Room for the river

an analysis of integrated water basin management strategies for the province of Overijsssel in the Netherlands

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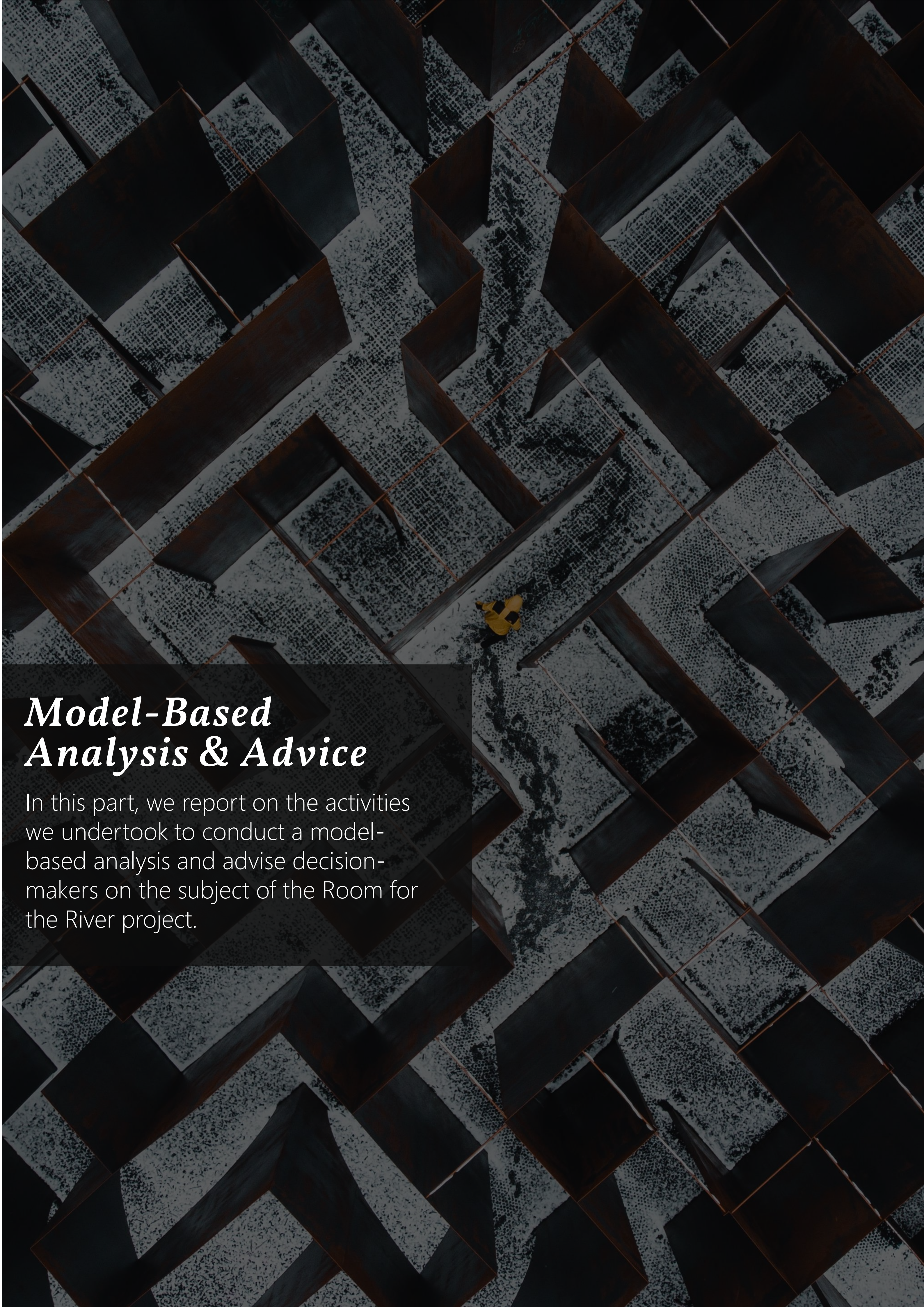


Model-Based Analysis & Advice

In this part, we report on the activities we undertook to conduct a model-based analysis and advise decision-makers on the subject of the Room for the River project.

Summary

Room for the River (RfR) is an approach focused at providing room for the water flow through river-widening activities and it was proposed as part of the Dutch flood protection policy. Extreme river water levels almost caused dike breaches and evacuation of 250,000 people in 1995 and set off alarm bells on politicians, administrators and water professionals that new ways of management of the rivers were required. The RfR programme is characterized by a multi-objective nature, making it necessary to balance policies for different decisionmakers with different goals, perceptions, and values. Such policies should take into consideration safety concerns (such as casualties and property damage), disturbance (in the form of evacuations) and different forms of costs (such as RfR and dike investments costs, evacuation costs and economic loss caused by damages). Decisions made in one part of the river can lead to (positive or negative) impacts in other parts, which also contributes to the complexity of the whole project.

This report addressed the case study of the upper branch of the IJssel River, which aimed at developing a flood risk management plan as scope of EPA1361 - Model-based Decision-making. Our role in the project was to be analysts of the Overijssel province, who are directly responsible for dike rings 4 (situated in the Gorssel village, a mostly rural area) and 5 (located in the urban city of Deventer, which has a population of over 100k people). In our analysis, we framed the problem according to the client's perspective, which had fairness (no winners versus losers outcomes), shared responsibility (every dike ring should share burdens and benefits of final policy), regional wellbeing (protecting the interest of the regions they represent) and safety (ensure safety of the citizens of the province). Based on this, we decided to keep all policy levers (RfR and dike investment decisions and early warning system), as well as all the outcomes but the RfR costs (expected annual damage, expected number of casualties, dike investment and evacuation costs). RfR costs were not included, since they represent investments at the national level and our client didn't voice specific concerns on those.

In order to provide a high-quality analysis to support Overijssel in its decision-making process, we formulated the problem with the following guidelines: **(a)** consider all outcomes mentioned above for both the dike rings 4 and 5 (direct responsibility of our client); **(b)** consider also the outcomes for other dike rings (1, 2 and 3) in order to seek a fair solution; and **(c)** minimize all outcomes for the final policy. The approach chosen for the analysis was to use Multi-Scenario Many-Objective Decision Making (MS-MORDM), with the main reason being its ability to identify robust solutions even in deep uncertain situations such as the RfR project. Robustness was key in our analysis since the decision arena is composed of different actors with different perspectives and objectives. Additionally, the fact that MS-MORDM addresses some drawbacks of MORDM approach (especially with respect to not having a single reference scenario) and being computationally less expensive than Many-Objective Robust Optimization (MORO) also contributed to the choice of this method. To support scenario discovery during the analysis process, we chose to use the Patient Rule Induction Method (PRIM) as our scenario discovery technique, mainly because PRIM is iterative and provides visualizations to support decisions.

From the results obtained in the analysis process, it's visible that there are no policies that guarantee low cost, low amount of deaths and low damage at the same time for all dikes which conflicts with our client, Province of Overijssel's, agenda. Therefore, the results show that there are a lot of robust policy alternatives that present the client with trade-offs to use within the debate and to make a decision over. We observed that in many cases, the main trade-offs were between the cost and safety, and not across provinces. Furthermore, policies that improve safety in Gelderland also resulted in a more benefiting setup for Overijssel.

We argue that these results point out to a large room for collaboration between our client and the province of Gelderland. Furthermore, our findings underline that the analyses conducted using averages do not perform robustly under more uncertain future states. Further research, where more time and computational resources are available to the analysts, can build on our findings.

Problem Framing

Room for the River (RfR) is a novel approach proposed as part of the Dutch flood protection policy (de Bruijn et al., 2015). The approach concerns, as the name suggests, providing room for the water flow through river-widening activities (Zevenbergen et al., 2013). RfR serves two key objectives: improving safety through increased flow capacity and raising spatial quality in the riparian area (Zevenbergen, et al., 2015). The RfR programme, similar to other integrated river basin management projects, is characterized by a multi-objective nature, implying a need for balancing policies for decision-makers (Rijke et al., 2012). These policies should consider, among many other, safety (in the form of minimized casualties and property damage), disturbance (in the form of evacuation) and costs (in the form of RfR and dike investments, evacuation costs and economic loss by damage). Making the project even more challenging, the RfR programme has a split incentive structure, meaning that the costs borne by one region (being infrastructure or relocation expenses) benefit another (de Bruijn et al., 2015).

Geographic and administrative scope of this analysis is the upper branch of the IJssel River delta, as given in Figure 1. This branch goes through two provinces: Overijssel and Gelderland. Both these provinces have been fighting long battle against river floods for centuries (Tol & Langen, 2000). During the infamous evacuation of quarter million people in 1995 due to extreme flood risk (which corresponded to the largest order since the times of war), Overijssel and Gelderland were among three provinces where the evacuation order was given (Dutch News, 2020; Rijke et al., 2012).

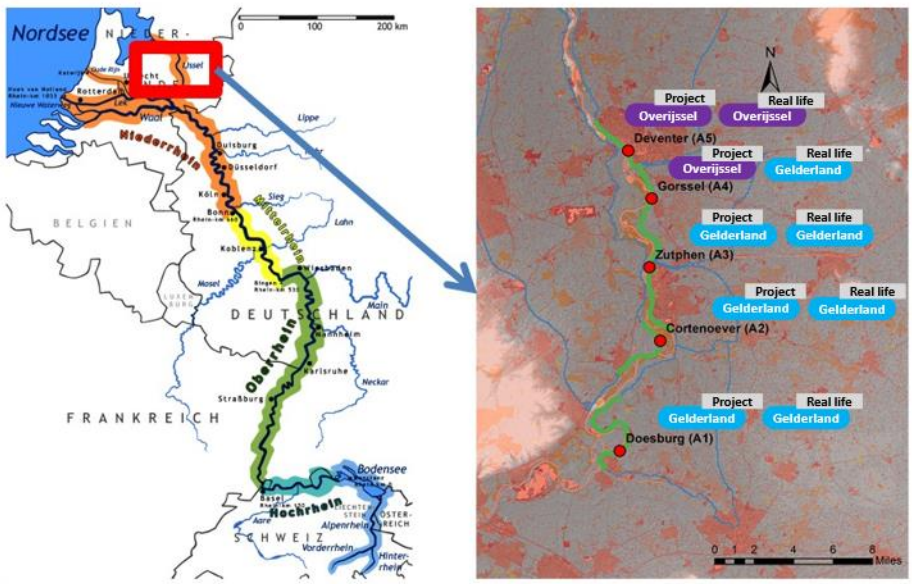


Figure 1 Geographic and administrative scope of the analysis

Our client, Overijssel, located in northeastern Netherlands, is in the downstream of Gelderland. It is home to over 1 million citizens (Statista, 2022). With the Ijssel River, numerous canals, lakes, polders scattered all over, the province has a close relationship with water (Encyclopaedia Britannica, 2011; Holland.com, 2021). It is one of the provinces where implementations of the RfR programme are being considered. It is also affected by any decision to be made in Gelderland, its neighboring province. The province is directly responsible for Deventer (as this municipality is within the borders of Overijssel) and Gorssel (as Overijssel is accountable for the Gorssel dike project).

In our analysis, we framed the problem according to the client's perspective. Since our client sought for a general understanding of the whole problem, we decided to keep all lever options (RfR and dike investment decisions per dike ring per planning step, day to threat call from the early warning system) and almost all the outcomes of interest that the model provides (expected annual damage, expected number of casualties, dike investment and evacuation costs). The only outcome of interest that we excluded from the list was RfR expenses, as these would be a burden of the national authorities and the representatives of Overijssel did not voice any concern about such costs.

Furthermore, following our client's view influenced how the objectives were defined, which in turn determined what "optimal" meant for the policies. From our discussion with the representatives of Overijssel, we identified the following elements as paramount for them:

- ***Fairness***: Our client aimed at reaching a final policy that is fair and does imply winners or losers; every stakeholder should be satisfied with the result. In that sense, they follow a more egalitarian approach rather than a utilitarian one. They wanted to consider the other province in the analysis and wanted to ensure that their policy would be desirable also for them.
- ***Shared responsibility***: They believed that for the greater good of the nation, each dike ring should have part of the benefits and burdens of the final policy.
- ***Regional wellbeing***: In the analysis, they care about protecting each of the dike rings that they are responsible for: their specific interests and concerns should be included in the analysis.
- ***Safety***: The main concern of our client was to ensure safety of the citizens of the province. In this case, this concern underlined the desire to keep the number of deaths low for the whole region, under the threshold of 0.12 deaths per region as it was agreed with the other actors during preliminary debates.

From these points we settled on the following way to formulate the problem:

- The analysis should consider all the outcomes of interest for both the dike rings our client is responsible since both dike rings are equally important. These are the main outcomes that the analysis should investigate.
- Since a fair solution for everybody is important for the client, the outcomes for the other dikes will be considered, but on a more aggregate level.
- The goal of the final policy should be to minimize these outcomes of interest.

Moreover, aiming at keeping the number of objectives at a manageably low level and motivated by the fact our client did not express any particular interest in adaptative policy planning, we aggregated the outcomes over time.

Approach

This section is dedicated to discussing the approach taken for the Room for the River (RfR) project throughout the course. First, a summary of the approach which was chosen, Multi-Scenario Many-Objective Decision Making (MS-MORDM), will be given followed by its description and the justification behind its use. Further down the report, the setting up of the framework, optimization under the reference scenario, re-evaluation of the policy set and scenario discovery and its iterative nature will be touched upon.

A summary of the adopted approach is given in Figure 2. Each step is discussed in more detail in following subsections.

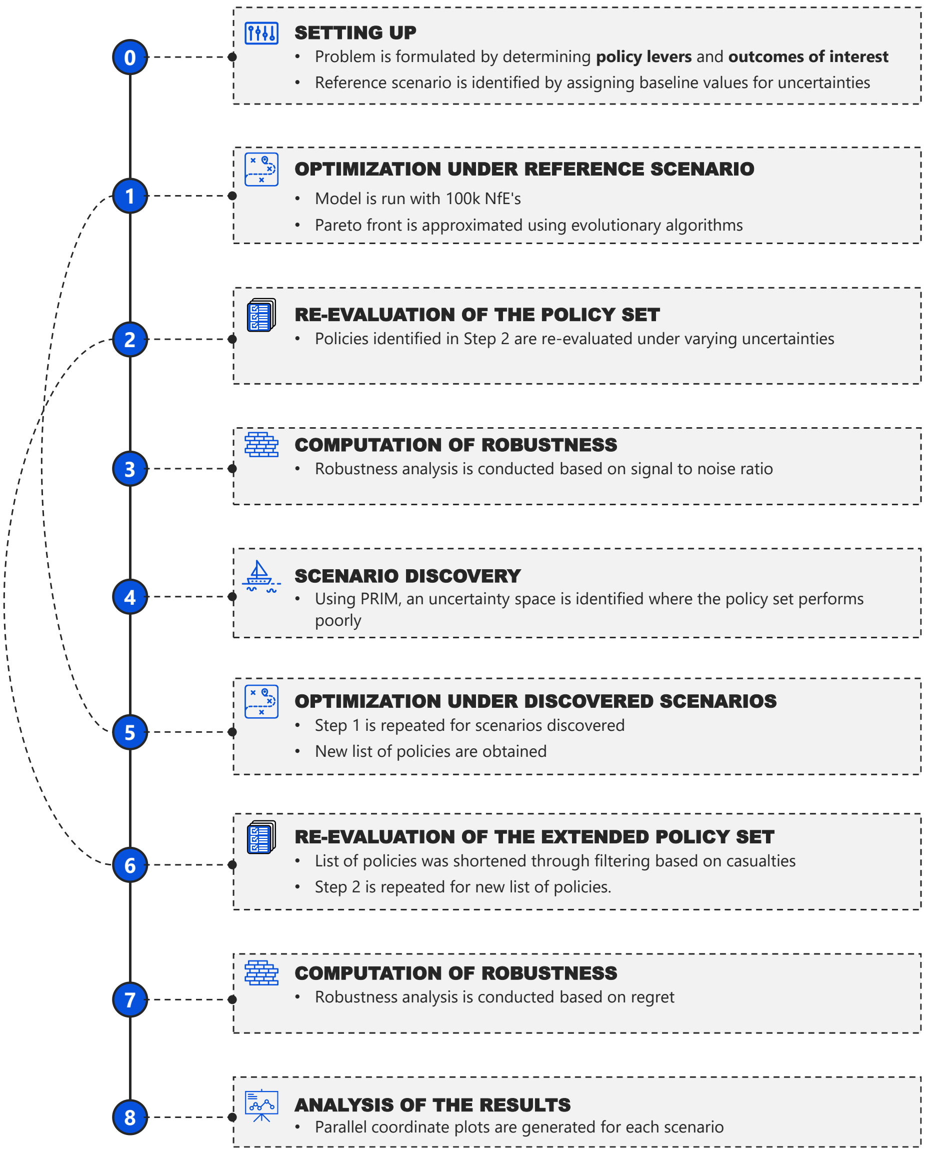


Figure 2 Summary of the approach

After careful consideration, the approach for the project was chosen to be the implementation of MS-MORDM. MS-MORDM is a framework that builds on Robust Decision Making (RDM) which is able to get multiple perspectives and objectives from the actors within the decision arena on a problem According to (Bartholomew & Kwakkel, 2020) MS-MORDM appears to be a good approach to implement in our case. RDM was crucial to incorporate in our analysis due to it providing good utility where there are many deep uncertainties within the problem context. The problem demarcation of the

Room for the River project has made it apperant that the XLRM framework was at play. Each letter of the XLRM represent the following; (X) denotes the uncertainties, (L) for the policy levers, (R) for relationships, and (M) for outcomes. This framework fits the problem as the deep uncertainty was met with policy levers which through casual relationships ensured a certain outcome. However, it was also important that the solutions found were robust under a plethora of significant scenarios and thus justifying the first choice of RDM.

It is important to discuss Many Objective Robust Decision Making (MORDM) Framework as the MS-MORDM is a framework that builds on top of it. MORDM is a framework that consists of four steps. Firstly, the problem formulation, then generating alternatives, uncertainty analysis (where we also utilized robustness analysis) and lastly scenario discovery to show vulnerabilities of the set of solutions. The previous sections touch on the problem formulation step. For the second step, MORDM utilizes many-objective evolutionary algorithms (MOEA) to select a pareto optimal set, also called a pareto front, of policy alternatives as candidate solutions for the generating alternatives step. Then uncertainty analysis, robustness analysis and scenario discovery are initiated which are written more explicitly in the upcoming sections. It is also important to note that the approach utilized, the MS-MORDM framework (and its contemporary, the MORDM framework) is iterative. This iteration is reflected under Figure 2 – the summary of the approach where after scenario discovery the steps are reiterated. Due to time constraints there have been 2 iterations where the analysis of the final results occurred after the second robustness analysis (step 7 - as seen in Figure 2).

The choice of using MS-MORDM specifically is that, although very similar in how they are conducted, MS-MORDM addresses the drawbacks of using MORDM where due to the single refence scenario being utilized, solutions that are optimal in the reference scenario become unlikely to be optimally robust (Bartholomew & Kwakkel, 2020). This makes it so that better robustness considerations are taken in the search phase. Also, due to time constraints and being relatively computationally less expensive, MS-MORDM was selected over Many-Objective Robust Optimization (MORO).

Setting up

As discussed in the previous section, the problem formulation in our analysis is deeply connected with the mandate and perspective of the client. Since Overijssel province aimed at conducting a thorough investigation on alternatives, we refrained from eliminating any levers beforehand and included all options. Unfortunately, due to the limiting factors of **(a)** computational load, **(b)** rapidly growing number of non-dominated policies and **(c)** difficulty in comprehending model outcomes, we could not have the same inclusionary approach when selecting objectives to consider. Again, as it is not our place to make value judgments as computational analysts (Jafino et al., 2021), we based this decision on the mandate and perspective of our client—more specifically, on their values and interests. Table 1 provides an overview of the chosen objectives, aggregation level and motivation for selection as well as for aggregation.

Table 1 Overview of objective selection

Objective	Aggregation level	Motivation for selection and aggregation
(A4) Dike Investment Costs (A5) Dike Investment Costs	Dike ring	Minimize for the clients' dike ring because the local authorities will have a share in the budget required for the dike investment (Jorissen et al., 2016).
(Others) Dike Investment Costs	Multiple dike rings	Minimize for the others since we want fair solutions in the end. Aggregate as we are not the main responsible authority for this group.
(A4) Expected Annual Damage (A5) Expected Annual Damage	Dike ring	Minimize for the clients' dike ring because the province's citizens will suffer from these damages.
(Others) Expected Annual Damage	Multiple dike rings	Minimize for the others since we want fair solutions in the end. Aggregate as we are not the main responsible authority for this group.
(A4) Expected Number of Casualties (A5) Expected Number of Casualties	Dike ring	Minimize for the clients' dike ring because the province's citizens will suffer from these damages.

(Others) Expected Number of Deaths	Multiple dike rings	Minimize for the others since we want fair solutions in the end. Aggregate as we are not the main responsible authority for this group.
Expected Evacuation Costs	All dike rings	Minimize because the province and citizens will be affected by these costs.

To come up with the initial set of optimized policies, a reference scenario was required. It is worth noting that our selected methodology (MS-MORDM) mitigates bias caused by the selection of the reference scenario to some extent. We assumed that the mean values would be a good starting point, as they are less likely to correspond to extreme values that would hinder the trust in the initial optimized set. That's why we opted for the average values of the range. For flood wave shape the value of 5 was an arbitrary choice.

Table 2 Overview of uncertainties and reference values

Uncertainty	Unit	Range	Reference value
Flood wave shape		0-140	5
Dike failure probability (per dike)		0-1	0.5
Final breach width (per dike)	m	30-350	190
Breach width model (per dike)	1/day	(1, 1.5, 10)	1.5
Discount rate		(1.5, 2.5, 3.5, 4.5)	2.5

Optimization under reference scenario (Finding Candidate Solutions)

The search for the candidate solutions necessitated the choice over what MOEA should be utilized. The MOEA used was the E-dominant NSGA2 which is an evolutionary algorithm which introduces non dominated sorting and is known to be used to solve Many-objective optimization problems. This algorithm is based on pareto dominance where certain indicators have different weights, some higher and some lower respectively. (Yun,2021) The candidate solutions have been found by optimizing over all the possible combinations of policy levers that have been pre-determined using 100 thousand number of evaluating functions (nfe's) and an epsilon value of 0.1, to ensure an adequate number of solutions being detected on the pareto front in terms of our important outcomes, namely, number of deaths. A smaller epsilon number (e.g., 0.01) would have resulted in a larger set of solutions, however, there was optimization performed with such value. The policy set -the candidate solutions- then are re-evaluated for uncertainty and robustness.

Re-evaluation of the policy set

After candidate solutions, namely the pareto front, are generated the policy set needs to be met with uncertainty analysis before the computation of robustness. Uncertainty analysis is conducted to expose the candidate solutions to a range of values which represent deep uncertainties. Varying values for these external uncertainties have been utilized to stress test the solutions within the code over 100 experiments.

Computation of robustness

Upon conclusion of these experiments, we computed robustness of the optimized set of policies. For this purpose, we used the signal to noise ratio as the main robustness metric. This metric quantifies robustness by using the mean and the standard deviation of the dataset. If the mean performance of the policy is on the desired level (high for maximization, low for minimization) and the standard deviation is low, the policy is said to be robust.

Scenario discovery

Using the dataset resulting from Step 2 of the analysis, we applied scenario discovery. Scenario discovery concerns steps taken with the aim of identifying a set of future states where the optimized policy set performs poorly (Bryant & Lempert, 2010). In line with this definition, we intended to choose the worst-case scenarios. This was also in accordance with our communication with the client, as they expressed high concerns for the safety of their citizens and desired to be conservative.

We chose the Patient Rule Induction Method (PRIM) as our scenario discovery technique. This choice was motivated by the fact that PRIM is highly interactive and provides visualizations that guide the users (Bryant & Lempert, 2010). The PRIM algorithm identifies a box where the scenarios of interests are densely located. To define "scenarios of interest", we made assumptions on the threshold value of the outcomes of interest. The threshold was found via trial and error, in order to have an adequate amount of data for a meaningful analysis.

Optimization under discovered scenarios

After scenarios were identified, the e-dominant NSGA2-MOEA was used again as MS-MORDM is an iterative process, per identified scenario to include the policies that perform well under these worst-case scenarios. As the initial optimization, 100 thousand nfe's and an epsilon value of 0.1 was used.

Re-evaluation of the extended policy set

Our extended policy set resulting from the previous step was fairly long. We filtered these policies to ensure that they stay within communicable and comparable terms. As the main concern of our client was safety and the objective that they put more emphasis on was casualties, our filtering strategy was based on this objective. Firstly, we removed the policies in which the expected number of deaths had a value bigger than 0.01 (not only for dikes 4 and 5 which were our client's main concern but also for the rest of the dikes). Since the number of policies was still high, we decided to re-filter them. We filtered the policies that were "performing successfully". Our criteria for "successful performance" were to be within 25th percentile of the whole policy set. The percentile value was selected based on trial and error, considering the number of desired policies that are to be left.

Computation of robustness

This time the Robustness Analysis has been performed through measuring regret. According to McPhail et al. (2018) regret-based metrics are one of the robustness metrics that are used to measure system performance under deep uncertainty. Regret is defined as the discrepancy between the performance of the selected option and the performance of the best possible option. This is coded into our analysis through utilizing data frames to find the regret for each policy in each scenario by comparing it to the best performing policy alternative per scenario. Thus, then the regret-based metrics are found to analyze the robustness of the policy alternatives.

Analysis of the results

For the Analysis of the results, we utilized parallel coordinate plots to visualize the results and then analyzed them accordingly about how they perform. We discuss these results in more detail in the following chapter.

Results

In this section we present the results of our analysis:

Optimization under reference scenario

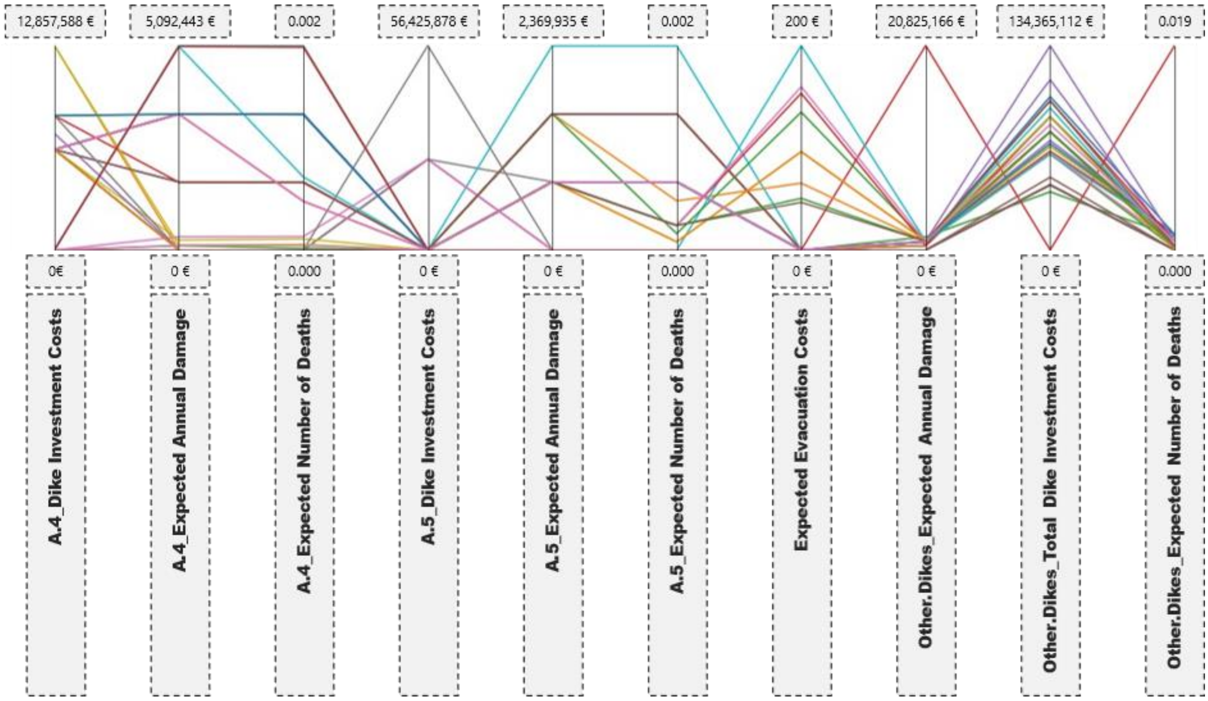


Figure 3 Results from first optimization

The results of the first optimization can be found in Figure 3. From this picture we can draw the main conclusion that trade-offs are needed to be made when choosing a policy because there is no policy that guarantees low cost and low damage at the same time. Additionally, there are policies where we have low-cost, high damage and high deaths, which is reasonable. And also, the opposite case is reasonable and can be found: e.g., the grey and dark orange policies prioritize safety (meaning low levels of deaths) but which also result in higher costs. While this pattern is clear for the other dikes, this is not the case for the dikes in our interest (namely 4th and 5th dike). Indeed, for our dikes, if we look at the deaths, for some policies there is the trade-off one would expect (lower deaths but higher cost – e.g., grey policy), but there are also policies where there is an unexpected trade-off (lower deaths and lower cost).

One possible reason for that is the fact that we have many objectives, which probably conflict with each other and cause different Pareto optimum points. These are unexpected results in these policies and imply that further steps are needed to draw more certain conclusions. But we should also keep in mind that while we say that we have 'higher' deaths with some policies, the actual numbers still seem to be very low.

Re-evaluation of the policy set & Computation of robustness

When analyzing the results of the re-evaluation of the policy set, we get a picture that seems to go against the previous results. In Figure 4, where all the robustness of all outcomes is plotted, we see clearly patterns in our dike rings, but no unique conclusion can be drawn for the other dike rings. Our conclusion about trade-offs is confirmed: it is realized that there is no avoiding tradeoffs in dikes primary for our analysis, 4 and 5. The trade-offs come mainly from low costs corresponding with higher damages incurred.

If we focus only on the trade-offs that are more of interest to our analysis, the death rates, in Figure 5, we see that although there are a few policies where we can have low numbers of deaths, for most of them we cannot achieve low numbers. It seems that our client can't find policies that are optimal for what they care. It can be due to the fact that in our problem formulation we are considering many objectives that are in conflict with one another, as the pictures are telling us.

There must be further research done to ensure a more desirable optimal solution to be found that is line with our client's core values. So far, the lack of such policies could also be due to a reference scenario in our model being a random one, not very meaningful to the situation. Also, as our main concern is safety, it is justified that we want to keep looking for scenarios by utilizing a conservative approach and to look for the worst-case scenario.

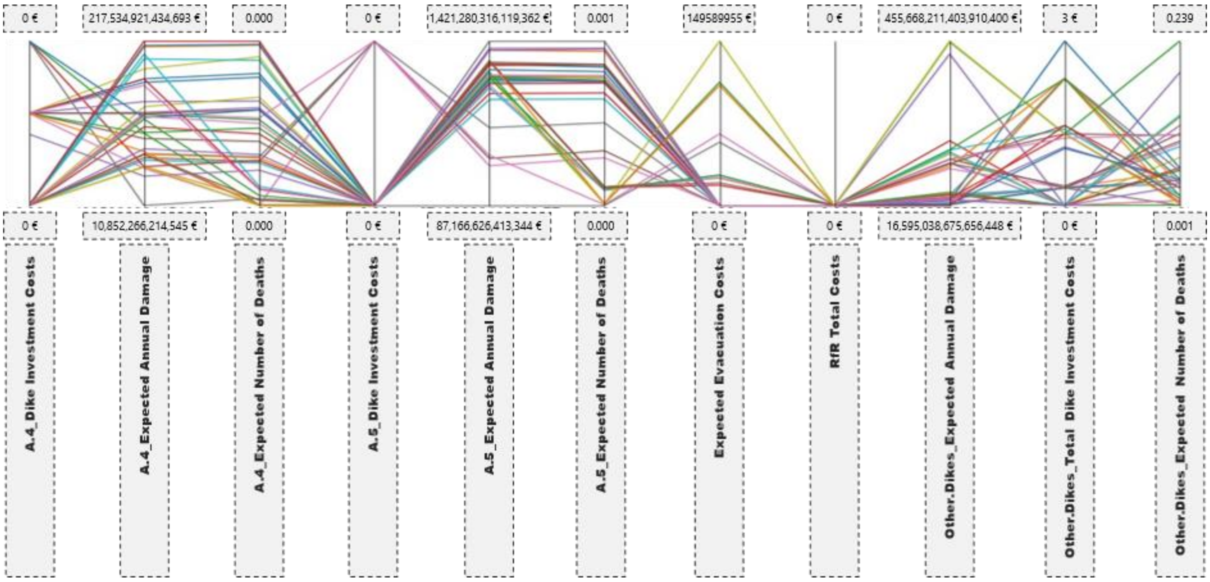


Figure 4 Robustness of First Set Of Policies

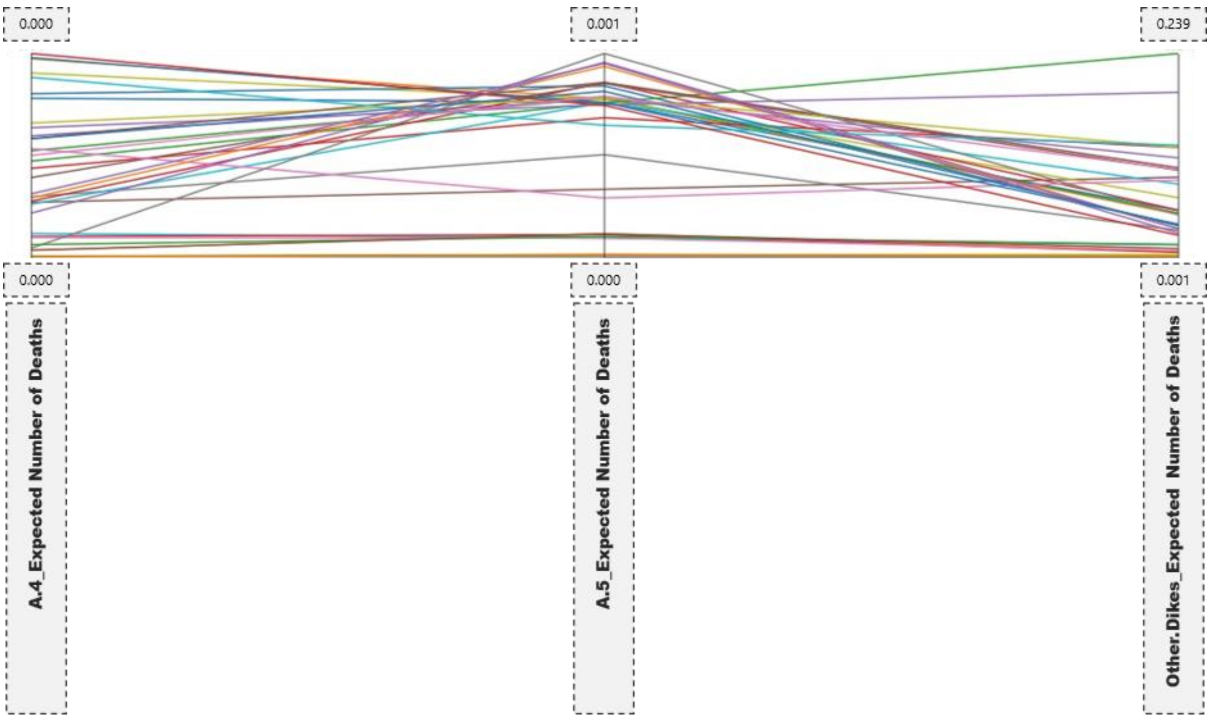
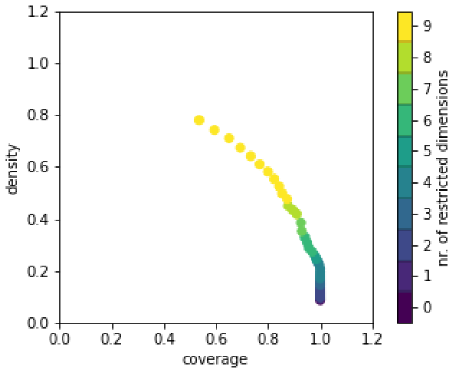


Figure 5 Robustness of First Set of Policies, only Safety Outcomes



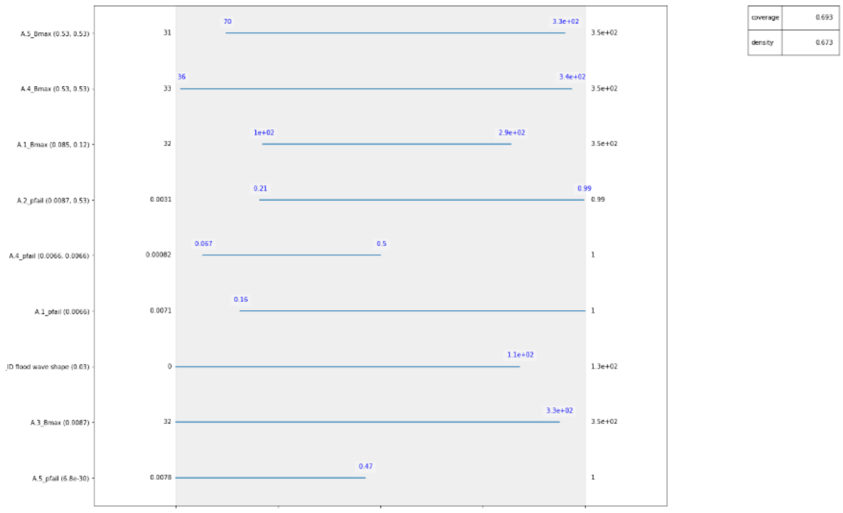


Figure 6 PRIM Algorithm *C*overage vs Density Graph

Figure 7 Characteristics of the Chosen Box (36) from the PRIM Algorithm

Scenario discovery

Figures 6 and 7 above depict the results of the scenario discovery. Under the coverage vs density graph that is depicted in figure 6, the trade-offs make it noticeable that when we try to optimize for one of them, the other one shall be reduced. The chosen box (36) has a density of 67% and a coverage of 69%. This was considered to be a good trade-off since off them being relatively high.

Due to utilizing a conservative approach, from this analysis we keep the worst-case scenarios that have maximum deaths in all dikes and not only the dikes in our primary concern (dikes 4 and 5 respectively). This can be justified thanks to the “shared responsibility” value that our client holds as mentioned in the Problem Framing section.

Re-evaluation of the extended policy set & Computation of robustness

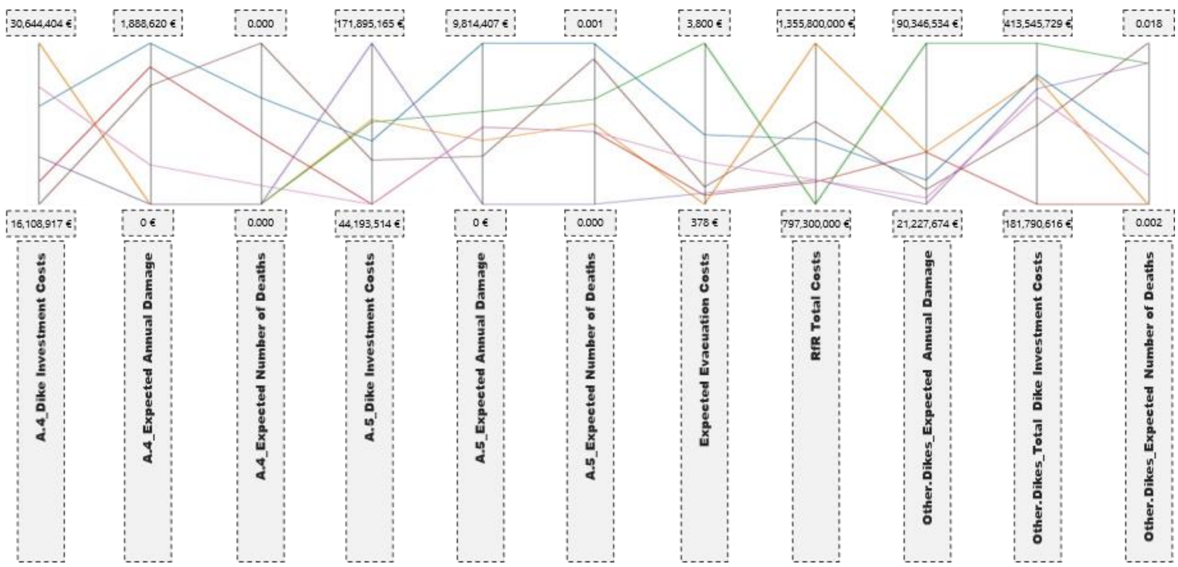


Figure 8 *Robustness of Selected Policies from the Second Policy Set*

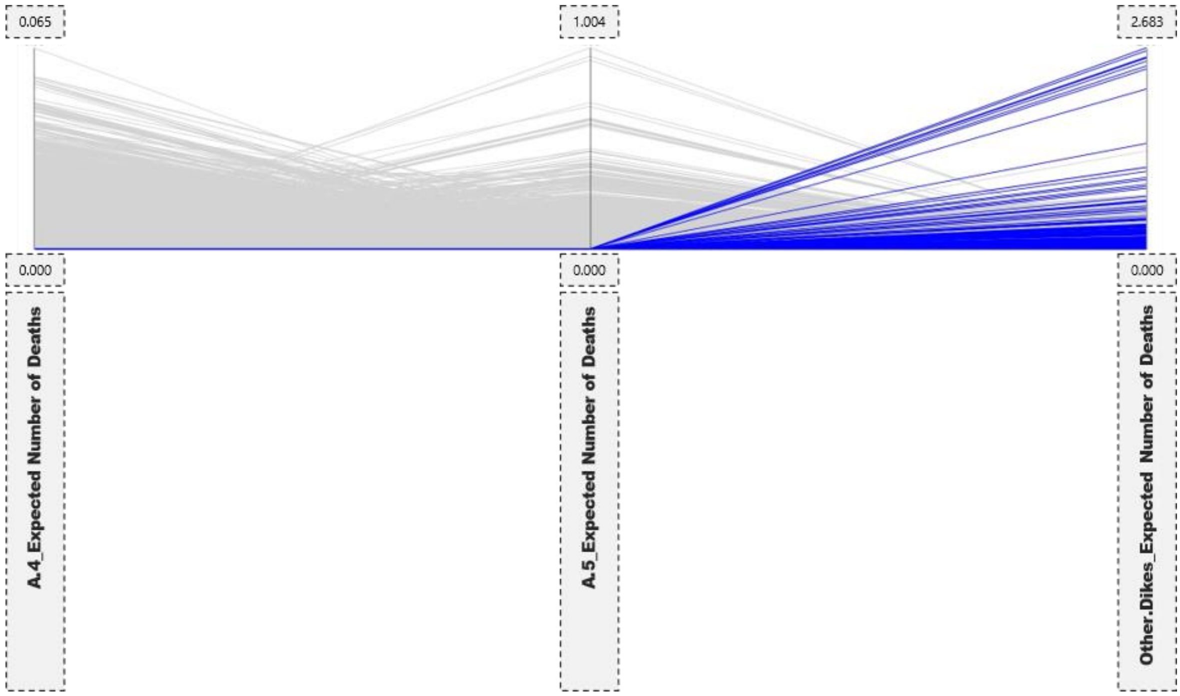


Figure 9 Performance of Second Policy Set, only Safety Outcomes

Again, the analysis of the robustness of the new policy set (obtained by optimizing for the worst-case scenarios found thanks to Prim) shows that trade-offs among conflicting outcomes need to be made. This can be seen in Figure 8 where we plot the robustness of the policies that score the lowest in terms of deaths for the dike rings. We can see no clear overall pattern and there are policies where still lower costs can be achieved because higher deaths numbers are allowed.

If only focus on the death outcomes because our client stressed their interest in safety, we can't seem to find a policy that scores the best for the death numbers in all the dikes. This can be seen in Figure 9. In blue we highlight the policies that score the best for the dike rings our client oversees but this is apparently achieved at the cost of higher deaths for the other dikes. This complicates relations with other stakeholders because the other province cares for the safety for its citizens.

In conclusion, there is no clear pattern in this optimization process, so it means that it is up to the decision maker to choose the trade-offs they want. They must be aware that these trade-offs may conflict with other stakeholders' interests. The analysis doesn't show a clear direction to follow.

A way we can suggest choosing a final policy for our client is based on our client's mandate: they want 'equal distribution' of burdens and benefits. The policy could be the one that shows the lowest standard deviation among the death numbers for the dike rings. In this way, despite the fact that dikes 4 and 5 are our client's interest, the concerns of the other province are also considered. This can facilitate negotiations.

Discussion

Limitations

A large portion of the limitations that our analysis is subject to are due to time and computational constraints. There are points of improvements that can be realized in future research, given that more time and more computational power are available to the analyst group.

We enlist these limitations as follows:

- **General limitations**:
  - *Treating the model more as black box* cost a considerable amount of time (especially at the beginning), which could have been invested in deepening our knowledge of the model and working on fixing the other limitations.
  - Our analysis could utilize more *iterations* as prescribed by the literature that constitues the MS-MORDM approach such as (Bartholomew & Kwakkel, 2020).
- **Problem framing**:
  - Investigating a *larger number of problem formulations* could enhance insights gained:
    - A more strategic-level problem formulation could be utilized, where all the other stakeholders' interests are included and optimized. That way, we could increase the chance of optimized policies being accepted by everybody and therefore pursued.
  - *Number of objectives* was bounded by what e-dominant NSGA2-MOEA could handle. Therefore, we had to filter and/or aggregate number of objectives. As to not impose our value judgments while filtering and/or aggregating, we communicated with our client whenever possible.
  - We *aggregated the outcomes of interest over time*. This meant that for each objective, we assumed that the periods when the policy was performing well compensates completely for the periods where it failed.
- **Optimization under reference scenario**:
  - For the *reference scenario*, we used the mean values and chose the flood wave shape randomly. A better strategy to build a reference scenario would be in discussion with the experts of the field, and after preliminary exploration of the system.
  - To increase the quality, accuracy and reproducibility of our analysis, we could have conducted more research into
    - the *nfe values* (by conducting convergence analyses)
    - the *epsilon values* (by testing with different values)
    - *multiple reference scenarios*
    - the *seed analysis* (by setting up and changing the seed)
- **Re-evaluation of the policies & calculation of robustness**:
  - We could have used *more scenarios* as to have a deeper understanding of the performance of our policies under uncertainty.
- **Scenario discovery**:
  - The *threshold value* was found via trial and error based on desired number of policies identified. It is likely that the threshold value generated through this approach does not reflect real priorities and requirements. Again, expert know-how and further clarification on stakeholder values would be useful in selecting more meaningful threshold values.
    - Our initial idea for the threshold value was to select policies based on *0.12 threshold for deaths* for each dike ring, which was the benchmark agreed during debates. This approach did not provide us with enough specification as all optimized policies already met this requirement.
  - The choice of the box was guided by making trade-offs without double-checking our assumptions. Instead of making such assumptions, we could have broadened the scope of the project and *kept all boxes that were interesting*. We could have carried out the analysis with all these boxes and then compared the results.

    - PRIM can sometimes lead to some *errors regarding statistical significance* of the uncertain parameters, so we should have used diagnostic tools to evaluate the algorithms' results (Bryant & Lempert, 2010). Those tools could be (1) quasi-p value tool (which uses p-value testing to estimate the likelihood that PRIM constrains some parameter purely by chance) and (2) resampling test (which evaluates a scenario definition by assessing how frequently the same definition arises from different samples of the same database).
- **Optimization under multiple scenarios**:
    - Similar with the optimization under the reference scenario, a deeper look into the *nfe, epsilon parameters and seed* was required.
- **Re-evaluation of the policies & calculation of robustness**:
    - Similar with the initial re-evaluation and calculation of robustness, *more scenarios* could be used.
    - Likely due to the selection of epsilon, we ended up with a large number of policies which had to be filtered. We did this filtering by trial and error. Nonetheless, we still considered our clients' main concerns and values while doing so.

We would like to emphasize that despite these limitations, we tried to be consistent throughout the whole analysis with our choices (e.g., since we used 100 scenarios in the first evaluation, we used 100 scenarios for the second one as well), with which we aimed at making our results more comparable.

Future research suggestions

There are several suggestions to improve the analysis of flood risk management:

- As there are a lot of scenarios and objectives to be included in the model, greater computational power and time available to run the model will enable broader implementation on the actual system. This also includes more optimization for contextualized objective, even could also include metrics which seem not relevant at first but makes the model closer to the reality of the system. In addition to the technical capabilities, a longer timeframe will help to explore different techniques and more testing to improve the model accuracy.
- As occurred during the debates, all the actors were much more focusing on the number of death as the sole identifier for a failure in the flood management system. Thus, excluding the financial obligation to repair the damage of floods such as building repair costs, business loss and environmental reclamation. By including these other financial losses, there will be many more scenarios to be explored to find better solutions.
- There is an uncertainty of the flood wave shape which is not analyzed further in the model. As it was not included in the model, there is no conclusion whether this could lead to a worse flood and implicate on the policy outcomes in such a way. Thus, implementing this uncertainty into the model will also help to acquire more knowledge for the optimal policy options.
- Future research can greatly benefit from a closer collaboration with stakeholders and domain experts. Although we refrained from making value judgments as the analyst group as much as we could, we still incorporated our understanding and interpretation of the system functions and stakeholder values. Improvements in the applicability of our work could be achieved through a more interdisciplinary research pipeline where qualitative analysis supports the quantitative work to a greater extent.
- Other way to define robustness could be utilized such as expected value metrics, metrics of higher-order moments (variance and skewness) or threshold based satisficng metrics to study the effects on outcomes and recommended policy levers (McPhail et al. 2018). Thus, it will conclude a better result than utilizing signal-to-noise and regret-based measures for robustness criteria.

Conclusions

After reviewing the result and considering limitations of the contextualized model analysis, there are several critical points to be disclosed. First, it is clear that no matter which policy our client chooses, trade-offs will always need to be faced, as there is no policy that has the best performance for every considered outcome. For instance, even from the first optimization it is obvious that there are policies, which result in lower death numbers (our client's main objective) but come with greater costs. Also, although there are a few policies with low death numbers, these numbers are still not so low. That could be justified by the fact that, apart from the dikes on their interests, our client is considering also the dikes in the other provinces. As analysts, we advise our clients to be aware of these trade-offs and keep on mind that in case they opt for the lowest death numbers their objectives should be modified. If we want to achieve highest level of safety in their dike rings this will be in conflict with other stakeholders' interests. Caring for the other stakeholders' interests should be pursued during further analysis and negotiating sessions if the client wants to achieve shared responsibility among all the actors.

Another interesting observation was that policies that were generated using the reference scenario, where external factors were in their average value, did not perform well under more uncertain future states. They resulted in unacceptably high levels of annual damage for every dike ring. This observation again underlines that decision making should not rely on the averages, but uncertainty should be incorporated deeply into the analysis.

Furthermore, we observed that the decisions made on the upstream of the river also benefit our client, and the expected number of casualties for Overijssel province is in most cases lower compared to its neighboring province. As the main trade-offs we observed were between costs and safety, and not across dike rings, we argue that this create a ground for cooperation. Collaborating with Gelderland Province, who share similar interests and bear similar financial burdens, will help increasing Overijssel's status-quo in the political debate arena yet still moving along with the proposed solution by Rijkwaterstaat. With the high population and financial burdens from these two provinces, their concern about the quantified flood damage could be clarified and having a strong substantial proof.

Political Reflection

In this part, we summarize our reflection on the events that took place in the political arena.

Introduction

Decision-making over big projects with large amounts of budgets spared for them are seldom easy to navigate. The decision arena, consisting of a plethora of actors with their own understandings of the problem, interests, values, and objectives ensure that the analyst must be aware and, as such, provide valuable input which will be used in a most appropriate manner. It is observed that the complexity being mentioned within the decision arena is caused by mainly two dimensions: high level of uncertainty and increasing number of stakeholders (Schut et al.,2010). Although general concepts, these directly relate to any type of wicked problem studied such as the project that is undertaken for the course EPA1361.

The project undertaken under the course Model Based Decision Making (MBDM) is about the "Room for the River"(RfR) project over the Ijssel River, where the RfR relates to an integrated water basin management, creating a mixed centralized-decentralized governance approach that "*aligns multiple objectives in a river basin across different spatial scales and temporal dimensions*." (Rijke et al. 2012, p. 371). The main reason behind the RfR project was that extreme river water levels almost caused dike breaches and evacuation of 250,000 people in 1995 (Rijke et al. 2012), leading the general public, politicians, administrators and water professionals to conclude that the nature cannot be controlled and new ways of management of the rivers were required. High water episodes in 1993 and 1995 have created the policy window where the three streams (problem, policy, and political streams) met and generated the opportunity for extensive dike improvement works (Enserink et al., 2010). The policy window that has been created at the time thus have been filled with the RfR framework which created a new way of integrated water basin management that is comprised of smart solutions such as lowering of floodplains, removal of obstacles, dike relocation, among other measures.

The actors within the context of the course EPA1361 project are the Rijkswaterstraat, Delta Commission, an Environmental Interest Group, a Transport Company, and the Overijssel and Gelderland Provinces. The rest of the actors were analysts, where our team was among them as the analysts of the Overijssel Province. Among the stated actors Gelderland, Overijssel Provinces and the Rijkswaterstraat are the critical actors who have direct control of the Dike rings situated under them. Rijkswaterstraat, being an entity that trespasses the provincial borders in the Netherlands and having the overall control over the water policies in the Netherlands, is also the actor who will create a policy plan after reaching consensus on critical values of the involved actors. The EPA1361 RfR project also has some interesting nuances, such as the fact that dike ring 4 (situated in the Gorssel village) is under responsibility of Overijssel, whereas, in reality, Gorssel belongs to the Gelderland province. Project specificities such as these have created certain confusions among the actors involved, which will be discussed further in following sections.

Certain actual conflicts and dilemmas from real-world for this framework were the involvement of many actors, disagreement about the nature of the problem, complex decision making which is unsuitable for standard operation procedures, and the blurring boundaries between research and politics. A specific example from real-world is that the Ministry of Transport (denoted as Transport Companies within the scope of EPA1361) has ridiculed the scientific research that conflicted with the Room for the River policy even though they were adamant that such research were critical for decision making. They noted that the scientific research that were not in their agenda as "*emotions [not scientific data] presented by activists [non-objective scientists] who were subjective in their analysis and conclusions*" (Schut et al. 2010, p. 620) showing that research was discarded if it conflicted with an actor's agenda.

The way interactions took place on EPA1361 RfR project among the relevant actors can be well explained based on the rounds model. As Enserink et al. (2010) notes, decision-making takes place in rounds and arenas, not necessarily following chronological phases. Moreover, actors and activities involved in each round might differ significantly, with some rounds more focused on exploring a problem, while others focused on designing solutions. Still according to Enserink et al. (2010), a round ends with a 'crucial decision' being made (which can also be to not make a decision) and influences possible following rounds. The round model is seen to be prevalent throughout the course structure as the debate structure was made into stages which also incorporated rounds of negotiations and alliance building. A generic structure can be seen as some initial rounds focused on joint fact finding and negotiations (in which analyst teams were sometimes also present), followed by the first debate (in which three separate loosely structured debates took place). After that, additional rounds of joint fact finding and negotiations took place and everything culminated in the final policy debate in order to reach a decision.

Tensions and Challenges

During the whole Room for the River project for EPA1361, many challenging and tense situations were faced. Initially, understanding our own role was challenging, given the broad scope of our mandate as analysts for our client (the Overijssel province). Based on Mayer et al. (2012) hexagon model of policy activities, it was possible to frame our approach in multiple ways. One way could be as *advising strategically* our client on what would be the best strategy to achieve their goals, given the stakeholder arena and problem demarcation. A second approach could have been to focus on *researching and analysing* the model and additional literature, trying to enhance the data used as inputs to the model, as well as the validity of its outputs and the uncertainty space. *Clarifying values and arguments* was also a possible approach, in which we would aim at improving the political debate, trying to identify aspects underpinning the political and social debates. Finally, just as well as the other approaches, a *mediation* approach, in which we would focus on identifying different perceptions about the problem at hand in order to find room for negotiations, was also perfectly possible. Given time and resource availability restrictions, choosing the right approach was imperative to provide the best service to our client, but it was also difficult to define initially. Since our client was also facing challenges to navigate the uncertain territory of the EPA1361 RfR project, they were not able to communicate with clarity their objectives and concerns to us since the beginning of the project.

We also witnessed tense situations during the debates, specially the final one. Since it became clear that different actors had different perceptions about the problem, as well as how to address it (if at all), the debates were permeated with arguments trying either to challenge the effectiveness of the model or to broaden the scope of the proposed policy. Overall, the main challenges and tensions we encountered can be grouped in the following categories: **(a)** difficulties understanding the problem and how to use the model and its results; **(b)** strategic use of the model; and **(c)** information and collaboration barriers.

Difficulties understanding the problem and how to use the model and its results

In contexts of high complexity and uncertainty such as the EPA1361 RfR project, being able to fully grasp the problem, its uncertainties, policy options and potential feedbacks and delays present among system elements is far from trivial. This is associated with the concept of *bounded rationality*, in which decisionmakers, due to limited capacity to process complex information, as well as concurrent issues being faced, might try not to optimize their objectives, but to satisfy them (Simon, 1957, as cited in Enserink et al., 2012). Additionally, as pointed by Hermans and Cunningham (2018), decisions are often made based on incomplete information and under time pressure circumstances.

In the context of the EPA1361 RfR project, poor understanding of the problem and the model was visible among the actors involved. As briefly mentioned on the introduction section, in one episode, another team of analysts addressed us asking "*but why are you worried about Gorssel? That is Gelderland's responsibility*". Another episode of unfamiliarity with the model happened during the debates. Prior to the final debate, Rijkswaterstaat made available its proposed policy (to be discussed and voted during the debate) to the actors involved. During its opening statement at the final debate, Gelderland representatives questioned the death rate indicator in the policy proposition, stating that there was no explanation about its unit of measurement (it only mentioned a maximum death rate of around 0.12 and average of 0.02). This made it unclear to the actors if they were discussing a policy that would yield a maximum of 0.12 deaths per million habitants, or what was the corresponding time and geographic aggregation of those numbers. Rijkswaterstaat was not successful at answering such questions in a quick and convincing manner, ultimately contributing to an even greater feeling of distrust on the proposed policy on the part of some actors. A final episode worth mentioning involves the Environmental Group. Their representatives asked Rijkswaterstaat why it was stated on the proposed policy that it was necessary have dike heightening in dike ring 3 and its relationship with a port also mentioned on the proposed policy. After Rijkswaterstaat response, the Environmental Group representatives still looked somewhat confused, showing signs of either not fully understanding or believing in the reasons provided.

Strategic use of the model

Following Douglas and Wildavsky (1983, as cited in de Bruijn et al., 2012) classification of policy problems, it became clear during the EPA1361 RfR project that the problem seemed to be situated more towards the *untamed problem* classification, in which there is little consensus on normative standards, as well as high uncertainty regarding the available knowledge. Such problems depict values in conflict, since players will defend different trade-offs between the relative importance of aspects such as economic profit, environmental concerns, and safety (de Bruijn et al., 2012). Furthermore, this can lead to decisions that create winners and losers and make actors act strategically.

Situations such as the ones illustrated in the literature above could be clearly observed during the debates. For instance, the Transportation Company representatives mentioned right at their opening statement that they had issues with the initial policy proposed. They stated that the proposed policy would limit the company's ability to do business and emphasized the major role that company plays on transport and logistics activities across the entire Netherlands. At a later moment, the Transportation Company representatives also stressed the need to have guarantees of navigability levels across the entire river in the final proposal and that, if that was guaranteed, they wouldn't have further restrictions on the proposal. Such behaviour depicts a strategic approach to the whole decision-making process, choosing to focus on the (potential) negative economic impacts that could happen to the whole country's economy if the company's operations were jeopardized.

Gelderland province representatives also demonstrated strategic behaviour towards the model and the debate itself. On several occasions they challenged the model's results, scope, or assumptions. At some point, Gelderland province representatives mentioned "*are we willing to take this what-if? In 200 years, are we willing to have at most 20 people dying? Is this ok*?". This could be seen as Gelderland trying to safeguard the higher ground, making it seem like they are the ones that truly care about safety of the population, while the other actors were giving higher importance to other factors such as biodiversity or economic growth. Gelderland representatives also stressed at various times the absence of important factors both in the model and in the proposed policy, such as sea level rise, relocation of dike rings and increasing river depth. They also stated at some point "*we will be hindering the economic growth of the region, losing the most efficient agricultural land of Netherlands*". Although we do recognize that many of Gelderland's claims during the debates were very pertinent and reasonable, such interventions and arguments were often heavy on appealing language, which seems to depict a strategic behavior towards the model (even if it's one to debunk its effectiveness), specially when we consider that they didn't have veto powers over the proposed policy.

Information and collaboration barriers

The way the project was structured, each actor had specific mandates, which were secret to them and should not be made public. Of course, actors were also free to negotiate and seek to influence one another in order to reach their objectives, as addressed previously on the rounds model reference. The EPA1361 RfR project also did not promote formal opportunities for the actors to collaborate and exchange knowledge amongst themselves other than the two rounds of debates. This setup is somewhat coherent to real life projects, in which actors might have hidden agendas or deliberately try mislead others.

The first challenge (difficulties understanding the problem and model) combined with different objectives and values and a setup that did not directly promote collaboration ended up generating a decision arena in which actors exhibited certain levels of uncertainty and apprehension about each other's goals, perceptions, and values. This can be very detrimental to effective decision-making, since, as mentioned by Hermans and Cunningham (2018), different actors may realize they are all facing the same problem, but still have different beliefs regarding its origins, how it should be addressed, and what their role is in all of it. Understanding the perceptions of different actors therefore is key in order to identify reasons for conflicts, as well as to reach *negotiated knowledge*, which demands collaboration and exchange of perspectives about data, model settings and an inclination to achieve a joint interpretation of the evidence by the relevant actors (Daviter, 2017).

Measures taken to address tensions and challenges

Given that we acted as analysts in the EPA1361 RfR project, our main role was to advise and support Overijssel Province during the decision-making process, seeking to maximize results for them as well as (as far as possible) for the other actors involved. However, as our team did not have a speaking role during the debates, our ability to influence the final voted policy was limited.

The measures our team took during the RfR project were mainly:

- **Helping actors navigate the uncertainties of the model and fostering an environment for knowledge sharing**. Whenever possible, our team helped Overijssel Province, and the other actors understand how to solve errors faced while running the model and how to properly use model's factors (uncertainties, policy levers and outcomes of interest). This was mainly for specific situations in which actors looked for guidance from other actors regarding how to use the model. In some opportunities, other actors also provided valuable input to solve problems with the model.
- **Seeking solutions that would minimize 'winners' and 'losers' situations**. In our model, we approached this by choosing problem formulations that would aim to minimize the dike outcomes for our client and also the other dikes outcomes, so that nobody would be left behind. For that, based on some trial-and-error approach, we used threshold values for critical parameters such as death rate, in which solutions that yielded values above such thresholds were not considered for subsequent analyses.

Future strategies to limit challenges and tensions

The challenges mentioned in previous section are seriously pointing out the collaboration barriers which are caused by the different perception on specific values and the meanings behind those values. Also, lacking ways to present the meaning of these values visually worsens the situation of clarity in the debate.

Thus, we decided to implement several measures to limit the challenges and tension in future debates:

- **Collaborative modelling to bridge collaboration barriers**. Collaborative modelling methods could be defined as a joint creation of a shared graphical representation of a system (Renger, Kolfschoten & de Vreede, 2008). This model will be a tool to acquire, highlight, and communicate different perspectives, assumptions, or intentions among group members. During the debates, there was visible tension between values and indicators meaning between Gelderland and the rest of the actors. It was because Gelderland could not comprehend the value justification that was shown by Rijkwaterstraat models. This gap of knowledge suggests that there is disintegration in the perceived meanings by Gelderland group. With the ongoing back-and-forth discussion on this debated value, the status quo is shifted. Without any additional tools to improve the perceived understanding of these values, the decision-making process will be completely halted or even broken down to no agreement at all. Thus, we believe that setting up a collaborative model will help to bridge those differences.
- **Intuitive and Integrated Visualization Tools (such as dashboard solutions).** Adding integrated visualization tools as comparative methods for differences in meaning in the analysis results. Using only collaborative without the addition of visualization tools will still left some results un-analized and un-compared, because most of the concerns, assumptions and perspectives are included in the model but not the compared results. Thus, adding this presentation of visualized results will reduce the challenges of different perspectives on the model or the result of the model itself.

Strategy risks

As mentioned previously, the EPA1361 RfR project depicts an *untamed problem* situation. Undisputed interpretations are therefore unlikely, since values are in conflict, and stakeholders probably have different understanding about preferred outcomes and trade-offs to be made. As de Bruijn et al. (2012) state, when values and knowledge are being contested, interaction among stakeholders is the only way forward, and policymakers must engage in such interactions in order to achieve the necessary space for decision making.

Measures such as collaborative modelling and interactive visualization tools as addressed in the previous section can be of great help in order to facilitate informative discussions, improve insight discoveries and hopefully ultimately achieve negotiated knowledge to move forward on pressing issues such as environmental ones illustrated by the EPA1361 RfR project. However, those strategies are not without risks. Botti and Iyengar (2006) point out that, as complexity increases, being able to choose (which in theory should be beneficial and desirable) can turn out to be paralyzing and debilitating and result in suboptimal decision making. As addressed earlier, in such situations, decision makers might end up focusing not on optimizing their objectives, but on satisfying them.

This can also ultimately lead to what is called *analysis paralysis*, in which decision makers reach a stalemate and are unable to move forward with the decision-making process. In situations of such deep uncertainties, where decisions can lead to huge economic impacts and potential human losses, the fear of not having the perfect information to reduce uncertainty and make decisions might lead decision makers to engage in a never-ending process of collecting data, updating estimates, and (re)analysing without being able to reach a decision. Although not committing to a decision might be sensible in some cases, especially if actors disagree on crucial characteristics of the model, not making any decision in itself is also a decision, which can in turn bring huge consequences. In a study from 2008, the OECD aimed to assess the costs of inaction of key environmental challenges. These costs relate to the implementation of "*no new policies beyond those which currently exist*" (OECD, 2008, p. 20), and they can act as significant brake in productivity and growth. This can be seen on research on climate change impacts for instance, in which impacts can end up being as high as 18% of global GDP by 2050 under the most severe scenarios, where temperatures rise by 3.2°C (Marchant, 2022).

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