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AssociationExplorer: A user-friendly shiny application for exploring associations and visual patterns

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ABSTRACT

AssociationExplorer is an open-source interactive R Shiny application designed to help non-technical users explore statistical associations within multivariate datasets. Aimed particularly at journalists, educators, and engaged citizens, the tool facilitates the discovery and interpretation of meaningful patterns between variables without requiring programming or statistical expertise. Users can upload structured data (e.g., from surveys or open government datasets), select relevant variables, and dynamically visualize relationships via a correlation network and contextual bivariate plots. To illustrate its capabilities, we present a case study based on the European Social Survey (ESS), showcasing how users can investigate links between attitudes, behaviors, and socio-demographic indicators across countries. The app supports a range of association measures adapted to variable types (Pearson's *r*, Eta, and Cramer's V), ensuring both flexibility and statistical rigor. The visual interface enables users to adjust thresholds for association strength and examine results through interactive graphs and summary tables, making the app particularly well-suited for data storytelling, exploratory research, and public communication. AssociationExplorer demonstrates how open-source statistical tools can enhance transparency, accessibility, and insight in the interpretation of complex social data.

Metadata

The metadata associated with the current version of the software is summarized in Table 1. The application has been developed and tested using R version 4.4.1 [1], ensuring compatibility with the package versions listed in the repository documentation.

The remainder of this paper is structured as follows. Section 1 outlines the motivation and significance of the application, highlighting its contribution to data accessibility and exploratory analysis. Section 2 provides a detailed description of the software's architecture and functionalities. Section 3 presents an illustrative example using data from the European Social Survey. Section 4 discusses the potential impact of the application on research, education, and journalism. Finally, Section 5 concludes with a summary and future directions.

1. Motivation and significance

The growing availability of large, complex, and high-dimensional datasets in the social sciences and public policy domains offers unprecedented opportunities for insight but also presents significant challenges for exploration and interpretation, particularly for non-specialist audiences. Journalists, educators, and engaged citizens often struggle to identify and interpret meaningful relationships between variables without the aid of programming skills or formal statistical training. This barrier limits the broader societal impact of open data initiatives, which are designed to promote transparency, accountability, and informed public discourse.

To address this gap, we developed AssociationExplorer, a free, open-source R Shiny [2] application that enables intuitive and statistically grounded exploration of multivariate associations. The tool guides users through a visual journey of variable relationships by automatically computing appropriate bivariate association measures–Pearson's *r*, Eta, and Cramer's V–depending on variable types, and presenting the results in an interactive correlation network. Users can set thresholds for the strength of association and explore linked bivariate plots or tables with descriptive labels. This workflow supports transparent, reproducible, and non-technical exploratory data analysis (EDA).

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Table 1
Code metadata.

Nr.	Code metadata description	Metadata
C1	Current code version	v3.5.7
C2	Permanent link to code/repository used for this code version	https://github.com/AntoineSoetewey/AssociationExplorer
C3	Permanent link to Reproducible Capsule	https://codeocean.com/capsule/7707308/tree
C4	Legal Code License	MIT License
C5	Code versioning system used	Git/GitHub
C6	Software code languages, tools, and services used	R, R Shiny
C7	Compilation requirements, operating environments & dependencies	See a list of the required R packages at https://github.com/AntoineSoetewey/AssociationExplorer/blob/main/packages.md
C8	If available link to developer documentation/manual/screencast	https://github.com/AntoineSoetewey/AssociationExplorer/tree/main/documentation
C9	Support for questions or issues	https://github.com/AntoineSoetewey/AssociationExplorer/issues

Our software is particularly suited to survey-based datasets and public opinion studies. As an illustrative case, we apply AssociationExplorer to the European Social Survey (ESS), a cross-national survey that collects attitudinal, behavioral, and socio-demographic data across European countries. The tool allows users to uncover associations between trust in institutions, policy preferences, media usage, and demographic characteristics without any coding. This type of interactive analysis can empower journalists to build data-driven narratives, educators to teach statistical thinking, and citizens to explore evidence underlying public debates.

While several tools and libraries exist for correlation analysis (e.g., `corrr` [3], `GGally` [4], `corrplot` [5], `ggstatsplot` [6], `correlation` [7,8], `lares` [9] and `Hmisc` [10] in R [1], or Python packages like `seaborn` [11] and `pingouin` [12]), they typically require programming proficiency and focus primarily on numerical associations. Most of these tools do not handle nominal categorical variables directly; if included, such variables are often transformed using one-hot or dummy encoding, which can alter their original structure and limit interpretations.

In contrast, AssociationExplorer is designed to handle both quantitative and qualitative variables (including nominal factors) natively and transparently. It provides a guided, end-to-end workflow that begins with data upload and preprocessing, continues through variable selection and association filtering, and ends with interpretable visualizations. This structured process is intuitive and accessible for users of all backgrounds, making the app especially suitable for those without programming experience or formal statistical training. By lowering the technical barrier for statistical exploration, AssociationExplorer contributes to a more inclusive data culture and supports data-driven discovery in both academic and public-facing contexts.

2. Software description

2.1. Software architecture

Upon upload, the dataset is preprocessed to exclude variables with zero variance, as these variables do not vary across observations and therefore cannot contribute to meaningful associations or visualizations. Removing them helps reduce noise and ensures that only informative variables are included in the analysis. Optionally, the user can provide a variable description file, which is integrated and used to annotate visual elements. The backend computes association measures tailored to the variable types: Pearson's r for numeric pairs, Cramer's V for categorical pairs, and the correlation ratio (η) for mixed pairs. Associations are filtered using user-defined thresholds and represented in a correlation network and complementary bivariate plots. The app handles both CSV and Excel files.

The application is currently available as a standalone open-source R Shiny application on GitHub.[1] It can be launched directly from an R session using the following command, provided the `shiny` package is installed:

```
library(shiny)
runGitHub("AssociationExplorer", "AntoineSoetewey")
```

A fully web-based version, requiring no installation or technical setup, is also planned as part of its integration into a broader online platform developed within the ODALON (Open Multimodal Data for Automated Local News) research project, which aims to support the production of local news (more information about this project in Sections 3 and 4).

2.2. Software functionalities

The major functionalities of the AssociationExplorer application include:

- **Data upload and cleaning:** The app supports CSV and Excel files. It automatically removes variables with only one unique value, as they lack variability and cannot contribute to association analyses. Additionally, it can optionally integrate user-supplied descriptions of variables, which are used to enhance the clarity and interpretability of visualizations, particularly for non-technical users. The description file must be structured with two columns: `Variable` (containing the exact variable names as in the dataset) and `Description` (containing the corresponding descriptions).
- **Variable selection interface:** Users can interactively choose which variables to explore. When a description file is provided, a summary table links variable names to their descriptions.
- **Dynamic association filtering:** The app computes pairwise association measures between all selected variables, using a method tailored to the types of variables involved:
  - For pairs of numeric variables X and Y, the app calculates Pearson's correlation coefficient (r), and retains the association if the coefficient of determination (R^2) exceeds a user-defined threshold:

$$R^2 = r^2 = (\text{cor}(X, Y))^2 \tag{1}$$

    where the Pearson's correlation coefficient $\text{cor}(X, Y)$ is defined as:

$$r(X, Y) = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \tag{2}$$

    where $\bar{X}$ and $\bar{Y}$ are the sample means of X and Y, respectively, and n is the number of observations.
  - For pairs of categorical variables, it computes Cramer's V, a normalized measure of association derived from the chi-squared

[1] https://github.com/AntoineSoetewey/AssociationExplorer.

statistic:

$$V = \sqrt{\frac{\chi^2}{n \cdot \min(k-1, r-1)}} \tag{3}$$

where χ^2 is the chi-squared statistic, n is the total number of observations, and k, r are the numbers of categories in each variable.

– For mixed pairs (one numeric and one categorical variable), the app computes the correlation ratio (η), which quantifies how much of the variance in the numeric variable is explained by the grouping structure of the categorical variable. It is defined as:

$$\eta = \sqrt{\frac{\mathrm{SS}_{\text{between}}}{\mathrm{SS}_{\text{total}}}} \tag{4}$$

where:

– $\mathrm{SS}_{\text{total}}$ is the *total sum of squares* of the numeric variable:

$$\mathrm{SS}_{\text{total}} = \sum_{i=1}^{n} (y_i - \bar{y})^2$$

with y_i the observed numeric values and $\bar{y}$ their overall mean.

– $\mathrm{SS}_{\text{between}}$ is the *between-group sum of squares*, computed as:

$$\mathrm{SS}_{\text{between}} = \sum_{g=1}^{G} n_g (\bar{y}_g - \bar{y})^2$$

where G is the number of groups (categories), n_g is the number of observations in group g, $\bar{y}_g$ is the group mean, and $\bar{y}$ is the overall mean.

This formulation captures the proportion of the total variance in the numeric variable that can be attributed to differences between the categorical groups. A pair is retained only if η^2 exceeds the numeric threshold defined by the user.

Each association is retained only if its corresponding strength metric–R^2, η^2, or Cramer's V–exceeds the threshold set by the user. These thresholds can be adjusted interactively through the interface, and the filtering process is reactive: updates to the thresholds immediately propagate to the network and bivariate visualizations. This allows users to dynamically control the sensitivity of the association analysis and focus on relationships of substantive interest.

- **Interactive correlation network:** The filtered associations are displayed as an interactive graph where nodes represent variables and edges represent associations. Edge thickness and length reflect the strength of the association: stronger associations are shown with thicker and shorter edges, whereas weaker associations are displayed with thinner and longer edges. For quantitative–quantitative pairs specifically, the color of the edges conveys direction: red edges indicate negative associations, while blue edges indicate positive ones. This combination of visual cues helps users quickly identify the most meaningful relationships in the network. When hovering over nodes, variable descriptions are displayed if a description file has been provided by the user; otherwise, the variable names are shown by default. This allows for quick access to additional context without cluttering the visualization, enhancing interpretability while keeping the network clean and readable. The network is built using the `visNetwork` R package [13], which supports interactive and customizable graph layouts. Full documentation is available at https://datastorm-open.github.io/visNetwork/.
- **Bivariate visualization of variable pairs:** For each variable pair exceeding the threshold:
  – Scatter plots with linear regression lines are shown for numeric pairs, helping visualize the direction and strength of the relationship. The regression line is computed using the ordinary least squares (OLS) method, which minimizes the sum of squared vertical distances between the observed data points and the fitted line.
  – Colored contingency tables with marginal sums are shown for categorical pairs, where cell background colors vary in intensity according to the frequency of observations, using a blue gradient to highlight higher counts.
  – Mean plots are shown for numeric-categorical pairs, with bars ordered by mean value to make it easy to compare and rank categories based on the quantitative variable.

  Confidence intervals for the regression lines and standard errors in the mean plots are intentionally omitted to maintain a clean, uncluttered visualization that prioritizes ease of interpretation. Mean plots were selected over boxplots to avoid overwhelming non-expert users with distributional information, focusing instead on clear, accessible insights about average group differences.
- **Accessibility and user guidance:** A dedicated help section explains each step, allowing users with a limited statistical background to interactively explore their data.

2.3. Sample code snippets analysis

A representative excerpt from the application is provided in Code 1. This snippet illustrates how the software selects the appropriate association measure based on the types of the variable pair and applies user-defined thresholds to retain only sufficiently strong associations.

```
# Numeric vs numeric case
if (is_num1 && is_num2) {
...
r <- cor(x, y, use = "complete.obs")
cor_val <- ifelse(r^2 >= threshold_num, r, 0)
cor_type <- "Pearson"

# Categorical vs categorical case
} else if (!is_num1 && !is_num2) {
...
tbl <- table(x, y)
...
n_obs <- sum(tbl)
df_min <- min(nrow(tbl) - 1, ncol(tbl) - 1)
if (df_min > 0) {
  v_cramer <- sqrt(chi$statistic/(n_obs * df_min))
  cor_val <- ifelse(v_cramer >= threshold_cat,
  v_cramer, 0)
  cor_type <- "Cramer"
}
# Mixed case (numerical vs categorical)
} else {
...
means_by_group <- tapply(num_var, cat_var,
mean, na.rm = TRUE)
overall_mean <- mean(num_var, na.rm = TRUE)
n_groups <- tapply(num_var, cat_var, length)
bss <- sum(n_groups * (means_by_group - overall_mean)^2,
na.rm = TRUE)
tss <- sum((num_var - overall_mean)^2, na.rm = TRUE)
if (tss > 0){
eta <- sqrt(bss/tss)
cor_val <- ifelse(eta^2 >= threshold_num, eta, 0)
cor_type <- "Eta"
  }
}
```

Code 1: Selection of the association measure according to variable types.

This conditional structure ensures that the correct statistical method is applied for each type of variable pair, supporting a robust and interpretable exploration of associations.

3. Illustrative example

To demonstrate the core functionalities of AssociationExplorer, we use a curated subset of data from the European Social Survey (ESS), Round 11. The ESS is a large-scale, cross-national survey that measures attitudes, beliefs, and behaviors across European countries. The original dataset includes responses from over 46,000 individuals on topics such as politics, trust, well-being, media use, and health. The full ESS dataset, codebook, and documentation are freely available at https://ess.sikt.no/en/ [14,15].

For this example, we focus on the Belgian respondents, resulting in a reduced dataset of 1,594 individuals. We selected 60 variables covering areas highly relevant for understanding public opinion and everyday life in Belgium: interest in politics, confidence in institutions, lifestyle behaviors, perceived discrimination, vaccination, and more. These variables include both numbers (quantitative data) and labels or categories (qualitative data), making the dataset ideal for exploring diverse forms of associations.

This example is particularly relevant for our research project ODALON, which aims to develop a platform that supports the (semi-)automated production of local news in Belgium. AssociationExplorer plays a key role in this effort by offering journalists, researchers, and citizens an intuitive tool to explore potentially newsworthy patterns in public and survey data, without requiring programming skills or statistical training.

Data preparation for the curated dataset was carried out in R and included:

- Filtering the dataset to include only Belgian respondents.
- Converting survey-specific nonresponse codes (e.g., `77`, `88`, `9999`, etc.) to `NA` values, based on the ESS codebook.
- Recoding several categorical variables to have meaningful and interpretable labels (e.g., for gender, religion, political participation, or health behaviors).

The full R script used to perform this transformation is openly available in the `data` folder of the GitHub repository at https://github.com/AntoineSoetewey/AssociationExplorer/tree/main/data.

Once the dataset is uploaded into AssociationExplorer via the `Data` tab (see Fig. 1), users are guided through a step-by-step process. In addition to the main dataset, users can optionally upload a separate description file that provides human-readable explanations for each variable. In our example, this file was created using information from the official ESS codebook, allowing for clearer interpretation throughout the app interface. If no description file is provided, the application will automatically use the variable names themselves as default labels in all visualizations and summary tables.

In the `Variables` tab, they select the variables they wish to explore, optionally assisted by a table of the variables' names and descriptions (see Fig. 2).

Next, users can adjust the association thresholds in the `Correlation Network` tab to focus on the most meaningful relationships among the selected variables (see Fig. 3).

Finally, the `Pairs Plots` tab displays detailed bivariate visualizations, including scatter plots, mean plots, and contingency tables, for each retained association (see Figs. 4–6).

In addition, the `Help` tab provides a concise, step-by-step guide on how to use the application (see Fig. 7).

Each visualization panel includes contextual download controls to facilitate the reuse of figures and tables (e.g., in reports or data-journalism pieces). The correlation network can be exported directly as a PNG image, and each pairwise association displayed in the Pairs Plots tab can likewise be downloaded as an image. Scatterplots, mean plots, and contingency tables are saved with the same styling and labels as shown on screen, ensuring full visual consistency between the interactive interface and the exported outputs.

This example shows how non-expert users, such as journalists or engaged citizens, can uncover unexpected or important relationships in a public opinion dataset. These insights can serve as the starting point for local news, public debates, or policy communication. A screencast demonstrating the full workflow of the application is available in the documentation folder of the GitHub repository.

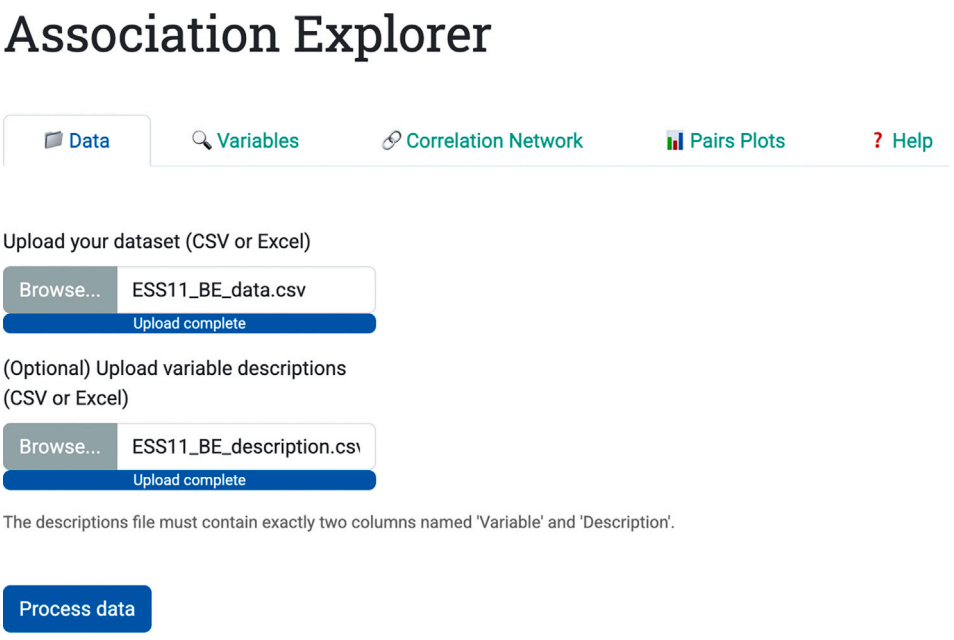

Fig. 1. Data upload tab. Users upload their dataset and can optionally provide a variable description file containing variable names and descriptions.

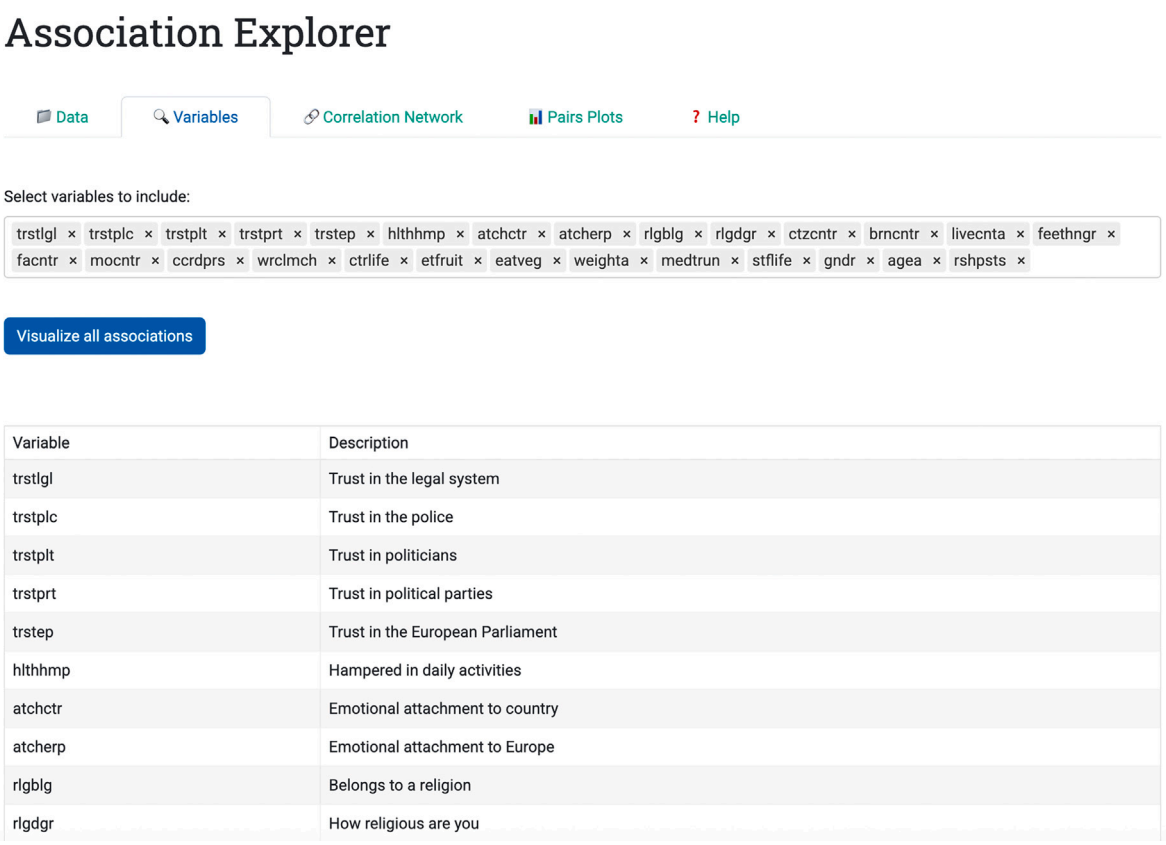

Fig. 2. Variables tab. Users select the variables to include in the analysis, with access to descriptions (if provided in the data tab) for easier selection.

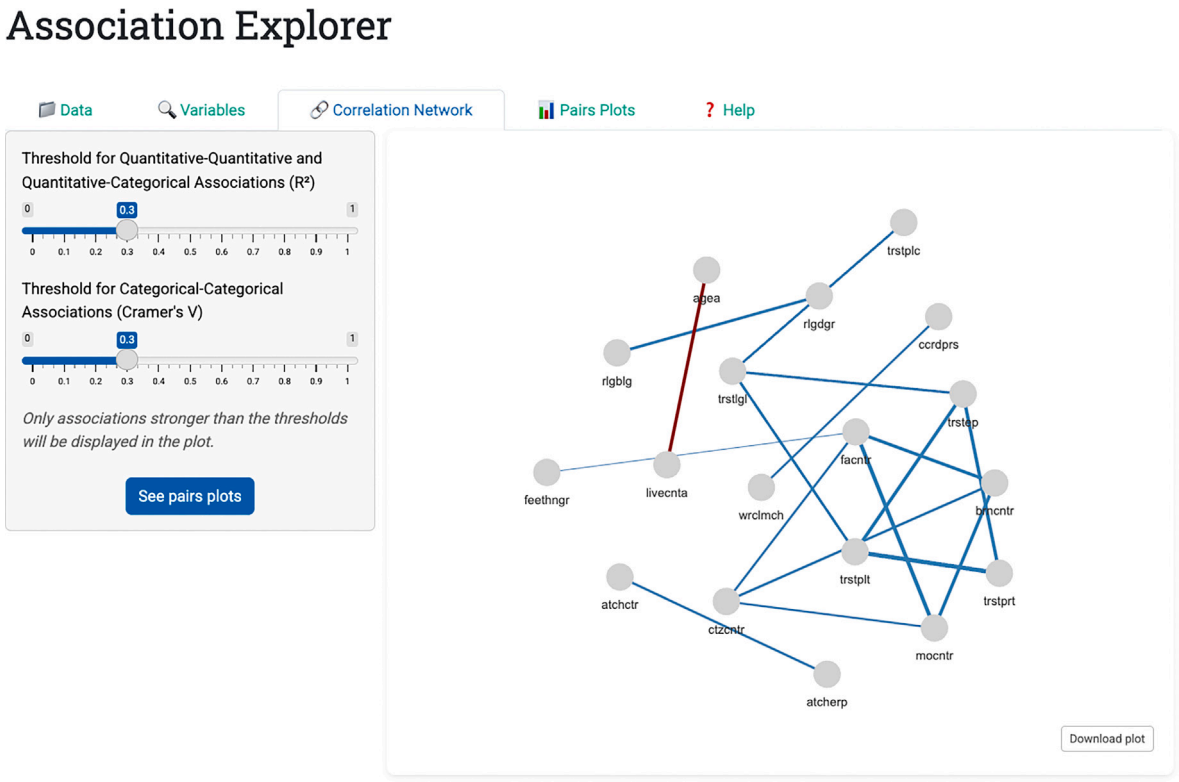

Fig. 3. Interactive correlation network. Nodes represent variables and edges represent associations; edge thickness and length indicate strength, and edge color reflects direction (for numeric pairs only).

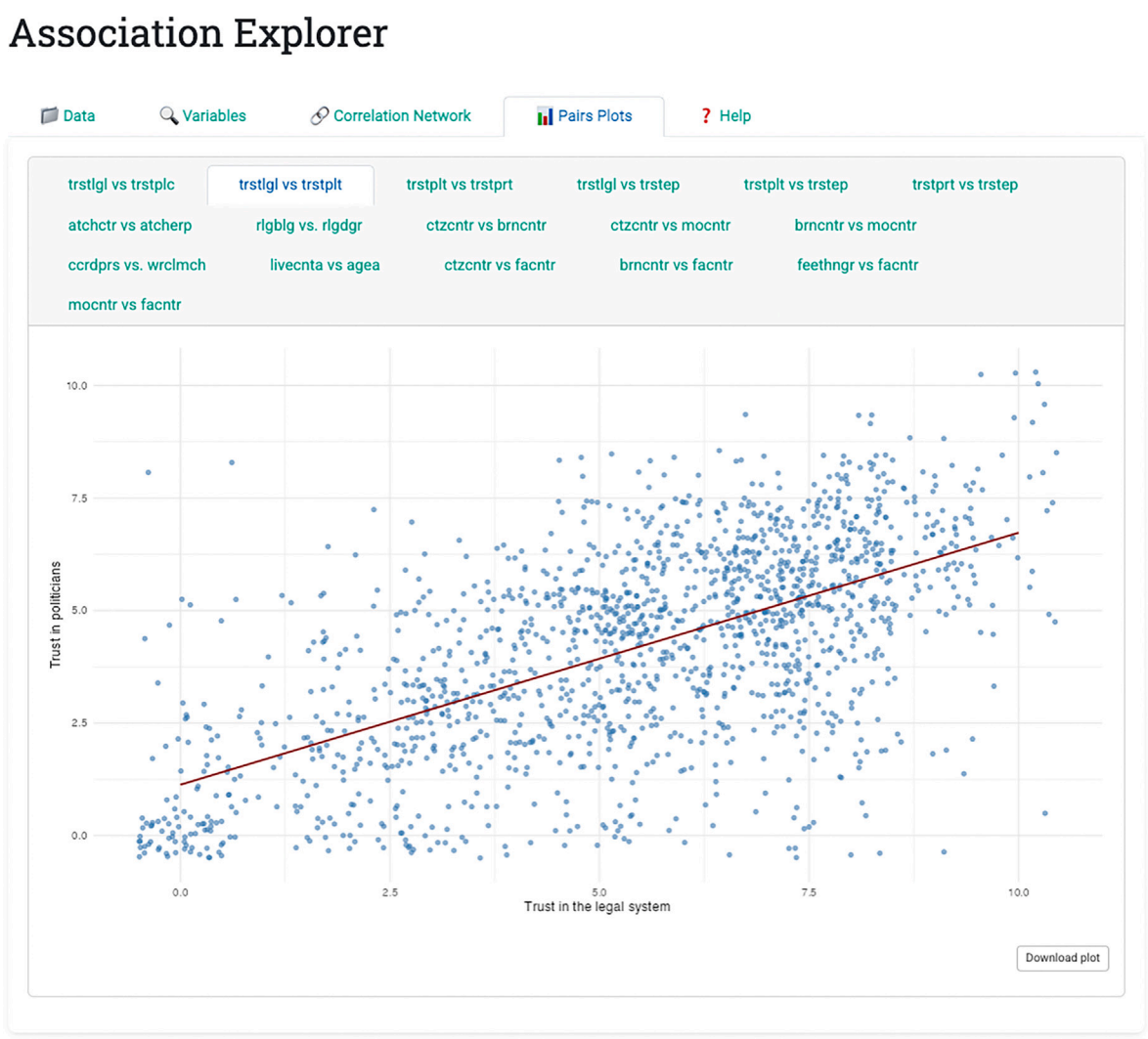

Fig. 4. Example of a scatter plot for a numeric-numeric pair. The plot includes a linear regression line fitted via ordinary least squares (OLS).

Note that in this example, no survey weights have been applied. While the ESS dataset includes weights to account for complex sampling designs, we chose not to use them here in order to maintain clarity and responsiveness in the interface, and because our focus is on demonstrating the app's core functionality rather than producing nationally representative statistics.

4. Impact

AssociationExplorer enables a broader range of users, including researchers, students, journalists, and engaged citizens, to explore complex datasets involving both quantitative and qualitative variables. By eliminating the need for advanced programming or statistical knowledge, the software lowers the barrier to entry for data-driven discovery and interpretation. The app facilitates the systematic screening of pairwise associations in survey or public data, offering insights that can guide hypothesis generation, variable selection, or further multivariate modeling.

It also facilitates the assessment of relationships between variables of different types (numeric, ordinal, and nominal) within a single unified interface. Unlike many tools that require preprocessing steps such as dummy coding, AssociationExplorer handles categorical variables natively and automatically selects the appropriate statistical association measure (i.e., Pearson's r, Cramer's V, correlation ratio η). This ensures that users can obtain meaningful and interpretable results without needing to master complex preprocessing steps or statistical diagnostics.

Beyond supporting research, we are convinced that automating these statistical processes can contribute to the promotion of open public data repositories. In fact, the scientific literature points to a chronic underuse of open public data [16], particularly due to the resources and knowledge required to process these data. By lowering this barrier to entry, this tool makes it possible to utilize databases that would otherwise remain inactive. The exploitation and understanding of these data respond to crucial issues of transparency in public action [17].

Although this tool is open to anyone, its development was particularly inspired by its use in a journalistic context. Data journalism, in particular, is one of those examples of virtuous practice that we believe is best suited to supporting the open data movement. This practice, which relies on the use of digital data as material for journalistic investigation [18], is now used to analyze election results, explain climate change, and track the evolution of health crises. However, it comes at a cost, which explains why this practice is still limited to a few large national media outlets.

However, it would be detrimental to leave these practices inaccessible to local newsrooms. By covering events that are often overlooked by national media, these local media outlets can highlight data that would otherwise be ignored (finance, consumption, police, municipal council records, etc.). Supporting data journalism at the local level can also help

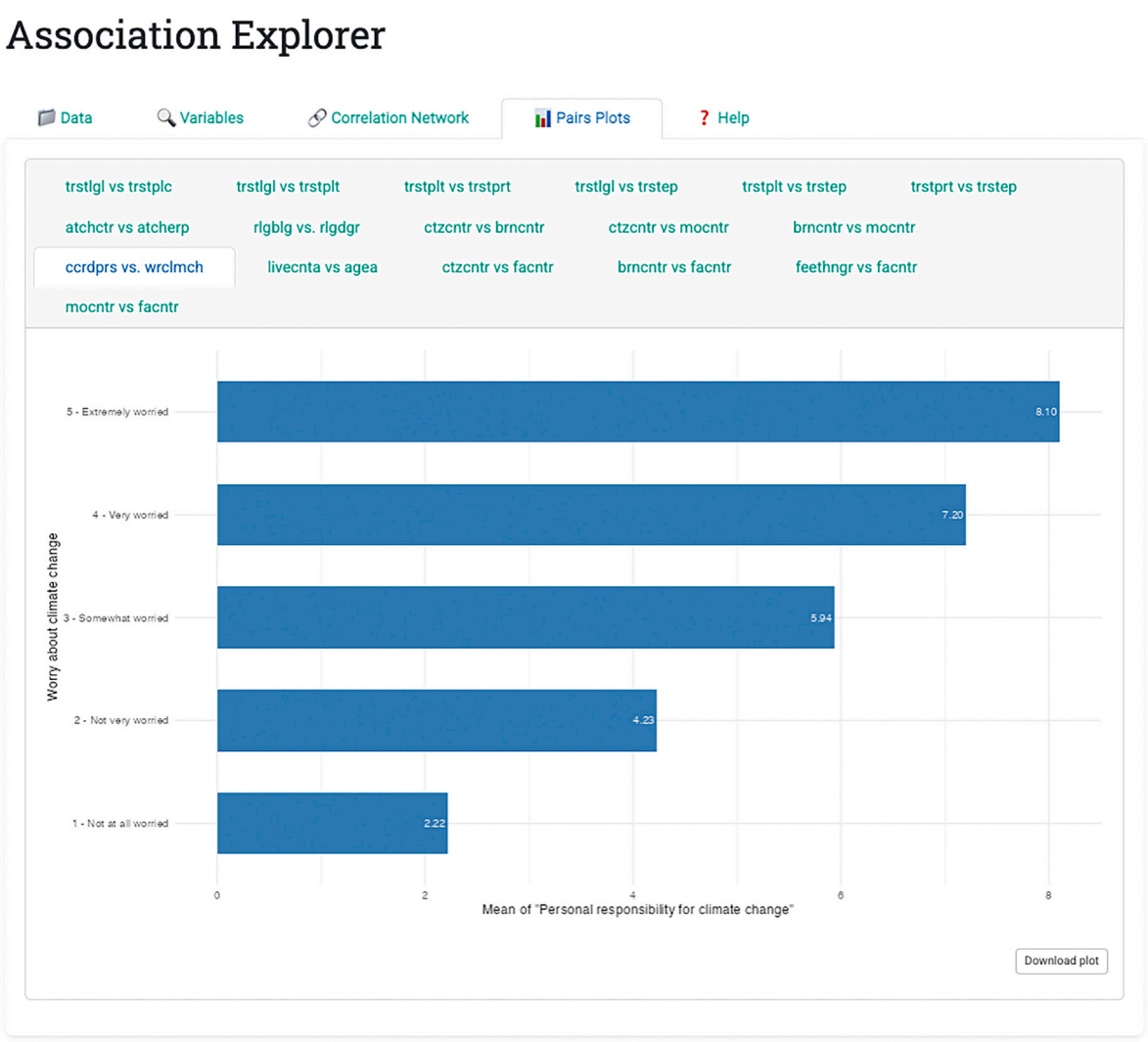

Fig. 5. Example of a mean plot for a numeric-categorical pair. Categories are ordered by the mean value of the quantitative variable to aid interpretation.

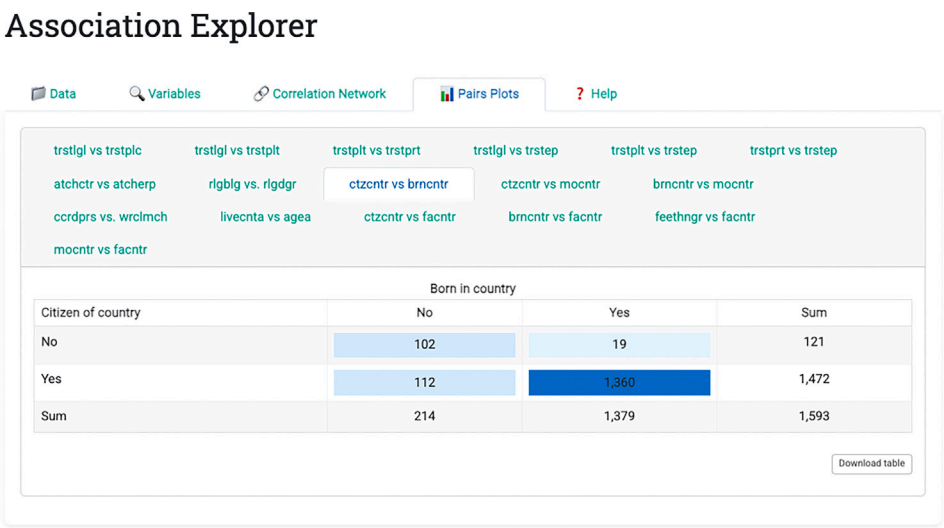

Fig. 6. Example of a colored contingency table for a categorical-categorical pair, with color intensity reflecting frequencies and marginal sums displayed.

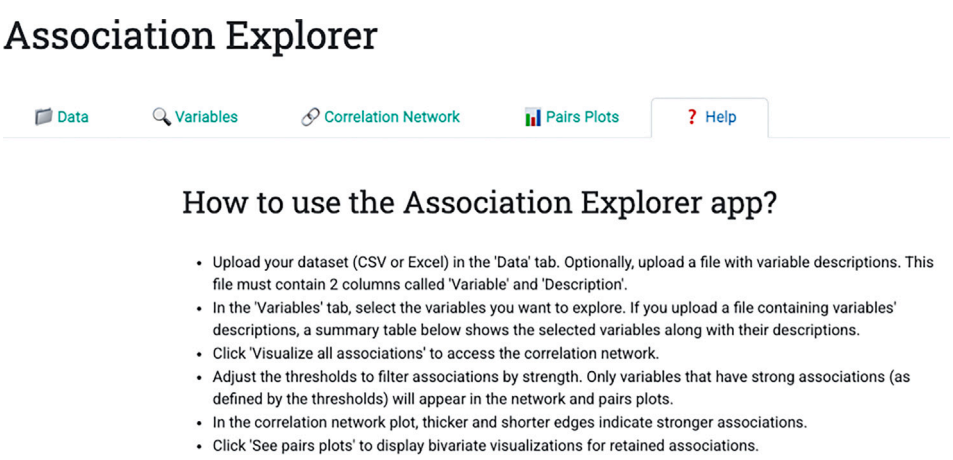

Fig. 7. Help tab, offering guidance on how to use the application.

to enhance the value of this journalistic practice, which has been shown to strengthen social cohesion [19], stimulate civic participation [20], and influence public policies [21].

While national media outlets are struggling, these challenges are even more pronounced for local media, which generally face the same problems but with even more limited resources [22]. As a result, few institutions have the means to meet the labor and skill requirements necessary for this investigative practice [23]. We hope that AssociationExplorer can help meet these needs. The app is also planned to be used as an interactive teaching aid in statistics and data literacy courses. It will allow students to upload real datasets and immediately visualize how variables relate, reinforcing theoretical concepts through intuitive, hands-on exploration. By presenting associations visually, the app encourages learners to engage with their data more actively and reflect critically on patterns, variable relationships, and data quality.

Although already fully functional, the software is currently made available as a standalone open-source R Shiny application on GitHub and can be launched directly from R. At this stage, it is therefore only accessible to users who have R installed on their machine. As part of a broader research project called ODALON, which aims to build an integrated platform combining multiple tools for automated local news production, AssociationExplorer will serve as a key building block. A public, fully online version of the app will be released as the project progresses, and no later than December 2026 (which corresponds to the end of the project), ensuring that anyone, including those without access to R, can freely use the application through a user-friendly web interface.

Future impact is expected through integration into platforms for civic data storytelling, local journalism, and public communication. While not intended for commercialization, the application's role in supporting open, inclusive, and responsible data exploration reflects its potential for broader societal relevance.

5. Conclusions

AssociationExplorer provides a user-friendly, open-source solution for exploring statistical associations within multivariate datasets. By integrating robust statistical measures with dynamic and intuitive visualizations, the app empowers non-expert users, such as journalists, educators, and engaged citizens, to uncover patterns and relationships that might otherwise remain hidden. Its ability to handle both quantitative and qualitative variables, combined with an interactive interface and an easy-to-follow workflow, makes it especially suitable for exploratory research, data storytelling, and public communication.

Beyond its technical features, the application contributes to democratizing access to statistical tools and supports data literacy in a wide range of contexts. The case study using the European Social Survey illustrates how users can navigate from raw data to meaningful insights with minimal technical knowledge.

While the app is currently accessible through R for users with basic technical setup, a fully web-based version will make it universally available as part of a broader data exploration platform being developed under the ODALON project. Before public deployment, performance will be systematically tested on larger datasets to ensure both responsiveness and reliability. Any identified limitations, such as reduced interactivity with high-dimensional data or memory constraints, will be clearly communicated to users through the application's documentation. By lowering barriers to data exploration and interpretation, AssociationExplorer supports more inclusive, transparent, and evidence-informed engagement with complex social data.

Future improvements will be guided by user feedback and community contributions. One planned feature is the ability to incorporate user-specified weights, especially relevant for survey data. However, this functionality is not yet implemented in the current version to preserve simplicity and ensure responsiveness in the user interface, particularly for users unfamiliar with survey weighting procedures. In the same spirit, future versions will also include a dedicated panel for basic graphic customization (e.g., color palettes, titles, and labels). Although not implemented at the current stage to preserve a lightweight and responsive interface for non-technical users, this feature is planned for the forthcoming public web-based release to enhance usability and flexibility.

Additional avenues for future research and development include extending the application to compute partial correlations, which can help isolate direct relationships between variables by controlling for confounders. Visualizations involving three variables could also be introduced, for instance, scatter plots where the size or color of points reflects a third variable, to uncover more nuanced patterns. Furthermore, users could be allowed to filter variables based on missingness thresholds or variable types, and a module for longitudinal data (e.g., panel structures or time series) could expand the app's relevance to temporal analyses. For contingency tables, adding conditional distributions (by row or by column) in addition to the joint distribution could provide more informative insights. This would allow users to better explore subsets of the data. For example, even if a group such is underrepresented in the sample (and therefore lightly colored in the joint table), the conditional distribution would still reveal the relative patterns within that group. Another enhancement could involve enabling two-sided intervals for the association thresholds, rather than the current one-sided sliders. This would allow users not only to focus on the strongest associations, but also to deliberately examine the weakest ones, thereby uncovering cases where variables appear largely independent. In addition, users

could be given the option to flip the X and Y axes in quantitative–quantitative pairs plots, providing greater flexibility when comparing variables and improving interpretability when relationships are more intuitively viewed in the reverse orientation. Providing interpretive text alongside tables and plots (especially if the application is deployed for non-specialist audiences) could also help ensure that outputs are understood correctly and used responsibly. Lastly, although the application includes built-in export options for visualizations and tables, future extensions could incorporate a dedicated panel for basic graphic customization, and even automated summaries of key associations, to further enhance its use in reporting and collaborative workflows.

A more ambitious extension would integrate a large language model (LLM) to enable users to enter a free-text prompt or a thematic query. The app would then automatically identify variables that are semantically similar or potentially associated with the theme, based on the dataset and the optional description file provided by the user. These extracted variables would be pre-selected in the interface, as if the user had chosen them manually, after which the analysis would proceed as in the current version. This feature could significantly enhance accessibility for users unfamiliar with the dataset or its structure, and accelerate the discovery of relevant associations.

CRediT authorship contribution statement

Antoine Soetewey: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Cédric Heuchenne:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Arnaud Claes:** Writing – review & editing, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Antonin Descampe:** Writing – review & editing, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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