Sensitivity of Bayesian Decision Analysis

A tool for robust climate adaptation decision making

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1. Objectives

Apply Bayesian Decision Analysis (BDA) to an idealised example of climate adaptation decision-making to investigate:

- Uncertainty: How robust is our decision to variation in financial cost?
- Sensitivity: Which parameters is our decision most sensitive to?
- How do uncertainty and sensitivity vary spatially?

2. Example

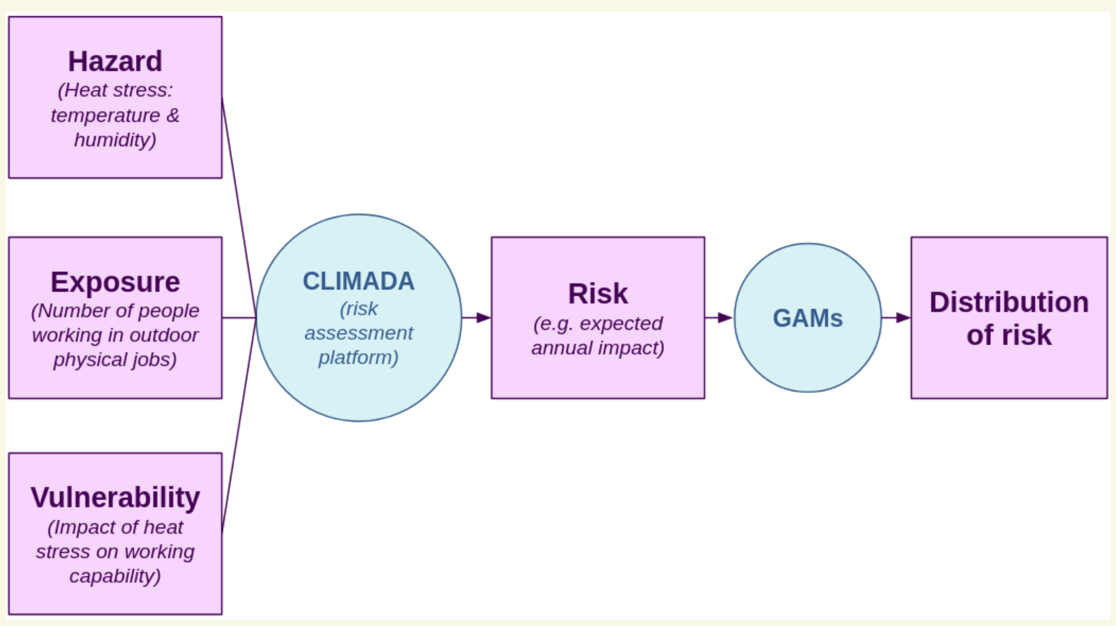
UK company seeking to mitigate the effects of heat stress on their workers via one of three possible options:

Action	Cost/person	Added cost/day of use	Reduced cost/day	s_i
d_1: Do nothing	$0	$0	$0	5
d_2: Modify working hours	[$80, $120]	[$20, $60]	[$40, $60]	7
d_3: Buy cooling equipment	[$350, $800]	[$1.50, $2.50]	[$60, $90]	4

- $s_i \in [1, 10]$: how much does decision i meet organisational objectives
- For decisions d_2 and d_3, 1000 samples of combinations of the financial cost parameters were generated using Latin hypercube sampling from uniform distributions

3. Uncertainty in risk

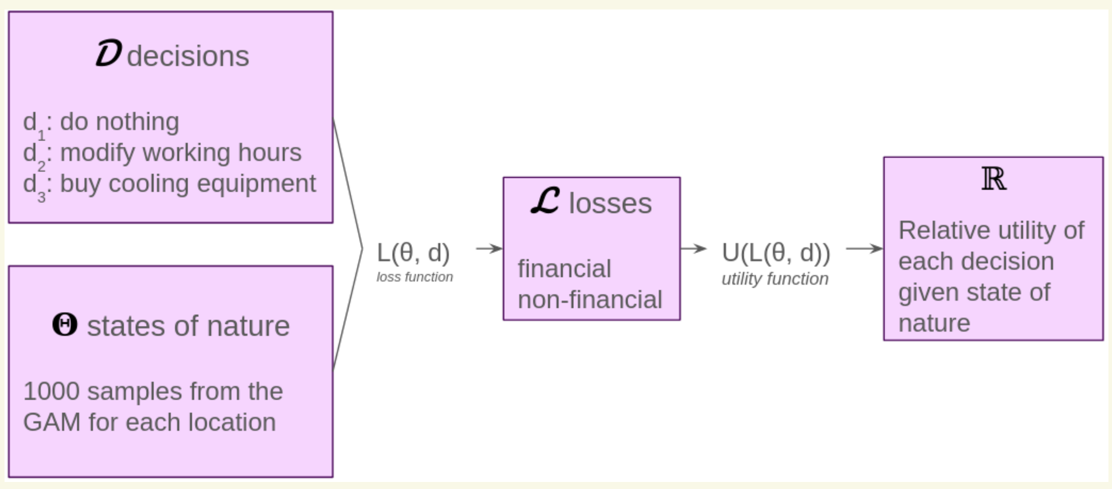
Estimate the distribution of risk due to heat stress:[1,2]



- Risk: Potential for negative consequences, arising from interaction between hazard, exposure, and vulnerability
- Generalised Additive Models (GAMs) model risk as a sum of smooth functions: generates a more complete representation of uncertainty

4. Bayesian Decision Analysis

Decision-making framework under an uncertain state of nature:[3]



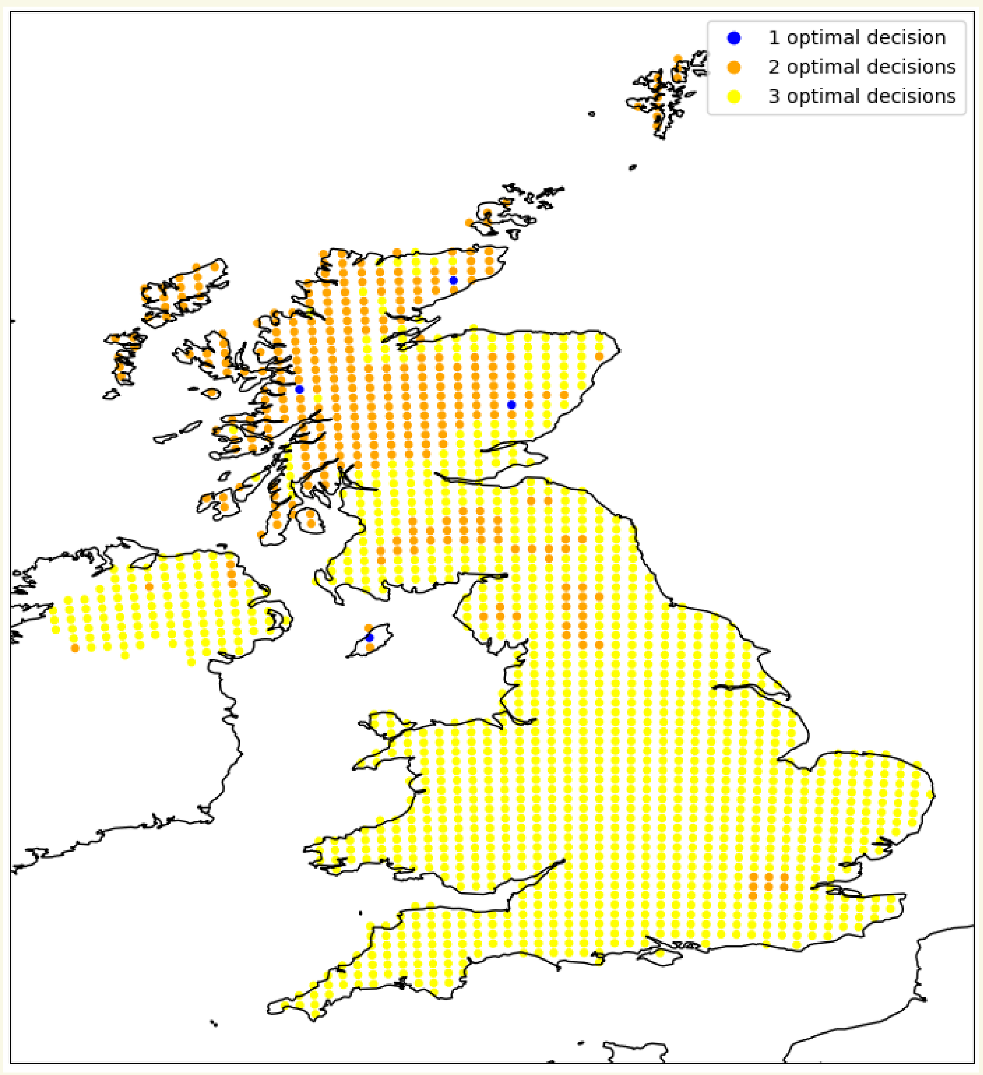
- Loss functions: $L(\theta, d) : \Theta \times \mathcal{D} \to \mathcal{L}$ represents loss of making decision d if the true state of nature is θ
- Utility functions: $U(L(\theta, d)) : \mathcal{L} \to [0, 1]$ represents the relative value of each decision

Bayes decision under utility U Select the decision that maximises expected utility:

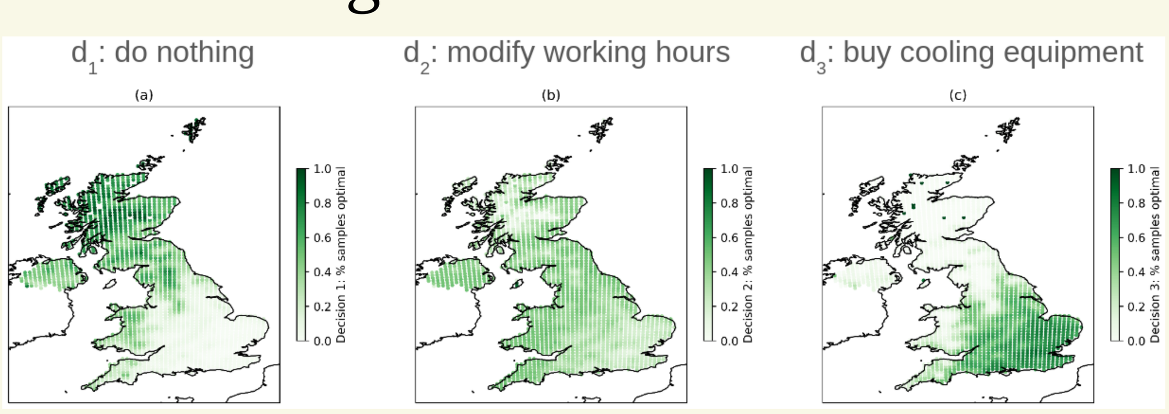
$$d^* := \arg\max_d \sum_{\theta \in \Theta} U[L(\theta, d)]p(\theta)$$

5. Uncertainty analysis

In most cells, any decision option could be optimal depending on the financial cost parameter values:



Different decisions dominate in different regions:



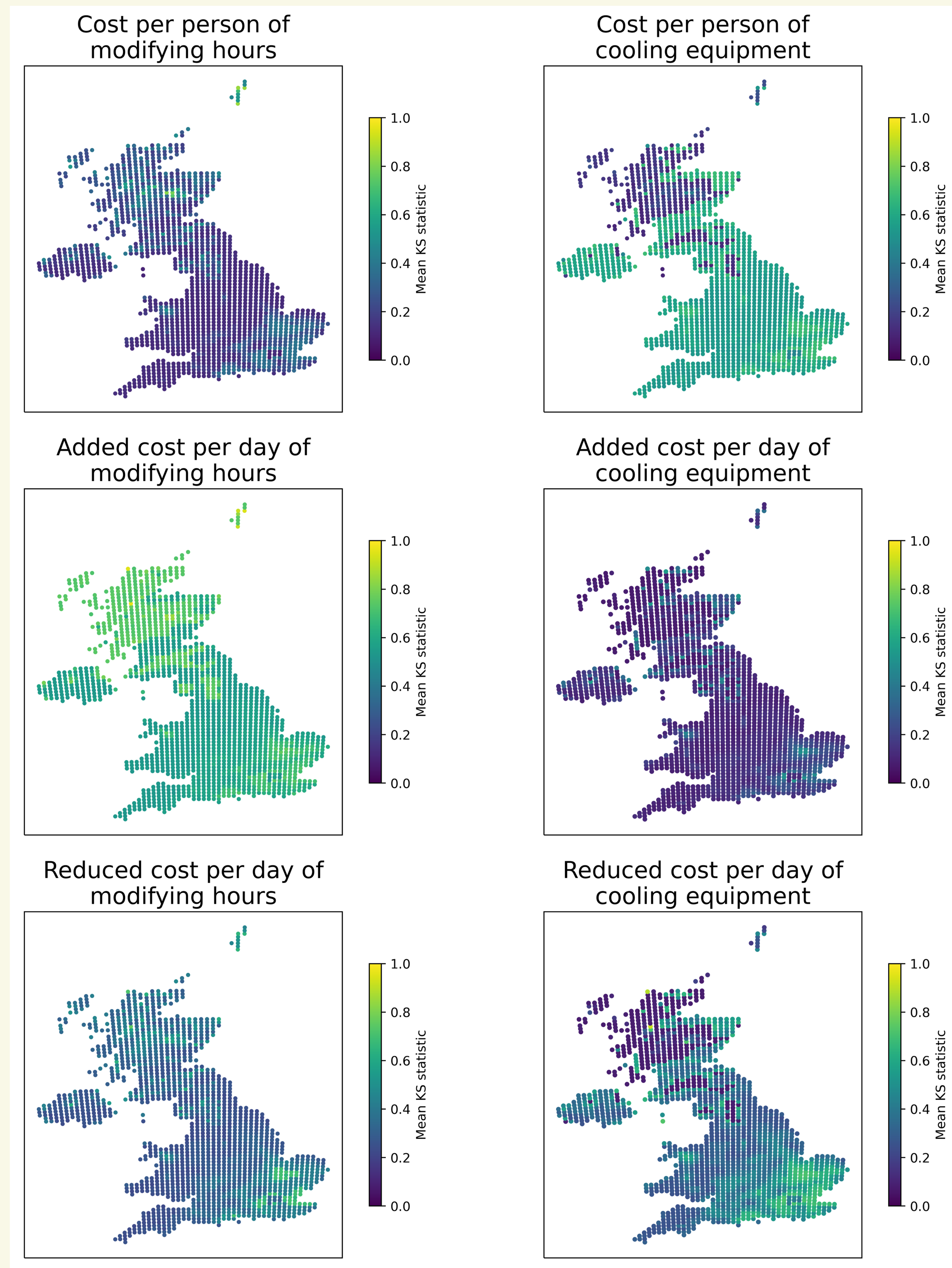
6. Sensitivity analysis

Regional Sensitivity Analysis measures sensitivity by comparing the conditional CDFs of the inputs x_i conditioned on the output d_j.[4]

Take the average Kolmogorov-Smirnov (KS) statistic between each CDF $F_{x_i|d_j}$, i.e. $\text{mean}_{j,k \in \{1,2,3\}} [KS_{j,k}(x_i)]$ where

$$KS_{j,k}(x_i) = \max_{x_i} \left| F_{x_i|d_j}(x_i|d^* = d_j) - F_{x_i|d_k}(x_i|d^* = d_k) \right|$$

Sensitivity of the Bayes decision to different financial cost components of each decision option varies spatially:



7. Conclusions & future work

- BDA yields plausible decisions by region
- The optimal decision is not very robust to variation in financial cost parameters
- Decision sensitivity to the financial cost parameters varies both spatially and by parameter
- The optimal decision *may* be more sensitive to variations in the decision attributes than to variations in risk[5]

What happens when we vary both risk and decision attributes?

References

[1] L. C. Dawkins, D. J. Bernie, J. A. Lowe, and T. Economou, "Assessing climate risk using ensembles: A novel framework for applying and extending open-source climate risk assessment platforms," *Climate Risk Management*, vol. 40, p. 100510, 2023.

[2] L. C. Dawkins, D. J. Bernie, F. Pianosi, J. A. Lowe, and T. Economou, "Quantifying uncertainty and sensitivity in climate risk assessments: Varying hazard, exposure and vulnerability modelling choices," *Climate Risk Management*, vol. 40, p. 100511, 2023.

[3] J. Smith, *Bayesian Decision Analysis: Principles and Practice.* Cambridge University Press, 2010.

[4] F. Pianosi, K. Beven, J. Freer, J. W. Hall, J. Rougier, D. B. Stephenson, and T. Wagener, "Sensitivity analysis of environmental models: A systematic review with practical workflow," *Environmental Modelling & Software*, vol. 79, pp. 214–232, 2016.

[5] L. C. Dawkins, D. J. Bernie, J. A. Lowe, T. Economou, and F. Pianosi, "Exploring robust climate adaptation: A novel risk assessment and decision framework incorporating uncertainty and sensitivity analysis." Unpublished work, 2023.