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Computational Social Science Simulation for Democracy

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Abbreviations

D	Deliverable
EC	European Commission
WP	Work Package
WT	Work Task
GUI	Graphical User Interface
LLM	Large Language Models
SVRE	Simulation Visualization and Replay Environment

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1 Overview

The Simulation Visualization and Replay Environment (SVRE) is a modular software framework designed for the creation, execution, and analysis of agent-based simulations. It provides an integrated environment that enables users to model complex systems and socio-technical processes through the definition of autonomous agents and their interactions within a dynamic environment. Typical use cases include political, economic, or organizational scenarios where multiple heterogeneous actors interact based on configurable behavioural rules.

At its core, the system adopts a dynamic ontology-driven architecture, allowing the flexible definition and evolution of agent structures and relationships. This architecture supports semantic consistency across simulation components while enabling high levels of customization. Users can define or modify agent classes (e.g., voters, political parties, institutions) and their associated properties, such as preferences, decision rules, or interaction networks, directly within the platform.

A key innovation of the SVRE is its integration with Large Language Models (LLMs) for automated agent and property generation. Through the system's graphical user interface (GUI), users can configure LLMs for data generation, prompt design, and fine-tuning to produce realistic agent profiles or behavioural attributes. This hybrid approach significantly reduces manual data preparation efforts and enhances the representational richness of simulation models. Alternatively, users may import pre-defined agent data or attributes via structured formats such as CSV or Excel files, ensuring interoperability with external datasets or analytical workflows.

The results of simulation runs are captured and rendered through a dashboard-based visualization and analytics layer. Users can track temporal dynamics, compare scenario outcomes, and perform post-simulation analysis using predefined visual components or custom-built dashboards. The system supports custom dashboard creation, enabling domain-specific visualization of indicators and metrics relevant to decision-making or model validation.

Overall, the SVRE provides a robust and extensible infrastructure for agent-based modelling, simulation management, and result analysis, bridging the gap between human expertise and machine intelligence in complex decision environments.

2 Objectives

Objective of this deliverable is to establish the Simulation Visualization and Replay Environment (SVRE) prototype as the operational interface for scenario creation, execution, visualization, and replay, ensuring both the technical and analytical components of the HYB simulation ecosystem function cohesively.

3 Description of Work

The work package involves the integration of developed simulation components and data models into a unified and extensible architecture. The SVRE provides a modular, ontology-driven environment where users can define, configure, and deploy simulation scenarios involving heterogeneous agents such as voters, political parties, or institutions.

The framework's dynamic ontology structure ensures semantic consistency and interoperability between agents and datasets, facilitating the transition from conceptual simulation models to fully executable systems. This enables flexible customization of agent attributes, behaviours, and interaction rules to suit various modelling contexts.

A key enhancement is the integration of Large Language Models (LLMs) for automated agent and property generation. Through the SVRE's graphical interface, users can configure LLMs to produce diverse agent types, behavioural parameters, and environmental factors based on natural language

prompts or predefined templates. Alternatively, structured datasets (e.g., CSV or Excel files) can be imported to define agent properties and environmental parameters, ensuring interoperability with external data sources.

A distinctive and innovative component of the framework is its simulation replay capability. This function allows users to record, review, and analyse simulation runs post-execution, offering detailed playback of agent behaviours, interactions, and key decision events. Replay functionalities are essential for model validation, debugging, comparative scenario analysis, and enhancing the transparency and reproducibility of the simulation process.

Simulation outputs are visualized and analysed through a dashboard-based analytics layer. Users can monitor performance metrics, explore temporal trends, and compare simulation outcomes across scenarios. Moreover, the SVRE allows users to design and customize dashboards, enabling domain-specific visualization and reporting aligned with the analytical needs of researchers, policy analysts, or decision-makers.

4 Key Results

Integration of Agent-Based and RL Simulation Core: The HYB framework now incorporates both agent-based and reinforcement learning mechanisms, enabling adaptive and goal-oriented simulation behaviours.

Dynamic Ontology Framework Implemented: A flexible ontology system ensures semantic interoperability and scalability across diverse simulation datasets.

LLM-Driven Agent and Property Generation: Integration of LLMs facilitates automatic creation and configuration of agents and properties, reducing setup complexity and enhancing representational fidelity.

Data Import and Interoperability: Support for structured data inputs (CSV, Excel) allows seamless integration with external data sources and prior work packages.

Simulation Replay Capability: A full replay mechanism enables recording, playback, and detailed analysis of simulation dynamics, improving transparency, repeatability, and validation processes.

Customizable Dashboard Analytics: Users can design and manage personalized dashboards for visualizing outcomes and key performance indicators, facilitating targeted analytical insights.

5 User Features and Interface Capabilities

This section describes the main user-facing features and interface capabilities of the simulation and visualization platform. Each component provides a specific functionality for scenario design, data integration, simulation execution, and result analysis. Together, they form an integrated workflow from scenario definition to interactive visualization and reporting.

5.1 Select scenario template

The user interface allows users to select from a set of predefined scenario templates. These templates represent pre-configured models or simulation structures that serve as starting points for different use cases, such as political behaviour modelling, social network analysis, or policy impact simulations. Each template defines initial conditions, agent categories, ontology elements, and visualization parameters that can be further customized within the environment.

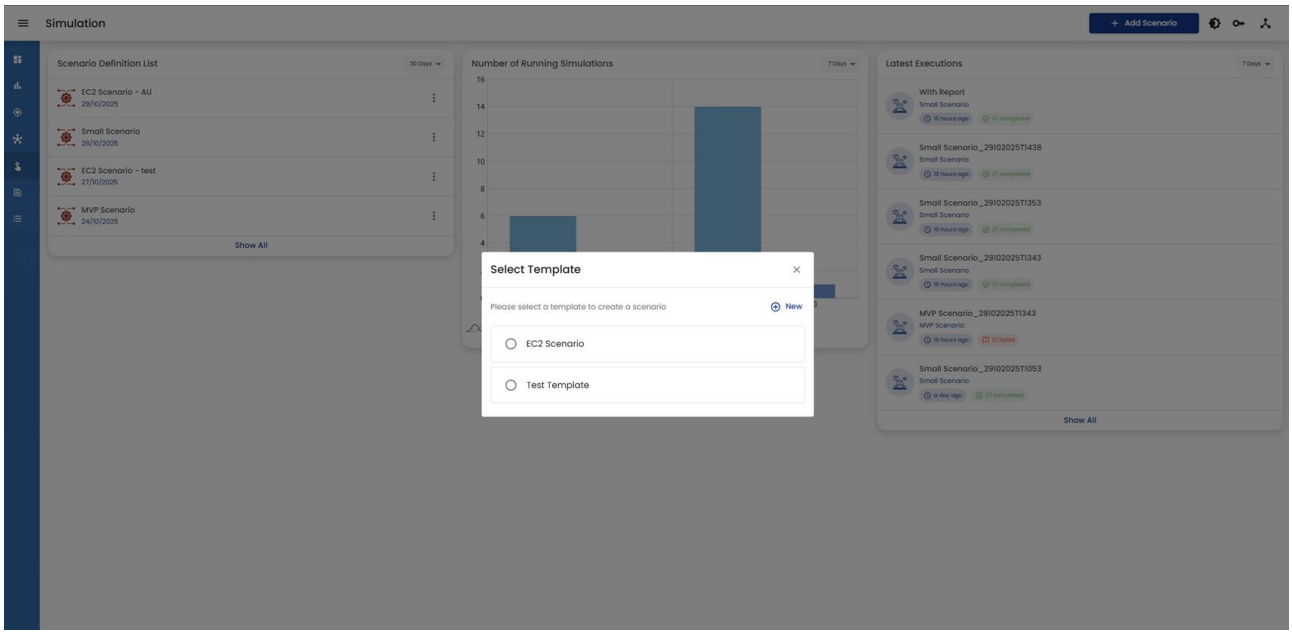

Figure 1. Select scenario template

5.2 Scenario template creation screen

This screen enables users to create and configure new scenario templates. Users can define agent classes, interactions, and structural parameters that can later be reused across multiple simulations. The interface provides form-based configuration tools and ontology integration to ensure semantic consistency between different scenario components.

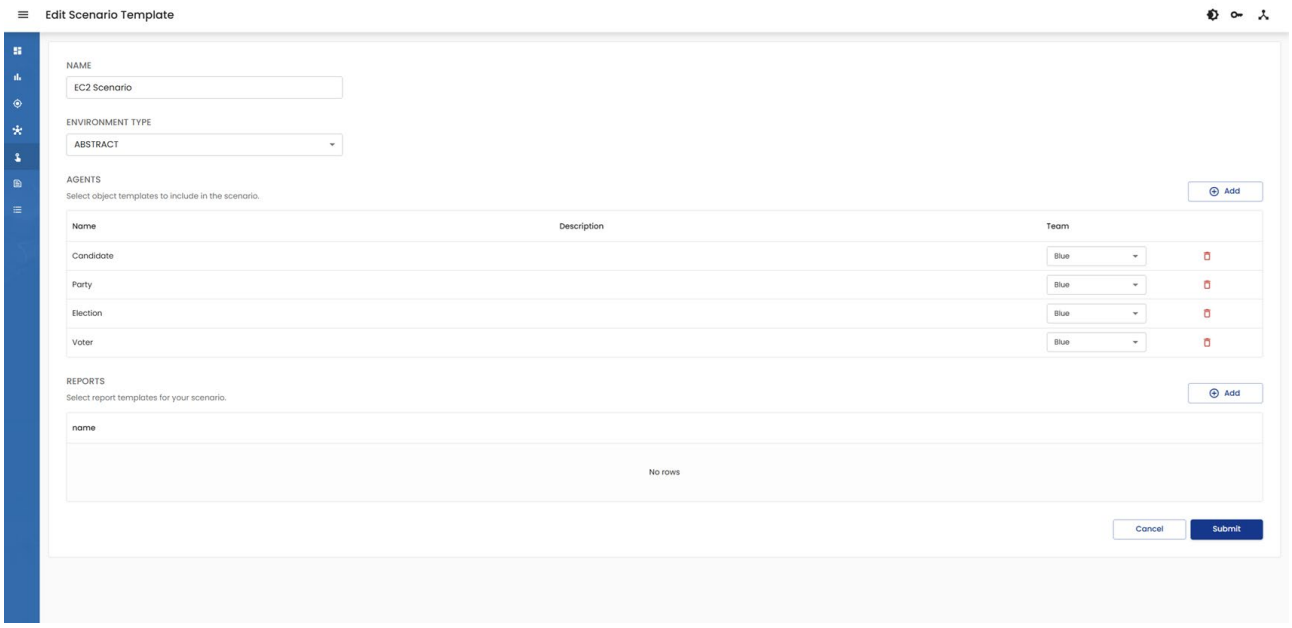

Figure 2. Scenario template creation screen

5.3 Scenario definition list

The scenario definition list provides an overview of all available scenarios in the system. Each entry includes metadata such as scenario name, type, creation date, and associated datasets. Users can

filter, sort, and select scenarios for further editing, duplication, or execution. The interface supports quick access to scenario configuration and execution modules.

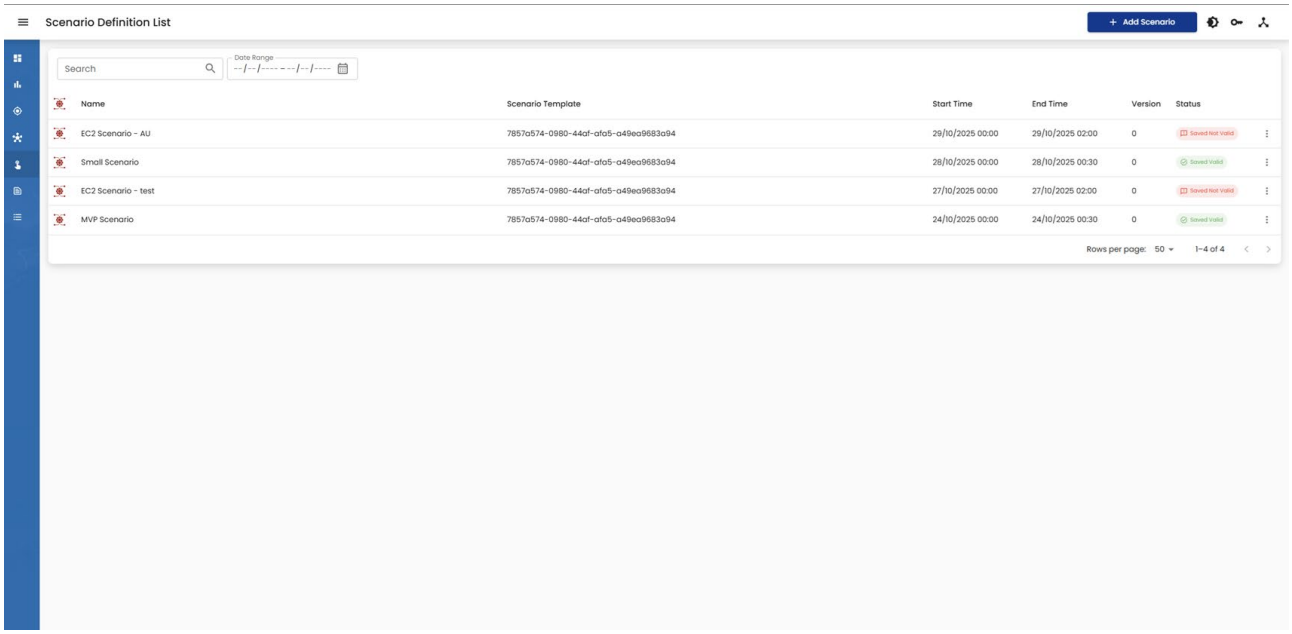

Figure 3. Scenario definition list

5.4 Scenario creation screen

The scenario creation screen allows users to define new simulation scenarios from scratch or modify existing templates. Users can specify the agent population, behavioural rules, simulation duration, and environmental parameters. Additionally, LLM-based agent generation tools can be invoked to automatically create realistic agent attributes or interactions, based on user-defined prompts or contextual data.

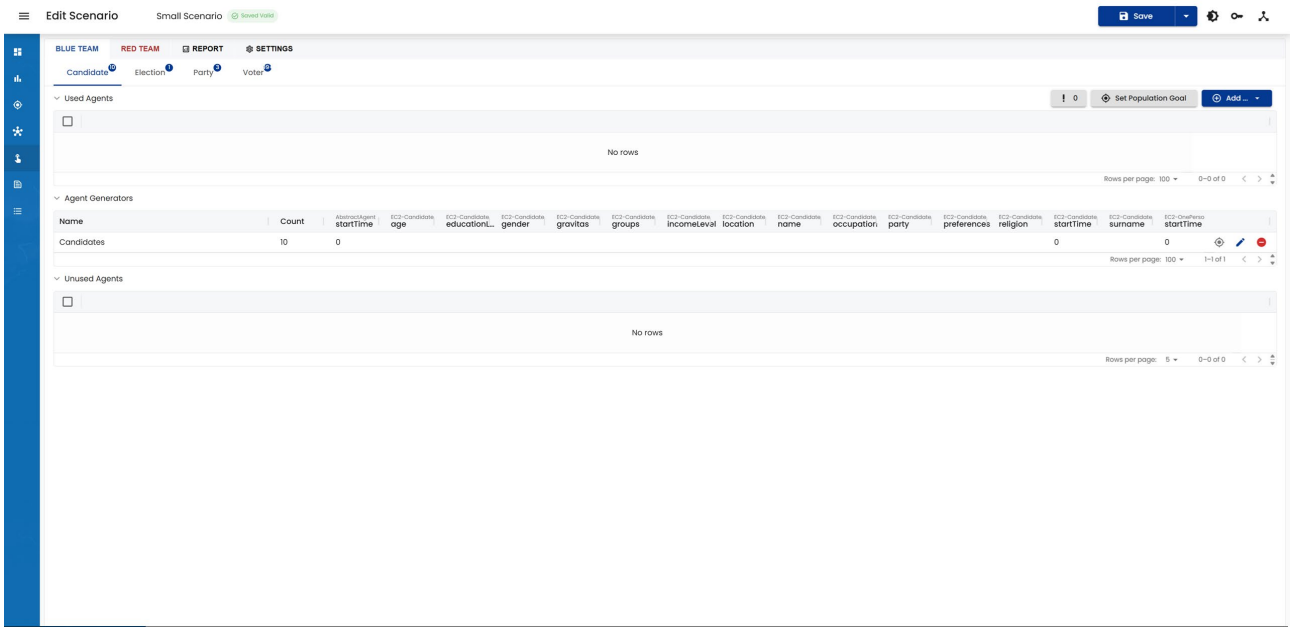

Figure 4. Scenario creation screen

5.5 Population import from CSV

The platform supports bulk population import through structured files such as CSV. This functionality enables users to load large datasets containing agent properties, demographic variables, or behavioural parameters. The system automatically validates and maps imported data to the ontology schema, ensuring consistency and correctness before simulation execution.

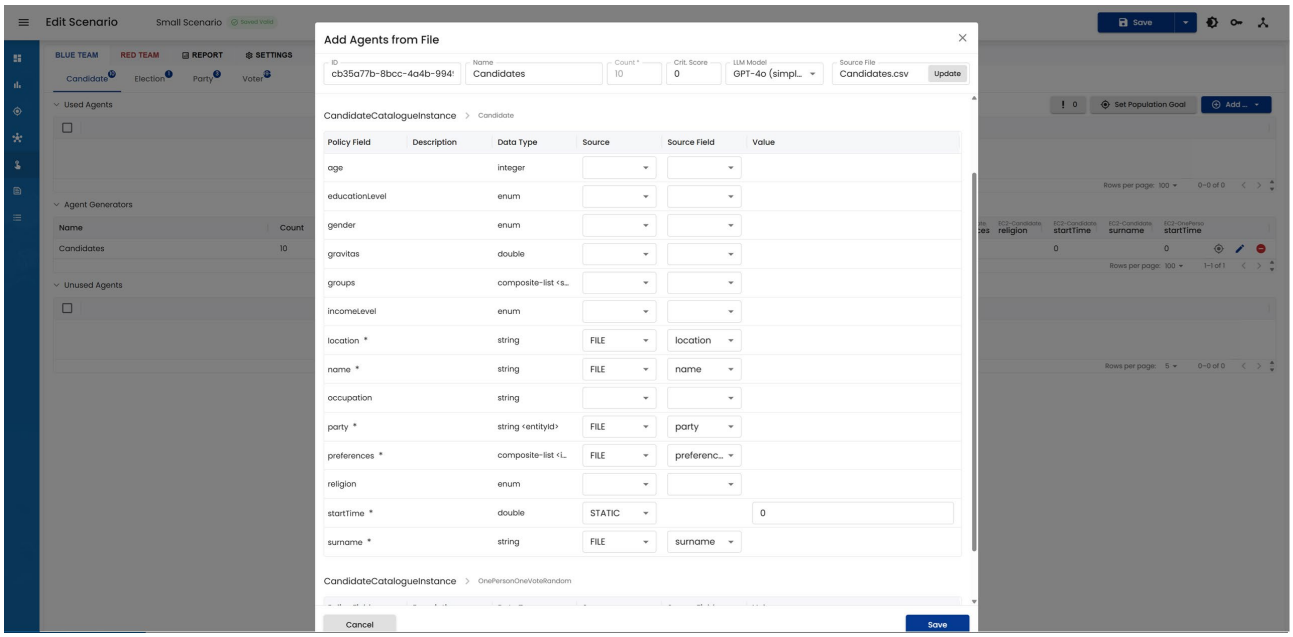

Figure 5. Population import from CSV

5.6 Creating individual agents

Beyond bulk import, users can manually create individual agents through the GUI. This feature is useful for adding specific actors or testing custom agent configurations. Users can define agent attributes (e.g., demographics, affiliations, preferences) and behaviours directly or generate them through LLM-assisted configuration tools integrated into the interface.

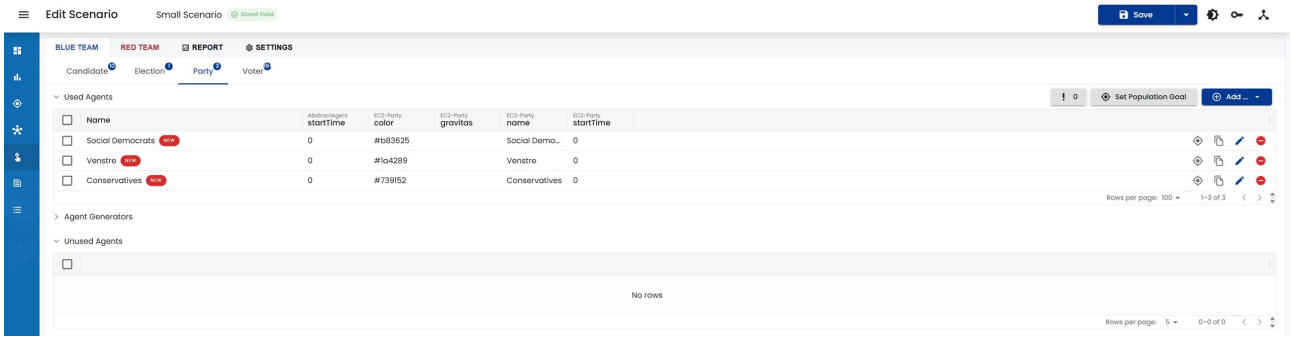

Figure 6. Creating individual agents

5.7 Configuring streaming data report for a scenario

Users can configure real-time streaming data reports that monitor ongoing simulations. This module allows users to select which variables or indicators to stream (e.g., vote shares, opinion shifts, interaction frequencies) and define update intervals. The streamed data is visualized through charts, dashboards, or exported in structured formats for further analysis.

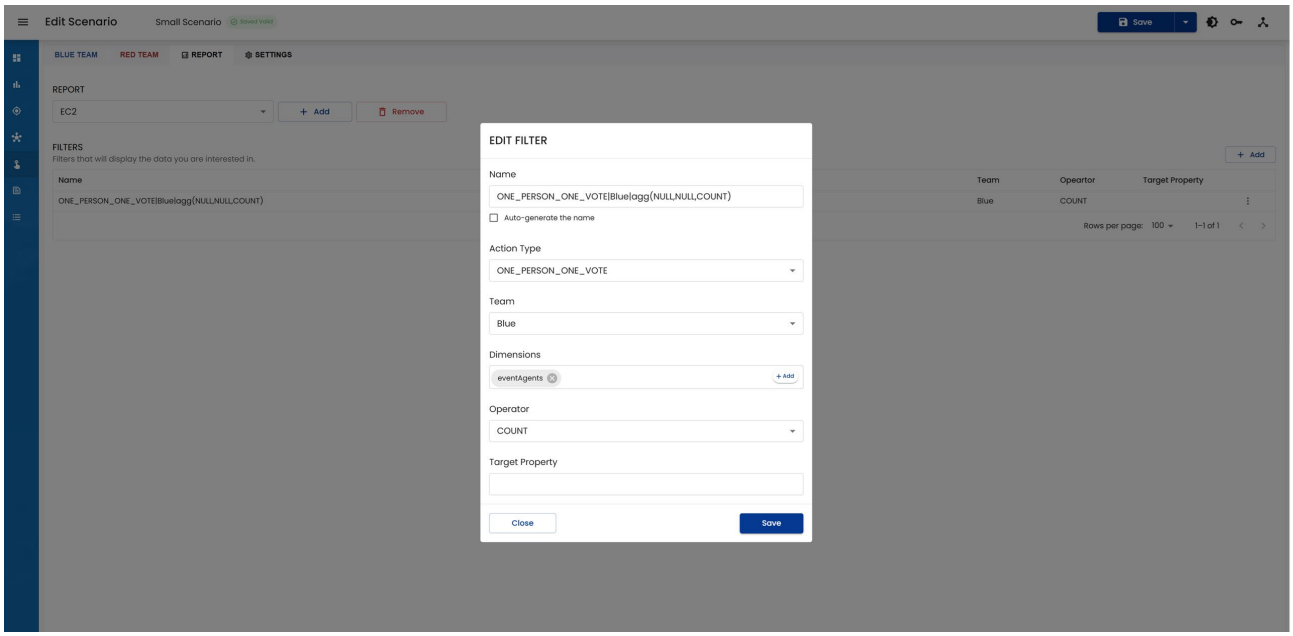

Figure 7. Configuring streaming data report for a scenario

5.8 Creating individual agents

Beyond bulk import, users can manually create individual agents through the GUI. This feature is useful for adding specific actors or testing custom agent configurations. Users can define agent attributes (e.g., demographics, affiliations, preferences) and behaviours directly or generate them through LLM-assisted configuration tools integrated into the interface.

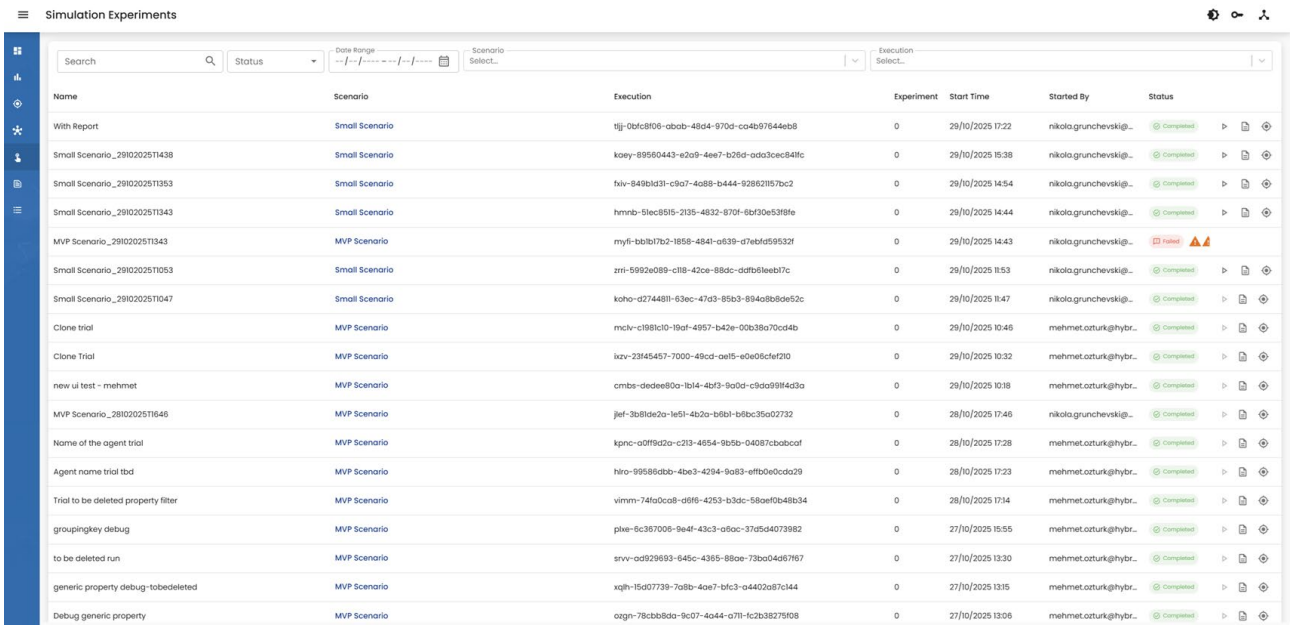

Figure 8. Creating individual agents

5.9 Summary report from streaming data

Following simulation execution, the system automatically generates a summary report based on the collected streaming data. The report includes statistical summaries, key indicators, and graphical

representations of simulation outcomes. Users can export these reports or customize them through the dashboard interface for documentation and comparison purposes.

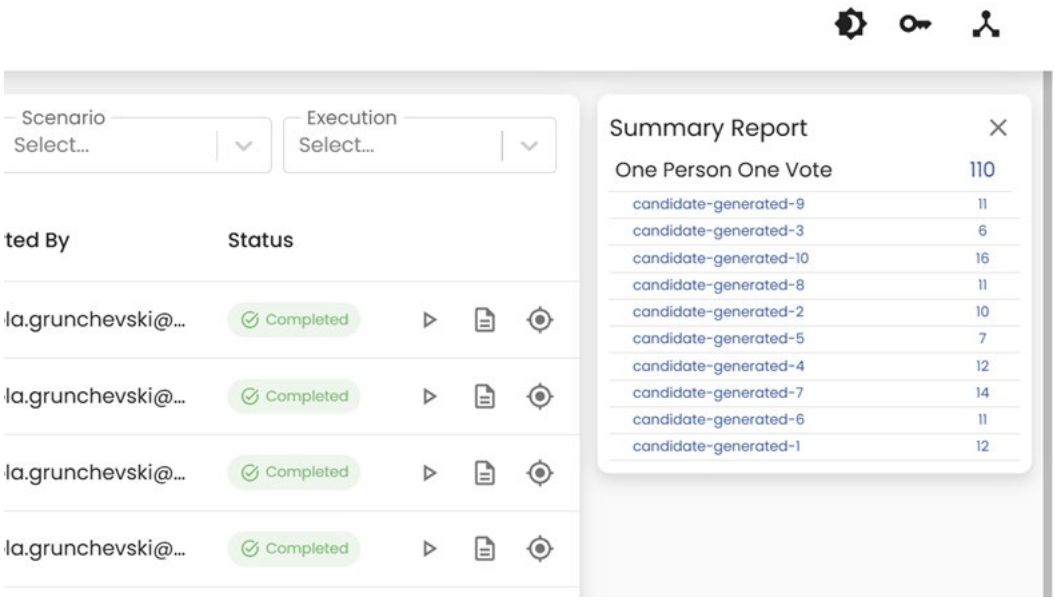

Figure 9. Summary report from streaming data

5.10 Dynamic ontology screen

The dynamic ontology screen provides an interactive interface for ontology management. Users can view, create, and edit ontology elements such as entities, relationships, and attributes. This ensures semantic alignment across all simulation components and facilitates data interoperability between different modules. Ontology modifications are automatically propagated throughout the system to maintain model consistency.

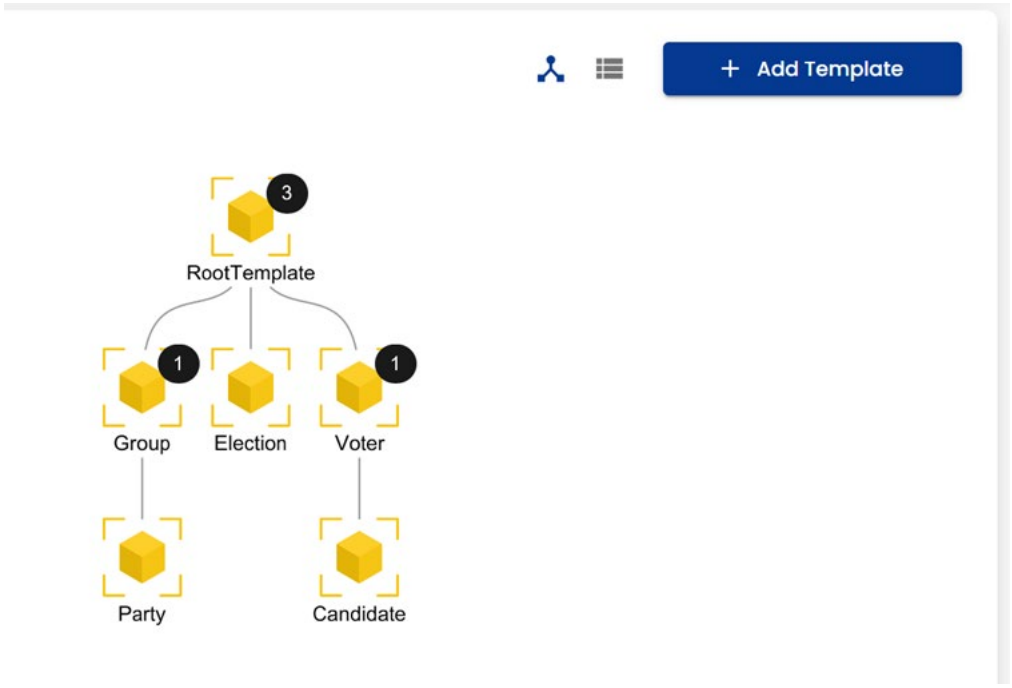

Figure 10. Dynamic ontology screen

5.11 Sample Dashboard: Election map

Users can visualize election results on a geographic map representing the city, segmented by postcode. Each region is color-coded according to the political party that received the highest number of votes. On the right panel, a data table lists all candidates along with the total votes they earned.This visualization provides an intuitive geographic overview of electoral dynamics and regional voting patterns.

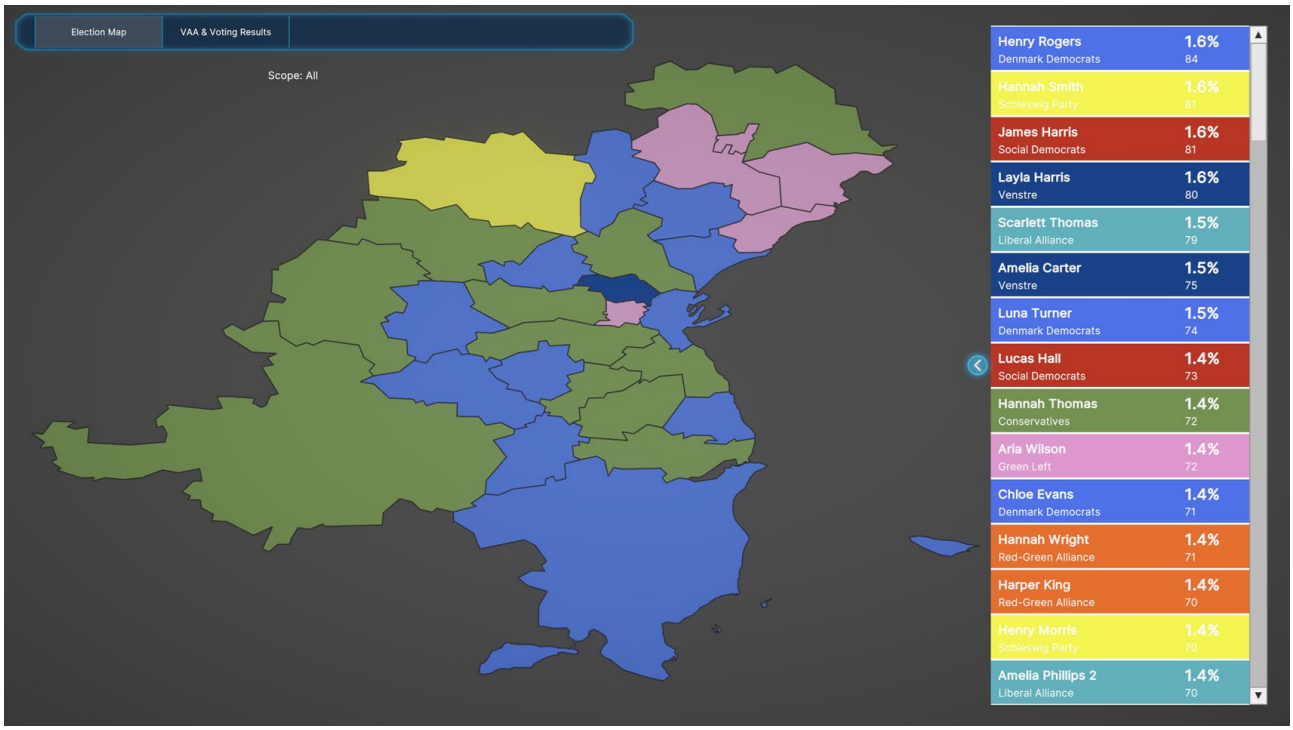

Figure 11. Sample Dashboard: Election map

5.12 Sample Dashboard: Election map info per region

The election map is interactive. Users can click on any region (postcode) to display detailed data specific to that area. The information panel updates dynamically, showing local candidate performance, vote distributions, and other region-specific metrics. This feature enables localized analysis and supports spatial exploration of voter behaviour.

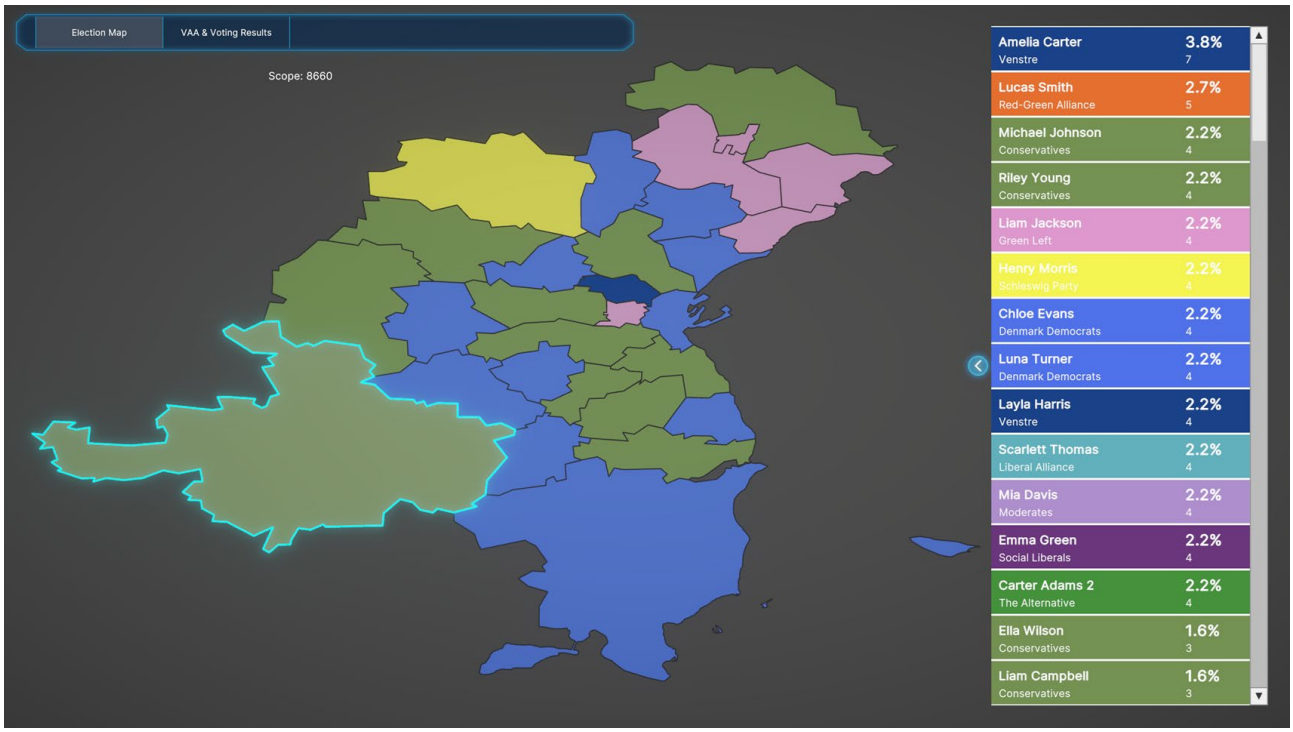

Figure 12. Sample Dashboard: Election map info per region

5.13 Sample Dashboard: Election map with charts of results per candidate and per political party

The dashboard allows users to add analytical charts to visualize results per candidate or per political party. These charts can be configured to display either overall results or data filtered by region. This feature supports comparative analysis between parties and candidates and provides a multi-dimensional understanding of election outcomes.

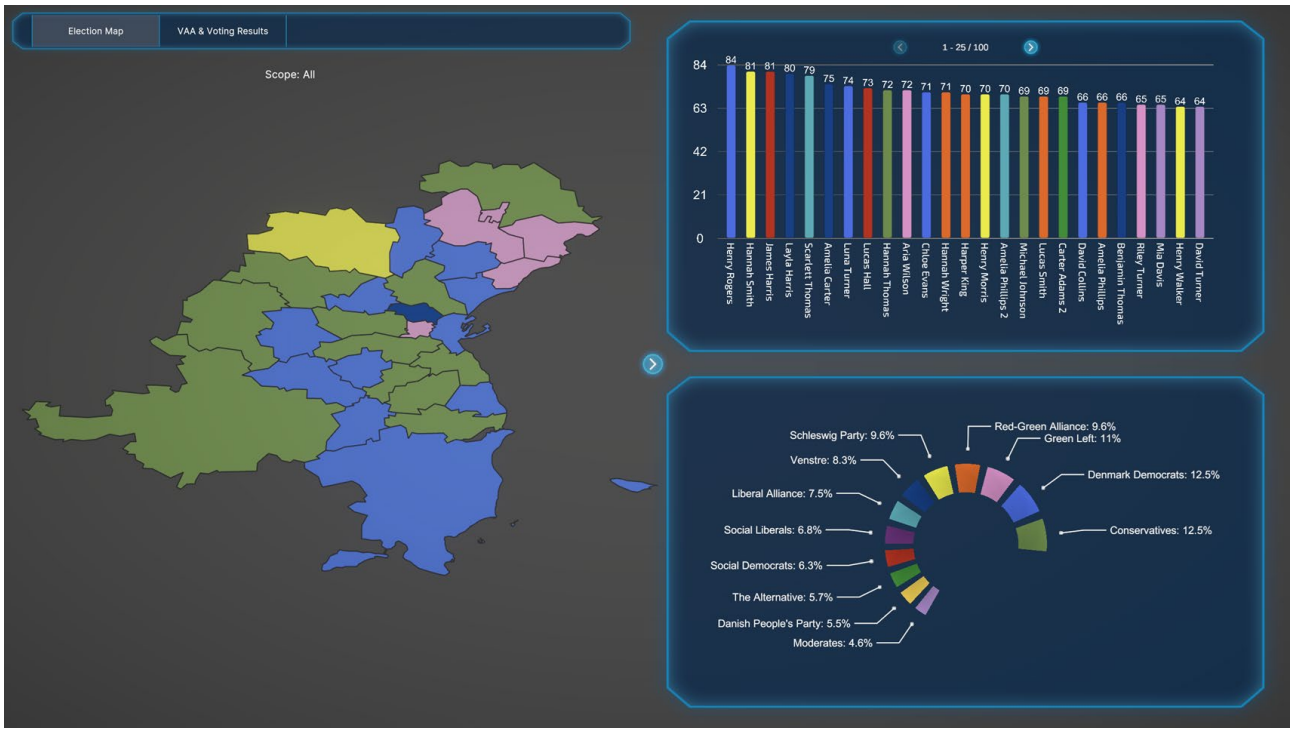

Figure 13. Sample Dashboard: Election map with charts of results per candidate and per political party

5.14 VAA candidate test visualization

The system enables the visualization of four-dimensional (4D) data within the simulation environment. One of the key visualization components focuses on the Candidate Test (Voter Advice Application – VAA).

In this visualization, the left panel displays all political parties represented through a radar graph, allowing users to compare their multidimensional positions based on various policy dimensions or test parameters. On the right panel, the user can select a specific question from the candidate test.

Once a question is selected, the visualization dynamically shows the distribution of votes: it illustrates the percentage of each party's voters who gave the same response to that particular question. The system categorizes responses into four options, agree, strongly agree, disagree, and strongly disagree, providing an intuitive overview of voter alignment patterns across different political entities.

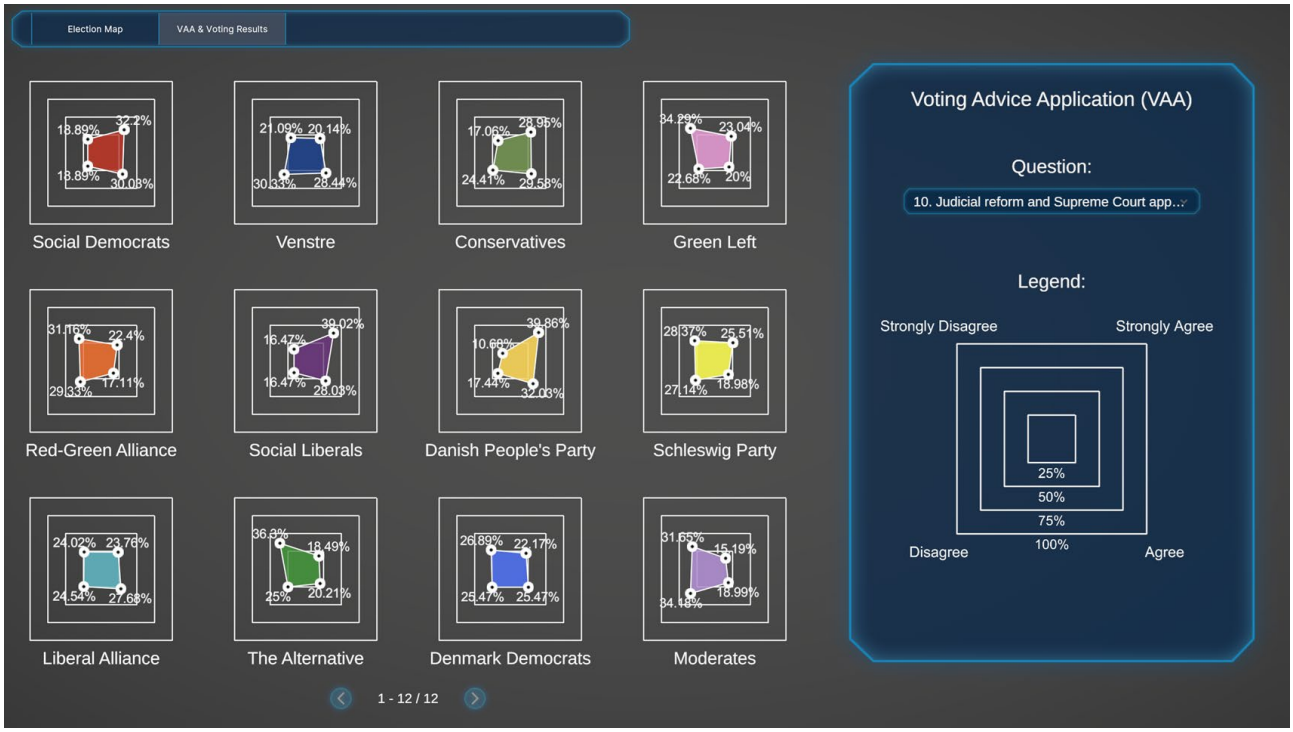

Figure 14. VAA candidate test visualization

5.15 VAA candidate test visualization question selection

The system includes an interactive question selector that allows users to change the question displayed in the VAA visualization. Through a combo box interface, users can switch between different candidate test questions in real time, enabling exploration of voter alignment patterns across multiple topics and dimensions.

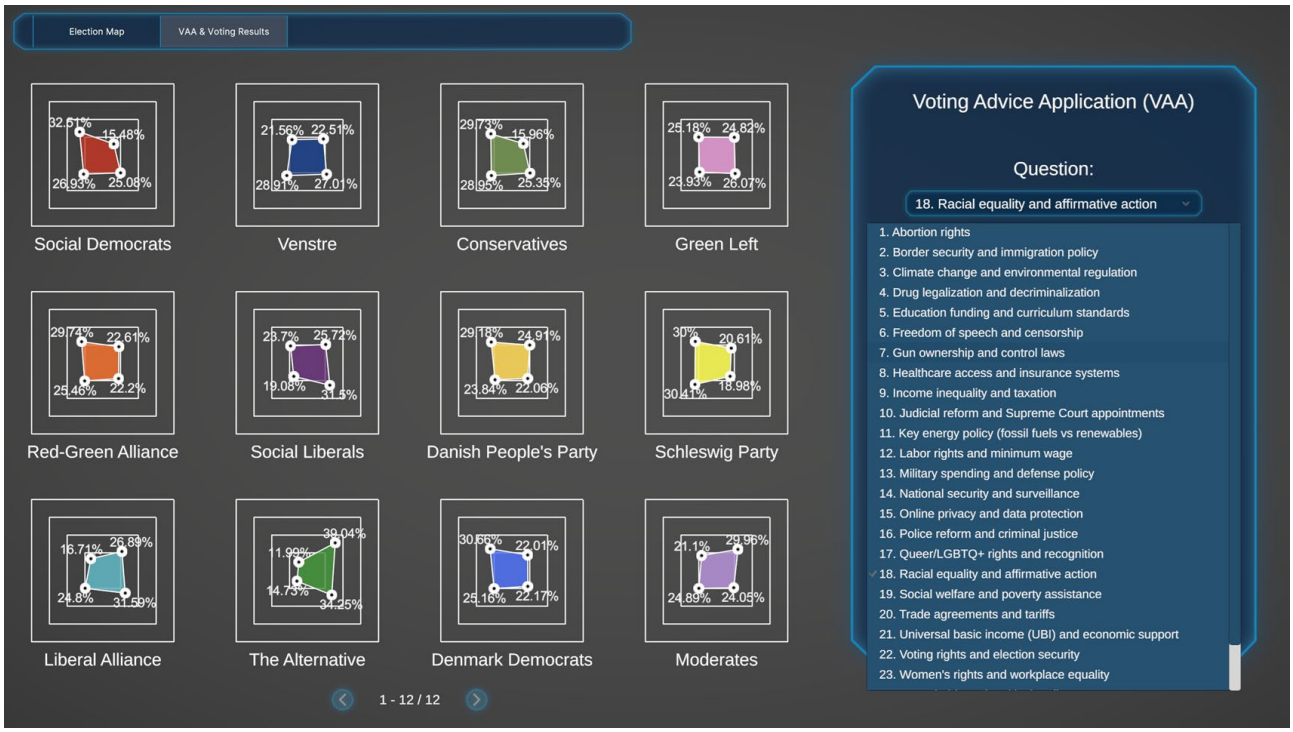

Figure 15. VAA candidate test visualization question selection