WeaponsWatch: A Global Volatility Index and Interactive Visualisation of Arms Trade Patterns

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***Abstract*—Global military expenditure and arms transfers shape geopolitical stability yet remain challenging for non-specialists to interpret. In this project, we integrate Stockholm International Peace Research Institute (SIPRI) military expenditure and arms-transfer databases with World Bank development indicators to examine socio-economic volatility and arms trade patterns from 1970 to 2023. First, we processed and merged heterogeneous time-series data—standardising ISO codes, imputing gaps, and normalising indicators—and applied principal component analysis to derive a Global Volatility Index (GVI) that quantifies instability via trajectory vectors in a reduced-dimensional space. Second, we developed a web-based interactive dashboard which includes a 3D globe with data-mode toggles, time-slider animations, and click-to-inspect controls for country-level analysis. Our evaluation demonstrates that the GVI captures volatility spikes coinciding with major events, such as the end of the Cold War, the Iraq War, and the Arab Spring, and that our web-based dashboard offers a comprehensive, non-technical interface for exploring global arms-trade partnerships, analysing how these relationships change over time and visualising military-expenditure trends in both absolute figures and as a share of GDP. Together, these components form WeaponsWatch: a web-based platform that combines a rigorously derived Global Volatility Index with interactive 3D visualisations to democratise the exploration of global military arms-trade patterns.**

***Index Terms*—global arms trade, military expenditure, volatility index, data visualisation, interactive dashboard**

I. Introduction

Global military spending has reached unprecedented levels: in 2023, world military expenditure increased to $2.44 trillion, a 6.8% real-term increase and the steepest rise since 2009, rising across every region, from Europe to Asia–Oceania and the Middle East [1].

Meanwhile, the underlying network for arms trading is constantly evolving along with geopolitics: for example, European arms imports more than doubled in 2020–24 as NATO states raced to rearm in response to Russia's invasion of Ukraine [2].

Policymakers, journalists, NGOs, and civil society groups depend heavily on transparent arms-transfer data to perform crucial monitoring functions, such as identifying illicit arms flows, uncovering potential corruption, and preventing conflicts through early detection of destabilising arms accumulations [3].

Although detailed public datasets such as SIPRI's arms-transfer and military-expenditure databases exist, these resources can be challenging for non-specialists to interpret [4] [5]. Furthermore, there is space to provide a structured framework for understanding the underlying drivers of changes in the global arms network. We propose two complementary solutions:

1) *Visualisation Tool*: A general-purpose, web-based visualisation tool that enables non-technical stakeholders such as journalists and policymakers to interactively explore and arms-transfer flows alongside socio-economic indicators
2) *GVI*: A Global Volatility Index that synthesises SIPRI's arms-transfer and military-expenditure data with World Bank development indicators to quantify and contextualise instability over time.

A. Visualisation Tool

We seek to provide an intuitive tool that allows users to examine relationships between countries and explore contextual socioeconomic indicators that may influence arms trading patterns. By clicking on any country, users can see a 3D visualisation of the country's arms trading partners, a timeline of its military expenditure and a list of their top trading partners. Users can also move through time to see how these relationships evolve and change how countries are coloured to understand how different socioeconomic factors may affect the arms network.

B. Global Volatility Index

The Global Volatility Index (GVI) is introduced as an analytical tool designed to quantify instability within the global arms market by combining SIPRI arms databases with World Bank Development Indicators [6].

We sought to build the GVI with similar academic practices exemplified by Lopes da Silva (2018), who merges SIPRI military and arms trade data with World Bank indicators to explore intersections between defence, economic stability, and development metrics [7]

We also drew on the methodologies used to build similar existing indices such as the Arms Sales Risk Index, which combines multiple indicators including country instability, corruption and conflict involvement, and the Global Militarisation

Index (GMI), which evaluates countries based on their military expenditures, personnel ratios, and weapon density [8] [9].

By quantifying each country's movement through a reduced-dimensional embedding of combined military and socioeconomic indicators, the GVI provides a quantitative framework for evaluating how major geopolitical events, such as the Iraq War, can manifest as distinct volatility spikes in the global arms market. This enables stakeholders to systematically analyse the impact of specific events on worldwide instability.

C. Weapons Watch: A comprehensive platform

Together, these components operate synergistically: detailed insights derived from the Global Volatility Index enhance the depth and context provided by our general-purpose visualisation platform. Consequently, *Weapons Watch* not only facilitates transparency but also fosters a deeper understanding of the dynamics underpinning international arms trade fluctuations.

D. Evaluation Framework

To evaluate the success of our project, we formulated two objectives centred around strategic questions that map directly to the findings of our report, as seen in Section VI:

1) *Event Impact Assessment*: How effectively does the Global Volatility Index quantitatively capture volatility shifts induced by major geopolitical events across NATO, BRICS and war-conflicted nations?
2) *Interactive Exploration of Arms Trading*: To what extent can users employ the dashboard's mode toggle, time slider and click-and-inspect controls to interrogate Europe's military expenditure and arms-trade networks in both absolute and % GDP terms?

The following sections elaborate on our approach, including necessary data preparation (Section II, exploratory data exploration (Section III), the methodology behind the GVI (Section IV, how we visualised the data (Section V), our key findings derived from our evaluation framework (Section VI and the discussion and evaluation (Section VII).

II. Data Preparation

A. SIPRI Military Expenditure Database

The core military expenditure figures were obtained from the Stockholm International Peace Research Institute (SIPRI) military expenditure database. After being downloaded, the data was converted to a tidy CSV format, where each row represents a single country-year observation. The key columns were Country, Year, Expenditure (in constant USD), and ISO Code. ISO country codes were defined by the ISO 3166 standard using the Alpha-3 code-set [10].

To facilitate nested, API-ready structures, the flat CSV was converted to a hierarchical JSON. In this step, each country object was augmented with a list of year-specific expenditure entries.

B. World Development Indicators Database

To contextualise military spending, we incorporated select World Bank development indicators, such as GDP per capita, population size, and trade openness, which were available via their API. These indicators were normalised and stored in a compact JSON format, mirroring our SIPRI schema for seamless integration.

We generated pivot tables to visualise temporal trends and assessed the breadth of country coverage. Identifying countries or years with missing data guided our choice of indicators, ensuring that subsequent merges would maximise overall completeness.

Using time-series plots for G20 members (1970–2022), we evaluated indicator stability and data gaps. Indicators exhibiting sparse coverage or erratic values were deprioritised. The final feature set balanced domain relevance (e.g., economic size, governance indices) with robust data availability, ensuring each variable could contribute meaningfully to downstream analysis.

C. Merging databases

The merging logic uses ISO codes as the primary key. For each SIPRI country object, the script locates matching World Bank records and appends the indicator values to the corresponding year entry, preserving the original SIPRI hierarchy.

We encountered some integration hurdles when merging databases. Some small states or recent countries appear in one source but not the other. We flagged these instances and either dropped or retained them based on analysis relevance. Where World Bank data were absent for particular years, we inserted nulls and logged the gaps for transparency. Post-merge assertions validated that no duplicate years were created and that every SIPRI entry retained its original expenditure figure.

The final master dataset maintains the SIPRI JSON schema as its backbone. Each year record now includes a World Bank object containing all selected indicators, plus a combined metadata section that references the source datasets and timestamp of extraction

D. SIPRI Arms Transfer Database

This dataset is maintained as a separate CSV, rather than integrated into our main JSON schema, because its relational focus doesn't conform well to the nested JSON structure we used for the core data.

We imported the Latin–1–encoded CSV into pandas and coerced the "Year(s) of delivery," quantity, and TIV columns to numeric types, converting any invalid values to NaN. We added ISO 3166-1 alpha-3 codes for both suppliers and recipients via fuzzy matching, ensuring consistency with our expenditure and development datasets. We then split the "Year(s) of delivery" field into lists, then extract the first and last delivery years to compute each transfer's duration. Finally, we exported the cleaned table as a stand-alone CSV, still keyed by the same ISO country codes, so it can be joined on demand for analysis or in our API without disrupting the core SIPRI–World Bank data model.

E. Geospatial Integration with GeoJSON

A globally standardised GeoJSON dataset containing detailed polygon geometries and associated country metadata was employed to provide the spatial framework visualisation. All geometries were maintained in the WGS84 coordinate reference system to ensure full compatibility with prevailing GIS platforms and web-mapping libraries [11].

Military expenditure figures were spatially enabled by linking each country's ISO 3166-1 alpha-3 code to the corresponding GeoJSON feature via a left-join operation, thereby preserving the integrity of the full geographic layer while appending expenditure attributes where available. To optimise performance, separate GeoJSON snapshots were exported for selected analysis years rather than constructing a single time-enabled feature collection.

Two discrete GeoJSON products were produced: one embedding absolute military expenditure values and a second expressing expenditure as a percentage of GDP. Each output retains the original boundary attributes and seamlessly incorporates the processed metrics, laying the groundwork for efficient mapping, interactive spatial analysis, and integration into the dashboard interface.

III. Data Exploration

A. Summary Statistics

Our final JSON file contains information on 217 countries. Each country has data for 17 indicators spanning from 1960 to 2023. While the combined SIPRI–World Bank dataset dates back to 1948, data coverage for many countries begins later, resulting in 8,358 rows in total.

To support analysis throughout the report, countries have been grouped into 4 blocs: NATO, BRICS, war-affected and other. Fig. 1 shows how military expenditure differs significantly between these groups. NATO countries led during the Cold War, but BRICS nations overtook them after the fall of the Soviet Union and have continued to rise since. Finally, war-affected countries, including Ukraine, have rapidly increased their expenditure since 2022, most likely due to Russia's Invasion.

B. World Bank Development Indicators

The World Bank Development Indicators were chosen to give context to the military expenditure, capturing a range of socioeconomic and political factors for each country. The table in Fig. 2a shows the selected features, which are numbered to keep visual clarity in subsequent plots. The Pearson correlation between these indicators for NATO countries is shown in Fig. 2b, which reveals underlying relationships not immediately apparent from the raw data. NATO countries are used here as a representative subset to explore patterns in more detail.

There are strong negative correlations between GDP growth and the percentage of income held by the top 10%, and GDP growth and levels of rural population. This may imply

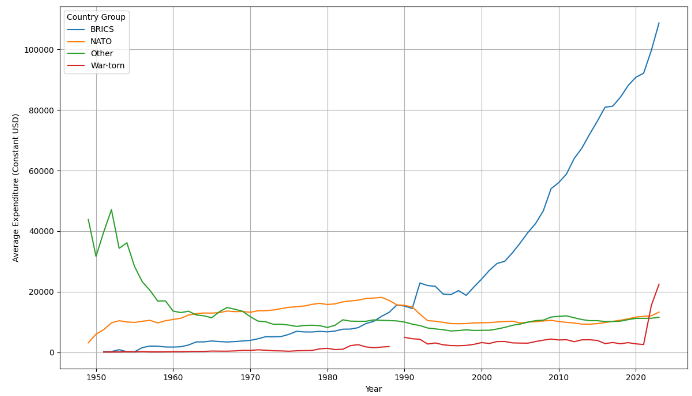


Fig. 1: Average Military Expenditure Over Time ($ Millions) for NATO, BRICS, war-affected and other countries. Missing values for any war-affected countries (1988–1990) cause a break in the line.

economic growth in NATO countries is driving migration to urban areas, and the benefits of this economic growth are being distributed more fairly.

GDP growth has the strongest positive correlation with many indicators, notably military expenditure, political stability, arms imports, income share of the lowest 10%, and the percentage of internally displaced people due to conflict. This may be as a result of economic growth fostering internal stability, but also increased militarisation in these countries.

C. Data Quality

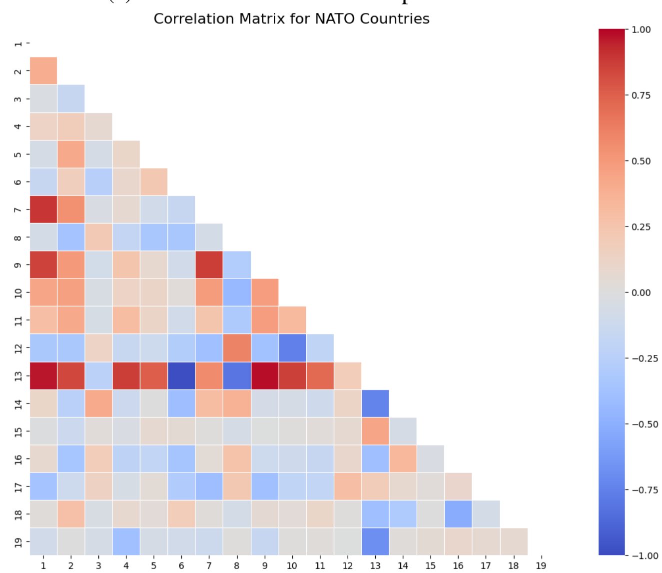
Despite choosing indicators with relatively low amounts of missing data, the presence of NaN values still posed a significant challenge to data integrity. Indicators with more than 50% null values across all countries were not included in the calculation of GVI. The data availability varied markedly across indicators; for instance, Fig. 3 illustrates the high levels of missing data for Income Share held by the top 10%. These gaps may be attributed to either non-reporting by sovereign entities or the legitimate absence of measurable values for certain indicators, for example, the UK reporting a negligible number of civilians internally displaced due to conflict. Some countries, such as Japan, had over 60% of values missing, with countries like Syria and Libya recording no data for any indicator.

IV. GVI Methodology

The methodology for creating The GVI began with selecting appropriate features which would allow the index to pick up changes in the stability of a country. Subsequently, these features were grouped and broken down using dimensionality reduction to visualise and simplify the yearly development of countries. Both PCA (Principal Components Analysis) and t-SNE (t-Distributed Stochastic Neighbour Embedding) were explored as options for dimensionality reduction. The GVI hinges on the movement of countries through this dimensionally reduced space, and the vectors between the data points

Index	Indicator
1	Military Expenditure
2	Military Expenditure Gdp
3	Arms Exports Sipri Trend Indicator Values
4	Political Stability and Absence of Violenceterrorism Percentile Rank
5	Armed Forces Personnel Total
6	Income Share Held By Highest 10percent
7	Refugee Population By Country or Territory of Origin
8	Rural Population Percent of Total Population
9	Arms Imports Sipri Trend Indicator Values
10	Income Share Held By Lowest 10percent
11	Internally Displaced Persons Total Displaced By Conflict and Violence Number of People
12	International Migrant Stock Percent of Population
13	Gdp Growth Annual Percent
14	Foreign Direct Investment Net Outflows Percent of Gdp
15	Individuals Using the Internet Percent of Population
16	Tax Revenue Percent of Gdp
17	Tariff Rate Applied Simple Mean All Products Percent
18	Fossil Fuel Energy Consumption Percent of Total
19	Ores and Metals Exports Percent of Merchandise Exports

(a) Numbered table of Development Indicators



(b) Correlation Heatmap of Development Indicators for NATO member states

Fig. 2: Visualisation of correlation matrix and missing data, with corresponding indicator descriptions.

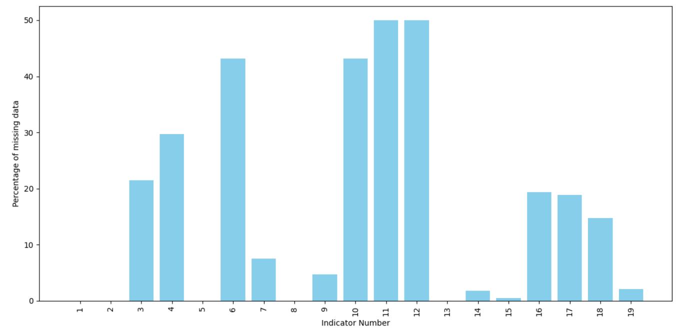


Fig. 3: Percentage of missing data per indicator

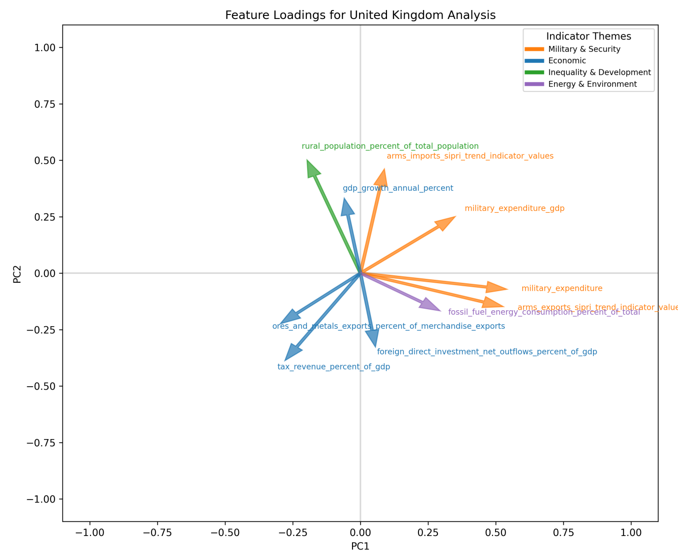


Fig. 4: Directional loadings in PCA-space for World Bank Development Indicators. The magnitude and direction of each arrow represent the influence of the indicator on each vector in the PCA-space.

determine the final value of the GVI. Inspiration was taken in this regard from the Cato Institute and their 'Arms Sales Risk Index' [8].

A. Dimensional Interpretation Framework

First, the indicators were thematically grouped into Military & Security, Economic, Inequality & Development, and Energy & Environment. Theming the indicators allows us to understand the PCA dimensions in greater detail, as seen in Fig. 4, where the loadings of the dimensionally reduced data can be seen thematically and as individual indicators. As countries move around the PCA-space over time, the path they take will be due to how their socioeconomic factors are changing.

B. Dimensionality Reduction

Dimensionality reduction via PCA, which collapses high-dimensional data into 2D or 3D spaces, is central to the GVI methodology. We opted for PCA over t-SNE because its explicit, linear loadings let us directly quantify and weight each indicator's contribution; t-SNE's non-linear embeddings offer no straightforward way to derive reproducible feature weightings, although it provides superior clustering. We can see in Fig. 5 how 'like-minded' countries tend to cluster together: China and India, the UK and France, South Africa and Australia. The United States appears alone on the right, largely unaffected by Component 2 but at the highest level of Component 1.

The loadings in Fig. I reveal how these clusters were influenced; Military expenditure and arms exports hold the largest influence in Component 1, whereas in Component 2, economic factors are the most influential. Countries such as the US, Saudi Arabia and Russia are seemingly much more military-

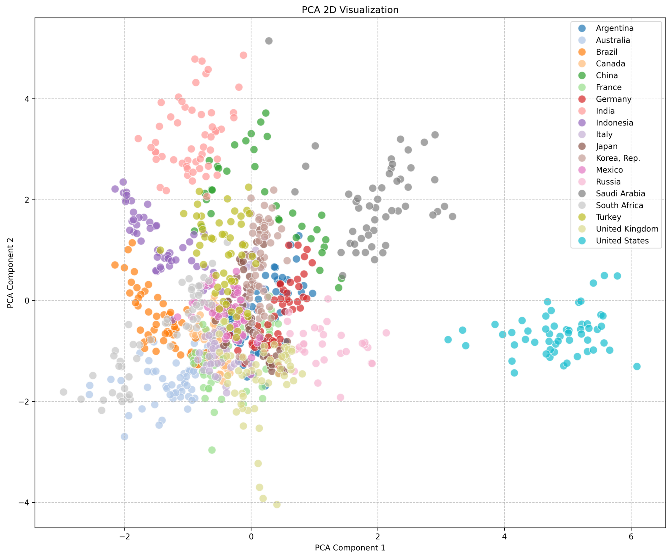


Fig. 5: PCA of development indicators for G20 member states.

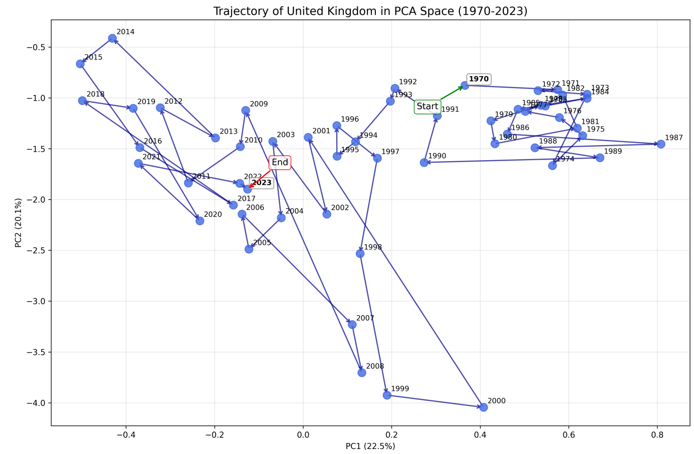


Fig. 6: The Trajectory of the UK from 1970-2023 through the PCA-space.

focused than the European countries, and developing countries like China, India, Turkey and Indonesia are clustered along a separate axis, potentially reflecting a focus on industrial growth, resource exports, and rapid development dynamics. The vectors defining the movement of countries through the PCA-space form the backbone of the GVI.

TABLE I: Thematic Component Analysis

Component	Theme	%	Direction
1	**Military & Security**	56.1	+
1	**Economic**	25.7	–
1	**Energy & Environment**	10.9	+
1	**Inequality & Development**	7.3	–
2	**Economic**	44.3	–
2	**Military & Security**	32.5	+
2	**Inequality & Development**	17.5	+
2	**Energy & Environment**	5.8	–

C. Normalisation

The trajectory of a country through the PCA space is defined by a set of vectors, one for each year. The GVI hinges on the idea that the dynamics of this trajectory define a country's volatility. To accurately compare changes in the magnitude, acceleration, and angle of the vectors over time, it is essential to first normalise these components. Fig. 6 shows the trajectory of the vector for the UK, where we can see some large jumps, such as 2000–2001, and sporadic direction changes. These shifts correspond to changes in magnitude (how drastically the UK's position in the embedding space changes), acceleration (the rate at which that change occurs), and angle (the direction of movement, indicating shifts in geopolitical or economic alignment).

Normalisation is a key part of the process as it ensures none of these three components dominate the volatility calculation. In this case, normalisation was performed by determining the maximum value for each of the three components, and subsequently dividing each component by its respective maximum value, performing exponential smoothing and weighting each component based on importance.

D. Mathematical Definition of the GVI

To create the GVI, we combined three distinct components: movement magnitude, direction change, and acceleration, each normalised and weighted before summation, followed by temporal smoothing. Let $\mathbf{x}_t \in \mathbb{R}^m$ be the vector of normalised indicators at time t, and let $\mathbf{P}_k \in \mathbb{R}^{m\times k}$ be the matrix of the first k principal component (or t-SNE) loadings. We first embed:

$$\mathbf{y}_t = \mathbf{P}_k^\top \mathbf{x}_t \in \mathbb{R}^k$$

and define the trajectory vector

$$\mathbf{v}_t = \mathbf{y}_t - \mathbf{y}_{t-1}.$$

Let the movement magnitude at time t be

$$M_t = \|\mathbf{v}_t\|_2,$$

the direction change be the angle between successive vectors,

$$\theta_t = \cos^{-1}\Big(\frac{\mathbf{v}_{t-1}\cdot\mathbf{v}_t}{\|\mathbf{v}_{t-1}\|_2\,\|\mathbf{v}_t\|_2}\Big),$$

and the acceleration be

$$a_t = M_t - M_{t-1}.$$

Each component is normalised by its global maximum over all countries and years: let

$$M = \max_{t,\text{country}} M_t, \quad \Theta = \max_{t,\text{country}} \theta_t, \quad A = \max_{t,\text{country}} |a_t|.$$

With weights w_m, w_d, w_a (defaulting to 0.6, 0.25, 0.15), the raw index is

$$\mathrm{GVI}_t^{\text{raw}} = w_m\frac{M_t}{M} + w_d\frac{\theta_t}{\Theta} + w_a\frac{|a_t|}{A}.$$

Finally, exponential smoothing (with smoothing factor $\alpha = 0.2$) yields the final index:

$$\mathrm{GVI}_t = (1-\alpha)\,\mathrm{GVI}_t^{\mathrm{raw}} + \alpha\,\mathrm{GVI}_{t-1},$$

ensuring temporal coherence and reducing erratic jumps.

V. DATA VISUALISATION

A. System Architecture Overview

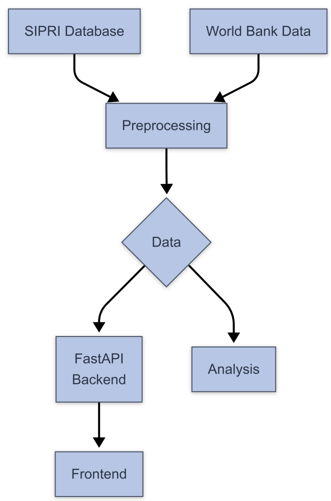


Fig. 7: System Architecture

The visualisation layer of our platform relies on a clear separation between the React-based frontend and the FastAPI back end. The frontend is responsible for rendering interactive charts, maps, and dashboards, while delegating all data retrieval, filtering, and aggregation tasks to back end endpoints.

A system component diagram (Fig. 7) illustrates the end-to-end data flow: raw data files are ingested into the FastAPI service, preprocessed into multiple in-memory formats, and served to React visualisation modules.

The architecture incorporates built-in fallback mechanisms for resilience: when servicing visualisation requests, the API first attempts to fetch nested JSON structures optimised for the requested mode; if unavailable, it automatically degrades to the tidy CSV back end. This guarantees that visualisations remain available even when certain preprocessed sources are missing.

B. Data Management and Caching Strategy

To deliver fast response times for user interactions, we implement a multi-level caching strategy. During application startup, key datasets are bulk-loaded into an in-memory cache in three representations: Native JSON for rapid attribute lookups, GeoJSON for map rendering, Tidy tabular frames for ad-hoc filtering and aggregation.

This design minimises the need for data re-projections at runtime, ensuring that each API call can retrieve pre-formatted data slices. Our data management strategy supports flexible data representation modes through a *DataMode* enumeration that signals whether numeric outputs should be expressed in absolute totals or normalised by GDP percentage.

We also used dynamic adaptation capabilities, reconciling request parameters against dynamic column headers detected from upstream data frames. This allows flexibility as data sources evolve, without requiring code changes to accommodate new fields or attributes.

C. API Design

The FastAPI service exposes a coherent set of RESTful routes, each conforming to resource-oriented URIs. Path parameters undergo case-insensitive normalisation, allowing clients to supply ISO codes or country names in any letter case. All routes are defined using FastAPI's app decorator pattern, providing a clear structure for endpoint organisation as new data sources are integrated.

Query parameters are declared with Python typing to enforce schema correctness at request time. Optional temporal bounds (start year, end year) permit clients to restrict time-series spans, while trade endpoints accept supplier and recipient filters.

For robust error management, the API employs FastAPI's HTTPException mechanism, returning appropriate status codes (404 for missing resources, 500 for data-availability failures) with descriptive error messages.

D. Frontend Architecture

The frontend layer of the application is constructed using React with Vite as the build tool, implementing a component-based architecture. This modular design facilitates the reuse of visualisation elements. Visualisation elements such as maps, charts, and interactive controls are composed within container components that manage data flow and coordinate interactions, allowing for independent development and testing of visualisation capabilities.

We also use asynchronous data loading patterns to maintain interface responsiveness. Each visualisation component implements appropriate loading states, error handling mechanisms, and fallback displays. This approach decouples the rendering cycle from data retrieval operations, allowing the interface to remain responsive while data processing occurs asynchronously.

E. Interactive Visualisation Components

The first component type we developed consists of a 2D map built with React-Leaflet, where a country's military expenditure was represented by dynamically-sized circle markers. The implementation applies square root scaling to circle radii, ensuring visual proportionality between marker area and expenditure magnitude.

We then developed a 3D globe component using WebGL-based rendering. This delivers an immersive spatial visualisation with arc-based trade flows and orbital camera controls. After comparing both components, we decided the 3D representation allowed users to be more immersed in our platform.

Fig. 8: A snapshot of the *WeaponsWatch* platform showing the trading partners of India in the year 2000. The screen capture also reveals limitations of the current interface, notably non-graceful handling of legacy countries such as the Soviet Union and suboptimal spacing of on-screen components.

We also developed a chart component to handle temporal data constructed with Chart.js. These components render time-series data with adaptive formatting based on the selected data mode, switching between absolute values and GDP percentage representations as appropriate. The implementation incorporates context-sensitive tooltips and responsive layout adjustments.

F. Data Flow and State Management

Each front-end component maintains its internal state while exposing interaction events to parent containers, enabling coordinated updates across the visualisation ecosystem.

We implemented a unidirectional data flow pattern wherein parent components fetch data via API calls and distribute processed results to child components to ensure consistent state across related visualisations.

When processing expenditure data, the application organises information hierarchically by year and country, simultaneously identifying maximum values for appropriate visual scaling. This preprocessing stage transforms the flat data structure received from the API into a nested representation optimised for visualisation requirements, allowing for efficient lookup operations.

This approach integrates with React's state management hooks to coordinate component lifecycle and state transitions. We also implemented selective re-rendering strategies to prevent unnecessary rendering operations when data or interaction state changes do not affect the visual output.

G. User Interaction Model

We identified three primary interaction patterns that we wanted users to be able to engage in on our platform. The first interaction pattern enables users to drag a slider to indicate the year they want to visualise.

The second interaction pattern allows users to select a country to view information about its military expenditure, arms trading and socioeconomic indicators. When a country is selected, the system extracts historical data specific to that nation and reformats it for temporal analysis components and sorts it chronologically.

The third interaction pattern, data mode switching, involves users alternating between absolute expenditure values and GDP percentage representation. These mode changes trigger coordinated data re-fetching and visualisation rescaling, with appropriate unit conversions and axis reformatting.

H. Visual Design System

The visualisation layer implements a consistent design system underpinning all visual components. The system employs a dark theme foundation, and data intensity is encoded through carefully calibrated colour gradients. We primarily utilised the orangeHeat scale as the primary gradient, which is paired with functional colours. Blue consistently represents imports, and orange highlights exports and interactive elements. The colour system employs percentile-based categorisation to represent data magnitude.

We implement a consistent typographic hierarchy using Arial as the primary font family. Headers employ specific font weights and graduated sizing to establish visual hierarchy, while quantitative values utilise bold styling to improve readability.

Contextual annotations such as tooltips, legends, and information panels employ semi-transparent backgrounds with backdrop blur effects to maintain visibility of underlying globe data while providing additional analytical context. Interactive elements are visually distinguished through consistent styling with hover states and active indicators. Charts are configured with grid colours that complement the dark theme, consistent axis styling, and data representation using the established colour system.

All these design choices were chosen after experimentation, and in keeping with a consistent design system to ensure the best user experience.

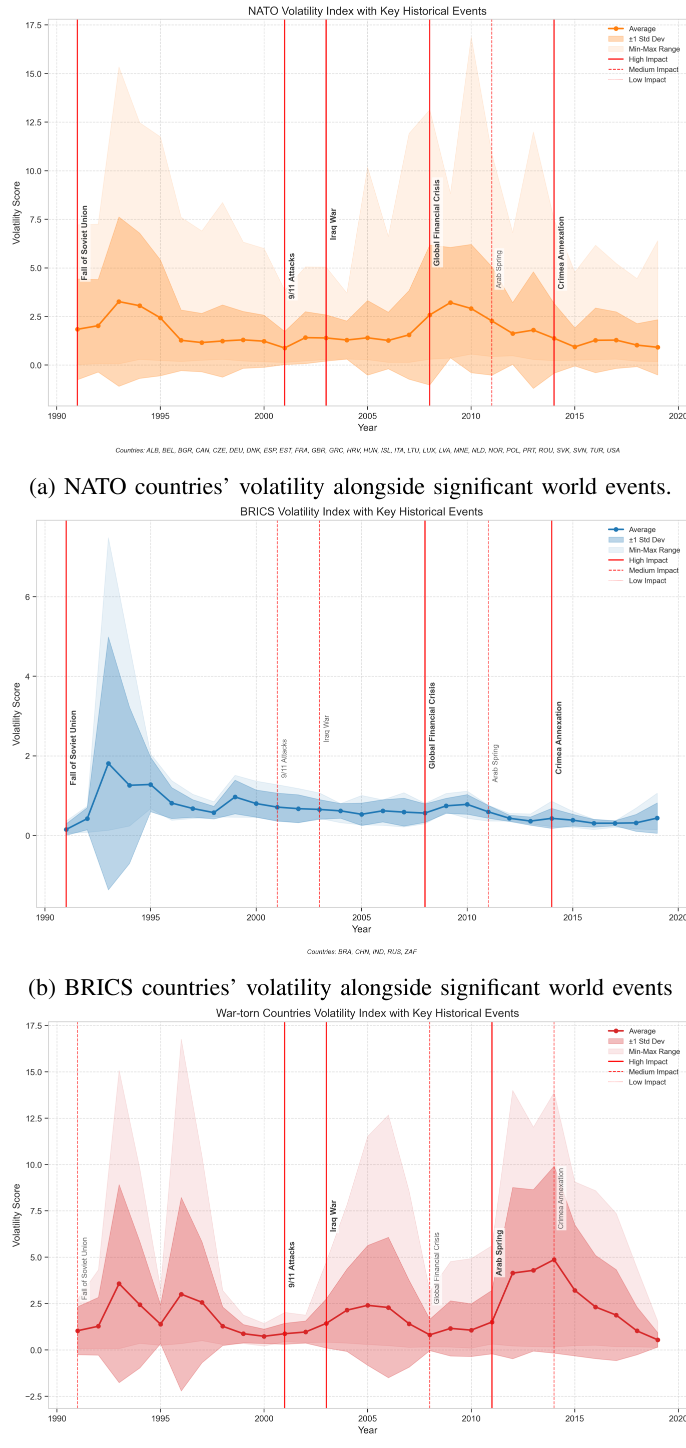
VI. Findings

In this section, we present our project's principal findings, derived from addressing the two evaluation-framework questions outlined in the introduction (see Section I-D).

First, we assess the validity of the Global Volatility Index (GVI) by comparing subgroup trajectories (NATO, BRICS, and nations experiencing armed conflict) against historical events. Next, we demonstrate the utility of our interactive visualisation platform through a representative enquiry into Europe's military expenditure and trade patterns. Together, these findings illustrate both the robustness of the GVI as a metric of volatility and the power of our visual tools.

A. Event Impact Assessment

To validate the claim that the GVI can accurately reflect volatility, the GVI of subgroups (NATO, BRICS & countries at war) is projected alongside key world events that should have an impact on the volatility of the relevant group in Fig.9. This validation process provides varying results. NATO countries seem to be significantly more volatile than BRICS countries, which react very little to a lot of the events. This may also be because the events chosen are Western-centric, as the years following the fall of the Soviet Union contain large spikes in the GVI for all three groups. Arguably, the GVI seems to provide the most accurate insight when looking at war-affected countries in Fig. 9c. The Iraq War and the Arab Spring can be seen happening around spikes in the GVI. This group of countries was impacted significantly by these events, and so the next question is whether this spike is causation or correlation. To further validate these claims, the GVI would need to be cross-checked against more events and perhaps with individual countries. Viewing the GVI on our visualisation platform will further allow users to validate the GVI and determine whether the volume of arms transfers significantly impacts volatility.



(a) NATO countries' volatility alongside significant world events.

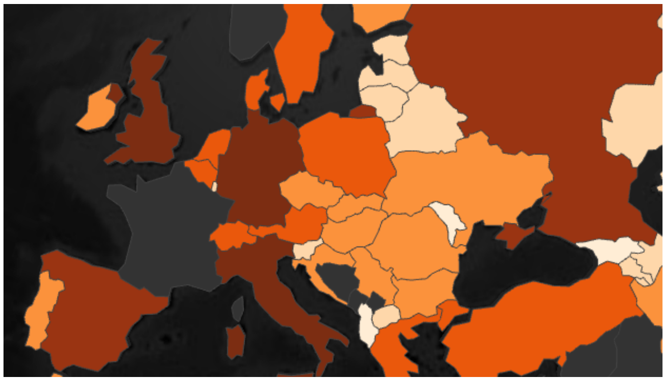
(b) BRICS countries' volatility alongside significant world events

(c) War-affected countries' volatility alongside significant world events

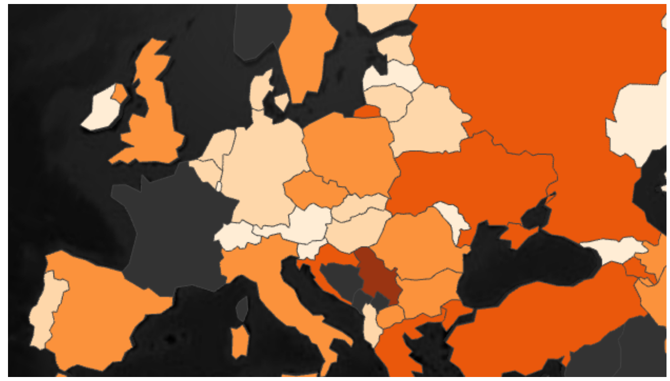
Fig. 9: GVI of subgroups against key historical markers to validate findings.

B. Interactive Exploration of Arms Trading

To evaluate how useful our interactive visualisation is, we formulated an example question that an end-user may attempt to answer using our platform:



(a) Absolute military expenditure mode



(b) % GDP mode

Fig. 10: Snapshot of Europe in Year 2000: (a) absolute expenditure highlights Europe's large total spend due to European countries being richer on average, while (b) relative % GDP view reveals Europe's lower defence prioritisation compared to smaller states like the UAE. The snapshot also shows an API limitation whereby certain countries, such as France, are not retrieved correctly.

> "What are Europe's main trade partners, and how much does it spend on military in both absolute and *% GDP* terms?"

There are three key user interaction patterns. First, they can change data mode to switch between *Absolute Expenditure* and *% GDP* views. They can use the time slider to observe the evaluation of military spending, socioeconomic factors and military trade partnerships. They can also click on any country to reveal its trading partners, with arc sizes representing trade volume between two partners.

The qualitative evaluation reveals that the mode toggle delivers immediate insight into relative prioritisation: for example, Europe's total military expenditure remains among the highest worldwide in absolute terms, yet when switched to % GDP view its sphere shrinks markedly compared to smaller states such as the UAE, illustrating that Europe allocates a smaller share of its economy to defence, shown in Fig. 10. By dragging the time slider from 2020 through 2023, users observe a darkening of colours across most EU member states, reflecting the surge in spending triggered by the Ukraine war. Finally, clicking directly on Ukraine before and after the Ukrainian war shows thickened trade arcs emanating from the United States and Europe, revealing a spike in arms imports alongside rising domestic expenditure.

VII. Discussion and Conclusion

A. Synthesis of Key Findings

With the GVI, we successfully created a quantitative metric that enables direct comparison of volatility across countries, removing the need to parse complex qualitative datasets. Major geopolitical shocks such as the collapse of the Soviet Union, the Iraq War, and the Arab Spring produce clear spikes in the GVI (Section VI), confirming that users can both quantify and contextualise instability over time. The interactive dashboard further enables users to better understand country-level and global arms-trading relationships that would be difficult to discern from raw tables alone.

B. Limitations

Despite these strengths, several limitations and challenges were faced throughout the development of *WeaponsWatch*.

The primary concern with the GVI is data quality and incompleteness in both our development indicators and arms-transfer records (Section III-C). This may be due to various factors such as sporadic reporting from certain countries (e.g. Libya, Syria). Whilst we adopted data imputation and normalisation strategies to mitigate the impact, data quality issues remain a key challenge to be addressed.

Another limitation of the GVI is its capacity for event attribution, as spikes in volatility may coincide with, but not necessarily be caused by, major events. Disentangling causation from correlation will require more granular event tagging and perhaps sentiment or news-flow analysis.

The visualisation aspect of *WeaponsWatch* demonstrates a proof of concept tool. However, there remain bugs and functionality concerns that would need to be addressed before validating its output with end users. An example of one of these functionality concerns is dealing with legacy countries. This can be seen in Fig. 8 where the Soviet Union and Russia are defined as separate countries. In the future, some method of integrating this would be required. Further issues have been identified with API endpoints not recognising certain countries, potentially due to nomenclature or data retrieval problems. This can be seen in Fig. 10 where France is missing from the visualisation even though the data is available.

To date, we have also not conducted formal usability testing with target end-users (journalists, NGOs, policymakers). Real-world feedback will be essential to refine both the methodology used to build the GVI, as well as to improve the user experience of the website.

C. Future Development

One potential enhancement is the integration of an automated event-detection layer (e.g. parsing news APIs) so that users can click directly on GVI spikes to see contextual headlines and summaries. The GDELT (Global Database of Events, Language, and Tone) has been explored as an option to improve *WeaponsWatch* in this manner [12]. To further prepare the platform to a production-level standard, deployment of streaming connectors to SIPRI and World Bank APIs, would deliver near-real-time updates to both the GVI and map visualisations.

A further improvement could be annotation and sharing capabilities, as this would allow analysts to bookmark insights, attach narrative commentary, and export custom reports directly from the dashboard.

We could also add other visualisations, like chord diagrams, to more intuitively represent bilateral arms-trade flows. We prototyped chord diagrams during our project, but encountered integration challenges. However, existing examples such as the World Bank's interactive chord diagram for global trade demonstrate the potential of this technique [13].

The technical specifications used in building the GVI could be continually improved so that the index uses the most up-to-date and robust measure of volatility. Experimentation with hybrid dimensionality-reduction methods (e.g. combining PCA with graph neural network embeddings) could better capture non-linear relationships in arms-trade networks.

Overall, the key area we would like to develop in the future is the synthesis of the GVI with our visualisation. Overlaying economic indicators, such as GDP per capita, onto volatility visualisations may reveal the primary factors driving the evolution of international arms-transfer relationships. Answering questions such as this will bring our platform to the next level and build on the two main pillars of our project.

D. End-User Value

By combining a robust volatility index with an intuitive, web-based visual exploration environment, *WeaponsWatch* offers value to key stakeholders. Journalists can quickly find and illustrate stories behind sudden shifts in the arms trade. Policy Analysts gain quantitative evidence to support or question defence budgets and alliance strategies. Finally, NGOs and Civil Society, can monitor potential arms-flow red flags and advocate for greater transparency.

E. Conclusion

WeaponsWatch demonstrates a fusion of index creation, data exploration and advanced visualisation to aid a user's desire to answer complex questions. The GVI provides a succinct, comparable measure of volatility across time and regions, while our interactive dashboard enables users to explore the "why" and "how" behind the numbers. As global security challenges continue to evolve, we believe this toolkit will serve as a valuable resource for transparency, early warning, and informed decision-making.

VIII. GitHub Repository

https://github.com/sidneyoneill/weapons-watch

IX. Website

https://arms-trade-dashboard.onrender.com/

X. Video Demonstration

https://www.youtube.com/watch?v=oaARCDusd_0

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