

1      **Dossier: visualizing/ understanding decision choices in data analysis via**  
2      **decision similarity**  
3

4      **ANONYMOUS AUTHOR(S)**  
5

6      In data analysis, analysts are expected to clearly communicate the decisions they make, as these choices inform how results are  
7      interpreted and compared across studies. Such decisions – for example, selecting the degree of freedom for a smoothing spline – are  
8      often not systematically studied, since once an analysis is published, it is done seldom revisited or replicated with alternative choices.  
9      In this work, we focus on a body of data analysis studies on the effect of particulate matter on mortality, conducted by researchers  
10     worldwide, which naturally provide alternative analyses of the same question. We automatically extract analytic decisions from the  
11     published literature into structured data using Large Language Models (Claude and Gemini). We then proposed a pipeline to calculate  
12     paper similarity based on the semantic similarity of these extracted decisions and their reasons, and visualize the results through  
13     clustering algorithms. This approach offers an efficient way to study decision-making practices than traditional interviews. We also  
14     provide insights into the use of LLMs for text extraction tasks and the communication of analytic choices in data analysis practice.  
15

16     CCS Concepts: • **Applied computing** → *Document analysis*; • **Human-centered computing** → *HCI theory, concepts and models*.  
17

18     Additional Key Words and Phrases: Large language models  
19

20     **ACM Reference Format:**  
21

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24     XXXXXXXX  
25

- 26     • Something about “analysis review” - Roger thinks it’s a better to have a new word for this.  
27     • demonstrate - analytically homogeneous - the table won’t look like that  
28

29     **1 Introduction**  
30

31     Decisions are everywhere in data analysis, from the initial data collection, data pre-processing to the modelling  
32     choices. These decisions will impact the final output of the data analysis, which may lead to different conclusions  
33     and policy recommendations. When such flexibility can be misused—through practices such as p-hacking, selective  
34     reporting, or unjustified analytical adjustments—it can inflate effect sizes or produce misleading results that meet  
35     conventional thresholds for statistical significance. They have been demonstrated through many-analysts experiments,  
36     where independent teams analyzing the same dataset to answer a pre-defined research question often arrive at markedly  
37     different conclusions. These practices not only compromise the validity of individual studies but also threaten the  
38     broader credibility of statistical analysis and scientific research as a whole.  
39

40     Multiple recommendations have been proposed to improve data analysis practices, such as pre-registration and  
41     multiverse analysis. Bayesian methods also offer a different paradigm to p-value driven inference for interpreting  
42     statistical evidence. Most empirical studies of data analysis practices focus on specially designed and simplified analysis  
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53 scenarios. While informative, these setups may not adequately capture the complexity of the data analysis with  
 54 significant policy implications. [In practice, studying the data analysis decisions with actual applications is challenging.]  
 55 Analysts may no longer be available for interviews due to job changes, and even when they are, recalling the full set  
 56 of decisions and thinking process made during the analysis is often infeasible. Moreover, only until the last decades,  
 57 analysis scripts and reproducible materials were not commonly required by journals for publishing. [As a result, it  
 58 remains challenging to study how analytical decisions are made.]

60 In this work, we focus on a specific class of air pollution modelling studies that estimate the effect size of particulate  
 61 matter (PM2.5 or PM10) on mortality, typically using Poisson regression or generalized additive models (GAMs).  
 62 While individual modelling choices vary, these studies often share a common structure: they adjust for meteorological  
 63 covariates such as temperature and humidity, apply temporal or spatial treatments, like including lagged variables and  
 64 may estimate the effect by city or region before combining results. Because these studies investigate similar scientific  
 65 questions using a shared modelling framework, they form a natural many-analyst setting. This allows us to examine, in  
 66 a real-world context, the range of analytical decisions made by different researchers addressing the same underlying  
 67 question.  
 68

69 In this work, we develop a structured tabular format to record the analytical decisions made by researchers in the air  
 70 pollution modelling literature. Using large language models (LLMs), we automate the extraction of these decisions from  
 71 published papers. This allows us to treat decisions as data – allowing us to track them over time, compare methodology  
 72 across papers, and query commonly used approaches. We further introduce a workflow to cluster studies based on  
 73 decision similarity, revealing three distinct groups of papers that reflect the modelling strategies differ in the European  
 74 and U.S. studies, which offers a new way to visualize the field in the air pollution mortality modelling.  
 75

76 The contribution of this work includes:

- 77 • A new approach to study data analysis decision choices through automatic extraction of decisions from scientific  
 78 literature using LLMs,
- 79 • A dataset compiled from 62 papers to study decision-making in air pollution mortality modelling,
- 80 • A pipeline to construct similarities between papers based on decision similarities, and
- 81 • Issues we found from existing data analysis reporting

82 The rest of the paper is organized as follows. In Section 2, we review the background on data analysis decisions.  
 83 Section 3 describes the data structure for recording decisions, the use of large language models to process research  
 84 papers, and the validation of LLM outputs. In Section 4, we present the method for calculating paper similarity based  
 85 on decision similarities. Section 5 reports the finding of our analysis, including the clustering of papers according to  
 86 similarity scores and sensitivity analyses related to LLM providers, prompt engineering, and LLM parameters. Finally,  
 87 Section 7 discusses the implications of our study.  
 88

## 90 2 Related work

### 91 2.1 Decision-making in data analysis

92 A data analysis is a process of making choices at each step, from the initial data collection to model specification, and  
 93 post-processing. Each decision represents a branching point where analysts choose a specific path to follow, and the  
 94 vast number of possible choices analysts can take forms what Gelman and Loken [18] describe as the “garden of forking  
 95 paths”. While researchers may hope their inferential results are robust to the specific path taken through the garden,  
 96 in practice, different choices can lead to substantially different conclusions. This has been empirically demonstrated  
 97

105 through “many analyst experiments”, where independent research groups analyze the same dataset to the same answer  
106 using their chosen analytic approach. A classic example is Silberzahn et al. [42], where researchers reported an odds  
107 ratio from 0.89 to 2.93 for the effect of soccer players’ skin tone on the number of red cards awarded by referees. Similar  
108 variability has been observed in structural equation modeling [40], applied microeconomics [22], neuroimaging [8],  
109 and ecology and evolutionary biology [19].

110 Examples above have rendered decision-making in data analysis as a subject to study in data science. To collect  
111 data on how analysts making decisions during data analysis, researchers have conducted interviews with analysts and  
112 researchers on data analysis practices [2, 24, 29], visualization of the decision process through the analytic decision  
113 graphics (ADG) [30]. Recently, Simson et al. [43] describes a participatory approach to decisions choices in fairness ML  
114 algorithms. Software tools have also developed to incorporate potential alternatives in the analysis workflow, including  
115 the DeclareDesign package [7] and the multiverse package [39]. The DeclareDesign package [7] introduces the  
116 MIDA framework for researchers to declare, diagnose, and redesign their analyses to produce a distribution of the  
117 statistic of interest, which has been applied in the randomized controlled trial study [6]. The multiverse package [39]  
118 provides a framework for researchers to systematically explore how different choices affect results and to report the  
119 range of plausible outcomes that arise from alternative analytic paths. Other systems have been developed to visualize  
120 multiverse analysis [31].

## 126 2.2 Visualization on scientific literature

127 Much of the work on IEEE visualizing scientific literature focuses on helping researchers stay aware of relevant  
128 publications, given the rapidly growing volume of scientific output and the difficulty of navigating it. Systems have  
129 been developed to support the discovery of relevant papers, where relevance is typically determined by keywords [23],  
130 citation information (e.g. citation list, co-citation) [13], or combinations with other relevant paper metadata (e.g. author,  
131 title) [5, 14, 17, 20]. More recent approaches incorporate text-based information from the abstract or sections of the  
132 paper to [obtain a better similar metric]. This includes using topic modelling [1], argumentation-based information  
133 retrieval [44], and text embedding [36]. While these metadata information and high level text-based information are  
134 valuable for discovering relevant papers, for data analysis, researchers need tools that help them *make sense* of the  
135 literature rather than simply *finding* it. Capturing the decisions and reasoning expressed during analyses within a  
136 similar theme can reveal common practices in the field and guide decisions choices in new applications. With recent  
137 advances in Large Language Models (LLMs), it has become possible to automatically extract structured information from  
138 unstructured text through prompting. This allows scientific literature to be clustered and visualized using information  
139 about the underlying decisions and reasoning made during analysis, providing a basis for studying analysts’ decision  
140 choices.

## 146 3 Methods

### 148 3.1 Decisions in data analysis

149 Decisions occur throughout the entire data analysis process – from the selection of variables and data source, to  
150 pre-processing steps to prepare the data for modelling, to the model specification and variable inclusion. In this work,  
151 we focus specifically on modelling decisions in the air pollution mortality modelling literature. These include the  
152 choice of modelling approach, covariate inclusion and smoothing, and specifications of spatial and temporal structure.  
153 Consider the following excerpt from Ostro et al. [37]:

157 Based on previous findings reported in the literature (e.g., Samet et al. 2000), the basic model included a  
 158 smoothing spline for time with 7 degrees of freedom (df) per year of data. This number of degrees of  
 159 freedom controls well for seasonal patterns in mortality and reduces and often eliminates autocorrelation.  
 160

161 This sentence encode the following components of a decision:

- 162 • **variable**: time
- 163 • **method**: smoothing spline
- 164 • **parameter**: degree of freedom (df)
- 165 • **reason**: Based on previous findings reported in the literature (e.g., Samet et al. 2000); This number of degrees of  
 166 freedom controls well for seasonal patterns in mortality and reduces and often eliminates autocorrelation.
- 167 • **decision**: 7 degrees of freedom (df) per year of data

168 The decision above is regarding a certain parameter in the statistical method, we categorize this as a “parameter”  
 169 type decisions. Other types of decisions - such as spatial modelling structure or the inclusion of temporal lags - may  
 170 not include an explicit method or parameter, but still reference a variable and rationale, which we will provide further  
 171 examples below.

172 To record these decisions, we follow the tidy data principle [47], where each variable should be in a column, each  
 173 observation in a row. In our context, each row represents a decision made by the authors of a paper and an analysis  
 174 often include multiple decisions. To retain the original context of the decision, we extract the original text in the paper,  
 175 without paraphrase or summarization, from the paper. Below we present an example of how to structure the decisions  
 176 made in a paper, using the paper by Ostro et al. [37]:

Paper	ID	Model	variable	method	parameter	type	reason	decision
ostro	1	Poisson regression	temperature	smoothing spline	degree of freedom	parameter	NA	3 degree of freedom
ostro	2	Poisson regression	temperature	smoothing spline	degree of freedom	temporal	NA	1-day lag
ostro	3	Poisson regression	relative humidity	LOESS	smoothing parameter	parameter	to minimize Akaike's Information Criterion	NA
ostro	4	Poisson regression	model	NA	NA	spatial	to account for variation among cities	separate regression models fit in each city

209 Most decisions in the published papers are not explicitly stated, this could due to the coherence and conciseness of  
210 the writing or authors' decision to include only necessary details. Here, we identify a few common anomalies where  
211 decisions may be combined or omit certain fields:

- 212 1. **Authors may combine multiple decisions into a single sentence** for coherence and conciseness of the  
213 writing. Consider the following excerpt from Ostro et al. [37]:

214 Other covariates, such as day of the week and smoothing splines of 1-day lags of average temperature  
215 and humidity (each with 3 df), were also included in the model because they may be associated with  
216 daily mortality and are likely to vary over time in concert with air pollution levels.

217 This sentence contains four decisions: two for temperature (the temporal lag and the smoothing spline parameter)  
218 and two for humidity. These decisions should be structured as separate entries.

- 219 2. **The justification does not directly address the decision choice.** In the example above, the stated rationale  
220 ("and are likely to vary over time in concert with air pollution levels") supports the general inclusion of temporal  
221 lags but does not justify the specific choice of 1-day lag over alternatives, such as 2-day average of lags 0 and 1  
222 (lag01) and single-day lag of 2 days (lag2). As such, the reason field should be recorded as NA.

- 223 3. **Some decisions may be omitted because they are data-driven.** For instance, Katsouyanni et al. [26] states:  
224 The inclusion of lagged weather variables and the choice of smoothing parameters for all of the weather  
225 variables were done by minimizing Akaike's information criterion.

226 In this case, while the method of selection (minimizing AIC) is specified, the actual degree of freedom used is not.  
227 Such data-driven decisions may be recorded with "NA" in the decision field, but the reason field should still be recorded  
228 as "by minimizing Akaike's information criterion"

- 229 4. **Information required to interpret the decision may be distributed across multiple sections.** In the  
230 previous example, "weather variables" refers to mean temperature and relative humidity, as defined earlier in  
231 the text. This requires cross-referencing across sections to identify the correct variables associated with each  
232 modeling choice.

### 233 3.2 Automatic reading of literature with LLMs

234 **TODO:** Prompt engineering: these models may paraphrase or hallucinate unless explicitly told not to since it is  
235 generative in nature based on the predicted probability of the next word from the text and the instruction

236 **TODO:** The Prompt Report: A Systematic Survey of Prompt Engineering Techniques <https://arxiv.org/pdf/2406.06608.pdf>  
237 While decisions can be extracted manually from the literature, this process is labor-intensive and time-consuming.  
238 Recent advances in Large Language Models (LLMs) have demonstrated potential for automating the extraction of  
239 structured information from unstructured text [ref]. In this work, we use LLMs to automatically identify decisions  
240 made by authors during their data analysis processes.

241 Text recognition from PDF document relies on Optical Character Recognition (OCR) to convert scanned images into  
242 machine-readable text – capability currently offered by Anthropic Claude and Google Gemini. We instruct the LLM  
243 to generate a markdown file containing a JSON block that records extracted decisions, which can then be read into  
244 statistical software for further analysis. The exact prompt feed to the LLM is provided in the Appendix. The `ellmer`  
245 package [48] in R is used to connect to the Gemini and Claude API, providing the PDF attachment and the prompt in a  
246 markdown file as inputs.

### 261 3.3 Review the LLM output

262 • TODO something about result validation of LLM output: We also observe data quality with the extraction:  
 263 for example in Lee et al. [28], the variable recorded is “smoothing parameter”. Authors are unclear about the  
 264 delivery Specify how much of validation and review has been done.  
 265

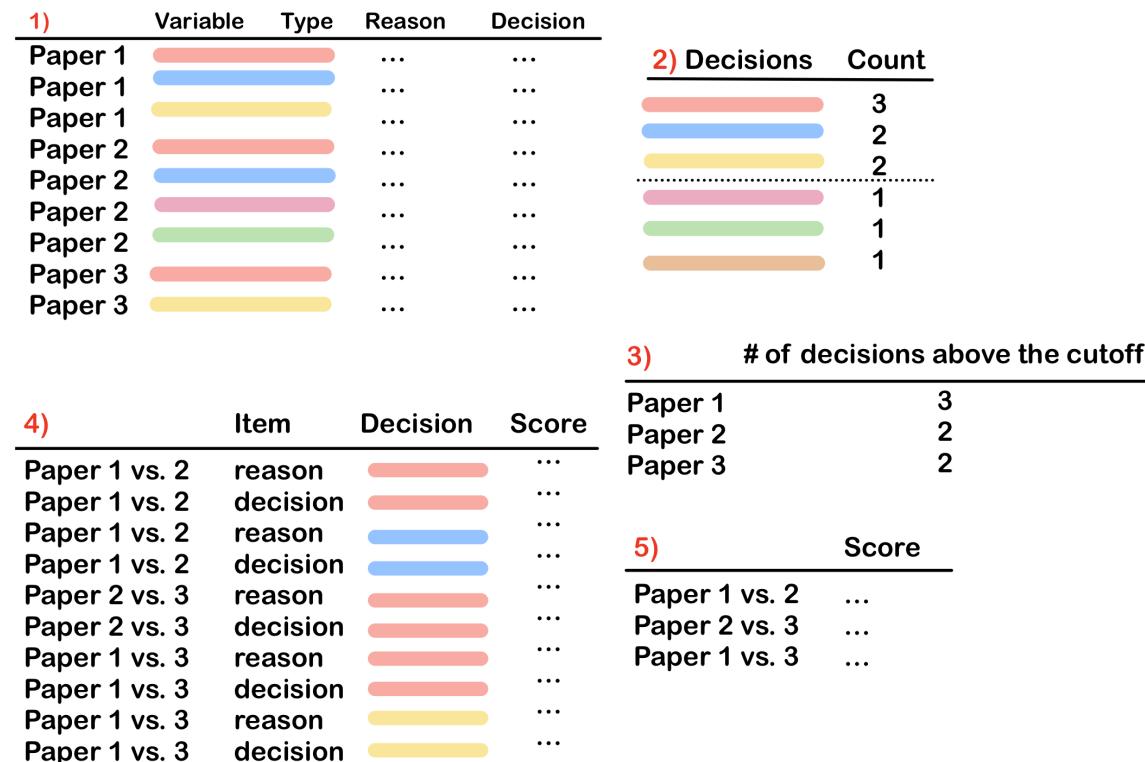
266 The shiny app is designed to provide users a visual interface to review and edit the decisions extracted by the LLM  
 267 from the literature. The app allows three actions from the users: 1) *overwrite* – modify the content of a particular  
 268 cell, equivalently `dplyr::mutate(xxx = ifelse(CONDITION, "yyy" , xxx))`, 2) *delete* – remove a particular cell,  
 269 `dplyr::filter(!(CONDITION))`, and 3) *add* – manually enter a decision, `dplyr::bind_rows()`. Figure 1 illustrates  
 270 the *overwrite* action in the Shiny application, where users interactively filter the data and preview the rows affected by  
 271 their edits—in this case, changing the model entry from “generalized additive Poisson time series regression” to the  
 272 less verbose “Poisson regression”. Upon confirmation, the corresponding tidyverse code is generated, and users can  
 273 download the edited table and incorporate the code into their R script.  
 274

paper	id	model	variable	method	parameter	type	reason	decision
anderson2008size	1	generalized additive Poisson time series regression	temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	2	generalized additive Poisson regression	deep-point temperature	smoothing spline	degrees of freedom	parameter	NA	4 or 5
anderson2008size	3	generalized additive Poisson regression	calendar time	smoothing spline	degrees of freedom per year	parameter	NA	3, 4 or 5
anderson2008size	4	generalized additive Poisson time series regression	pollutant concentrations	NA	NA	temporal	NA	log 0-5 days examined
barrett2004air	1	cose-crossover model	model	NA	NA	temporal	NA	to control for long-term temporal changes, seasonal effects by design
barrett2004air	2	cose-crossover model	temperature	NA	NA	temporal	NA	to control for weather patterns in previous day's temperature
barrett2004air	3	cose-crossover model	temperature extremes	percentile	75 and 99th percentiles	to control for extremes of hot and cold temperatures	NA	use coldest and warmest 1% days
barrett2004air	4	random effects meta-analysis model	model	NA	NA	spatial	NA	to estimate average across cities using random effects analysis
barrett2004air	5	cose-crossover model	air pollutants	NA	NA	temporal	NA	use average of previous day's day exposure
bel2003seasonal	1	2-stage Bayesian hierarchical model	temperature	natural cubic spline	6 degrees of freedom	parameter	NA	6 degrees of freedom
bel2003seasonal	2	2-stage Bayesian hierarchical model	deep point temperature	natural cubic spline	2 degrees of freedom	parameter	NA	2 degrees of freedom

304 Fig. 1. The Shiny application interface for editing Large Language Model (LLM)-generated decisions (overwrite, delete, and add). (1) the default interface after loading the input CSV file. (2) The table view will update interactively upon the user-defined filter condition – expressed using `dplyr::filter()` syntax (e.g., `paper == anderson2008size`”), (3) The user edits the model column to “Poisson  
 305 regression” and applies the change by clicking the Apply changes button. The table view updates to reflect the changes (4) After  
 306 clicking the Confirm button, the corresponding tidyverse code is generated, and the table view returns to its original unfiltered view.  
 307 The edited data can be downloaded by clicking the Download CSV button.  
 308

#### 313 4 Calculating paper similarity

314 Once the decisions have been extracted and validated, this opens up a structured data for analyzing these information.  
 315 For example, we can compare whether author's choices at different times changes, or across decisions varies at different  
 316 regions. In this section, we present a method to calculate paper similarity based on the decisions shared in the paper  
 317 pairs. The goal is to construct a distance metric based on similarity of the decision choice among papers that could  
 318 be further used for clustering paper based on choices made by different authors in the literature. An overview of the  
 319 method is illustrated in Figure 2.



350 Fig. 2. Workflow for calculating paper similarity based on decision choices: (1) standardize variable names, (2) identify most frequent  
 351 variable-type decisions across all papers, (3) identify papers with at least x identified decisions, (4) calculate decisions similarity  
 352 score on the *decision* and *reason* fields using transformer language models, e.g. BERT, (5) calculate paper similarity score based on  
 353 aggregating decision similarity scores.

- 355 • TODO some discussion on what it means by for two papers to be similar based on decisions.

356 The calculation of paper similarity is based on the similarity of decisions shared by each paper pair. A decision  
 357 comparable in two papers are the ones that share the same variable and type, e.g. temperature and parameter (a decisions  
 358 on the choosing the statistical method *parameter* for the *temperature* variable), or humidity and temporal (any *temporal*  
 359 treatment, e.g. choice of lag value for the *humidity* variable). While many decisions share a similar variable, different  
 360 authors may refer to them with slightly different names, such as "mean temperature" and "average temperature", hence  
 361 variable names are first standardized to a common set of variable names. For example, "mean temperature" and "average  
 362

temperature” are both standardized to “temperature”. Notice that “dewpoint temperature” is standardized into “humidity” since it is a proxy of temperature to achieve a relative humidity (RH) of 100%. For literature with a common theme, there is usually a set of variables that shared by most papers and additional variables are justified in individual research. For our air pollution mortality modelling literature, we standardize the following variable names:

- **temperature**: “mean temperature”, “average temperature”, “temperature”, “air temperature”, “ambient temperature”
- **humidity**: “dewpoint temperature” and its hyphenated variants, relative humidity”, “humidity”
- **PM**: “pollutant”, “pollution”, “particulate matter”, “particulate”, “PM10”, “PM2.5”
- **time**: “date”, “time”, “trends”, “trend”

Depending on the specific pairs, papers have varied number of decisions that can be compared and aggregated. While paper similarities can be computed for all paper pairs, using the similarity of one or two pair of decisions to represent paper similarity is less ideal. Hence, before calculating the text similarity of decisions, we also include two optional steps to identify and subset the most frequent decisions across papers, and to retain only papers that report more than a certain number of frequent decisions. Research questions in different fields may have different levels of homogeneity, depending on the maturity of the field and for air pollution mortality modelling, it is helpful to focus on decisions and papers that share a substantial number of decisions.

To assign numerical value for the similarity of reason, we use a transformer language model, such as BERT, to measure the semantic text similarity between the decision itself and its justification. The decision similarity is calculated by comparing the *decision* and *reason* fields of the decisions in each paper pair. To obtain paper similarity, we average the decision similarities across all decisions in each paper pair and other method can be customized for aggregation. The resulting paper similarity score can be used as a distance matrix to cluster papers based on their decision choices to understand the common practices in the investigated literature.

## 5 Results

From the 57 studies examining the effect of particulate matters (PM<sub>10</sub> and PM<sub>2.5</sub>) on mortality, we focus on the baseline model reported in each paper, excluding secondary models (e.g. lag-distributed models) and sensitivity analysis. We also exclude decisions on other pollutants, such as nitrogen dioxide (NO<sub>2</sub>). This yields 273 decisions extracted using Gemini, averaging approximately 5 decisions per paper. Table 2 summarizes the number of edits made during the review process using the Shiny app. [details]

Table 3 summarizes the missingness of the decisions and reason. While most papers report their decision choices (e.g. use of five degree of freedom), 57% of decisions lack a stated rationale for the choice. Table 4 lists the eight most frequently reported decision: parameter and temporal choice for time, PM, temperature, and humidity.

Table 2. tsdjflkajsldf.

Reason	Count
Recode for secondary LLM processing for standardization	42
Irrelevant decisions, e.g. other pollutants, sensitivity analysis	36
Decision captured not correct	10
Duplicates	9
General statements without specific decision, e.g. minimum of 1 df per year was required	6

417 Table 3. Missingness of decision and reason fields in the Gemini-extracted decisions. Most decisions report the choice (35.5 + 57.1 =  
 418 92%), but 57.1% lacks a stated reason.

Decision		
Reason	Non-missing	Missing
Non-missing	97 (35.5%)	16 (5.9%)
Missing	156 (57.1%)	4 (1.5%)

426  
427 Table 2. tsdjflkajksldf.  
428

Reason	Count
Definition of variables, e.g. season	5
Total	108

435 Table 4. Count of variable-type decisions in the Gemini-extracted decisions. The most commonly reported decision are the parameter  
 436 choices and temporal lags for time, PM, temperature, and humidity.

Variable	Type	Count
PM	temporal	56
time	parameter	45
temperature	parameter	37
humidity	parameter	26
temperature	temporal	25
humidity	temporal	20
PM	parameter	8
mortality	temporal	4

452 Table 5 reports the parameter-related decisions captured in the literature. They refer to the number of knots or degree  
 453 of freedom for spline methods (natural and smoothing spline) applied to variable time, humidity and temperature. For  
 454 consistency, all values have been converted to a *per year* scale. The selection of knot for natural spline has less variation  
 455 than the degree of freedom choices for smoothing spline. Choices for temperature and humidity tend to be close, given  
 456 they are both weather related variables, while the choices for time are more varied inherently. This tabulation offers a  
 457 reference set for potential options for future studies and help to identify anomalies and special treatment in practice.  
 458 Notable example includes the use of 7.7 degree of freedom in Castillejos et al. [12], and highly flexible choices of 30 and  
 459 100 in Moolgavkar [34] and Moolgavkar [35], respectively. While most papers choice to report the smoothing parameter  
 460 as a constant value, Schwartz [41] specifies it as a proportion of the data (“5% of the data” and “5% of the data”).

461 For temporal decisions, after an initial review, we observed that decisions are still highly varied. The decisions can  
 462 be divided into two groups: multi-day lags include expressions such as “6-day average”, “3-d moving average”, “mean of  
 463 lags 0+1”, and “cumulative lags, mean 0+1+2”, and single-day lags include “lagged exposure up to 6 days”, “lag days from  
 464 0 to 5” among others. To standardize these entries, we applied a secondary LLM process (claude-3-7-sonnet-latest) and  
 465

469 converted them into a consistent format: multi-day: lag [start]-[end] and single-day: lag [start], . . .  
 470 lag [end]. Table 6 summarizes the temporal lag choices for PM, temperature, and humidity. Both single and multiple  
 471 day lags are generally considered up to five days prior (lag 5). [TODO: check multi-day starts from one].  
 472

473

474 Table 5. Options captured for parameter choices for time, humidity, and temperature variables in the Gemini-extracted decisions.  
 475 The choices for natural spline knots are generally less varied than the degree of freedom choices for smoothing spline. Choices for  
 476 temperature and humidity tend to be close, given they are both weather related variables, while the choices for time are more varied  
 477 inherently.

478

479 Method	480 Variable	481 Decision
481 natural spline	humidity	3, 4
482 natural spline	temperature	3, 4, 6
483 natural spline	time	1, 3, 4, 6, 7, 8, 12
485 smoothing spline	humidity	2, 3, 4, 6, 8, 50% of the data
486 smoothing spline	temperature	2, 3, 4, 6, 8, 50% of the data
487 smoothing spline	time	1, 3, 4, 5, 6, 7, 7.7, 8, 9, 10, 12, 30, 100, NA, 5% of the data

488

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490

491

492 Table 6. Options captured for temporal lag choices for PM, temperature, and humidity variables in the Gemini-extracted decisions.  
 493 Both single-day lags and multi-day average lags are commonly used, generally considering up to five days prior (lag 5).

494

495 Lag type	496 Variable	497 Decision
497 multi-day average	PM	0-1, 0-2, 0-3, 0-4, 0-5, 0-7, 1-0, 1-5
498 multi-day average	humidity	0-1, 0-2, 0-3, 0-5, 1-3, 1-5
499 multi-day average	temperature	0-1, 0-2, 0-3, 0-5, 0-7, 1-3
500 single-day lag	PM	lag 0, lag 1, lag 2, lag 3, lag 4, lag 5
501 single-day lag	humidity	lag 0, lag 1, lag 2, lag 3, lag 4, lag 5, lag 6, lag 7
503 single-day lag	temperature	lag 0, lag 1, lag 2, lag 3, lag 4, lag 5

504

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506

507 For computing the decision similarity score, we include the first 6 most common variable-type decisions as suggested  
 508 in Table 4. Figure 4 shows the clustering of the 50 papers based on the decision similarity scores. The dendrogram is  
 509 generated using hierarchical clustering, and the labels are colored according to the most common smoothing method  
 510 used in each paper. The clustering reveals three distinct groups of papers, which reflect the modelling strategies differ  
 511 in the European (LOESS) and U.S. (...) studies [more on the APHENA].  
 512

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## 6 Sensitivity analysis

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516 In this section, we examine the reproducibility for using LLMs for text extraction tasks in Section 6.1, discrepancies  
 517 between different LLM models: Gemini (gemini-2.0-flash) and Claude (claude-3-7-sonnet-latest) in Section 6.2,  
 518 and the sensitivity of our paper similarity calculation pipeline to the choice of text model used for computing decision  
 519 similarity scores in Section 6.3.

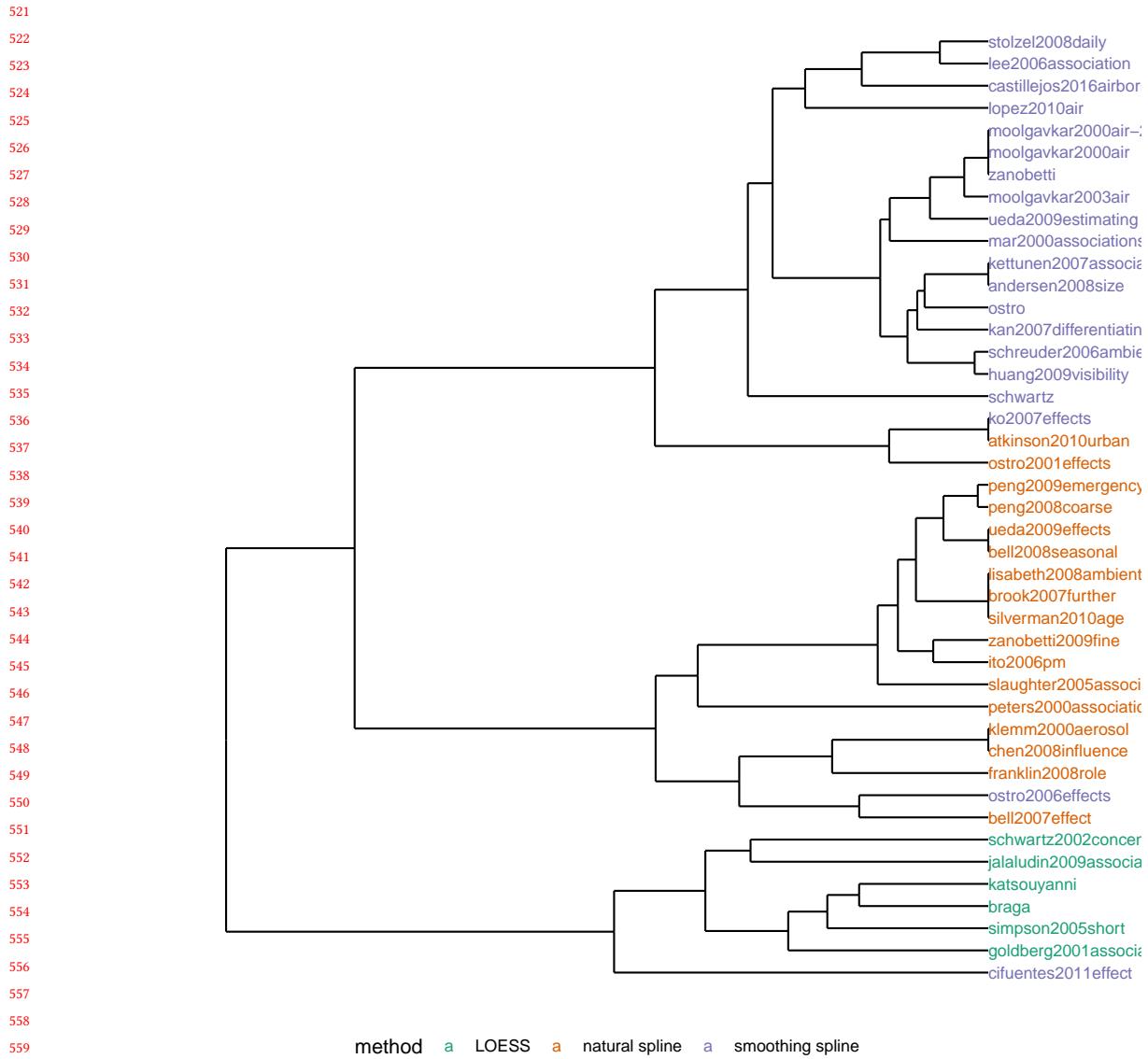


Fig. 3. The dendrogram (left) and multi-dimensional scaling (MDS) (right) based on paper similarity distance for 62 air pollution mortality modelling literature. The papers are colored by the most common smoothing method used. The MDS reveals the three distinct groups of papers. This grouping corresponds to the modelling strategies differ in the European and U.S. studies, documented in ALPHENA.

## 6.1 LLM reproducibility

For our text extraction task, we test the reproducibility of Gemini (gemini-2.0-flash) by repeating the text extraction task 5 times for each of the 62 papers. For each of the 31 papers, five runs yield  $5 \times 4/2 = 10$  pairwise comparisons per field and including both the “reason” and “decision” fields results in a total of  $31 \times 10 \times 2 = 620$  pairs. We exclude the

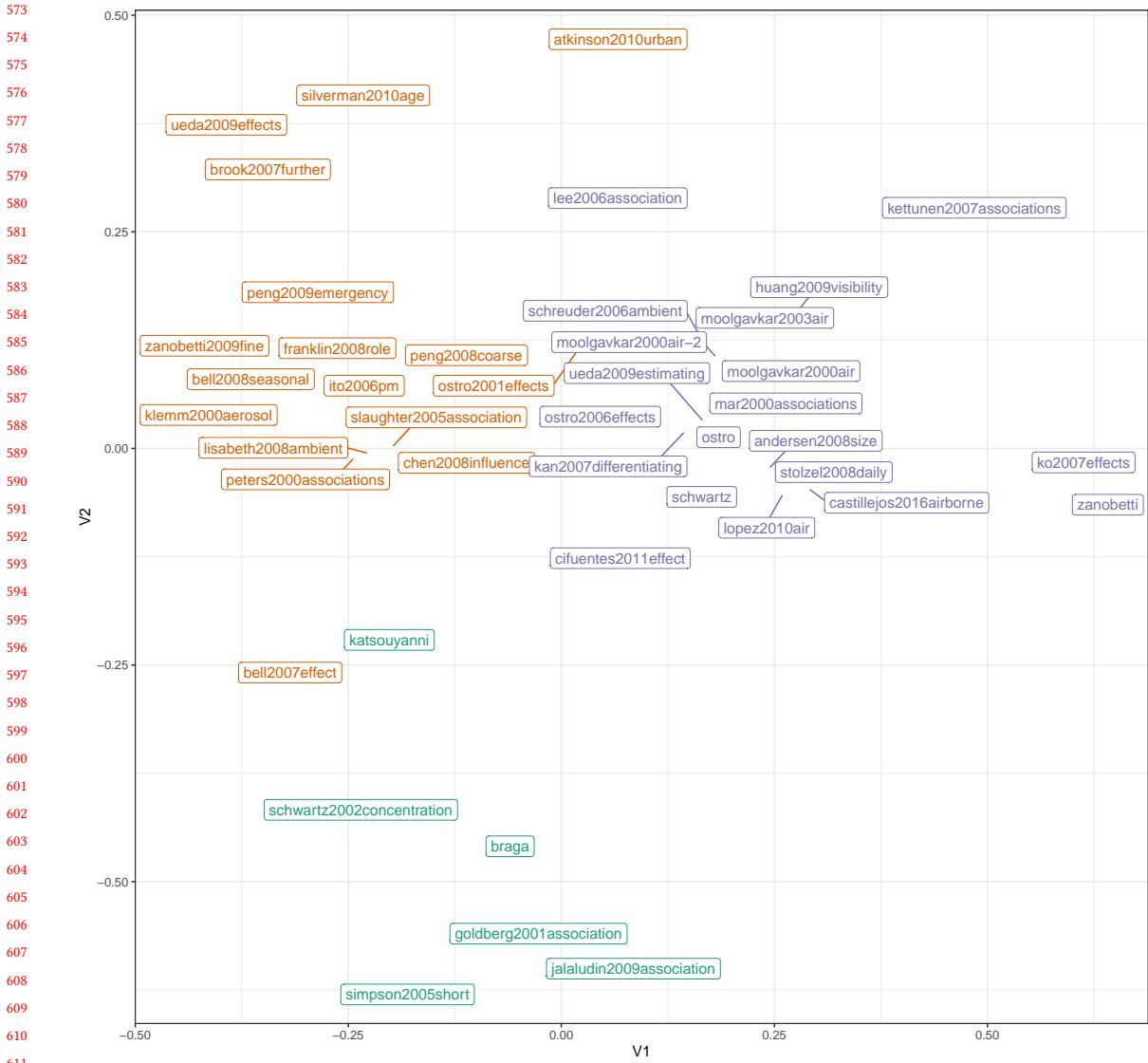


Fig. 4. The dendrogram (left) and multi-dimensional scaling (MDS) (right) based on paper similarity distance for 62 air pollution mortality modelling literature. The papers are colored by the most common smoothing method used. The MDS reveals the three distinct groups of papers. This grouping corresponds to the modelling strategies differ in the European and U.S. studies, documented in ALPHENA.

pairs that have different number of decisions since it would require manually align the decision to compare and this left us with 449 out of 620 (72%) pairwise comparisons. Table 7 shows an example of such comparison in Andersen et al. [3], where all the four reasons are identical among the two runs, hence a zero number of difference.

Table 7. An example of comparing the text extraction in decisions in Andersen 2008.

Variable	Run1	Run2
NCTot	6day average (lag 05)	6day average (lag 05)
calendar time	3 4 or 5 dfyear	3 4 or 5 dfyear
dew-point temperature	4 or 5 df	4 or 5 df
temperature	4 or 5 df	4 or 5 df

Table 8 summarizes the number of differences observed in each pairwise comparison. Among all comparisons, 80% produce the identical text in reason and decision. The discrepancies come from the following reasons:

- Gemini extracted different length for the same decision, e.g. in Kan et al. [25], some runs may extract “singleday lag models underestimate the cumulative effect of pollutants on mortality 2day moving average **of current and previous day concentrations** (lag=01)”, while others extract “singleday lag models underestimate the cumulative effect of pollutants on mortality 2day moving average (lag=01)”. Similarity, for decisions, some runs may yield “10 df for total mortality”, while other runs yield “10 df”. Similar extraction appears in Breitner et al. [9].
- Gemini fails to extract reasons in some runs but not others, e.g. in Burnett et al. [10], the first run generates NAs in the reasons, but the remaining four runs are identical. In Ueda et al. [46] and Castillejos et al. [12], runs 1 and 5 fail to extract the reasons and produce the same incomplete version, whereas runs 2, 3, and 4 produce accurate versions with reasons populated.

Table 8. Number of differences in the reason and decision fields across Gemini runs for papers with consistent number of decisions across runs.

Num. of difference	Count	Proportion (%)
0	358	79.73
1	12	2.67
2	8	1.78
3	0	0.00
4	24	5.35
5	12	2.67
6	3	0.67
7	0	0.00
8	10	2.23
9	6	1.34
10	10	2.23
11	6	1.34
Total	449	100.00

## 6.2 LLM models

Reading text from PDF document requires Optical Character Recognition (OCR) to convert images into machine-readable text, which currently is only supported by Antropic Claude (`claude-3-7-sonnet-latest`) and Google Gemini (`gemini-2.0-flash`).

We compare the number of decisions extracted by Claude and Gemini across all 62 papers in `?@fig-claude-gemini`. Each point represents a paper, with the x- and y-axes showing the number of decisions extracted by Claude and Gemini, respectively. The dashed 1:1 line marks where both models extract the same number of decisions. Most points fall below this line, indicating that Claude extracts more decisions – often from data pre-processing or secondary data analysis steps requiring more manual validation – whereas Gemini focuses more on modelling choices relevant to our analysis. Some of these decisions captured by Claude are

- the definition of “cold day” and “hot day” indicators in Dockery et al. [16] (“defined at the 5th/ 95th percentile”),
- the choice to summarize  $\text{NO}_2$ ,  $\text{O}_3$ , and  $\text{SO}_2$  using a “24 hr average on variable” in Huang et al. [21], and
- the definition of black smoke and in Katsouyanni et al. [26] for secondary analysis (“restrict to days with BS concentrations below  $150 \mu\text{g}/\text{m}^3$ ”).

Gemini sometimes also include irrelevant decisions, such as in Mar et al. [33], where secondary analysis choices like “0-4 lag days” for air pollution exposure variables ( $\text{CO}$ ,  $\text{EC}$ ,  $\text{K}_S$ ,  $\text{NO}_2$ ,  $\text{O}_3$ ,  $\text{OC}$ ,  $\text{Pb}$ ,  $\text{S}$ ,  $\text{SO}_2$ ,  $\text{TC}$ ,  $\text{Zn}$ ) are captured. However, these cases are less frequent, resulting in outputs with less noise overall.

For both Claude and Gemini, we find they fail to link the general term “weather variables” to the specific weather variables. For example Gemini misses this link in Dockery et al. [16] and Burnett et al. [11], while Claude does so in Dockery et al. [16] and Katsouyanni et al. [26]. Although our prompt specified that some decisions may require linking information across sentences and paragraphs to identify the correct variable, this instruction doesn’t appear to be applied consistently.

## 6.3 Text model

We have conducted sensitivity analysis on the text model for obtaining the decision similarity score from the Gemini outputs. The tested language models tested include

- 1) BERT by Google [15],
  - 2) RoBERTa by Facebook AI [32], trained on a larger dataset (160GB v.s. BERT’s 15GB),
  - 3) XLNet by Google Brain [49], and
- two domain-trained BERT models:
- 4) sciBERT [4], trained on scientific literature, and
  - 5) bioBERT [27], trained on PubMed and PMC data.

Figure 5 presents the distribution of the decision similarity (left) and paper similarity (right) for each text model. At decision level, the BERT model produces the widest variation across all five models, while the similarity scores from XLNet are all close to 1. These scores are not comparable across models since the difference of the underlying transformer architecture. However, the paper similarity scores from each model are comparable and `?@fig-text-mds` shows the multi-dimensional scaling (MDS) of the paper similarity scores from each text model: all showing a similar clustering pattern of the three main smoothing methods.

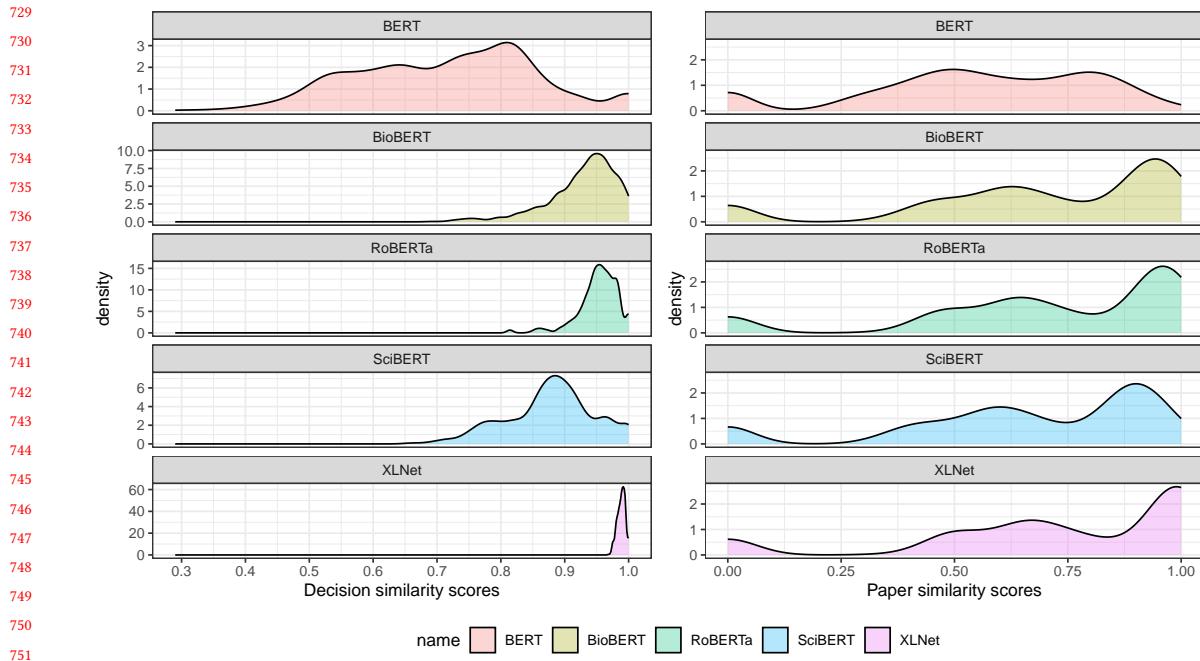


Fig. 5. Distribution of decision similarity (left) and paper similarity (right) scores for five different text models (BERT, BioBERT, RoBERTa, SciBERT, and XLNet). The default language model, BERT, produces the widest variation across the five models, while the similarity scores form XLNet are all close to 1. The model BioBERT, RoBERTa, and SciBERT yield decision similar scores mostly between 0.7 to 1.

## 7 Discussion

There are other decisions in an analysis that are worth comparing and documenting. For example data pre-processing decisions, e.g. how pollutant series are defined and collected, treatment on missing values, etc. Again, for a complete review of the field, these decisions ideally would be included, but for our demonstration of idea, we focus on the modelling decisions. Spatial decisions are generally not well captured because it often conducted uniformly as estimating the city individually to accommodate city heterogeneity. Some papers only consider a handful of cities, while in larger studies the individual city effects are then pooled together using random effect.

The variation in the choice of parameters degree of freedom or knot for smoothing can motivate separate investigation on the sensitivity analysis. For instance, parameters that exhibit a wide range of choices across studies may indicate areas of uncertainty or debate within the field, suggesting that further investigation is needed to assess their impact on study outcomes [38, 45].

With LLMs, the extraction of decisions from literature could be largely automated, but manual review is still needed to ensure the quality of the extracted decisions. We also find secondary LLMs can be used to standardize the extracted decisions, such as for temporal lag choices from text expressing this decision in various ways. In this work, we use prompt engineering to optimize the prompt for extracting decisions from general LLMs (Claude and Gemini). Fine-tuning a local model is an alternative approach for a locally-trained model. While it could potentially yield more accurate extraction and hence less manual review, for a systematic literature review, it would require substantially more

781 training efforts and a labelled decision dataset. We also find sometimes the prompt is not fully followed throughout the  
 782 extraction (example). Claude and Gemini...

783 With the advocacy for reproducibility in science, it is expected that more papers will share their code and data. The  
 784 availability of the code could be a supplementary source for understanding the decisions made in the analysis and cross  
 785 comparison of the manuscript with the code. However, given the lack of comments in the current practice, we are not  
 786 there to extract reasons for the decisions encoded in the script.  
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