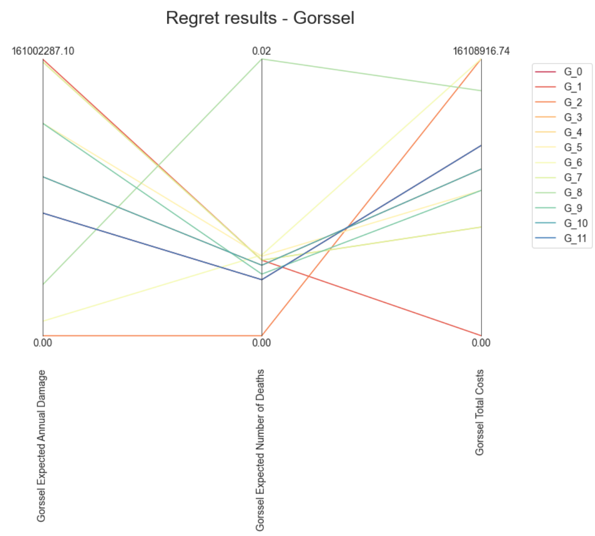

Figure 5: Results for Gorssel's maximum regret.

3.1.2 Deventer

The results for Deventer's satisficing analysis with the domain criterion are shown in Figure 6. Figure 6 shows that every policy is satisficing for "Deventer Expected Number of Deaths" and for "Deventer Total Costs". This means that later policy recommendations, just like in Gorssel's case, are ensured that all policies will meet the legal standards for citizen safety in all scenarios and that the budget of Deventer never overextends (within the set thresholds).

The policy D_9, together with D_8, performed the best with the satisficing scores for the expected damage. The other policies score only a little over half of this value. As such, policy D_8 and D_9 are the more robust policies.

Figure 7 shows the regret results for Deventer's policy options. Here it can be seen that policy D_8 and D_9 score the best on the 'average' regret with certain trade-offs. Especially policy D_9 shows a big trade-off compared to D_8 between expected damage and expected deaths versus the total costs that this brings with it. Another policy that reveals potential policy strategies for Deventer is policy D_4. This policy shows that the only way Deventer will not 'regret' their total costs is when they trade costs for high damages and a high expected number of deaths.

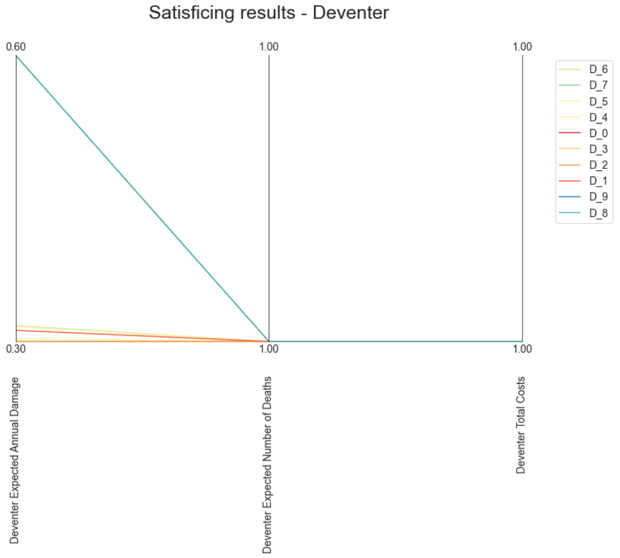

Figure 6: Results for Deventer's domain criterion.

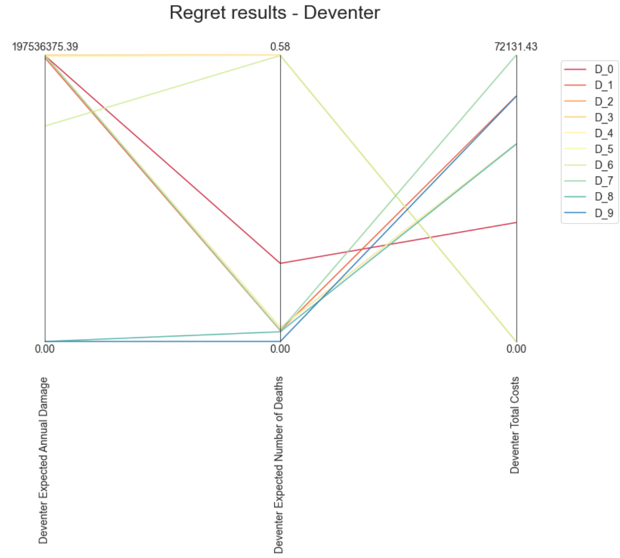

Figure 7: Results for Deventer's maximum regret.

3.1.3 Overijssel

Overijssel's satisficing analysis with the domain criterion is shown in Figure 8. Here, we can see that every policy is satisficing for "Gorssel and Deventer Expected Number of Deaths" and none except for O_6 for "Gorssel and Deventer Total Costs". And thus, all potential policy recommendations can be sure that the legal standards for citizen safety will be met in all scenarios while crossing the total cost threshold of Overijssel, except for O_6 because it does not satisfice for costs. Policy O_8 and policy O_10 are better choices, scoring low on regret based on their satisficing scores due to their scores on 'expected damage'.

Figure 8 shows the regret results for Overijssel's policy options. Here policy O_8 and O_10 score the best on the 'average' regret but show certain trade-offs. It is interesting to note that policy D_10 shows almost no trade-off compared to the other policies.

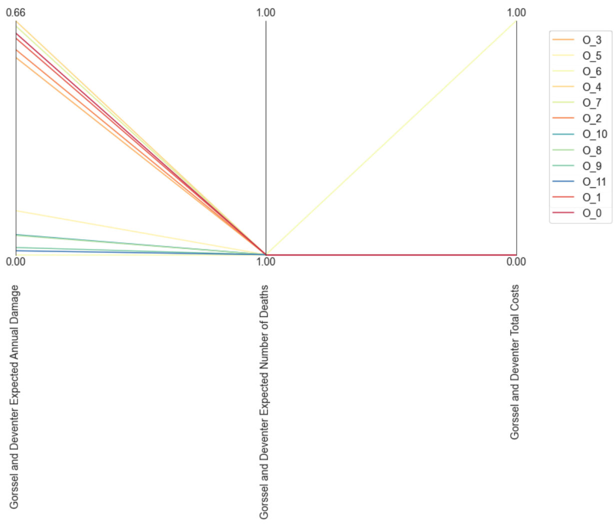

Figure 8: Results for Overijssel's domain criterion.

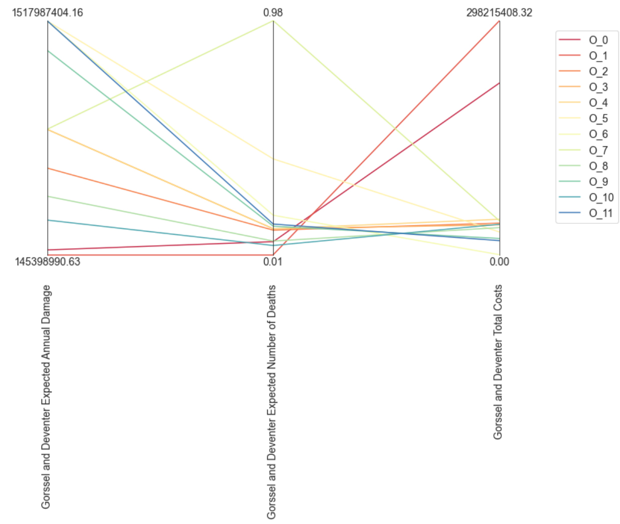

Figure 9: Results for Overijssel's maximum regret.

3.2 Sensitivity Analysis

We used the policies that were deemed best from the robustness analysis to initialise the model to perform the sensitivity analysis as explained in subsection 2.8. This allowed us to assess what uncertainties and levers significantly impact the outcomes when policies are in place. The analysis of these can be viewed per actor in the following section. The generated figures for the sensitivity analysis can be found in Appendix B.

3.2.1 Gorssel

From the earlier sensitivity analysis and scenario discovery, as explained in subsection 2.3, it became apparent that Gorssel's outcomes are not only sensitive to the durability of their own dike but also to the durability of Deventer's dike. When adding the policies, we observe that the sensitivity of the outcomes to the durability of Gorssel's and Deventer's dikes remains the highest.

3.2.2 Deventer

During the sensitivity analysis and scenario discovery step, we found that the biggest threat to damages and deaths for Deventer was their own dike durability. This was in line with expectations because only their own dike breaking would impact Deventer. And just as with Gorssel, we observed that the outcome was still least robust under the dike durability of their own dike when adding the policies.

3.2.3 Overijssel

For the costs of the province of Overijssel, we observed that they are sensitive to dike increase. Costs were most sensitive to dike increase in Gorssel, which is in line with reality as this is the most costly procedure in the province, other than Room for the River. However, because none of the policies for Overijssel recommended Room for the River, there is no observed sensitivity. Furthermore, the entire province showed a higher score on deaths and damages across the province as well when it comes to dike failure.

3.3 Qualitative assessment of shortlisted Policies per Actor

We identified a subset of the top five most robust policies (prioritising regret-based metrics). Here we present, a summary of each policy regarding dike heightening, Room for the River projects, and early warning systems for each actor. The damage, death, and cost outcomes are not included in these tables, as we have already optimised these policies to be within acceptable levels based on the robustness metrics in previous steps. We qualitatively interpreted for opportunities for coalition forming, with relevant policies highlighted yellow in each table.

Interpreting these policies for opportunities for coalition-forming, there is a commonly re-occurring objective of a three-day early warning, which presents an opening for consensus-building between actors in the Overijssel region. The tables below explore this in more detail.

3.3.1 Gorssel

The five most robust policies for Gorssel are presented in Table 4.

Table 4: Robust policies for Gorssel. RfR stands for Room for the River, dike increases are in decimetres and aggregated over all planning steps, EWS refers to Early Warning System in days.

Gorssel Policies	Gorssel RfR	Deventer RfR	EWS Days To Threat	Gorssel Dike Increase (dm)	Deventer Dike Increase (dm)
G6	0	2	1	8	15
G11	0	3	2	5	8
G0	0	3	2	5	17
G1	0	3	3	0	14
G2	0	3	3	8	10

Given that we optimised these policies for Gorssel's objectives, all of these policies are favourable for Gorssel. However, we highlight policies G1 and G2 for opportunities they present for coalition forming with Deventer and Overijssel. Arguably, these two policies are less favourable for Deventer, given the more significant investments in Room for the River and dike increases. However, they are well-aligned with many of Overijssel's preferred policies (seen in Table 6) which prioritise earlier warnings and modest dike heightening (although they do not include Room for the River policies).

3.3.2 Deventer

The five most robust policies for Deventer are presented in Table 5.

Table 5: Robust policies for Deventer. RfR stands for Room for the River, dike increases are in decimetres and aggregated over all planning steps, EWS refers to Early Warning System in days.

Deventer Policies	Gorssel RfR	Deventer RfR	EWS Days To Threat	Gorssel Dike Increase (dm)
D2	3	0	2	20
D5	3	0	2	23
D0	3	0	1	27
D9	3	0	3	0
D8	3	0	2	0

Deventer's policies offer the least to Gorssel in terms of potential coalition-forming/points for negotiation. Of interest, however, is policy D9. While requiring significant Room for the River investment in Gorssel, this policy does not require any dike heightening (as for all other robust policies for Deventer), relying instead on earlier warnings, similar to related robust policies of Deventer, Gorssel, and Overijssel.

3.3.3 Overijssel

The five most robust policies for Overijssel are presented in Table 6.

Table 6: Robust policies for Overijssel. RfR stands for Room for the River, dike increases are in decimetres and aggregated over all planning steps, EWS refers to Early Warning System.

Overijssel Policies	Gorssel RfR	Deventer RfR	EWS Days To Threat	Gorssel Dike Increase (dm)	Deventer Dike Increase (dm)
O3	0	0	3	5	5
O2	0	0	2	4	6
O4	0	0	3	9	5
O8	0	0	3	0	7
O10	0	0	3	0	8

Overijssel's policies prioritise dike increases in the first planning step, with none of the policies prioritising Room for the River (reflecting the relative expense of these policies compared to dike increases). Of interest to Gorssel are policies O8 and O10 (highlighted yellow in the table). These two policies are favourable for Gorssel and Overijssel (given minimal investment costs in Gorssel) and present an opportunity to start discussions with Overijssel Province to pursue such a policy.

3.4 Re-evaluation under other formulations

For the quantitave aspect of synthesis, we considered and compared the top five policies from Deventer and Overijssel in terms of their performance against Gorssel's outcomes of interest. Figure 10 shows the costs to Gorssel for Deventer and Overijssel's preferred policies. As expected, the costs for Deventer's policies were considerably higher than those deemed acceptable by Overijssel. For these reasons, we recommend that Gorssel focuses on engaging with Overijssel first in policy negotiations regarding Gorssel's preferences. These results suggest limited opportunities for coalition-forming with Deventer at the Overijssel-region scale and indicate a need for mediation from Overijssel to find a 'fair' distribution of costs within the region.

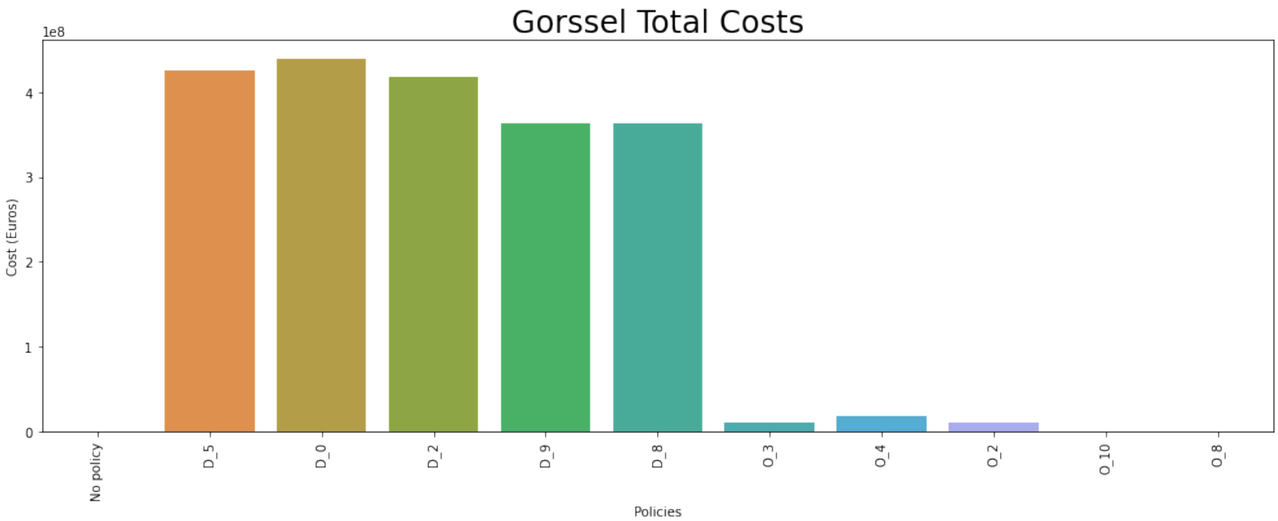

Figure 10: Costs incurred by Gorssel for Deventer's and Overijssel's top five most robust policies.

Figure 11 shows the spread of Gorssel's Expected Annual Damage when Deventer and Overijssel's policies are applied. The vertical axis shows the standard deviation in values for damage across a sweep of uncertainties. Interestingly, Deventer's policies generated less variable outcomes for Gorssel, suggesting that some measure of flood mitigation infrastructure in Gorssel (which is missing from Overijssel's policies) would prevent excess uncertainty in potential damages.

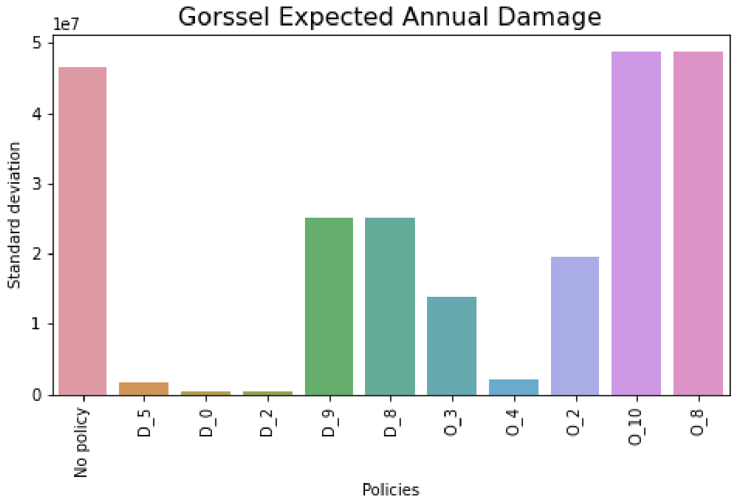

Figure 11: Expected Annual Damage incurred by Gorssel for Deventer's and Overijssel's top five most robust policies, values on the vertical axis are in Euros.

For this reason, we propose that Gorssel could negotiate with Deventer to advocate that Overijssel consider policies with more flood protection measures, mitigating this uncertainty in damage outcomes.

Additional plots of the effects of Deventer's and Overijssel's policies on Gorssel's outcomes are found in Appendix D. The results for "Difference in Expected Annual Damage (EAD) between Gorssel and Deventer" and "Difference in Expected Number of Deaths between Gorssel and Deventer" did not show any noteworthy results in this round of the analysis.

3.5 Summary of Policy Recommendations

Based on the above results, there are four key pieces of policy advice for the Municipality of Gorssel:

- Modest dike increases in Gorssel and Deventer in the first planning step present a robust solution to minimise flood risk in Gorssel.
- Gorssel should prompt the Overijssel regional government to increase the Early Warning System time frame to 3 days, or support already existing efforts to that end.
- The current scoping of the problem suggests that Room for the River projects are not favourable due to relative costs (compared to dike increases). However, the sensitivity of proposed policies to uncertainty in the probability of a dike failure suggests that these options may warrant further exploration as a policy option.
- We recommend - should Gorssel pursue dike heightening projects and EWS increases - that they complement these policies with other activities to improve their real-world robustness. For example, instantiating improved monitoring and evaluation of dike strength to proactively minimise uncertainty and risk, and/or public relations/community engagement strategies to improve the uptake and acceptance of the increased (and potentially more frequent) warnings.

4 Discussion

In this section, we look to identify the methodological and policy limitations of our analysis and policy advice and discuss solutions for future work that might help resolve them.

4.1 Methodological Limitations

In the analysis process, we made several methodological decisions to enable the effective modelling of the problem posed by Gorssel. While we have justified the critical in Section2, a few methodological threats to the validity of this report's policy advice remain.

4.1.1 Level of Aggregation in the Model

In choosing the problem formulations for Gorssel, Deventer, and Overijssel, several key variables in the model were either aggregated or disaggregated to achieve a problem formulation that adequately articulated the actor's objectives. Indeed, there is a trade-off between higher levels of aggregation, which may allow for more information to be embedded within fewer objectives, and lower levels of aggregation, which introduces more bias into the problem formulation. For example, Kasprzyk et al. (2016) explain that aggregated, lower objective approaches to modelling might bias decision support tools. However, due to limitations in computation and explainability for clients, some of the objectives had to be aggregated in our modelling approach (for example, Overijssel's problem formulation had an objective of combined deaths for Deventer and Gorssel, rather than optimising them separately).

The aggregation of outcomes overall planning steps also limits the type of policy advice we could provide. By aggregating these outcomes, we are unable to consider the timing of decisions in our policy analysis, limiting our ability to consider reversibility and timeliness of decisions necessary for presenting advice in the form of Dynamic Adaptive Policy Pathways (J. H. Kwakkel et al., 2016; Marchau et al., 2019).

It is also feasible that this aggregation created bias related to the influence of different uncertainties. Uncertainty analysis revealed that many of the uncertainties had little to no impact on the outcomes for the actors considered, with Probability of Failure of the Gorssel dike being the most influential factor for the outcomes in the Gorssel analysis.

Further to this, the model used is limited in terms of conceptual aggregation. This was necessary due to the balance between complexity and simplicity in the model - e.g. the model doesn't include climate change, international actors, or broader system scoping.

4.1.2 Validation with Stakeholders

We did not validate the assumptions applied in the development of problem formulations with input from the client (Gorssel) or the 'rival' stakeholders. Unfortunately, this meant that it wasn't possible to sanity-check the proposed policies or revise the problem formulations in light of expert input. As a result, only one iteration was performed over the complete Multi-Scenario MORDM process to generate the policy advice presented in Section 3. This may limit the relevancy and robustness of the proposed policies, as well as the likelihood of acceptance by stakeholders (Quinn et al., 2017).

Further to this, we made assumptions about the objectives and constraints for stakeholders, which influenced how the problem formulations structures. For example, in its problem formulation, Deventer has a hard constraint on dike increases. This generated some unusual policies, which warrants further investigation.

4.1.3 Limited Use of Uncertainty Analysis and Scenario Discovery

The uncertainty analysis and scenario discovery results from the preliminary round of MORDM were not employed effectively in the subsequent selection of scenarios. Time constraints in the analysis process meant that we did not adequately incorporate information on uncertainties to adjust the uncertainty ranges over which we sampled selected scenarios. We could have better incorporated the results from these analyses into decreasing the dimensionality and uncertainty of the selected scenarios, which could have reduced the computational intensity of other downstream tasks in the multi-scenario MORDM. This limitation may also explain why the final proposed policies remain highly sensitive to a single input factor (probability of dike failure at Gorssel).

4.1.4 Inefficient Order of Steps

As can be seen in Figure 2 in Section 2, we selected our subset of policies after we had re-evaluated under deep uncertainty. This wasted computational power on re-evaluating policies that we excluded by the next step. This is very unfortunate, as 1000 scenarios per policy is relatively small.

4.1.5 Limitations of RDM

RDM is a strong approach for handling wicked problems but is not without its own limitations (J. H. Kwakkel et al., 2016). For example, RDM enabled us to investigate the trade-offs of different policies, but this method is limited in its adaptability once implemented. Further to this, anecdotal evidence suggests that Rijkswaterstaat advocates adaptive planning, and policy proposals, even at the municipal level, should look to come in line with national approaches.

4.1.6 Creation of the 'Difference' Objectives

In translating Gorssel's mandate from problem framing into model problem formulation, we initially looked at minimising the difference between damage in Gorssel and Deventer. We proposed this as a means of quantifying the 'fairness' of different policies in terms of effects in rural and urban areas. However, after further consideration, we decided that minimising this as an objective was arguably too Machiavellian, given that minimising this to below zero is effectively choosing scenarios that maximise deaths in Deventer, often without any additional benefit to Gorssel.

Instead, we retained this objective to calculate sensitivities to capture the intangible concepts of fairness and equality between urban and rural areas. However, this decision meant that the objective is more for Gorssel's benefit and does not add any analytical rigour to the definition of 'fairness'. Further to this, the difference value in optimisations is always favouring Gorssel, but it remains uncertain that this covers the fundamental inequity between the rural and urban actors. For example, Gorssel probably receives a lot less revenue, so damages there are probably more impactful than in Deventer.

4.2 Policy Arena Limitations

The policy arena was demarcated in section 1. However, the manner thereof may leave some blind spots and create limitations that further analysis should address. We will address these concerns in the following subsections.

4.2.1 Model Scope versus Real World

To reiterate, the manner of scoping is that we have merely looked at decision making within the province of Overijssel. This means that our analysis fails to consider the implementations of upstream dike rings. However, in reality, the implementation of upstream strategies have the power to render our found policies ineffective.

Besides this, particularly within our defined scope, financial aspects significantly impact the choices each actor makes. This has to do with the "fairness" we seek for Gorssel, and others also seek this same "fairness" for their own dike ring. For instance, Dike Rings 1 to 3, located upstream, care about the funds being made available for Dike Ring 4 and 5, as this means there will be fewer funds available for the projects in their area.

Lastly, our regional scoping means we did not infer the complete consequences of an Early Warning System. The model consists of actors across Dutch provinces. The EWS is a "global" policy - meaning that it would affect all RfR actors and not merely the one within the scope. All actors, or critical mass, would need to be convinced instead of just those within the scope. Future model iterations could include more agents to confirm whether this global policy is desirable or not.

4.2.2 Decision Making Processes

The current scoping of the policy solutions may conflict with Rijkswaterstaat's actual manner of top-down planning. Conflicts between bottom-up and top-down planning and implementation of policies may create inefficiencies or results in missed opportunities (Koontz & Newig, 2014). For Gorssel, the focus of objectives was concerned with preparing a strategy on how to develop a proposal with the province of Overijssel. This means that while the analysis is relevant in this context, it may fail to account for the reality of how Rijkswaterstaat functions. Similarly, it may not always be possible to implement the decisions made in the model in reality. For instance, if the region invests first in dike strengthening and Room for the River follows after, the dikes would have to be altered or dismantled.

4.2.3 Dependency on Models

To better serve Gorssel, the base model given by Rijkswaterstaat was adjusted, such as the disaggregation of costs of Room for the River projects. This was done to suit Gorssel better but poses a problem when other actors in the policy arena use the same (base) model or have also made small adjustments, as we may not be able to assume a consensus exists among all actors, as J. H. Kwakkel et al. (2016) writes is important to have. Our client should treat this advice with a certain wariness, so they're not used to support actors' agendas. Models are frequently misused to support agendas (Saltelli et al., 2020). A way to prevent this negotiated nonsense is validation through stakeholders and experts.

4.3 Proposed Improvements and Further Work

Proposed solutions for each of these limitations are considered in light of current knowledge and available literature. These improvements are summarised in Table 7.

Table 7: Proposed solutions for each of the identified limitations.

Limitation	**Proposed Solution**
Levels of aggregation	Future work should look to disaggregate factors (especially cost objectives) to identify whether the aggregation of these factors introduced bias in the policy analysis favouring one approach or another.
Inefficient order of analysis	It is more efficient first to select a subset of policies, then re-evaluate under deep uncertainty.
Limitations of RDM and reversibility of decisions	Re-evaluate the problem for multiple time steps and consider applying dynamic adaptive policy pathways (DAPP). The selection of the style of proposed policy should ultimately match the client's risk tolerance and preferences regarding adaptive planning (Marchau et al., 2019).
Lack of validation with stakeholders	Analysts should conduct additional iterations on the model specification and frame in light of identified policies and scenarios. Having identified opportunities for coalitions (or tensions between policies of different actors), should iterate through the Multi-scenario MORDM process again following consultation with the client and stakeholders, re-specifying the problem formulations, or adding in new issues or objectives. For instance, running new problem formulations for actors in Gelderland province to test the policies against their objectives and preferences.
Limited application of uncertainty analysis and scenario discovery	Further iterations on the multi-scenario MORDM should better incorporate insights from the uncertainty analysis, such that a more specific set of scenarios are selected for the analysis and optimisation of the policies (Eker & Kwakkel, 2018; Watson & Kasprzyk, 2017).
Creation of difference objectives	Investigate alternative robustness metrics through consultation with stakeholders and client. There are a range of metrics that could serve to underline robustness in terms of inequities in proposed policies (McPhail et al., 2018).
Scoping of the model relative to reality	Additional iterations at various scopes of the problem with the recommended policies may work well to show how the chosen policy would function under different scopes.
Decision-making processes	A way to counter this would be to perhaps find a manner to be more involved in the final decision-making process at provincial level
Dependency on models	Better communication between analysts and modellers would allow for aligning the different models and perhaps allow for an understanding of differences. Furthermore, transparency and naming the vulnerabilities of the models used can build trust (Saltelli et al., 2020).

5 Conclusions

In this report, we have applied state of the art decision-making under deep uncertainty approaches to identify robust and cost-effective policy alternatives for flood risk management in the Municipality of Gorssel. We performed this analysis to answer the following question:

> How can Gorssel (Dike Ring 4) affordably protect its citizens and businesses from flood risk to a similar level as neighbouring urban areas while still preserving and protecting farmland from encroachment?

The Key Performance Indicators (set of objectives) chosen for Gorssel consisted of the expected annual damage, the expected number of deaths and the total costs of the entire IJssel river area. Multi-scenario MORDM was employed to generate an extensive range of scenarios and appropriate policies within these scenarios from the perspective of Gorssel, Deventer, and Overijssel. The identified policies were tested for their relative robustness and compared to identify opportunities for potential coalition forming. Given the conflicts between the preferred policies of Deventer and Gorssel, Overijssel's most robust policies present options for compromise between the objectives of the three actors.

5.1 Final Policy Recommendation for Gorssel

Based on the synthesis of the results, we found that an early warning system is likely to get consensus from all three actors within the Overijssel province. Therefore the first recommendation is to commence negotiations to establish commonalities and a basis for upcoming cooperation.

5.2 Next Steps

Based on these results and the points of discussion raised in Section 4, we strongly recommend re-visiting the problem formulations following policy discussions/negotiations with both Deventer and Overijssel. Gorssel can use analysis results for the three actors to inform policy discussions and reformulate a collective problem formulation for the three actors, which can adequately represent the trade-offs inherent in the region. Given the consensus between the Overijssel region's actors regarding a three-day early warning, we recommend that the following problem formulation fixes the Early Warning System lever at this value to search for more granularity in policy options, among other levers.

5.2.1 Pursuing Suggested Policies

Following this re-evaluation should Gorssel still wish to pursue local dike expansion options and increases to the early warning system, there are three key recommendations:

1. Gorssel (or the Province of Overijssel) should seek additional expert advice/testing to reduce uncertainty regarding the probability of failure of dikes in both Gorssel and Deventer.
2. Any dike expansions should be accompanied by a dike strength monitoring and evaluation program to manage risks of failure and ensure Gorssel can take preventive actions to further fortify or repair identified weaknesses.
3. Early Warning System increases should be accompanied by community engagement to ensure compliance with evacuation orders and improved understanding of why evacuation orders may become more frequent.

On a closing note, Gorssel should also keep in mind that we mean for these results to be utilised as support for the decision-making process and not be seen as *the* decision-making process. Readers should acknowledge the methodological and political limitations of the approach taken in this analysis. With this manner of modelling, we could explore a wide range of potential futures, and many uncertainties have been taken into account, resulting in possibilities but not predictions of the future.

6 Political Reflection

6.1 Introduction

Decision-making concerning large scale infrastructure projects such as RfR benefit immensely from exploratory modelling approaches. It allows us to deepen insight of systems in question, explore behaviours under a wide range of uncertainties and scenarios, and, using this understanding, formulate robust and effective policies to address these uncertainties, which would otherwise be left to chance (Bankes, 1993). As analysts, we are responsible for ensuring that the use of models and the information derived from them is correctly understood and utilised appropriately to aid in real-life decision-making (Pielke, 2007; Van Enst et al., 2014).

Through analysing this case and the simulated debate-style policy negotiation, several tensions and challenges arose that might affect the successful adoption of proposed policies. Here, we reflect on three of these challenges and describe how our analysis attempts to address these, and additional actions that an analyst could still take. Finally, we reflect on the risks of adopting these strategies and how our client, Gorssel, might adapt their approach in light of these risks.

6.2 Tensions and Challenges

We will discuss three fundamental tensions and challenges identified in the analysis process in the following subsections.

6.2.1 Information Asymmetry (IA)

Unequal levels of information and technological expertise of the different actors involved can mean that the chosen policy does not align with a perceived understanding of modelling or goes against the interests of less informed actors. It represents an “ethical threat” (Albertus, 2019), that stems from inadequate information sharing between “information-rich" and "information-poor" parties (vertical IA) or information that is distributed and incomplete among parties (horizontal IA) (Clarkson et al., 2007). This phenomenon was visible during the debate preparation and negotiation process, where high-level actors such as the Rijkswaterstaat and transport company had teams of analysts to support them, resulting in vertical IA. These actors may not act in good faith or hide relevant information from other actors creating more uncertainty for our modelling purposes. Moreover, they could use their expertise and reputation to legitimise their claims. We were provided with a mandate that was, in general, less technically focused than those of other actors. This made participation in policy debates and requests from other stakeholders to quantify our position a more challenging prospect, with more uncertainties to account for.

6.2.2 Intangibility of Costs and Benefits

Models which are designed based on achieving consensus between actors may fail to adequately capture or quantify intangible/ephemeral costs, benefits, and objectives, which may influence the behaviour of certain actors. Over the past decades, the urban-rural divide has caused a divergence in attitudes and political discourse between these factions. The rural discourse emphasises social, cultural, ecological, scenic and other ’normative’ values of the countryside (Andersson et al., 2009; Frouws, 1998). This is reflected in Gorssel’s policy mandate, highlighting their pride in organic and sustainable farming practices. More importantly, there was an expectation of ’fairness’ in the treatment of Gorssel relative to urban municipalities (mainly Deventer), a factor that is not formally part of the model. Furthermore, model outputs cannot account for actions that actors may take in relationship management. Given they are both administered by Overijssel’s provincial government, in reality, Deventer and Gorssel may make concessions to one another in the interests of maintaining good working relationships for the long term. These concessions are not simple to quantify in a model.

6.2.3 Fixed Goals

Goal definition is needed during decision-making processes to provide direction for any given project. Goals are the result of the first step of any decision-making process: problem scoping and formulation (Enserink et al., 2010). However, cognitive bias often leads actors to fixate on these predefined goals, even when the problem understanding changes through exploratory modelling analysis. This severely limits opportunities for the actor to engage with more expanded multi-issue agendas in the latter stages of policy analysis that modellers present. This fixation may also be a strategic choice for smaller actors to make a solid stance to obtain more significant concessions from a high-level actor (e.g. the Rijkswaterstaat) than letting goals be dictated by analysts, who can have biases or agendas of their own (Hans de Bruijn, Mark de Bruijne, Ernst ten Heuvelhof, 2015).

6.3 Effects on the Modelling Approach

The three challenges were essential drivers of our modelling approach. Each challenge impacted our approach in the following ways:

6.3.1 Information Asymmetry

IA is inherent to any political decision-making problem. Yet starting actors out with the same model already provided a first mean to combat information asymmetry. For this exercise, all actors/analysts were equipped with equivalent training in modelling approaches. This ensured a predefined consensus on deep uncertainties and that all actors acknowledge that something must be done by cooperating. By employing a collectively accepted model, even actors with less technological capabilities can engage with the analytical approach.

We tried our best to account for IA in our exploratory modelling approach and to conceive standpoints or problem formulations for actors, mainly within the Overijssel region, using actor analysis (Enserink et al., 2010). Specific to our modelling, the objectives of each actor were then scoped to only a small number of objectives per iteration (e.g. minimise deaths, damages, and costs) to not only reduce computational requirements but it also ensures that the most critical trade-offs modelled are well communicated to a non-technical stakeholder/decision-maker.

6.3.2 Intangibility of Costs and Benefits

Expanding the model to include additional model parameters to try and capture these "intangible" factors" was not seen as a solution to address this challenge. This is because the usefulness of the model is a balance between enough parameters to capture system behaviour, but also few enough to keep uncertainties manageable (Saltelli et al., 2020). Moreover, a model cannot and need not fully capture the actual system, as some models may lead to alterations in system behaviour (e.g. as is the case for RfR models being used to alter river flow) and thus become self-invalidating.

We opted instead to introduce an information reporter to Gorssel's problem formulation, which calculates the differences in expected annual damages and expected number of deaths between Gorssel and Deventer, as a proxy for the more intangible feature of 'perception of fair treatment. We then used this reporter in the final analysis of robustness and sensitivity for Gorssel, whereby the factors were used to inform both satisficing and regret-based robustness objectives (McPhail et al., 2018). In this way, our advice would address critical contextual factors for our client stakeholder that do not directly concern flood risk management.

6.3.3 Fixed Goals

To avoid rigid goals that reduce the potential policy space, we used an RDM approach. RDM is inherently iterative and should, from the outset, encourage actors to adjust their scope/objectives in light of unexpected outcomes through multiple iterations of the RDM process (Lempert et al., 2006).

For this assignment, following the policy debate, the problem formulations were updated and reframed due to new information brought up by other actors. For instance, after learning that Deventer wished to impose a hard constraint to prevent the dike heightening in their city, we updated the problem formulation to avoid policies that involve dike heightening in Deventer.

6.4 Solutions for Real World Situations

For real-world situations, a much more comprehensive range can address these tensions and challenges that were not available to us during this project report. Below we present four promising ways/ideas that can guide modeller behaviour in future decision-making processes like RfR.

6.4.1 Use of Serious Gaming to Build Consensus

Using interactive methods such as serious gaming can help to further consolidate consensus in an environment where not all stakeholders have the same level of knowledge or technological capacity. It can also serve as a means to build empathy between actors by asking them to take on the role of a different actor in the same problem domain. This could then lower the barrier to entry, such that a broader range of lower-power stakeholders can be genuinely involved in the decision-making process (for example, farmers and/or citizens in the municipality of Gorssel) (Savic et al., 2016).

A serious gaming approach would require the development and use of a "blokkendoos" or "planning kit", in essence, a simplified model designed to aid various stakeholders rapidly assess spatial measures for inclusion within adaptive flood protection management strategies, without needed formal modelling experience (Warren, 2015). This approach would reduce expertise asymmetry, meaning there is less incentive for less technical actors to oppose model outputs or attack the model as a whole. The empathy-building and social value of serious gaming approaches may also help to reveal intangible costs and benefits.

6.4.2 Support the Creation of a Multi-Issue Agenda

A fixed goal that opposes another actor's goal will lead to serious conflicts within the political arena. Conflicts are inevitable, but the introduction of new 'issues' to the agenda widens negotiation space, allowing for opportunities to find trade-offs, agreements and compromises, as well as opportunities to broaden the scope beyond the model analysis to help prevent actors from becoming too attached to specific goals or problem formulations throughout the policy process (Hans de Bruijn, Mark de Bruijne, Ernst ten Heuvelhof, 2015). Specifically, in our case, the RfR could be tied with other developmental projects in the region, such as making transport networks more efficient or making the region more attractive for certain companies, e.g. in the tourism industry. Creating a multi-issue agenda encourages cooperation when specific objective goals cause actors to behave in a non-cooperative manner, which in turn can also help reduce information asymmetry (Coehoorn & Jennings, 2004).

6.4.3 Reconceptualise Modelling with Dynamics Adaptive Policy Pathways

Acknowledging deep uncertainties, such as climate change, population growth, new technologies, economic developments, societal perspectives, preferences and stakeholders' interests, modelling can no longer be viewed as a predictive planning tool. Instead, a new planning paradigm has emerged: dynamic adaptive policy pathways (DAPP), which involves designing alternative policy options that are dynamically adapted depending on circumstantial factors. Central to the approach is the monitoring of a meaningful metric or "signposts" that can trigger the change from one policy option to another (Haasnoot et al., 2013).

Our recommended policy indicates that the use of dikes seems the most favoured solution for Gorssel and Overijssel as a whole. However, dike failure remains highly uncertain, and therefore somehow monitoring dike strength could serve as an adaptation tipping point and alter to a more appropriate policy. Since the MSMORDM approach results in a collection of favourable policies, Gorssel can combine these into a DAPP framework, whereby the most appropriate policy is implemented at appropriate time steps (J. H. Kwakkel et al., 2015).

This provides all actors to carefully adjust goals and analysts with more time to exchange information and re-evaluate if certain assumptions still hold.

6.4.4 Constructive Decision-Making & Quantitative Storytelling

Another critical idea concerns not necessarily the modelling approach but the general communicative approach itself. To analyse a complex system, the modeller must take the secondary role of being an "honest broker". The "honest broker" one engages in a constructive style of decision-aiding, which involves the analyst facilitating joint sense-making with the client (in this case, Gorssel), and with relevant stakeholders (Tsoukiàs, 2008). Even the finest model is useless if its insights are not communicated and comprehensive in a way that impacts decision-maker behaviour. The human mind is not built to comprehend large sets of data, but more so images and stories. It is natural then that in general, "numbers don't stick, stories do", meaning that more often than not, policy debates/decisions are determined by a leading narrative or anecdotes as opposed to empirical data (Kettl, 2016), see Table 8.

Given that a narrative is more effective in informing/guiding evidence-based policy debates than numerical data, policy analysts and modellers must find ways to work with this human limitation by tying data analysis to an overarching narrative. Gorssel can support this narrative historical accounts of flood from 1993 & 1995, including damage cost estimations would emphasise the need and incentive for actors to implement measures, despite being costly (Rijke et al., 2012). This is known as quantitative storytelling, which has manifested itself in the use of composite indicators, which are numerical metrics built to 'tell a story. For example, a simple composite actor is GDP and common narrative ties to progress and development (Kuc-Czarnecka et al., 2020). Gorssel can also use such metrics for flood risk to guide project implementation and address information asymmetry since QS is more intuitive and inclusive for actors to follow. However, like GDP, such composite indicators are criticised and come with considerable risks, discussed in the following paragraph (Kuc-Czarnecka et al., 2020)).

6.5 Reflection on Proposed Strategies

In the final section, we reflect on the potential risks which analysts may face and how Gorssel can adapt the proposed solutions, see Table 8.

Table 8: Risks of Strategies and their Responses.

Risk of Strategy	Potential Response
RDM strategies still require a decision and investment to be made, which (in the context of wicked problems) will likely be irreversible	Revisit the modelling using a DAPP approach to find if there are opportunities for generating more flexible
The requirement to iterate over RDM strategies may never resolve to a favoured solution by all actors.	Ensure there is a 'stopping point' for the iteration over the problem scoping. The analyst could base this on a deadline date at which the client must decide or a certain number of iterations.
Changes in leadership or government of involved actors result in changing priorities or disagreement with the consensus model.	Ensure that each step of the process is well documented, including all decisions and assumptions and past iterations of the scoping and their outcomes, such that the new or changed actor can become up to date on the process.
Participating actors have 'pet solutions', and they may influence the serious gaming or constructive modelling approaches to favour their solution.	Pot et al. propose several strategies to compensate for these behaviours, including the use of visions and scenarios.
Robust decisions can still be subject to other complications in their implementation as the model does not take into account limitations and uncertainties in implementation (for instance, delays in the actual building of flood mitigation measures)	Engage in expectation management with the clients and stakeholders around the limitations of the model. The model is just an abstraction of reality built to help inform decision making; scenarios are not forecasting. Saltelli et al., 2020 recommend that modellers be aware of hubris, ensuring they do not confer too much certainty in the modelling process.
The 'policy window' may not be open for the solutions to be implemented. Rijke et al., 2012 highlighted the importance of a sense of urgency that guided involvement in policy-making.	Being aware of the socio-political environment and long-term planning will allow rapid implementation when opportunities present themselves.
Even when all stakeholders use the same model, different problem formulations can result in significant differences in the nature of the policy advice.	The Serious Gaming approach can enable stakeholders to see how different conceptualisations can generate different results in the same model.
Quantitative storytelling using composite indicators may oversimplify multidimensional problems, resulting in simplistic or misleading policy messages if poorly constructed or misinterpreted	Acting as an "honest broker" ensures joint sense-making between client and analyst so that the analyst can address potential misconceptions.

Even when the analyst is aware of these risks, and their potential responses, the very nature of the wicked, highly contested problem spaces in which this analysis is occurring is such that uncertainties in the process itself could derail any one of these strategies, while also rendering the potential responses redundant. As analysts, we must practice what we preach; to be highly adaptable to the dynamic and uncertain political environment we are faced with.

The key is to uphold the trust and integrity of the modelling process. Managing expectations and the ability for a solution to be robust to different futures is essential to being an honest and transparent participant in the policy-making process. However, modellers must strike a balance between building stakeholder trust in their model and managing these expectations by using the many tools and methods at their disposal. Expectation management can backfire if it results in scepticism towards the outputs of the model. However, keeping all this in mind and utilising the proposed potential responses, we can find a favourable outcome for Gorssel and other clients in the future.

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A Assumptions

Here, a selection of important assumptions made during the analysis and problem framing are listed:

- RfR costs include all relocation costs for farms and houses.
- Model-land objectives of Deventer and Overijssel are consistent with mandates revealed in the debate
- Gorssel is in the province of Overijssel
- The Rijkswaterstaat has the power and tools to conduct land expropriations under Dutch Law
- Used population figures from the last available census to make values for the difference function per capita rather than absolute figures. It was not considered to be important to find very precise information for this value.
- Room for the River Projects 3 and 4 were assumed to be in Gorssel and Deventer respectively - costs for the project were disaggregated accordingly.
- Population for the town of Lochem was used as a proxy for Gorssel as it was considered a more realistic population size.
- Overijssel consists out of only Deventer and Gorssel/Lochem
- 10% of the maximum total costs can be damages for an institution like, Deventer, Gorssel and Overijssel.

B Sensitivity Analysis

Twice during the process sensitivity analysis was performed. Both were carried out by performing a feature scoring analysis. Feature scoring was chosen, as also described in section 2.8, because while still using the SOBOL sampling method, it has lower computational requirements Jaxa-Rozen and Kwakkel, 2018. Figure 2 shows sensitivity analysis was employed to look at the model without any policies in place, and to look at the effect of the uncertainties on the policies. The results from this can be seen in figures 12 - 14 (sensitivity analysis without policies) and figures 15 - 17 (sensitivity analysis with policies) below. Since the costs only regard the costs of implementing policies, all costs for the sensitivity analysis without policies were 0, hence its omission from the graphs. Since the levers for all actors were off, all these levers have an estimator value of 0. The levers for Deventer's dike are not included in their sensitivity analysis, as that is not a lever for them.

We opted to combine the results from the sensitivity analysis per policy, as all experiments proved to be sensitive to the same uncertainties (just to a different extent). Even with RfR-projects in place, A.4_pfail, the durability of Gorssel's dike, and A.5_pfail, the durability of Deventer's dike, are the most dominant uncertainties.

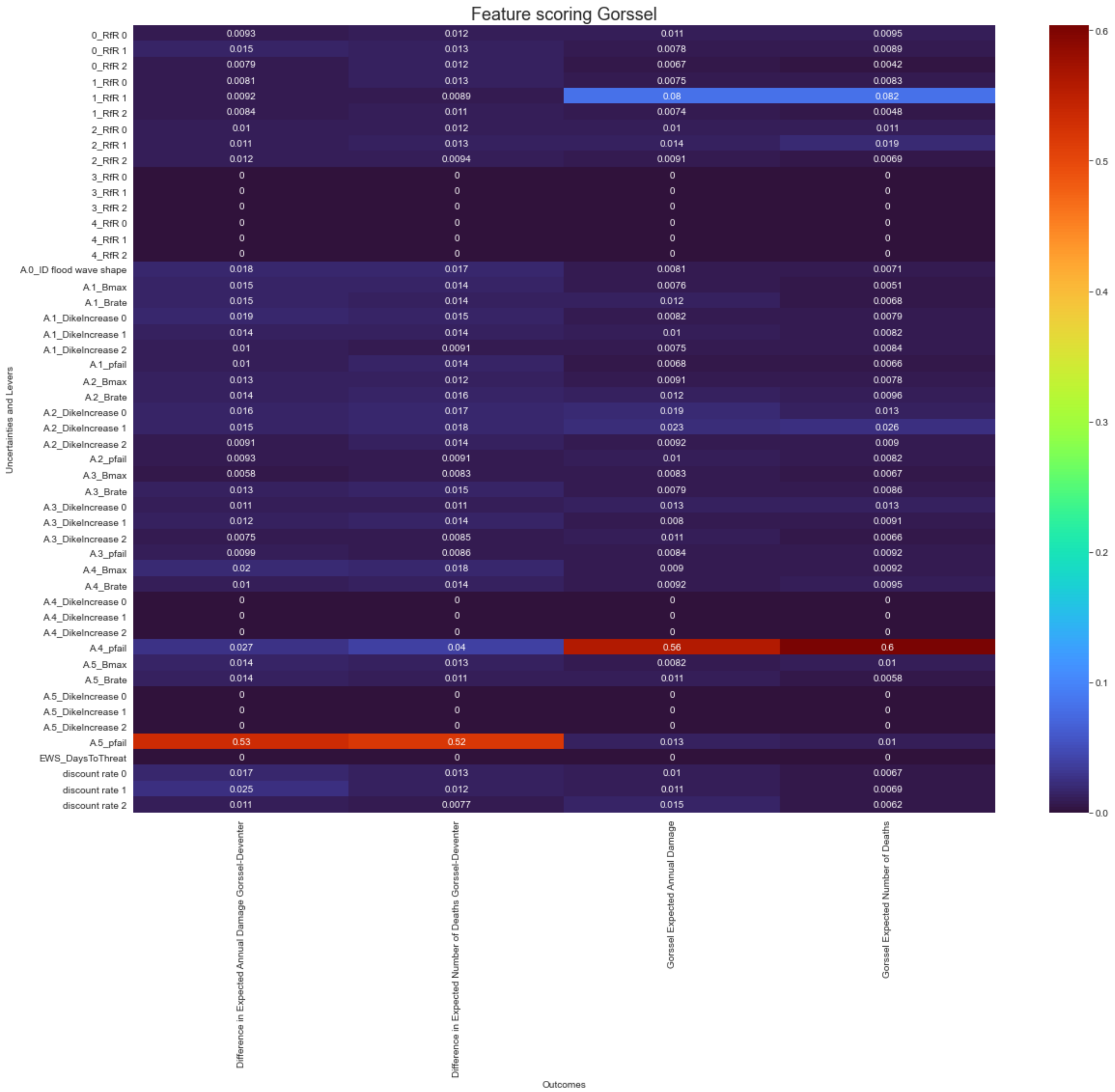

Figure 12: The results from feature scoring for the sensitivity analysis of Gorssel without policies.

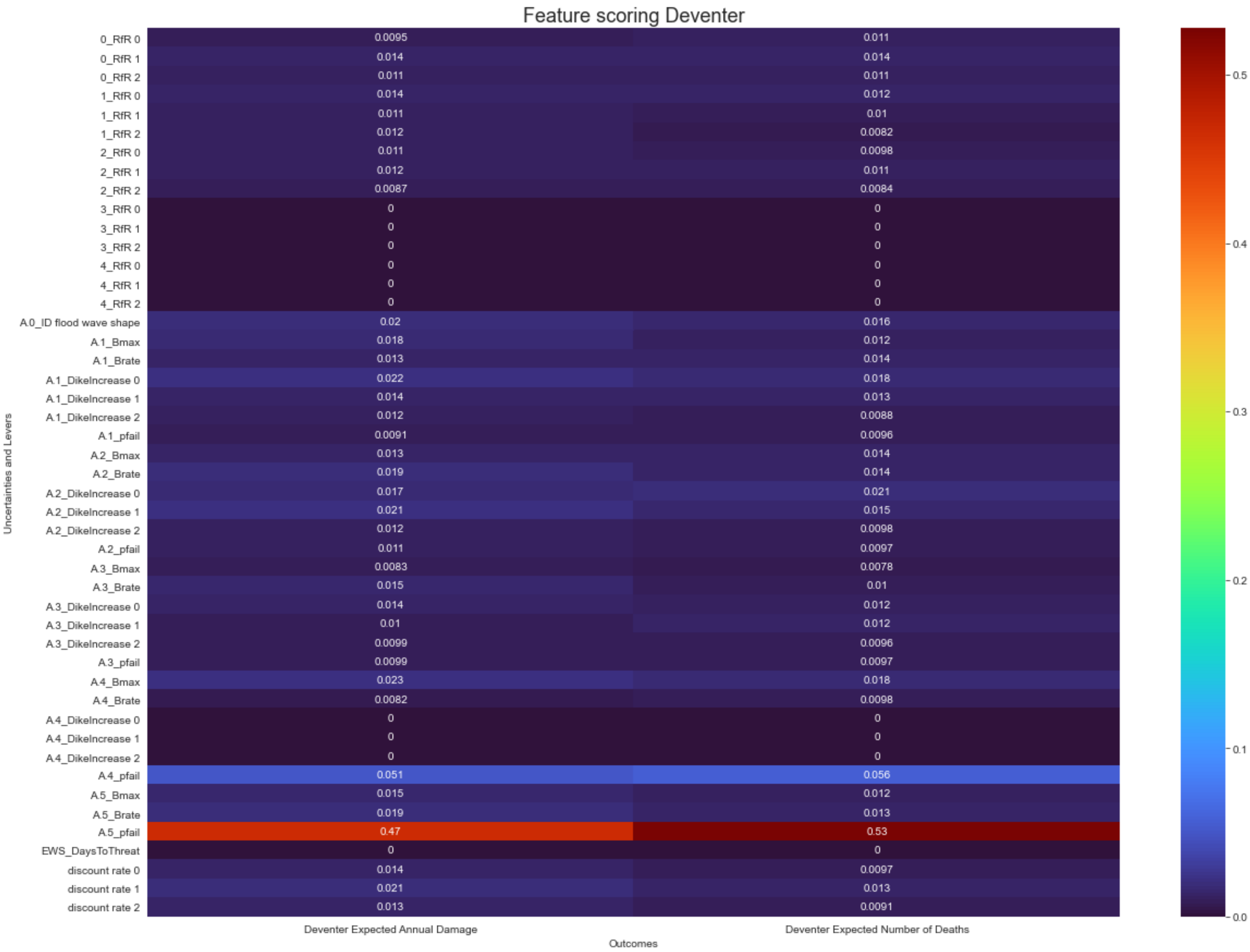

Figure 13: The results from feature scoring for the sensitivity analysis of Deventer without policies.

Figure 14: The results from feature scoring for the sensitivity analysis of Overijssel without policies.

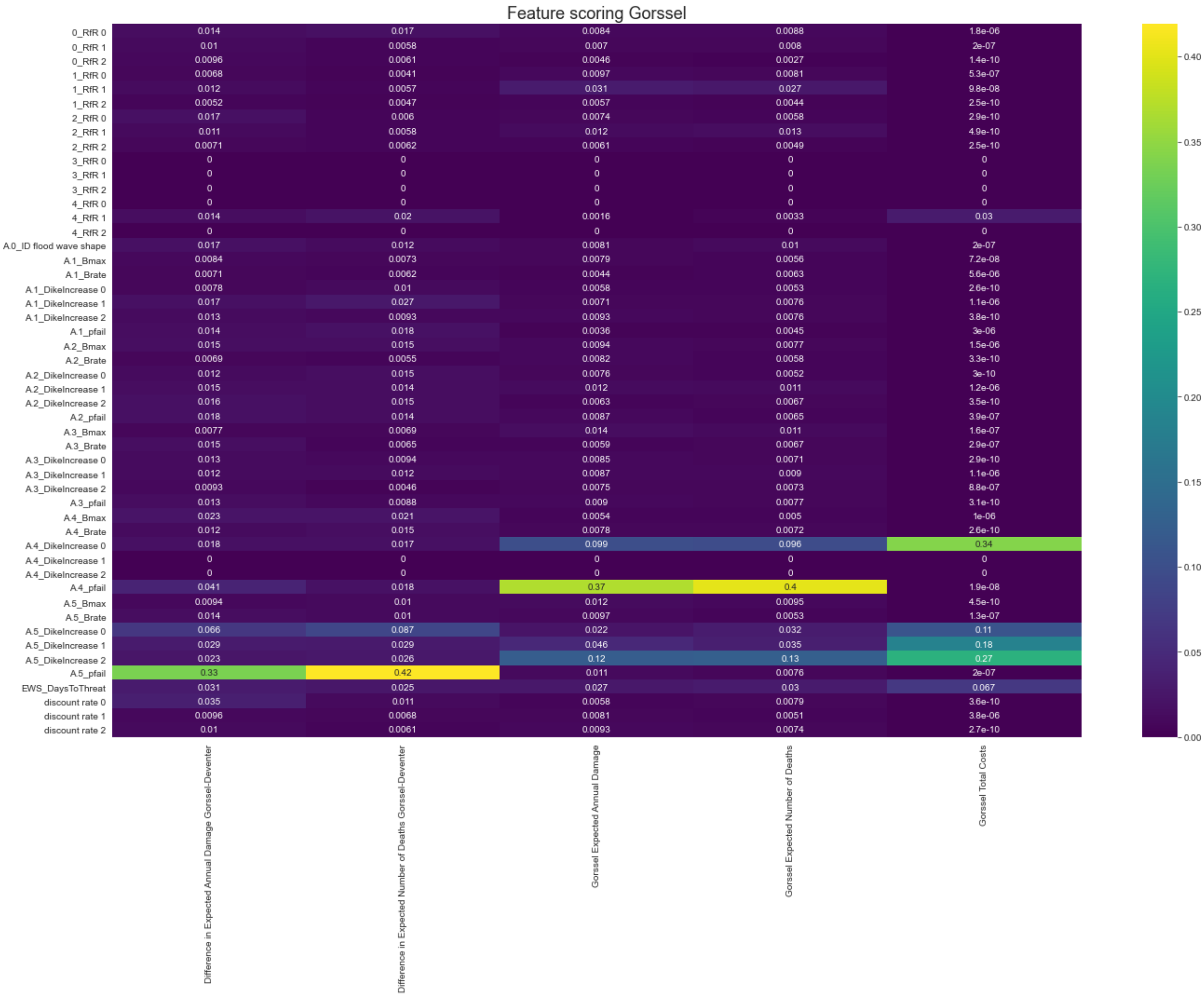

Figure 15: The results from feature scoring for the sensitivity analysis of Gorssel with policies.

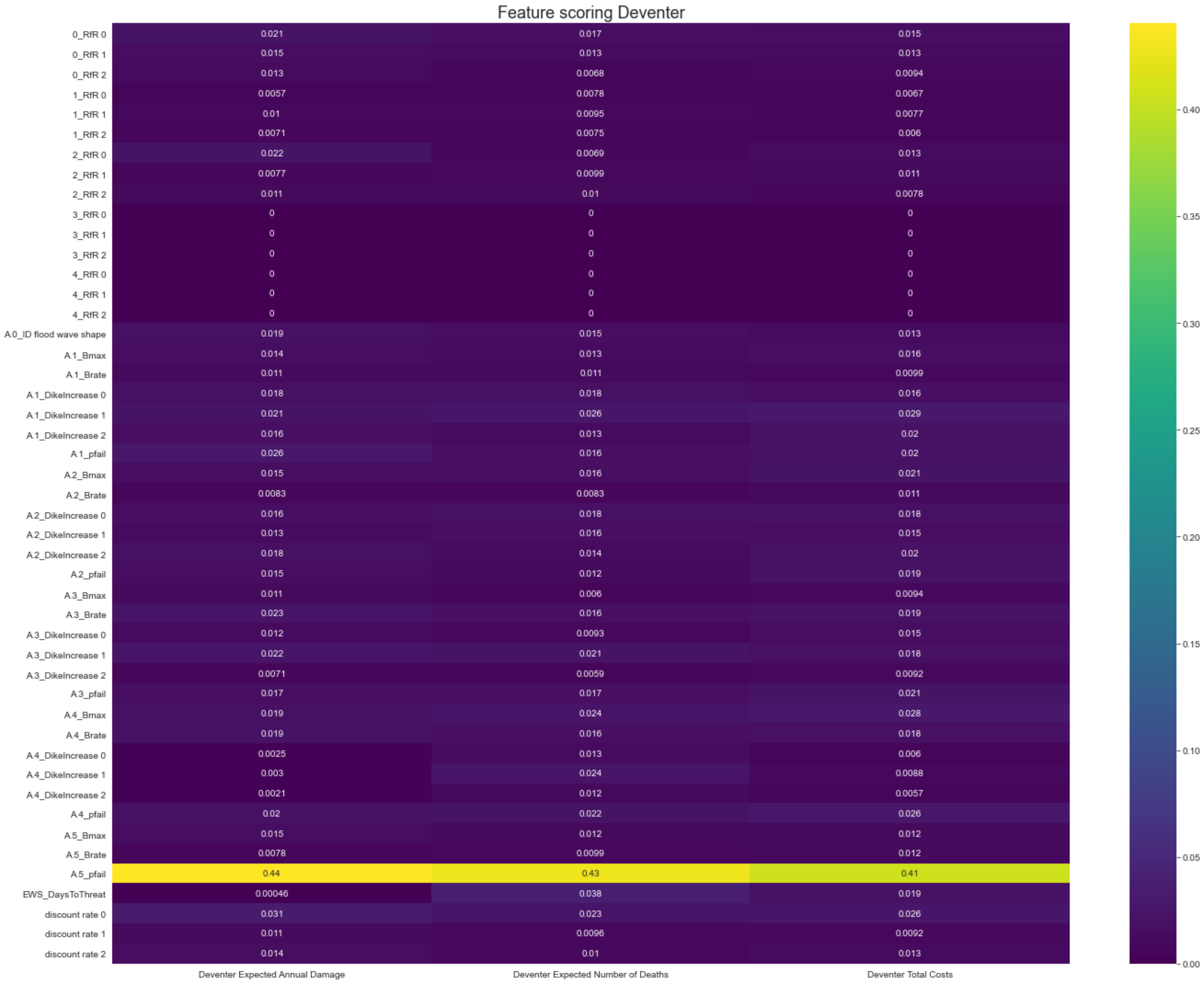

Figure 16: The results from feature scoring for the sensitivity analysis of Deventer with policies.

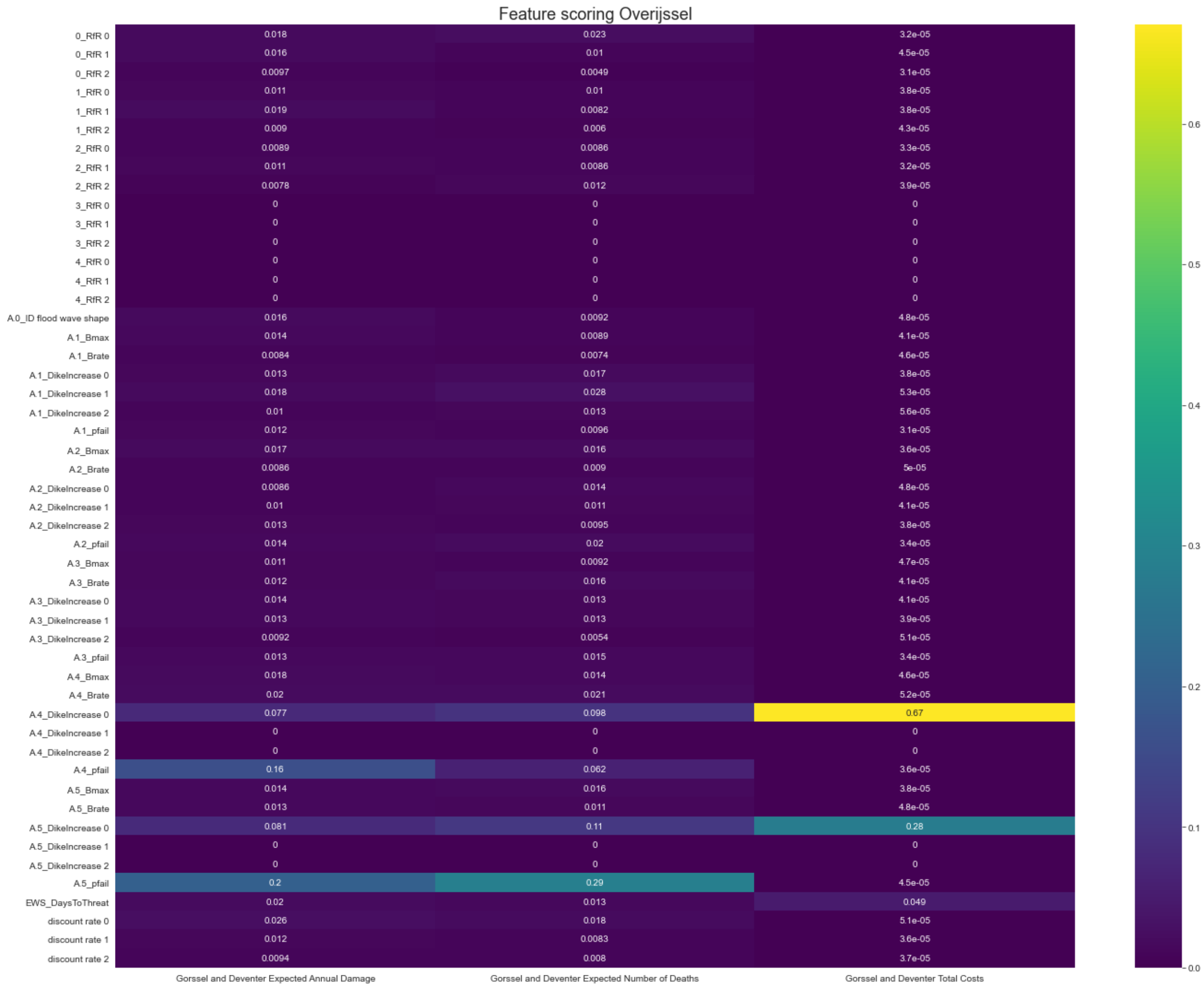

Figure 17: The results from feature scoring for the sensitivity analysis of Overijssel with policies.

C GitHub Repository

Link to the GitHub: https://github.com/Lischip/FabiosDecisions

D Impacts of Alternative Policies

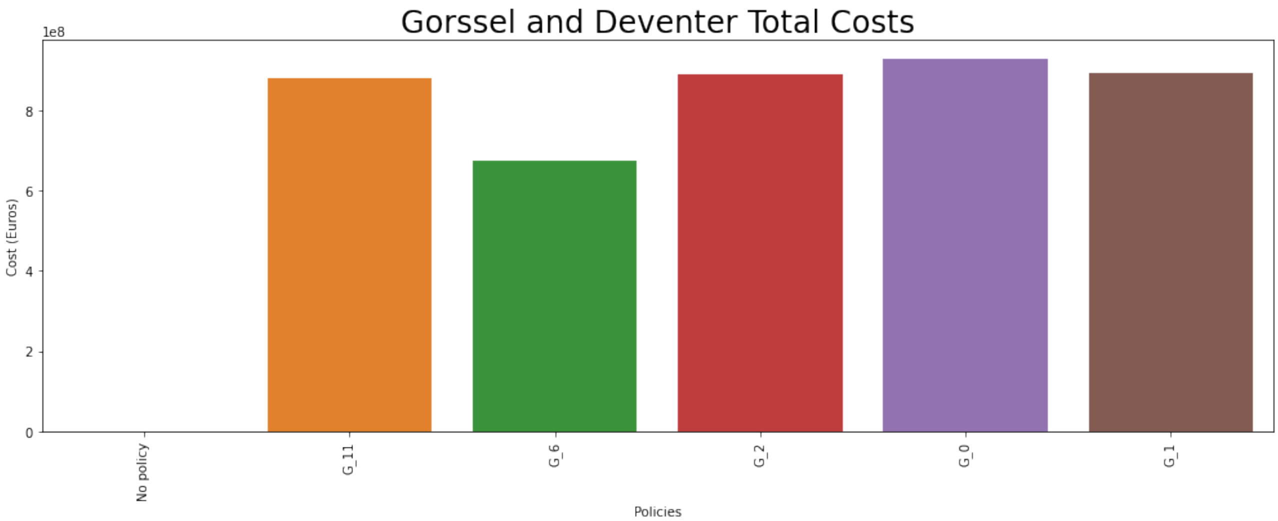

Figure 18: Costs incurred by Overijssel for Deventer's and Overijssel's top five most robust policies.

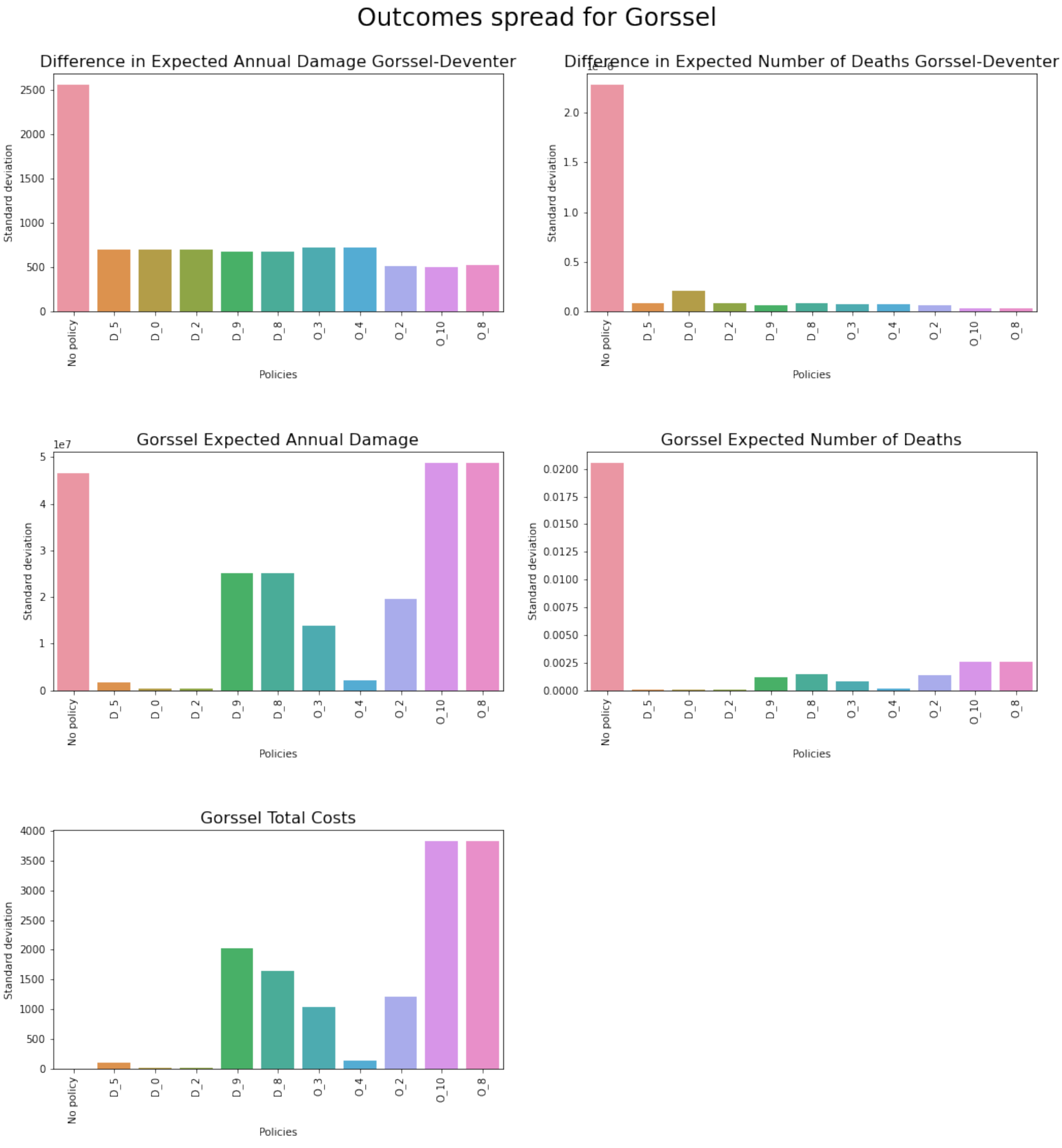

Figure 19: Spread in impacts incurred by Gorssel for Deventer's and Overijssel's top five most robust policies.

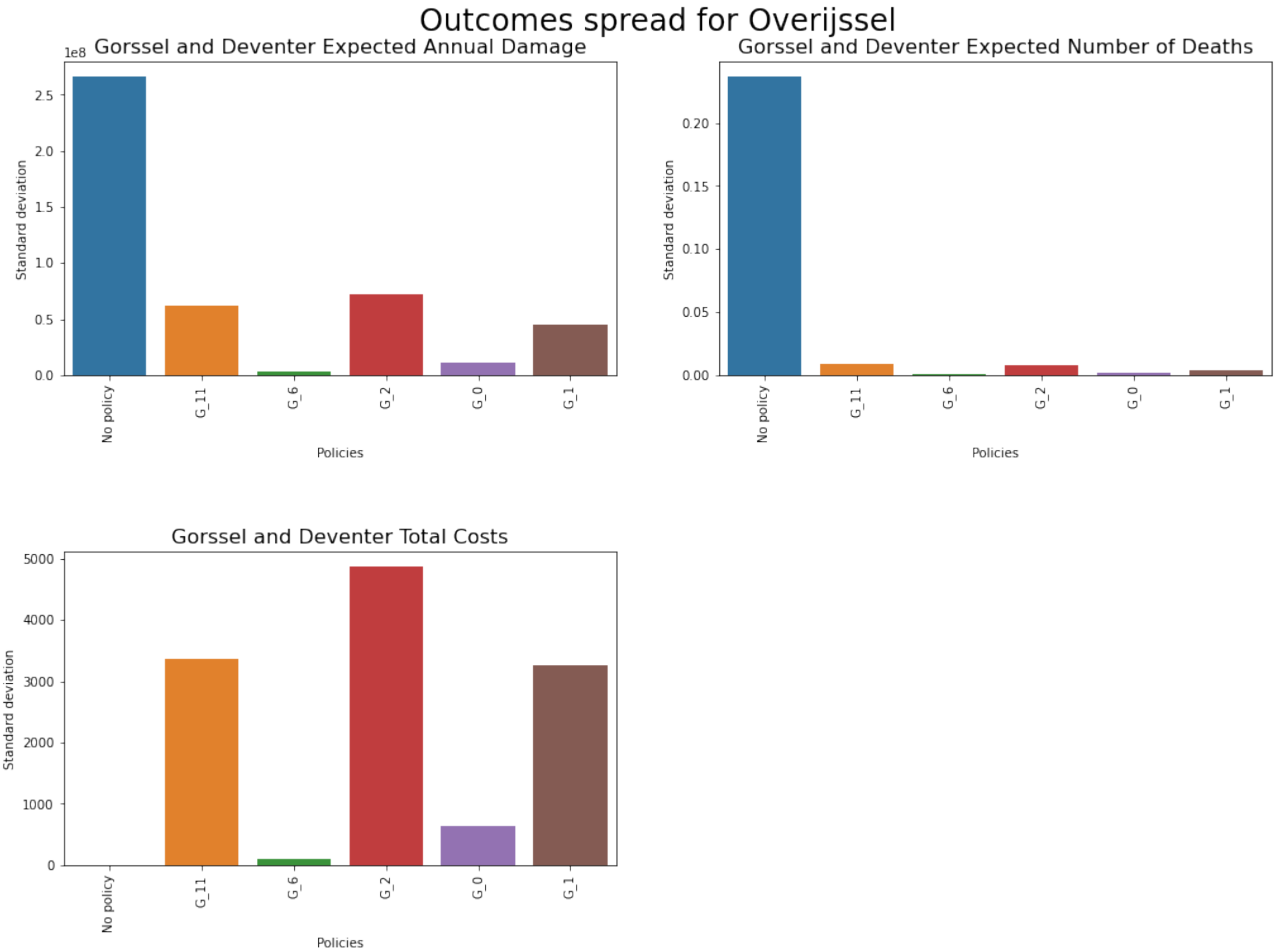

Figure 20: Spread in impacts incurred by Overijssel for Deventer's and Overijssel's top most robust policies.