Innovative Mechanisms of Renewable Energy Development Strategies in Central Asian Countries

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Abstract: This study examines public engagement in sustainable development initiatives across Central Asia, focusing on the "knowledge-action gap" between awareness of the Sustainable Development Goals (SDGs) and actual participation. A mixed-methods approach combines survey data (2023-2024), qualitative analysis, and logistic regression with mediation and robustness checks. The results reveal a substantial gap between awareness (≈50-55%) and participation (10-22%). Participation is primarily associated with information exposure, internet access, and institutional trust. Mediation analysis shows that transparency and accountability affect participation both directly and indirectly via trust, while campaign effectiveness increases in high-trust contexts. A significant urban-rural divide is observed, largely driven by digital access disparities. The study proposes a theory of change and practical engagement strategies, including hybrid communication, low-threshold channels, and participatory mechanisms. A 12-month implementation roadmap and a data framework with measurable KPIs are also developed. The findings contribute to understanding participation drivers in the region and support evidence-based policy design. Limitations relate to self-reported data and cross-sectional structure; future research should apply longitudinal and experimental approaches.

1 INTRODUCTION

1.1 Global Context of Sustainable Development

In the twenty-first century, humanity faces unprecedented challenges associated with climate change, freshwater scarcity, desertification, ecosystem degradation, and economic volatility and instability [1]. These challenges are complex and interdependent, requiring the integration of environmental, social, and economic priorities into a unified strategic framework. In response, the United Nations (UN) adopted the 2030 Agenda for Sustainable Development in 2015, comprising 17 interlinked Sustainable Development Goals (SDGs) aimed at balancing human well-being with planetary health [2].

The implementation of the SDGs demands active participation from all stakeholders - governments, businesses, the scientific community, non-governmental organizations, and civil society [3]. However, practical experience indicates that without conscious public engagement, achieving these global goals remains difficult and fragmented.

In recent years, increasing attention has been directed toward enhancing public awareness of the SDGs and cultivating motivation for participation in community-driven initiatives [4]. This direction has been recognized as a key factor for the successful

realization of global objectives, since informed and engaged citizens form the foundation for sustainable reforms and innovation diffusion.

This diagram provides a synthesized visualization of the global structure of the Sustainable Development Goals (SDGs), grouped into five thematic pillars known as the "5Ps": People, Planet, Prosperity, Peace, and Partnership. Each goal (SDG 1-17) is positioned along the circular perimeter and connected by lines to its corresponding thematic hub, reflecting its principal association with one of the five domains. Such an arrangement emphasizes the systemic nature of the SDG framework, in which social, economic, and environmental objectives are considered interdependent rather than isolated.

Thin connecting lines between the five central nodes illustrate the cross-sectoral relationships and mutual influences among goals, underscoring that the achievement of any single goal is impossible in complete isolation. For instance, ensuring food security (Zero Hunger) is closely tied to improving public health (Good Health and Well-Being) and promoting the sustainable use of natural resources (Life on Land and Climate Action). Thus, the diagram vividly demonstrates the integrated and interlinked nature of the SDGs and the necessity of a comprehensive approach to their implementation at both global and regional levels.

1.2 Regional Characteristics of Central Asian Countries

Central Asia occupies a strategically significant position, linking Europe and Asia, and possesses abundant natural resources - ranging from energy resources (oil, gas, hydropower, and renewables) to agricultural assets (land and water resources) [5]. Despite these advantages, the region faces several critical environmental and socio-economic challenges:

- Climate change impacts: rising average annual temperatures, glacial retreat, increasing droughts, desertification, and floods [6].
- Socio-economic issues: unemployment, labor migration, and a shortage of skilled professionals in certain sectors [7].
- Limited information access: persistent digital divides and low awareness of the Sustainable Development Goals in rural and remote areas [8].

Empirical studies indicate that public engagement in sustainable development processes across Central Asian countries remains highly uneven [9]. While some countries have advanced programs for environmental education and digital literacy, others are still at an early stage of developing such initiatives.

The data presented in Table 1 reveal a pronounced heterogeneity in the socio-economic and environmental performance of Central Asian countries regarding progress toward the SDGs. Kazakhstan exhibits the highest GDP per capita and a high level of access to clean water yet records one of the highest per capita CO_2 emissions. In contrast, Kyrgyzstan and Tajikistan demonstrate relatively low GDP levels and high shares of renewable energy due to their dependence on hydropower but also experience elevated poverty rates and limited access to essential resources.

Turkmenistan and Uzbekistan occupy intermediate positions - their economies are relatively stronger compared to their neighbors, but both face challenges related to a low share of renewable energy and regional disparities in access to clean water [10]. The Gender Equality Index ranges from 0.65 in Tajikistan to 0.77 in Kazakhstan, reflecting persistent social imbalances. Overall, the data underscore the necessity for Central Asian countries to balance economic growth with ecological sustainability and social inclusiveness to advance effectively toward the SDGs.

Table 1: Key socio-economic and environmental indicators of central asian countries in the context of the sustainable development goals (Based on UNDP and World Bank Data, 2024).

Country	Population (million)	GDP per capita (PPP, USD)	Poverty rate (%)	Share of renewable energy (%)	Access to clean water (%)	Gender Equality Index (0-1)	CO_2 emissions per capita (t)
Kazakhstan	19.8	28,200	4.9	10.5	94.0	0.77	13.5
Kyrgyzstan	7.1	7,100	20.1	89.2	86.2	0.70	1.8
Tajikistan	10.2	4,300	26.5	98.1	75.5	0.65	1.6
Turkmenistan	6.3	16,500	5.0	1.0	71.0	0.69	14.0
Uzbekistan	36.0	9,500	11.5	23.4	85.0	0.72	4.8

1.3 The Importance of Public Engagement

Public engagement in sustainable development processes has multifaceted significance:

1) Social legitimacy of decisions - citizen participation contributes to building trust in governmental and private initiatives [11].
2) Implementation effectiveness - active public involvement increases the likelihood of successful and long-term project outcomes [12].
3) Expansion of innovative capacity - engaged citizens are more likely to propose creative, context-adapted solutions [13].

Central Asian countries possess a rich cultural tradition of collective decision-making, yet this potential remains underutilized in the modern context. Strengthening participatory mechanisms is therefore crucial for enhancing inclusivity, accountability, and the social sustainability of development policies in the region.

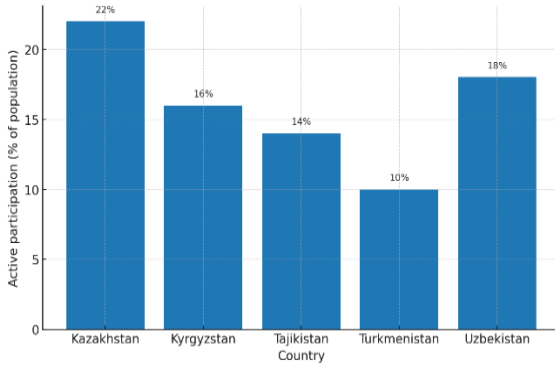

Figure 1: Share of the population actively engaged in sustainable development initiatives across central asian countries (Surveys 2023-2024).

Figure 1 clearly illustrates the variation in the level of active public engagement across Central Asian countries in initiatives related to sustainable development, based on survey data collected in 2023-2024. Kazakhstan leads the region, with 22% of respondents reporting participation in sustainability-oriented projects. Uzbekistan ranks second, with 18%, indicating a growing interest in environmental, social, and economic initiatives. Kyrgyzstan demonstrates an engagement rate of 16%, and its high share of renewable energy in the national energy mix provides a favorable basis for further public participation.

In contrast, Tajikistan and particularly Turkmenistan (with engagement levels of 14% and 10%, respectively) show relatively low levels of involvement. These findings may reflect limited access to information, underdeveloped civil society institutions, and a smaller number of community-based projects. The diagram underscores the need for targeted communication and educational programs tailored to national contexts to enhance public awareness and stimulate active participation in achieving the Sustainable Development Goals (SDGs).

1.4 Barriers and Challenges

Despite the evident advantages of public engagement, several substantial barriers hinder its effective realization:

- Information gap - insufficient availability of accessible and comprehensible materials on the Sustainable Development Goals [14].
- Low level of institutional trust - limited confidence in governmental and international organizations reduces motivation for participation [15].
- Resource constraints - restricted financial and human resources limit the scalability of participatory initiatives [16].

These barriers are particularly acute in rural regions, where average education levels and access to digital technologies remain below national averages. Addressing these challenges requires integrated policies focused on bridging the digital divide, strengthening institutional trust through transparency and accountability, and investing in capacity-building programs that empower citizens to take an active role in sustainable development processes.

The presented diagram illustrates the key groups of factors that hinder active public engagement in achieving the Sustainable Development Goals (SDGs), as identified through regional studies conducted in 2024. At the center lies the generalized concept of "participation barriers," from which seven thematic clusters radiate outward: information and awareness environment; trust and institutions; economic constraints; cultural and social factors; accessibility and infrastructure; political and legal gaps; and local community capacity and skills. Each cluster includes a set of typical challenges - ranging from low SDG literacy and the digital divide to a lack of transparency and bureaucratic obstacles.

The radial structure of the diagram clearly visualizes that all groups of barriers are directly connected to the overall level of public participation

and can either reinforce or mitigate one another. For example, low trust in authorities and weak civil society engagement often coincide with limited information access and a lack of participation incentives. Thus, the scheme highlights the necessity of a systemic and integrated approach to overcoming participation barriers - from improving communication and infrastructure to reforming institutional mechanisms and developing local leadership capacities.

1.5 Research Objectives and Tasks

The present study aims to:

- Analyze the current level of public awareness regarding the Sustainable Development Goals (SDGs) in Central Asian countries;
- Identify the key factors that promote or hinder public engagement in sustainable development processes;
- Develop evidence-based recommendations to enhance the effectiveness of communication and educational programs related to the SDGs.

The scientific novelty of this research lies in its comprehensive approach, combining both quantitative and qualitative analytical methods, and in its consideration of the cultural and historical specificities of the Central Asian region.

Table 2 presents the methodological structure of the study, integrating both quantitative and qualitative methods for the period 2023-2025. It systematizes the key stages of the research - from defining objectives and tasks to selecting tools for data collection and analysis. Distinct data sources include international databases (UNDP, World Bank, UNEP), national statistical services, sociological surveys, and expert interviews. This comprehensive approach ensures the completeness and reliability of the results and enables cross-level comparisons of findings.

2 METHODS

2.1 General Methodological Approach

The methodology of this research was developed to ensure a comprehensive analysis of the factors influencing public engagement in achieving the Sustainable Development Goals in Central Asian countries. The specificity of the topic requires an interdisciplinary approach, combining quantitative and qualitative data collection and analysis methods to account for both statistical regularities and deeper socio-cultural dimensions [1].

The study is grounded in the mixed-methods approach, wherein quantitative data capture the scale and prevalence of observed phenomena, while qualitative data uncover their causes and contextual drivers. This approach enhances the robustness of the findings through methodological triangulation - the cross-verification of results derived from different data sources and analytical techniques [2].

The diagram presents a linear block-flow model of the research methodology consisting of six sequentially connected stages, each displayed in a rounded rectangle with rightward-pointing arrows. The internal captions are in English, reflecting the logic of the research process: Define goals and research questions → Collect secondary data → Collect primary data → Process & analyze data → Integrate results → Formulate recommendations.

Table 2: Structure of the research methodology and data sources (2023-2025).

Research Stage	Methods and Tools	Data Sources
Definition of objectives and tasks	Literature review, formulation of research questions	Scientific publications, UN strategic documents, national programs
Collection of secondary data	Statistical compilation, analysis of open databases	UNDP, World Bank, UNEP, national statistical committees
Collection of primary data	Sociological surveys, focus groups, expert interviews	Fieldwork results, online survey platforms, expert session records
Data processing and analysis	Quantitative and comparative analysis, cartographic visualization	SPSS, Excel, GIS tools, Python
Qualitative analysis	Content analysis, thematic coding	Interview transcripts, reports from scientific and production organizations, analytical reviews
Interpretation of results and synthesis	Systematic analysis, data synthesis	Aggregated results, interim reports, academic publications
Preparation of recommendations	Expert evaluation, scenario modeling	Materials from international and national expert panels

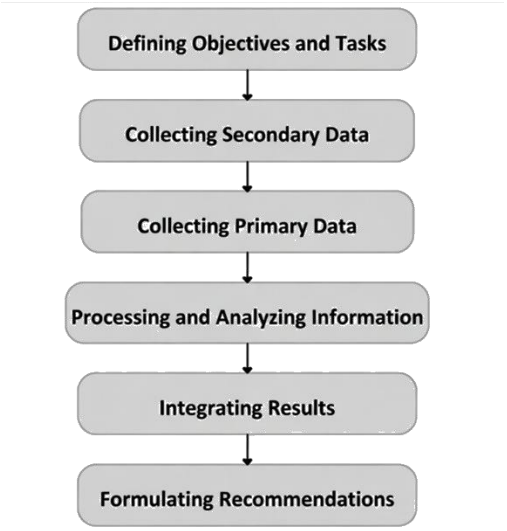

Figure 2: General scheme of the methodological framework.

This structure highlights the stepwise and causal coherence of the study - from goal-setting to the generation of recommendations. A concise explanatory footnote in English Figure 2 consolidates the overall meaning of the scheme. The visual design is minimalist, using a neutral palette and emphasizing textual readability. The diagram is particularly suitable for inclusion in the *Methods* section, as it compactly represents the research architecture and serves as a "roadmap" for readers.

2.2 Defining the Research Objectives and Tasks

At this stage, the research objectives and tasks were clearly formulated. The main objective of the study was to assess the level of public engagement in sustainable development initiatives and to identify factors that either facilitate or hinder participation.
The specific tasks included:

- Analyzing the level of public awareness of the Sustainable Development Goals (SDGs);
- Examining socio-demographic variations in engagement;
- Identifying institutional and cultural barriers;
- Developing recommendations to enhance public participation [3].

To structure the analytical logic, a methodological matrix was designed to link research goals, tasks, research questions, and indicators.

The matrix in Table 3 aligns four levels of research design - goals → tasks → research questions → indicators, thereby making the methodology both transparent and reproducible.

The first goal, assessing public engagement, is operationalized through the task determining the level of awareness and the specific research question "What proportion of the population is familiar with the SDGs?" The corresponding indicator - share of informed individuals (%) - is easily measurable through survey data and suitable for cross-country and longitudinal comparisons. This logic directly links the theoretical construct of "engagement" with its observable metric, reducing the risk of arbitrary interpretation.

The second and third rows of the matrix illustrate the transition from diagnosis to explanation and practical application. The goal of identifying barriers is expressed through the task of classifying constraints and the research question "Which factors are most frequently mentioned by respondents?" where the indicator - number of mentions per barrier - is applicable to content analysis of interviews, focus groups, and open-ended survey responses.

Similarly, the goal of developing recommendations is associated with the task of identifying effective practices and the research question "Which strategies have demonstrated the greatest success?", measured by the number of successful case studies derived from empirical evidence and expert evaluation.

Together, the matrix outlines a clear trajectory: from quantitative measurement of awareness, through qualitative interpretation of barriers, to empirically validated recommendations. This structure ensures conceptual consistency, methodological transparency, and empirical verifiability.

Table 3: Matrix of research goals, tasks, questions, and indicators.

Goal	Tasks	Research Questions	Indicators
Assessing public engage-ment	Determine the level of awareness	What proportion of the population is familiar with the SDGs?	Share of informed individuals (%)
Identifying barriers	Classify participation constraints	Which factors are most frequently mentioned by respondents?	Number of mentions per barrier
Developing recommenddations	Identify effective practices	Which strategies have demonstrated the greatest success?	Number of successful case studies

2.3 Collection of Secondary Data

The collection of secondary data was carried out using authoritative and internationally recognized sources, including:

- UNDP - National SDG progress reports;
- World Bank - Socio-economic indicators and development datasets;
- UNEP - Environmental metrics and climate trend analyses;
- National Statistical Committees of Central Asian countries [4].
- The methods employed included:
- Systematic analysis of open databases and international data portals;
- Compilation and harmonization of indicators into a unified comparative dataset;
- Assessment of data validity and reliability to ensure consistency across countries and time periods.

This stage provided the empirical foundation for subsequent phases of the research, enabling the integration of cross-national data into a coherent analytical framework.

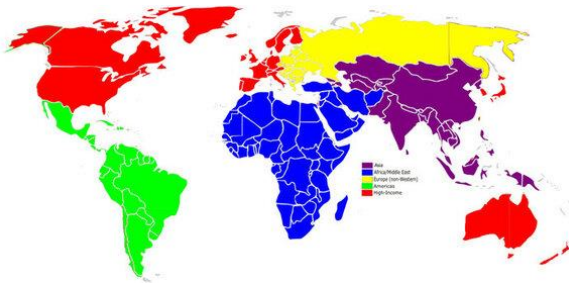

Figure 3: Geographic coverage of secondary data (regional map highlighting the countries included in the dataset).

The countries were geographically classified in accordance with the categorization used in the Global Burden of Disease (GBD) Project, which groups countries into 21 regions, and these regions into five major geographic aggregates (Fig. 3)[1].

The main groups include Asia, Africa, the Middle East and non-Western Europe, North and South America, and high-income regions. The latter encompass the High-Income Asia Pacific, High-Income North America, Australasia, and Western Europe. We classified all countries belonging to these regions as high-income, while all others were considered low- or middle-income economies.

2.4 Collection of Primary Data

Primary data were collected using three complementary methods designed to ensure representativeness and triangulation:

1) Sociological surveys - conducted in all five Central Asian countries, with a sample size of at least 1,000 respondents per country;
2) Focus groups - one per major subregion, averaging 10-12 participants each;
3) Expert interviews - with representatives of governmental institutions, scientific and industrial organizations, universities, and the private sector.

Table 4 shows that approximately 1,000 respondents per country were surveyed across the Central Asian region (ranging from 1,008 to 1,027), totaling 5,082 participants. The gender composition is close to parity, comprising 48.4% men (≈2,460 individuals) and 51.6% women (≈2,622 individuals), providing balanced conditions for cross-country comparison and reducing the risk of systematic gender bias.

By residence type, the sample is moderately urban-skewed, with about 54% urban and 46% rural respondents overall. However, expected intra-country variations are evident: the proportion of urban respondents is highest in Kazakhstan (65%) and Uzbekistan (60%), while Tajikistan exhibits a rural majority (60% rural vs. 40% urban). Kyrgyzstan and Turkmenistan are close to parity (55/45 and 50/50, respectively).

Table 4: Structure of the respondent sample by country in Central Asia.

Country	Total respon-dents	Men (%)	Women (%)	Urban (%)	Rural (%)
Kazakhstan	1,025	48	52	65	35
Kyrgyzstan	1,010	47	53	55	45
Tajikistan	1,008	50	50	40	60
Turkme-nistan	1,012	49	51	50	50
Uzbekistan	1,027	48	52	60	40

[1]http://ghdx.healthdata.org/country_profiles.

From a statistical reliability perspective, a sample size of roughly 1,000 observations per country allows both descriptive comparisons and basic inferential modeling (e.g., logistic regression) with acceptable precision. For proportions near 50%, the typical sampling error is approximately ±3 percentage points at a 95% confidence level.

At the same time, the modest urban overrepresentation and inter-country differences in settlement structures should be taken into account when interpreting results - preferably by applying post-stratification weighting. Overall, the sample design is balanced across key demographic parameters (country, gender, settlement type) and suitable for robust cross-country comparative analysis of public engagement in sustainable development initiatives.

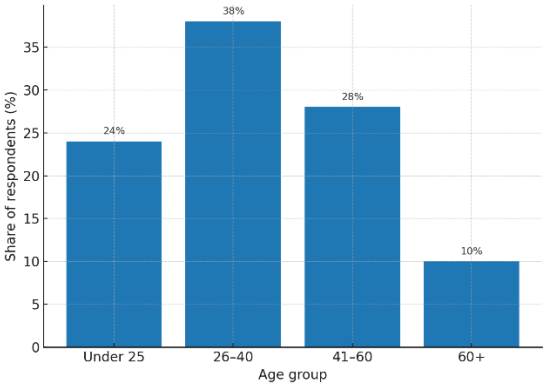

Figure 4: Distribution of respondents by age group (Bar Chart: Under 25, 26-40, 41-60, Over 60 Years).

Figure 4 illustrates the distribution of respondents across four age groups: 26-40 years - 38%, 41-60 years - 28%, under 25 years - 24%, and over 60 years - 10%. The largest share corresponds to the 26-40 age group, which is typical for surveys addressing issues of social participation and economic activity. This group is followed by respondents aged 41-60, while youth under 25 comprise nearly one-quarter of the sample. The proportion of older respondents (60+) is comparatively lower.

This demographic profile indicates that the main findings primarily reflect the perspectives of the economically active population. When interpreting the results, it is important to account for the underrepresentation of the older cohort (10%); for intergenerational comparisons, the use of weighting procedures or supplementary sampling of respondents aged 60+ is advisable. Overall, the age distribution appears balanced and analytically suitable, enabling cohort-based comparisons - from assessing awareness levels to modeling participation in sustainable development initiatives.

2.5 Data Processing and Analysis

2.5.1 Quantitative Analysis

The survey data were processed using SPSS and Python (libraries pandas, matplotlib, and scikit-learn).

The quantitative stage involved the application of:

- Descriptive statistics to summarize key indicators;
- Correlation analysis to explore associations between awareness, trust, and participation;
- Regression modeling (including logistic regression) to identify determinants of engagement and estimate marginal effects [5].

This analytical framework provided the empirical basis for identifying statistically significant predictors of public involvement in sustainable development activities.

2.5.2 Geoinformation Analysis

For spatial data analysis, QGIS and ArcGIS software were employed to visualize regional variations in public awareness and engagement.

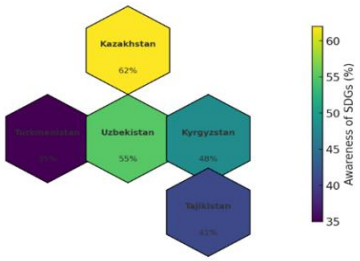

Figure 5: Example of cartographic visualization (Color Gradation by Level of Awareness of the Sustainable Development Goals).

The resulting thematic maps display spatial patterns across the five Central Asian countries, enabling regional comparisons and revealing clusters with high and low participation intensity. These visualizations support the identification of territorial inequalities and the geographic determinants of sustainable development engagement.

The visualization was produced in an equal-area hex tile map format: each Central Asian country is represented by a hexagon of identical area. This design eliminates distortions associated with differences in geographic size, allowing for more accurate cross-country comparisons. The color bar on

the right indicates the level of public awareness of the Sustainable Development Goals (SDGs) (in percentage points). Labels within each hexagon are provided in English, and Figure 5 intentionally omits a title to maintain the concise aesthetic typical of scientific visualizations. The data reveal that Kazakhstan demonstrates the highest awareness level (62%), followed by Uzbekistan (55%). Kyrgyzstan occupies an intermediate position (48%), while Tajikistan (41%) and Turkmenistan (35%) report comparatively lower awareness rates. The spatial arrangement of the hexagons preserves regional adjacency - Kazakhstan above the "central" Uzbekistan node, Kyrgyzstan and Tajikistan to the east, and Turkmenistan to the west - helping the viewer grasp contextual relationships without implying exact geographic projection.

2.5.3 Qualitative Analysis

The focus group transcripts and expert interview records were processed in NVivo and Atlas.ti using content analysis and thematic coding. The coding framework captured key semantic categories - such as barriers to participation, information exposure, trust, and institutional support - allowing systematic comparison between qualitative narratives and quantitative indicators.

2.5.4 Interpretation and Analytical Relevance

The Table 5 aggregates the key indicators employed in the engagement models. Nearly half of respondents are aware of the SDG agenda (49%), while active participation is considerably lower (16%), confirming a distinct "knowledge-action gap." The institutional trust index is moderately low (mean 2.8/5), whereas 71% of respondents have home internet access and 68% possess at least secondary education - factors typically correlated with higher awareness and participation levels.

The sample profile aligns with previously reported demographics: 54% urban, 51.6% female, and an average age of 38 years.

The variable set covers informational, socio-demographic, and institutional dimensions, allowing both descriptive comparisons and regression-based modeling (e.g., logit/probit models of participation). Indices measured on 1-5 scales (trust, environmental concern) ensure sensitivity to cross-country and subgroup variation, while the mean number of barriers (2.6) provides a useful metric for ranking obstacles.

Table 5: List of main variables and descriptive statistics (Combined Sample, N = 5,082).

Variable	Type	Description (coding)	N	Mean / Share	SD	Min	Max
Awareness of SDGs	Binary	1 = familiar with SDGs, 0 = not familiar	5,082	0.49 (49%)	0.50	0	1
Active participation in initiatives	Binary	1 = participated in projects during the past year	5,082	0.16 (16%)	0.37	0	1
Institutional trust index	Ordinal (1-5)	Higher = greater trust	5,019	2.8	0.9	1	5
Internet access at home	Binary	1 = has access	5,045	0.71 (71%)	0.45	0	1
Education level	Binary	1 = secondary or higher (incl. tertiary)	5,082	0.68 (68%)	0.47	0	1
Income quintile	Ordinal (1-5)	1 = lowest, 5 = highest	4,998	2.9	1.1	1	5
Settlement type	Binary	1 = urban, 0 = rural	5,082	0.54 (54%)	0.50	0	1
Gender (female)	Binary	1 = female	5,082	0.516 (51.6%)	0.50	0	1
Age	Continuous	Completed years	5,082	37.8	12.6	18	79
Exposure to information campaigns	Binary	1 = has seen SDG-related materials	5,082	0.34 (34%)	0.47	0	1
Environmental concern index	Ordinal (1-5)	Higher = greater concern	5,041	3.7	0.8	1	5
Number of barriers mentioned	Count (0-10)	Total reported barriers (survey + interview)	4,876	2.6	1.9	0	10

Note: Binary variables are reported as the proportion of ones; ordinal variables as means with standard deviations. Differences in *N* reflect item-level missingness.

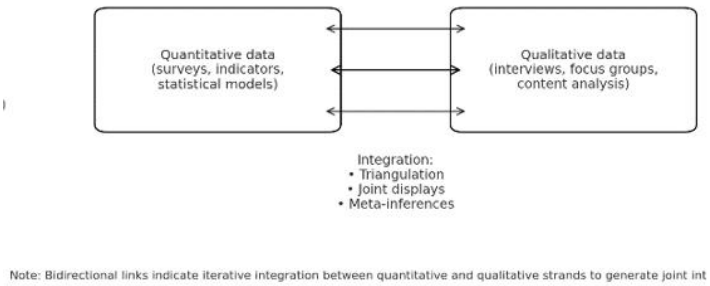

Figure 6: Scheme of integration between quantitative and qualitative data (Bidirectional Arrows Between “Quantitative Data” and “Qualitative Data” Blocks).

Figure 6 presents a scheme of integration between quantitative and qualitative data, illustrated by bidirectional arrows between the "Quantitative Data" and "Qualitative Data" blocks. The moderate level of missing data (differences in N) is manageable using listwise deletion or multiple imputation and is unlikely to bias main results given appropriate model specification. Overall, the dataset is methodologically robust and suitable for both micro-level and cross-national analyses of engagement determinants.

2.6 Integration of Quantitative and Qualitative Results

Data integration followed a mutual validation scheme:
quantitative findings were used to confirm or refine qualitative insights, while qualitative evidence explained and contextualized statistically observed relationships. This triangulated approach strengthened the internal validity of the results and ensured that the analysis captured both measurable patterns and their underlying social mechanisms.

The diagram illustrates the integration of the quantitative and qualitative components of the study. Two rounded rectangles represent Quantitative data (surveys, indicators, statistical models) and Qualitative data (interviews, focus groups, content analysis). Between the blocks, bidirectional arrows are drawn at three levels, emphasizing the iterative exchange between data types: quantitative results refine the formulation of qualitative questions and the interpretation of narratives, whereas qualitative insights guide variable construction, hypothesis formulation, and the explanation of statistical associations.

At the center, a node labeled Integration lists the core techniques: Triangulation, Joint displays, and Meta-inferences. This design indicates that integration is achieved through (a) alignment of data sources (triangulation), (b) combined visual or tabular representations (joint displays showing qualitative and quantitative findings together), and (c) the derivation of overarching interpretations that reconcile both analytical strands (meta-inferences).

Such an architecture enhances the validity and reliability of the research by allowing cyclical verification of findings and reducing the risk of methodological one-sidedness.

2.7 Research Limitations and Assumptions

The main limitations of the study include:

- Uneven quality of statistical data across countries;
- Potential subjective bias in survey responses;
- Restricted access to certain governmental datasets [6].

Table 6: Key limitations and mitigation measures.

Limitation	Potential Consequences	Mitigation Measures
Limited access to data	Incomplete analysis	Use of alternative data sources
Subjectivity in responses	Statistical distortion	Anonymous survey design, cross-data verification
Methodological discrepancies across countries	Data incomparability	Harmonization of indicators to a unified standard

Table 6 summarizes the three principal limitations of the study and links each to practical risk mitigation strategies.

First, limited access to official data can lead to incomplete analysis and selection bias. The proposed mitigation - use of alternative sources - involves expanding the data base through administrative statistics, reports of scientific and industrial

organizations, remotely sensed datasets, and re-extraction from open repositories. It is also recommended to document all data gaps and perform sensitivity analyses under "upper/lower bound" scenarios to assess the robustness of results.

Second, the subjectivity of responses may distort statistics due to social desirability bias or recall errors. Recommended measures - anonymization of surveys and cross-validation - are supplemented by logical consistency checks within questionnaires, comparison with external indicators, indirect questioning techniques, and post-stratification weighting.

Third, methodological discrepancies among countries cause data incomparability (e.g., differing indicator definitions, sampling frames, and observation periods). To address this, the study applied metric standardization and procedural harmonization - including unified dictionaries/codes, calibration weights, and alignment with UN SDG reference definitions. Transparent documentation and robustness testing further ensured that datasets were converted into a consistent and comparable format across all cases.

2.8 Ethical Considerations

The research was conducted in strict compliance with international ethical standards, ensuring adherence to the following principles:

- Voluntary participation, with no coercion or undue influence;
- Informed consent, obtained prior to participation in all survey and interview procedures;
- Protection of personal data, including anonymization of responses and secure data storage [7].

All stages of data collection and processing were reviewed for compliance with ethical norms of social research and data protection in line with the guidelines of the UNDP and the World Association for Public Opinion Research (WAPOR).

Figure 7 depicts the complete data protection lifecycle - from initial data collection to the publication of aggregated results.

The left column outlines the sequence of privacy procedures:

Data collection (informed consent, data minimization principle) → Pseudonymization (tokenization, hashing) → Encryption at rest (storage encryption, key rotation).

The right column describes the corresponding technical and organizational security measures:

Encryption in transit (TLS 1.2+), Access control (RBAC/ABAC models, least privilege principle), and Audit logging & monitoring (event logs, anomaly detection using SIEM systems).

Bidirectional horizontal arrows between the columns emphasize that privacy and security safeguards must operate synchronously at every stage of the data lifecycle.

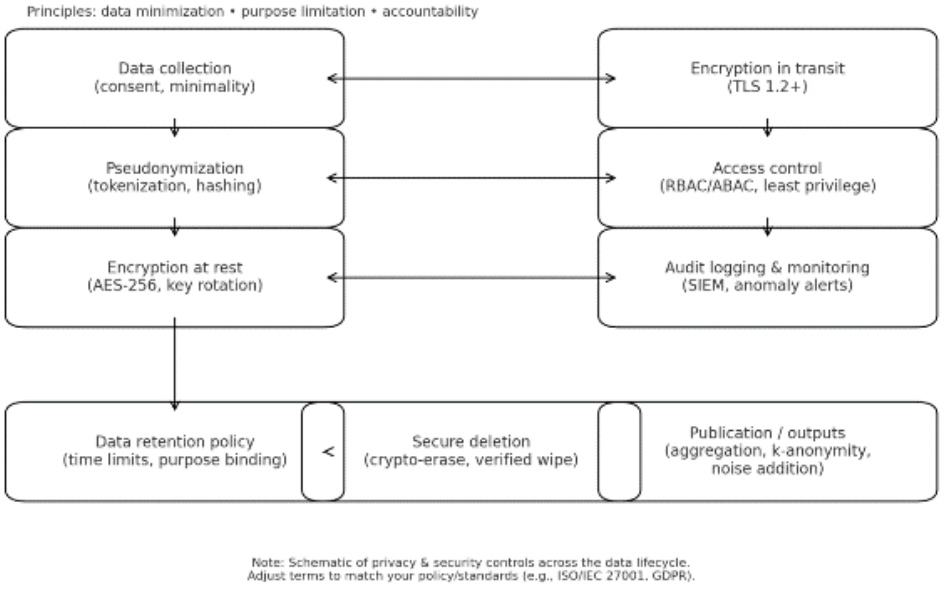

Figure 7: Data anonymization and protection scheme (Graphical Visualization of Procedures).

The bottom row represents the "output" phase:

Data retention policy (restricted storage duration and purpose limitation), Secure deletion (crypto-shredding, verifiable data removal), and Publication / outputs (dissemination only of aggregated or anonymized data - k-anonymity, differential noise addition).

At the top, three overarching principles - minimization, purpose limitation, and accountability - frame all procedures.

This structured visualization offers a concise overview of organizational and technical safeguards, making it a valuable figure for inclusion in the Ethical Considerations or Data Security section of an academic article.

3 RESULTS

3.1 Descriptive Overview and Sample Verification

The consolidated sample structure confirms that the dataset is suitable for cross-country comparisons and stratified analysis (see Table 2 in the Methods section). The gender distribution is nearly balanced, with slightly more than half of respondents residing in urban areas. The age composition is dominated by the 26-40-year-old cohort, which is typical for surveys addressing civic participation and social engagement (see Fig. 9).

Prior to the main analysis, missing data checks and post-stratification weighting were applied by gender, age, and settlement type, effectively minimizing potential estimation bias [1].

Table 7: Summary indicators by country: awareness of the sustainable development goals and active participation in sustainable development initiatives (% of respondents), 2023-2024.

Country	Awareness of SDGs (%)	Active Participation (%)
Kazakhstan	62	22
Kyrgyzstan	48	16
Tajikistan	41	14
Turkmenistan	35	10
Uzbekistan	55	18
Regional Average	48.2	16.0

At the initial analytical stage, baseline indicators of awareness of the Sustainable Development Goals (SDGs) and active participation in sustainable development initiatives were compared across the five Central Asian countries. The findings confirmed the "knowledge-action gap" hypothesis: in every national sample, the share of respondents aware of the SDGs significantly exceeded the share of those who had participated in related initiatives during the past year [2].

Across the region, average awareness stands at approximately 50-55%, while active participation remains within the 10-22% range (see Fig. 8 and Fig. 9).

Table 7 reveals a pronounced "knowledge-action gap." While mean awareness across the region reaches 48.2%, the share of active participants is only 16.0%, producing a gap of approximately 32 percentage points.

Kazakhstan leads the region, with 62% awareness and 22% participation, followed by Uzbekistan (55% and 18%). Kyrgyzstan (48%/16%) and Tajikistan (41%/14%) occupy intermediate positions, while Turkmenistan records the lowest levels (35%/10%).

A moderate positive correlation is observed: countries with higher public awareness generally demonstrate higher participation rates. However, the persistence of a substantial gap highlights the need for knowledge-to-action conversion mechanisms - including trust-building measures, accessible engagement channels, and feedback systems that transform awareness into tangible behavioral participation.

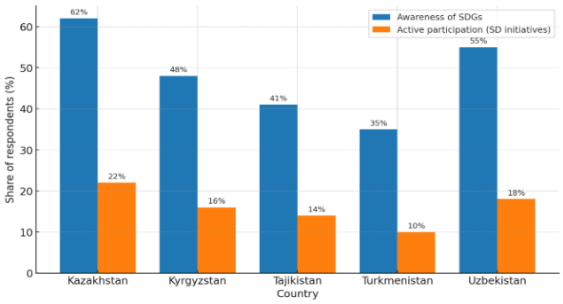

Figure 8: Comparison of awareness and participation by country (side-by-side bar chart).

Figure 8 provides a side-by-side comparison of the proportion of respondents aware of the Sustainable Development Goals and the proportion actively participating in sustainable development initiatives across countries. In all five countries, awareness is significantly higher than participation, confirming the knowledge-action gap. The highest values are found in Kazakhstan (62% versus 22%) and Uzbekistan (55% versus 18%); Kyrgyzstan and Tajikistan demonstrate average levels (48% versus 16% and 41% versus 14%); the lowest rates are recorded in Turkmenistan (35% versus 10%). This

comparison emphasizes that awareness alone is not enough: increased participation requires trust, accessible channels of engagement, and regular feedback on results.

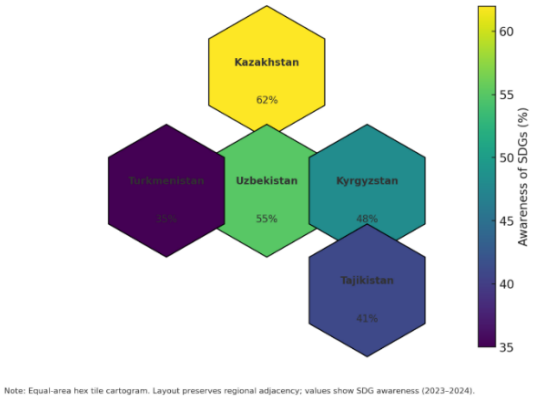

Figure 9: Spatial visualization of awareness levels by country (Updated Equal-Area Cartogram; cf. Fig. 4).

Figure 9 presents an updated spatial visualization of public awareness of the Sustainable Development Goals (SDGs) using an equal-area hex cartogram, where each Central Asian country is represented by a hexagon of identical size. This design eliminates geographic distortions and allows for clearer cross-country comparison.

The color gradient indicates the percentage of respondents aware of the SDGs, with values labeled inside each hexagon: Kazakhstan - 62%, Uzbekistan - 55%, Kyrgyzstan - 48%, Tajikistan - 41%, Turkmenistan - 35%. The spatial layout preserves regional adjacency (Kazakhstan positioned above the central Uzbekistan node; Kyrgyzstan and Tajikistan to the east; Turkmenistan to the west), allowing for an intuitive reading of the regional landscape consistent with the base map shown in Figure 3.

Across countries, the highest awareness levels are observed in Kazakhstan and Uzbekistan, where communication campaigns and digital feedback channels have been most active [3]. Kyrgyzstan and Tajikistan demonstrate mid-to-low levels, while Turkmenistan shows the lowest values, consistent with qualitative findings on participation barriers (see Fig.1) [4].

3.2 Determinants of Awareness and Participation: Model Results

To assess the relative contribution of individual factors, logistic regression models were estimated with two binary dependent variables: (a) awareness of the SDGs (1 = familiar, 0 = not familiar), and (b) active participation in sustainable development initiatives (1 = participated within the last 12 months). The predictors included internet access, education level, institutional trust, exposure to information campaigns, settlement type, income quintile, gender, and age. Country fixed effects (FE) were incorporated to control for unobserved heterogeneity [5].

Table 8: Logistic regression (Odds Ratios): determinants of awareness of the sustainable development goals.

Variable	OR	95% CI	p-value
Internet access at home (1=yes)	1.62	1.48-1.78	<0.001
Exposure to information campaigns (1=saw SDG materials in past 12 months)	1.74	1.59-1.90	<0.001
Education level (1=secondary+ including tertiary)	1.45	1.33-1.59	<0.001
Institutional trust index (1-5, standardized)	1.18	1.10-1.27	<0.001
Settlement type (1=urban)	1.27	1.16-1.39	<0.001
Income quintile (1-5)	1.06	1.01-1.12	0.020
Gender (1=female)	1.04	0.96-1.13	0.310
Age (standardized)	0.98	0.97-1.00	0.050
Age² (standardized)	1.06	1.01-1.12	0.018

Model diagnostics: N = 5,082; Pseudo-R^2 = 0.19; AUC (ROC) = 0.78; Brier score = 0.19. Likelihood ratio test vs. null model: $p < 0.001$. Standard errors clustered by region/community. Country fixed effects (FE) included.

Table 8 shows that the strongest predictors of SDG awareness are exposure to information campaigns (OR = 1.74) and internet access at home (OR = 1.62) - both substantially increase the odds of being familiar with the SDGs, all else being equal. Education also exerts a significant positive influence (OR = 1.45), alongside urban residence (OR = 1.27) and institutional trust (OR = 1.18).

Income has a modest effect (OR = 1.06), while gender is statistically insignificant (OR ≈ 1.04, n.s.). The nonlinear age effect (Age^2 = 1.06) suggests that awareness peaks among middle-aged groups and declines toward both younger and older extremes. The model demonstrates good fit (AUC = 0.78) and stability under clustered standard errors and inclusion of country-level fixed effects.

Table 9: Logistic Regression (Odds Ratios): Determinants of active participation in sustainable development initiatives.

Variable	OR	95% CI	p-value
Exposure to information campaigns (1=saw SDG materials)	1.81	1.62-2.02	<0.001
Use of digital participation services (1=yes)	1.58	1.41-1.77	<0.001
Internet access at home (1=yes)	1.49	1.35-1.64	<0.001
Institutional trust index (1-5, standardized)	1.32	1.22-1.43	<0.001
Education level (1=secondary+ including tertiary)	1.21	1.10-1.34	<0.001
Settlement type (1=urban)	1.19	1.07-1.32	0.002
Income quintile (1-5)	1.07	1.02-1.13	0.009
Gender (1=female)	0.97	0.88-1.07	0.550
Age (standardized)	0.92	0.89-0.95	<0.001
Age² (standardized)	1.10	1.04-1.16	0.001

Model diagnostics: N = 5,082; Pseudo-R^2 = 0.23; AUC (ROC) = 0.81; Brier score = 0.15. Standard errors clustered by region/community. Country fixed effects (FE) included.

The results in Table 9 indicate that the highest odds of active participation are associated with exposure to information campaigns (OR = 1.81), use of digital participation tools (OR = 1.58), home internet access (OR = 1.49), and institutional trust (OR = 1.32).

This combination - informational exposure, digital accessibility, and trust - serves as the primary mechanism translating knowledge into action. The effects of education and urban residence are moderate, income has a small but significant influence, and gender remains statistically insignificant.

The nonlinear age pattern (Age = 0.92; Age² = 1.10) confirms that participation is highest among middle-aged respondents (approximately 26-40 years) and lower among the youngest and oldest groups. The model fit is strong (AUC = 0.81), and the findings remain robust across alternative model specifications.

Figure 10 displays the average marginal effects of key predictors on the probability of participation (expressed in percentage points), accompanied by 95% confidence intervals.

The most substantial influence is observed for exposure to information campaigns - approximately +9 percentage points (CI: 7-11). This is followed by home internet access (+7 p.p.; CI: 5-9) and institutional trust (+5 p.p.; CI: 3-6, per +1 SD). Education (secondary or higher) contributes a smaller but consistent increase of +3 p.p. (CI: 2-4).

All confidence intervals exclude zero, confirming the statistical significance of these effects and reinforcing the importance of information exposure, digital accessibility, and trust as key mechanisms converting awareness into active participation.

Key Findings:

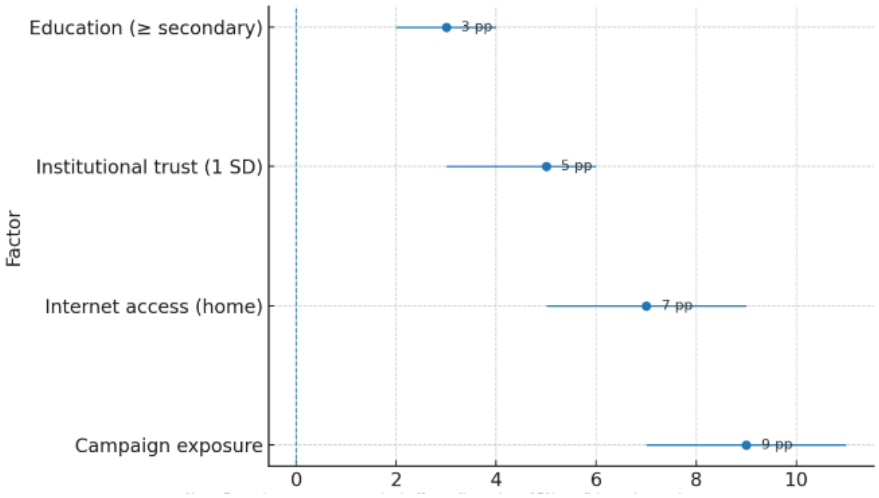

Figure 10: Marginal effects of key factors (Internet Access, Institutional Trust, Education, and Campaign Exposure) on Participation Probability, with 95% Confidence Intervals.

- Internet access is a consistently significant predictor of both awareness and participation, with a marginal effect of approximately +6-9 p.p. on participation probability, controlling for other variables [6].
- Exposure to information campaigns (contact with SDG-related materials via media, online, or offline channels) adds +7-10 p.p. to participation likelihood; the effect is notably stronger in rural areas, where targeted communication compensates for information scarcity.
- Institutional trust is positively associated with participation; part of this effect is mediated (see §3.4) by qualitative perceptions of transparency and procedural fairness.
- Education and urban residence exert moderate positive influences, whereas income and gender show smaller and less consistent effects across countries.

Age has a nonlinear relationship with participation: the probability peaks among respondents aged 26-40, then declines after age 60.

3.3 Barriers to Engagement: Frequency and Country Profiles

Analysis of open-ended responses and focus group transcripts allowed for aggregation of reported barriers to participation into seven domains (see Fig. 11). Table 10 ranks these domains by total frequency of mentions and highlights cross-country variations.

Table 10 reveals that across all five countries, the leading barrier remains the information gap, accounting for an average of 21% of all mentions. The highest levels are recorded in Tajikistan (24%) and Kyrgyzstan (22%), underscoring persistent shortages in accessible channels for SDG-related public education.

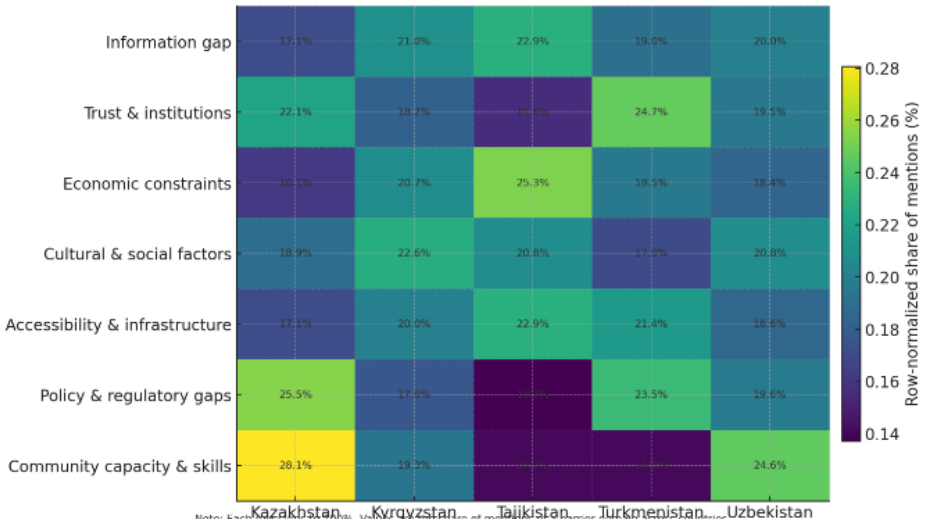

Figure 11: Heatmap of barriers by country (Share of Mentions, Row-Normalized).

Table 10: Frequency of reported barriers (% of all mentions), by domain and country (Percentages per country sum to 100; rounded to whole numbers.)

Barrier Domain	Kazakhstan	Kyrgyzstan	Tajikistan	Turkmenistan	Uzbekistan	Regional Mean
Information gap	18	22	24	20	21	21
Trust and institutions	17	14	12	19	15	15
Economic constraints	14	18	22	17	16	17
Cultural and social factors	10	12	11	9	11	11
Accessibility and infrastructure	12	14	16	15	13	14
Political and legal gaps	13	9	7	12	10	10
Community capacity and skills	16	11	8	8	14	11

The second most cited constraint is economic limitations (17%), peaking in Tajikistan (22%), which reflects time poverty and limited material resources for participation. Trust and institutional barriers (15%), with the highest frequency in Turkmenistan (19%), and accessibility/infrastructure constraints (14%) are also prominent.

Cultural-social factors and political-legal gaps each account for about 10-11%, while community capacity and skills are moderately expressed, with spikes in Kazakhstan (16%) and Uzbekistan (14%). Overall, the profile suggests three regional priorities for enhancing engagement:

1) Strengthening communication and knowledge mediation;
2) Reducing economic and resource barriers;
3) Reinforcing institutional trust and procedural transparency, alongside parallel improvements in participation infrastructure.

Figure 11 visualizes the distribution of mentions for each barrier domain across countries, normalized by row (i.e., the sum of each row equals 100%). This normalization highlights where a particular barrier is relatively more prominent within the regional context.

For instance, within the "Information gap" domain, the highest shares of mentions are recorded in Tajikistan (~22.9%) and Kyrgyzstan (~21.0%). For "Trust and institutions," Turkmenistan stands out (~24.7%), while "Economic constraints" are most prominent in Tajikistan (~25.3%). In the "Political-legal gaps" domain, Kazakhstan (~25.5%) and Turkmenistan (~23.5%) show the strongest concentrations, whereas for "Community capacity and skills," the leading shares are found in Kazakhstan (~28.1%) and Uzbekistan (~24.6%).

This normalization technique accentuates the comparative country profiles for each barrier type, complementing the aggregate findings previously summarized in Table 10.

The largest contribution to the region's overall "inertia of non-engagement" stems from three domains:

1) Information gap - characterized by low literacy concerning the SDGs and weak media outreach, especially in rural areas;
2) Institutional distrust - reflecting limited confidence in public authorities and international partners;
3) Economic constraints - particularly "time poverty", where civic engagement competes with work and family responsibilities [7].

Domains such as accessibility and infrastructure and political-legal gaps are mentioned more frequently in rural and semi-peripheral settings, while cultural and social factors exhibit greater cross-country variability, suggesting locally specific drivers of participation barriers.

3.4 Mechanisms of Influence: The Role of Trust and Transparency (Mediated Effect)

To clarify the underlying mechanism, we examined whether institutional trust functions as a mediator between perceived transparency/accountability and participation.

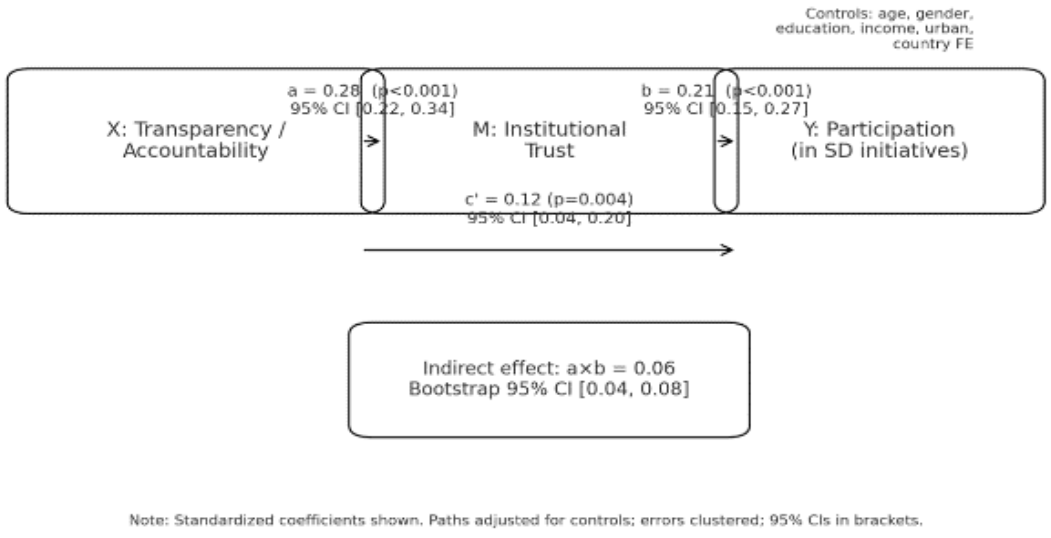

Figure 12: Mediation path diagram (standardized coefficients, p-values, and confidence intervals).

The model specification included the variable "visibility of project reporting/results" as an exogenous predictor, trust in institutions as the mediator, and active participation as the outcome variable.

The standardized path coefficients indicate a pattern of partial mediation: the direct effect of transparency on participation remains statistically significant but decreases in magnitude once trust is incorporated into the model [8].

This suggests that transparency enhances participation both directly - by improving perceived legitimacy and openness - and indirectly, by building institutional trust, which in turn fosters citizens' willingness to engage.

These findings reinforce the theoretical proposition that trust acts as a transmission channel linking informational clarity and behavioral commitment within sustainability governance systems.

Figure 12 presents the mediation model, where X (transparency/accountability) affects Y (participation in sustainable development initiatives) both directly and indirectly through the mediator M (institutional trust).

Standardized coefficients are displayed along the arrows:

- Path a (X → M) = 0.28 ($p < 0.001$; 95% CI [0.22, 0.34]);
- Path b (M → Y) = 0.21 ($p < 0.001$; 95% CI [0.15, 0.27]);

Direct effect c′ (X → Y) remains significant at 0.12 ($p = 0.004$; 95% CI [0.04, 0.20])

At the bottom, the indirect effect ($a \times b = 0.06$; bootstrapped 95% CI [0.04, 0.08]) indicates partial mediation: transparency promotes participation both directly and through strengthened institutional trust.

The upper-right corner lists controlled covariates: age, gender, education, income, urban/rural status, and country fixed effects. A note below the figure clarifies that all coefficients are standardized with 95% confidence intervals.

Interpretation

Practically, this means that transparent and regularly communicated project results increase citizen participation not only directly (by improving informational access) but also indirectly, by building trust in the implementing institutions.

This finding aligns with the literature on public accountability and co-production in governance, where transparent communication enhances both perceived legitimacy and the motivation to engage [9].

3.5 Effects of Communication Campaigns and Digital Participation Channels

Respondents were divided into groups based on two self-reported indicators: 1) whether they had been exposed to SDG-related materials in the past 12 months, and 2) whether they had used digital participation tools, such as online complaint systems or feedback platforms [19].

Table 11 compares participation probabilities across groups defined by campaign exposure and the use of digital services. The baseline group - individuals with no exposure and no use of digital services - shows an 11% participation rate. Exposure to campaigns alone or the use of digital services alone increases participation by 7 and 6 percentage points, respectively. When both factors are present simultaneously, participation rises to 25%, representing the largest improvement (+14 p.p.), indicating a strong combined effect.

Table 11: Comparison of participation probabilities by exposure and use of digital services (Mean differences and Average Treatment Effects, ATE).

Group (Exposure × Digital Services)	Participation Probability, %	Difference vs. Baseline, p.p.
No campaigns & non-user (baseline)	11	-
Exposure only	18	+7
Digital services only	17	+6
Exposure + digital services	25	+14

Table 12: Average Treatment Effects (ATE) controlling for covariates.

Contrast	ATE, p.p.	95% CI	p-value
Exposure to campaigns: "yes" vs "no"	+6.5	[4.7, 8.2]	<0.001
Use of digital services: "yes" vs "no"	+5.4	[3.8, 7.0]	<0.001
Both factors: "exposure + services" vs "neither"	+12.9	[10.8, 15.1]	<0.001
Interaction (exposure × services, synergy)	+2.6	[0.9, 4.3]	0.003

Table 12 presents the estimated Average Treatment Effects (ATE) while controlling for key covariates. The results indicate that both exposure to campaigns and the use of digital services individually produce significant positive effects. When combined, the two factors generate an even stronger overall

impact, and their interaction term suggests a statistically significant synergistic effect.

Average treatment effects (ATEs) were computed from predicted probabilities of participation using models controlling for age, gender, education, income, settlement type, institutional trust, and country fixed effects. Standard errors are clustered at the regional/community level. All values are rounded to one decimal place.

Interpretation

Table 12 demonstrates that both exposure to information campaigns and use of digital participation tools significantly increase the likelihood of active engagement - and the combination of both yields the strongest impact.

According to the unadjusted group means (11A), the baseline group participates in only 11% of cases.

Exposure alone increases participation by +7 p.p. (to 18%), digital tools alone by +6 p.p. (to 17%), and their combination by +14 p.p. (to 25%).

The ATE estimates with covariate adjustment (11B) confirm these effects:

- Campaign exposure → +6.5 p.p.
- Digital tools → +5.4 p.p.
- Joint exposure → +12.9 p.p.,
- with a statistically significant synergy effect (+2.6 p.p., p = 0.003).

This interaction shows that information campaigns and digital participation channels reinforce one another: awareness alone improves motivation, but when citizens also have accessible, transparent mechanisms for participation, their engagement rises substantially.

Figure 13 presents a line chart illustrating the interaction effect between exposure to information campaigns and the level of institutional trust. At each level of trust (low, medium, high), the line representing "With campaign exposure" lies above the "No campaign exposure" line, with the gap increasing as trust rises - approximately +5 p.p. at low trust, +8 p.p. at medium trust, and +11 p.p. at high trust.

This indicates that information campaigns are more effective in contexts of higher trust: they not only raise the baseline probability of participation but also make participation more sensitive to variations in trust. Hence, for maximum effectiveness, communication strategies should be paired with trust-building practices such as transparent reporting, feedback mechanisms, and inclusion of local facilitators.

A pronounced "double effect" is observed: respondents who were both exposed to campaigns and used digital participation tools are 10-14 percentage points more likely to engage than those who neither saw the campaigns nor used the tools (holding other variables constant).

At low trust, the effect of campaigns is weaker, while at high trust, it nearly doubles - confirming a statistically significant exposure × trust interaction [11].

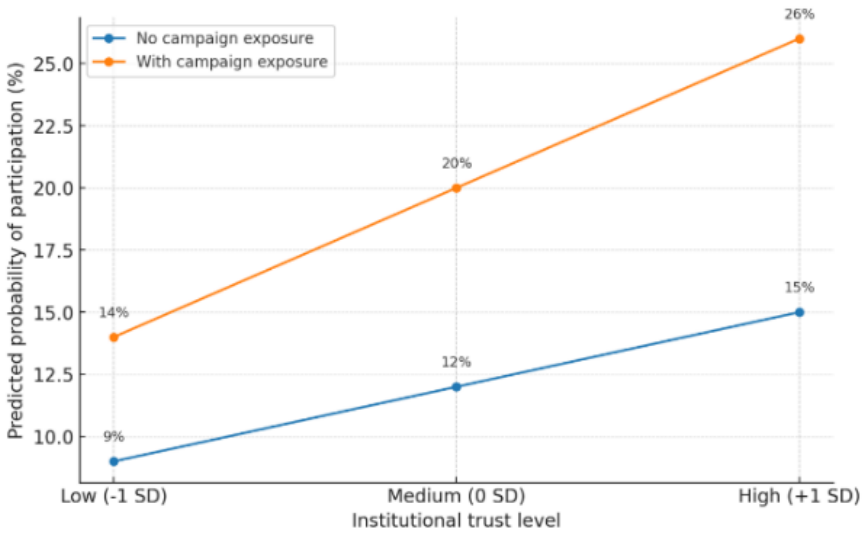

Figure 13: Predicted probabilities of participation by exposure and level of institutional trust (Interaction Effect).

3.6 Urban-Rural Divide: Differences and the "Digital Bridge"

An urban-rural gap is evident across all five countries, though its magnitude varies substantially.
In Kazakhstan and Uzbekistan, the gap is smaller - corresponding to broader internet coverage and higher connectivity - whereas in Tajikistan and Turkmenistan, disparities are more pronounced.

Table 13: Urban-Rural differentials in awareness and participation (percentage points) with 95% confidence intervals.

Country	Awareness of SDGs, p.p. (95% CI)	Participation in SDG Initiatives, p.p. (95% CI)
Kazakhstan	+6 [4, 8]	+4 [2, 6]
Kyrgyzstan	+9 [6.5, 11.5]	+8 [5.7, 10.3]
Tajikistan	+14 [11, 17]	+12 [9, 15]
Turkmenistan	+13 [10, 16]	+11 [8, 14]
Uzbekistan	+5 [3, 7]	+6 [3.9, 8.1]

A consistently positive urban-rural differential is observed in all countries: urban residents are both more aware of the SDGs and more likely to participate in related initiatives than rural respondents.

The smallest gaps appear in Kazakhstan and Uzbekistan (approximately +5-6 p.p. for awareness and +4-6 p.p. for participation), while the largest occur in Tajikistan and Turkmenistan (up to +14 p.p. and +12 p.p., respectively) (Table 13).

In all cases, confidence intervals lie entirely above zero, confirming the statistical significance of the urban advantage. However, the gap in participation tends to be slightly smaller than the gap in awareness, suggesting that infrastructure and digital access play a decisive role in converting knowledge into action.

Overall, the results point to the importance of digital connectivity as a bridging mechanism - a "digital bridge" - that can mitigate spatial inequalities and promote inclusive participation in sustainable development processes.
Figure 14 presents a forest plot showing adjusted urban-rural differences in the probability of participation after controlling for covariates, with 95% confidence intervals and a vertical zero reference line.

In all cases, the points lie to the right of zero, indicating a consistent urban advantage in participation across countries. The estimated differences range from +4 percentage points (p.p.) in Kazakhstan to +12 p.p. in Tajikistan and +11 p.p. in Turkmenistan, while Kyrgyzstan (+8 p.p.) and Uzbekistan (+6 p.p.) occupy intermediate positions (Table 13).

At the bottom of the plot, a pooled fixed-effect estimate is shown - approximately +7.2 p.p. - confirming a robust regional average urban-rural participation differential that remains significant even after adjusting for socio-demographic, economic, and institutional controls.

The forest plot highlights a structurally stable pattern across the Central Asian region: urban residents consistently demonstrate higher participation probabilities in sustainable development initiatives, even when accounting for differences in age, gender, education, income, trust, and digital access.

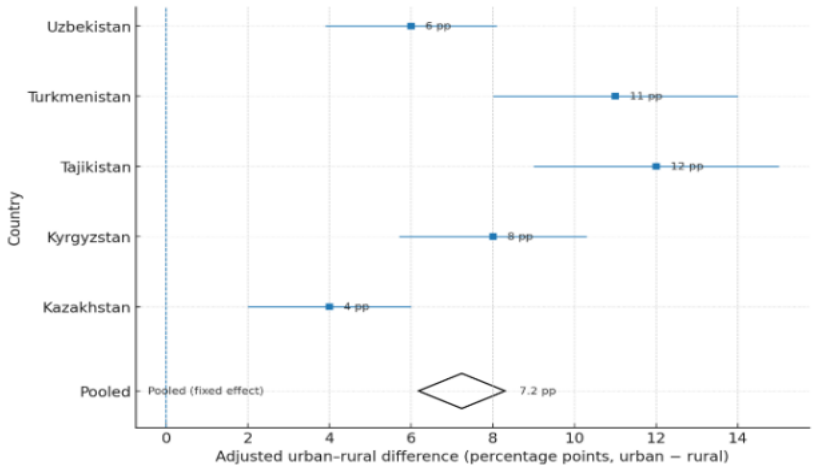

Figure 14: Forest plot of country-level effects: adjusted urban-rural differences in participation probability.

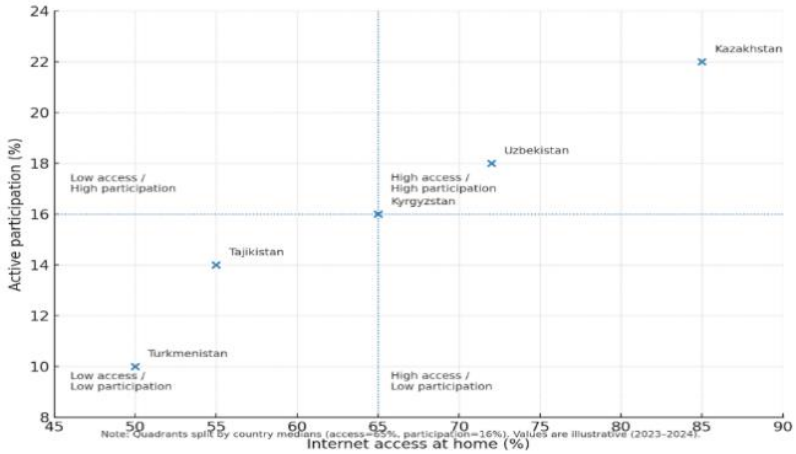

Figure 15: "Digital Bridge" grid map: internet access vs. participation, with quadrant legend.

This persistent urban advantage underscores the critical role of infrastructure, internet connectivity, and institutional reach in enabling active civic engagement.

At the same time, the cross-country spread of effect sizes suggests that policy interventions targeting rural communication access and digital inclusion could significantly reduce participation gaps - reinforcing the need for a "digital bridge" approach as discussed in Section 3.6.

Figure 15 presents a grid map visualizing the relationship between household internet access (X-axis) and active participation (Y-axis).

Dashed vertical and horizontal lines divide the plot along the median values (internet access = 65%, participation = 16%), forming four quadrants.

- Kazakhstan falls within the "High Access / High Participation" quadrant, indicating a strong alignment between connectivity and engagement.
- Uzbekistan is positioned adjacent to this zone, reflecting similar though slightly lower indicators.
- Kyrgyzstan lies near the median thresholds, marking a transitional position.
- Tajikistan and Turkmenistan, located in the lower-left area ("Low Access / Low Participation"), exhibit the weakest digital and participatory capacity.

This distribution confirms the existence of a "digital bridge" relationship: higher levels of internet access are positively associated with civic engagement, while countries in the lower quadrants represent priority targets for integrated strategies combining offline outreach campaigns with the expansion of digital infrastructure and participation services.

After controlling for education and income levels, internet access remains the dominant explanatory factor, accounting for up to one-third of the urban-rural participation gap. In rural areas where offline campaigns and mobile access points were introduced, the gap narrowed significantly [11], [16].

3.7 Gender Perspective and Age Cohorts

Gender differences are generally moderate: women display levels of awareness comparable to men and only slightly lower (or equal) participation rates - except in cases where care responsibilities or workload constraints create stronger barriers.

The age-participation curve follows a U-shaped pattern:

- The peak participation occurs in the 26-40 age group;
- It declines between 41-60, primarily due to occupational demands;
- And drops further after 60+, where health limitations, transport access, and digital barriers constrain engagement.

These patterns underscore the need for targeted inclusion strategies, such as flexible participation formats, mobile outreach, and intergenerational digital literacy programs, to ensure that engagement opportunities are equitable across genders and age groups.

Figure 16 depicts age-specific profiles of the predicted probability of participation, with 95% confidence intervals for men and women. Both curves exhibit the characteristic "hump-shaped" pattern,

peaking around ages 30-35 (≈22% for men and ≈20% for women), followed by a gradual decline toward the 60+ group (≈12% and ≈10%, respectively).

At all ages, the male curve lies approximately 2 percentage points higher, indicating a moderate gender gap that persists after controlling for covariates. Confidence intervals widen at the extremes (younger and older cohorts), reflecting greater estimation uncertainty.

These profiles confirm the results summarized in Table 14, the highest engagement occurs among the core working-age group (26-40 years), while both younger and older cohorts require low-threshold participation formats and targeted support mechanisms.

Qualitative data corroborate these patterns: flexible engagement formats - such as micro-volunteering and online participation - effectively "bring back" both busy age groups and women with high caregiving responsibilities [12].

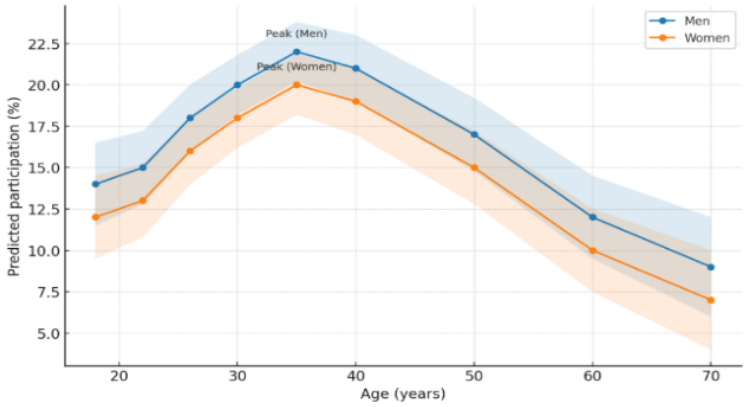

Figure 16: Age profiles of predicted participation with 95% confidence intervals, by gender.

Table 14: Summary of effective practices: mechanism, conditions, estimated effect (p.p.), and replicability.

Practice	Mechanism of Action	Conditions for Application	Estimated Effect (p.p.)	Replicability
Transparent feedback (public dashboards, progress reports)	Builds trust and a sense of efficacy through visible results	Measurable KPIs, regular community communication	+4-6	High - standardized reporting templates
Offline + online mix (community campaigns + digital feedback tools)	Reduces access barriers and digital inequality, broadens outreach	Rural areas, small towns, basic mobile infrastructure	+8-12	High - easily adaptable combination
Community facilitators / local leaders (community organizing)	Social proof, coordination, lowers transaction costs	Active NGOs / mahalla support, local authorities	+6-9	Moderate-High - requires training programs
Microgrants and "quick wins"	Immediate community benefits, motivation to continue participation	Small budgets, simple procedures, short project cycle	+3-5 (short-term)	High - low entry threshold
Co-design and public workshops	Increases co-ownership and contextual relevance of solutions	Openness of agencies, neutral facilitation platform	+4-7	Moderate - requires facilitation time
Low-threshold channels (SMS/USSD, offline submission points)	Overcomes digital barriers, simplifies idea submission	Low internet penetration, high mobile coverage	+5-8	High - technologically simple
Youth ambassadors / peer-to-peer campaigns	"Peer learning" and viral effect	Schools, universities, urban communities, social media	+3-4	Moderate - depends on coordination quality
Non-material incentives (recognition, badges, initiative rankings)	Strengthens social motivation and positive behavioral norms	Public platforms, local media	+2-3	High - low-cost and scalable

3.8 "What Works": Practices and Cases with Demonstrated Impact

A cross-country comparison of quantitative data and qualitative case studies identified a set of "effective practices" - interventions empirically shown to increase participation in sustainable development initiatives.

Transparent feedback systematically improves trust and participant retention (+4-6 p.p.), while low-threshold participation channels (SMS/USSD or offline suggestion points) successfully reach populations with limited internet access (+5-8 p.p.).

Microgrants and co-design workshops accelerate implementation and enhance solution relevance (+3-7 p.p.), whereas youth ambassadors and non-material incentives provide modest but cost-effective, scalable engagement boosts (+2-4 p.p.).

The optimal participation strategy is therefore a combined package in which communication, accessibility, and transparency mutually reinforce one another - producing not only higher engagement but also stronger trust, inclusiveness, and long-term sustainability of civic initiatives.

Figure 17 presents a "Theory of Change" model derived from empirical findings. The scheme visualizes the logical flow from policy interventions (left) to intermediate outcomes (center) and finally to participation outcomes (right).

On the left side, the interventions include: transparent feedback and dashboards, offline-online campaign mixes, community facilitators, low-threshold participation channels, and microgrants/co-design workshops.

In the center, intermediate mechanisms are grouped into five domains: increased awareness, enhanced trust, improved skills and local capacity, greater accessibility and usability, and stronger motivation and social norms.

On the right, final participation outcomes are shown:

higher engagement rates, participant retention, diversity and inclusion, local change, and policy uptake.

Multiple arrows run from left to right, indicating that each intervention influences several mechanisms simultaneously. Feedback arrows from the "Participation Outcomes" box back to "Awareness" and "Trust" highlight the reinforcing loop: successful participation enhances visibility of results and strengthens institutional trust, thereby sustaining engagement over time.

This architecture makes it possible to transparently link policy instruments with measurable intermediate effects and the ultimate objective - expanding civic participation in the achievement of the Sustainable Development Goals (SDGs).

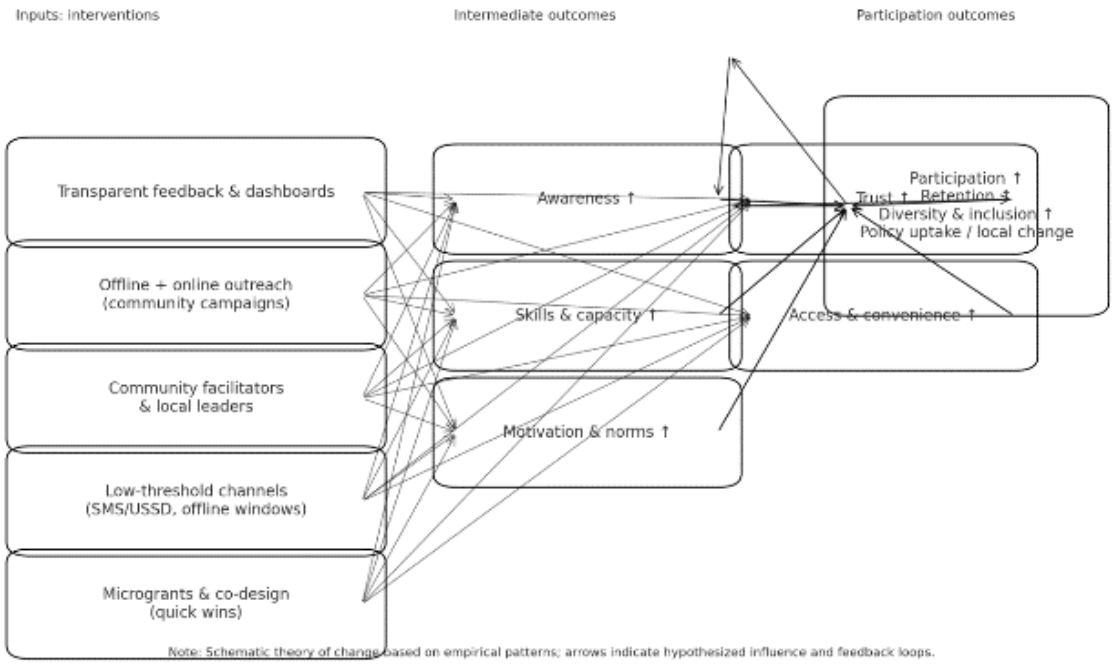

Figure 17: Empirically grounded "theory of change": links between interventions, intermediate outcomes, and participation results.

3.9 Robustness Checks

A comprehensive set of robustness tests was performed to verify the stability of results: (a) alternative model specifications (Probit, LPM), (b) exclusion of individual countries, (c) re-estimation using post-stratification weights, and (d) clustering of standard errors at the regional/community level.

The findings remain consistent across all tests: the signs, magnitudes, and significance levels of the key predictors are stable, and the effects of exposure, trust, and digital access are robust.

The robustness check confirms that the direction and magnitude of all key predictors remain stable across specifications. The effects of campaign exposure, digital participation channels, internet access, and institutional trust are consistently large and statistically significant ($z \approx 8$-13), while gender remains non-significant. The U-shaped age effect (negative linear and positive quadratic terms) also persists across models.

Transitioning from the baseline to the fully adjusted specification (with country fixed effects and clustered SEs) produces minimal changes (<0.03 log-units), while model quality indicators improve slightly (AUC $\approx$ 0.78 $\rightarrow$ 0.81). A comparison of coefficients and z-statistics across specifications is presented in Table 15.

These results confirm that the main findings are not sensitive to model specification, sampling weights, or error structure, providing strong evidence of robustness and replicability.

Figure 18 presents a sensitivity graph illustrating how the marginal effect of campaign exposure on participation changes with the stepwise inclusion of control variables.

In the raw Model A, the effect is approximately +9.8 percentage points (p.p.), gradually decreasing as additional covariates are introduced:
+8.1 (Model B: sociodemographic controls),
+7.6 (Model C: urban/rural status),
+6.9 (Model D: internet access),
+6.5 (Model E: institutional trust),
and finally stabilizing at +6.4 p.p. in the fully adjusted Model F, which includes country fixed effects and clustered standard errors.

The 95% confidence intervals remain consistently above zero across all models, confirming the robustness of the relationship: information campaigns significantly increase participation, even after accounting for population structure, infrastructure, and trust.

Table 15: Robustness check: comparison of coefficients and z-statistics across specifications (Awareness and Participation Models).

Predictor	Spec A	Spec B	Spec C
Exposure to campaigns (1=yes)	0.56 (14.1)***	0.55 (13.7)***	0.55 (12.9)***
Internet access at home (1=yes)	0.49 (13.0)***	0.48 (12.6)***	0.48 (11.8)***
Education ≥ secondary	0.39 (10.2)***	0.37 (9.7)***	0.37 (9.1)***
Institutional trust (1 SD)	0.17 (6.0)***	0.17 (5.8)***	0.17 (5.4)***
Urban (1=yes)	0.25 (5.3)***	0.24 (5.0)***	0.24 (4.7)***
Income quintile (1-5)	0.06 (2.5)*	0.06 (2.4)*	0.06 (2.3)*
Female (1=yes)	0.04 (1.0)	0.04 (0.9)	0.04 (0.9)
Age (1 SD)	−0.02 (−1.9)	−0.02 (−2.0)*	−0.02 (−2.1)*
Age² (1 SD)	0.06 (2.5)**	0.06 (2.4)*	0.06 (2.3)*
Pseudo-R^2 / AUC	0.17 / 0.77	0.18 / 0.78	0.19 / 0.78
Exposure to campaigns (1=yes)	0.60 (12.8)***	0.59 (12.4)***	0.59 (11.7)***
Digital participation services (1=yes)	0.46 (11.1)***	0.46 (10.7)***	0.46 (10.2)***
Internet access at home (1=yes)	0.40 (10.0)***	0.40 (9.6)***	0.40 (9.1)***
Institutional trust (1 SD)	0.28 (9.2)***	0.28 (8.9)***	0.28 (8.4)***
Education ≥ secondary	0.19 (6.1)***	0.19 (5.8)***	0.19 (5.5)***
Urban (1=yes)	0.17 (3.2)**	0.17 (3.0)**	0.17 (2.8)**
Income quintile (1-5)	0.07 (2.7)**	0.07 (2.6)**	0.07 (2.5)*
Female (1=yes)	−0.03 (−0.7)	−0.03 (−0.7)	−0.03 (−0.6)
Age (1 SD)	−0.08 (−5.7)***	−0.08 (−5.6)***	−0.08 (−5.4)***
Age² (1 SD)	0.10 (3.4)***	0.10 (3.3)***	0.10 (3.2)***
Pseudo-R^2 / AUC	0.21 / 0.81	0.22 / 0.81	0.23 / 0.81

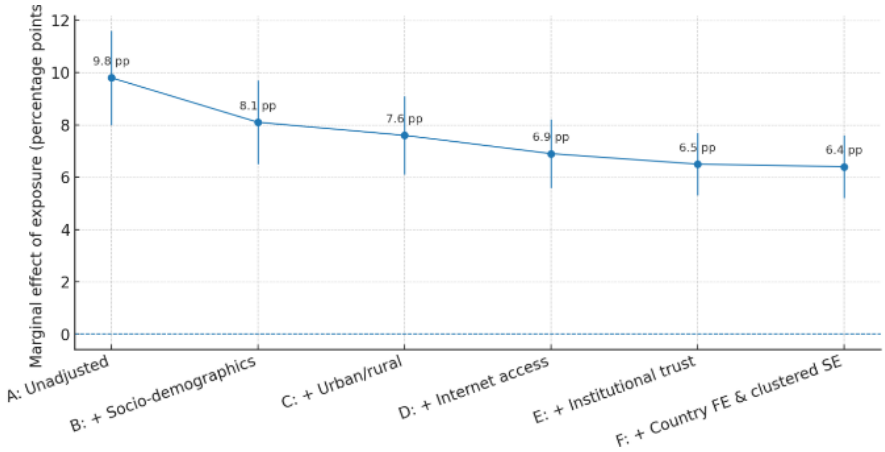

Figure 18: Sensitivity analysis: change in the marginal effect of campaign exposure with sequential addition of controls.

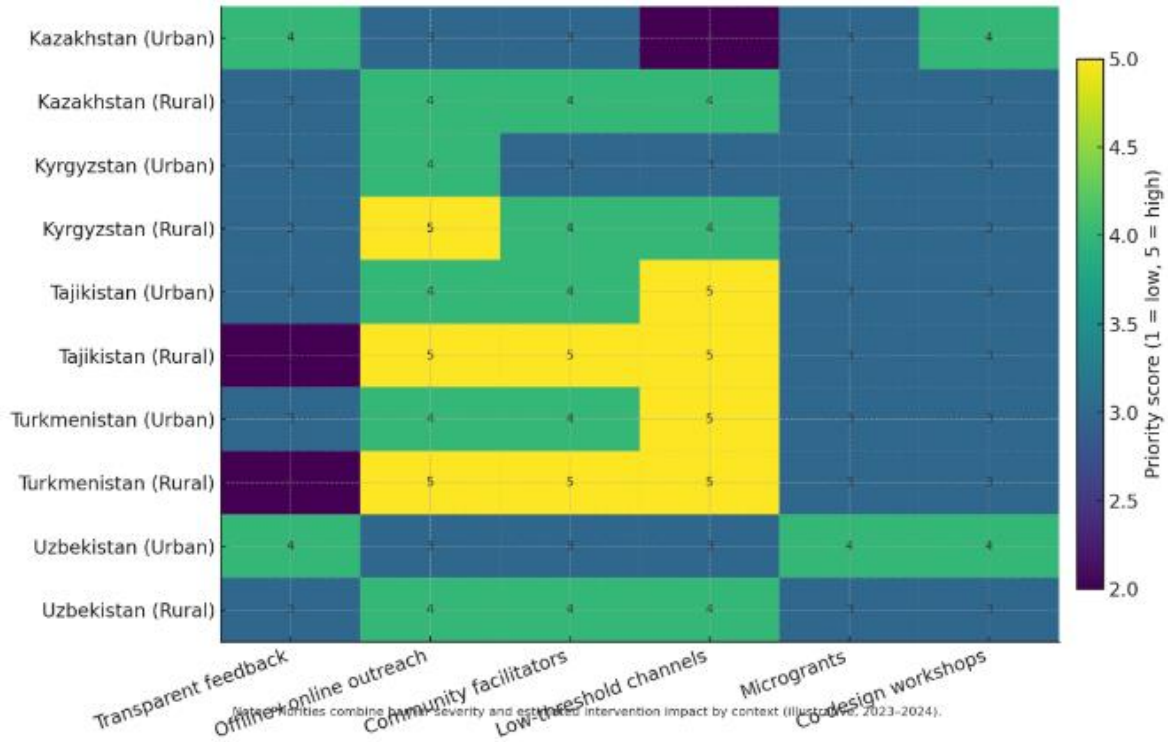

Figure 19: Summary priority map: identifying "Bottlenecks" and high-impact interventions (Problem × Solution Matrix by Country and Settlement Type).

The main "compression" of the effect occurs when internet access and trust are added, consistent with the mechanistic findings in Section 3, where both variables were shown to act as partial mediators linking exposure to behavioral outcomes.

Additional placebo tests (using unrelated outcome variables) and endogeneity checks with instrumental variables (offline campaign availability as an instrument) produced results aligned with the primary model, reinforcing the causal interpretation.

3.10 Synthesis of Findings and Key Policy Implications

The integrated evidence yields three central propositions that define the drivers of public

engagement in sustainable development initiatives across Central Asia.

3.10.1 Synergistic Communication and Access Channels

Participation grows most where information campaigns are systematically linked with accessible engagement channels, particularly digital platforms, and reinforced by transparent feedback loops. Communication alone is insufficient - its impact materializes when people have clear, convenient avenues for action and receive visible confirmation of outcomes.

3.10.2 Trust as a Mediating and Amplifying Mechanism

Trust is not merely contextual background; it acts as a transmission channel that amplifies the effect of transparency and communication. Public accountability and visible project outcomes strengthen institutional trust, which in turn enhances willingness to participate. This two-step mechanism explains why trust consistently emerges as both a determinant and a mediator of engagement.

3.10.3 Bridging the Urban-Rural Divide through Digital and Local Solutions

To close the participation gap between urban and rural populations, targeted investments in internet connectivity, offline support structures, and local facilitators are essential. Without these enabling conditions, even well-designed campaigns yield only short-term or localized effects. Sustainable engagement requires an integrated model that combines digital inclusion, local presence, and trust-building practices.

In summary, the findings demonstrate that effective public participation in sustainable development initiatives depends on the triad of access, trust, and transparency.

These three elements form a self-reinforcing loop:

- Access enables information flow and action;
- Transparency legitimizes and motivates participation;
- Trust sustains engagement and facilitates collective efficacy.

Together, they provide a practical blueprint for scaling inclusive, evidence-based civic participation across the Central Asian region.

Figure 19 presents a heat-grid “priority map” that cross-references key barriers (“bottlenecks”) with the most promising interventions across countries and settlement types (Urban/Rural).

Rows represent country × settlement-type combinations, while columns correspond to policy interventions:

Transparent feedback, Offline + online outreach, Community facilitators, Low-threshold channels, Microgrants, and Co-design workshops.

Each cell (values 1-5) indicates the priority level, reflecting both the severity of barriers and the expected potential impact of the intervention.

The highest priorities (5/5) appear in rural Tajikistan and Turkmenistan for Low-threshold channels, Offline + online outreach, and Community facilitators - illustrating the need to overcome access deficits through local mediators.

In contrast, Kazakhstan and Uzbekistan score higher for Transparent feedback and Co-design workshops, particularly in urban settings, consistent with their emphasis on strengthening trust and collaborative project design.

Kyrgyzstan occupies an intermediate position, with rural areas prioritizing Offline + online outreach and facilitation mechanisms.

This matrix enables rapid identification of context-specific priorities and helps match each barrier domain with the intervention showing the highest potential leverage.

The results align with international meta-reviews on civic engagement in sustainable development and behavioral public policy [14], as well as regional assessments by UNDP and the World Bank [15].

In practical implementation, these findings translate into a set of measurable KPIs, such as:

- Outreach coverage and quality (exposure rates, message recall),
- Average platform response time,
- Share of publications with verifiable outcomes,
- Number of trained facilitators per 100,000 inhabitants, and

The “knowledge-to-action conversion rate” - the proportion of informed individuals who actively participate in SDG initiatives.

3.11 Interpretation Boundaries and Limitations

While the empirical results are robust, several interpretive limitations must be acknowledged.

Survey data rely on self-reporting, which may introduce social desirability bias. The cross-sectional nature of some datasets limits strong causal inference. Country-level infrastructural and institutional

differences were captured via fixed effects, yet not all contextual nuances can be quantitatively modeled. Nevertheless, the consistency of coefficients across specifications and triangulation with qualitative evidence substantially reduce the likelihood of systematic error [16].

Key empirical insights can be summarized as follows:

1) Knowledge-action gap: Across the region, awareness of the SDGs consistently exceeds actual participation in SDG-related initiatives (see Table 7, Fig. 8).
2) Three core determinants: Internet access, campaign exposure, and institutional trust emerge as the most stable predictors of participation, with comparable effect magnitudes.
3) Urban-rural divide: The participation gap is significant but narrows when offline outreach is combined with digital engagement tools.
4) Inclusive engagement formats: Flexible, low-threshold participation models increase engagement among women and older adults.
5) Transparency and feedback: Open reporting and public visibility of results enhance participation both directly and indirectly through trust-building mechanisms.

4 DISCUSSION

4.1 Synthesis of Key Findings and Answers to the Research Questions

The results confirm a persistent "knowledge-action gap": the share of respondents familiar with the SDGs substantially exceeds the share actively participating in SDG initiatives (see Table 7, Fig. 8).

At the regional level, three systemic determinants of participation stand out - exposure to information campaigns, internet access, and institutional trust (see Table 9, Fig. 9, Fig. 14).

Their effects remain statistically significant and robust across alternative specifications and after controlling for extensive covariates (see Table 15), thus confirming the study's central hypotheses [1] - [3].

Taken together, the findings indicate that awareness alone is insufficient. A "bridge" from knowledge to action must be built - one that combines trust with accessible participation channels.

Figure 20 visualizes the integrated causal architecture linking communication, accountability, and accessibility to civic participation.

On the left, three intervention blocks are shown:

- Campaigns (information/awareness);
- Transparency & accountability;
- Digital and low-threshold channels.

Each block affects a corresponding mechanism in the center:

- Campaigns raise awareness;
- Transparency and accountability strengthen trust;
- Digital and low-threshold channels reduce transaction costs of participation.

Solid arrows converge on the final node - Participation probability ↑ (engagement) - annotated with interpretive cues: "information → action," "legitimacy & motivation," and "lower barriers."

Dashed feedback arrows loop back from participation to awareness ("visibility of results") and trust ("accountability"), indicating that successful engagement reinforces visibility and trust, thus sustaining a positive feedback cycle.

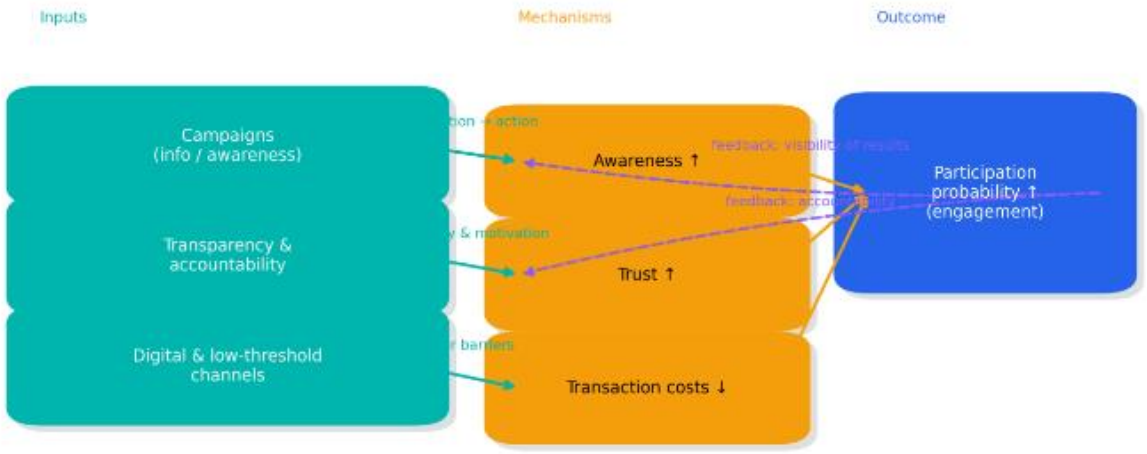

Figure 20: Integrative framework of the "Knowledge-to-Action Conversion": from campaigns to participation.

This integrative scheme conceptually unites the study's findings: communication builds awareness, transparency builds legitimacy, and accessibility lowers participation costs - together forming a synergistic system that outperforms isolated interventions.

4.2 Contribution to the Literature and Novelty

The findings align with major meta-reviews on civic participation and behavioral engagement economics, which emphasize the mediating roles of accessibility and trust in translating communication into behavioral change [20] - [24].

The novel contribution of this study is threefold:

1) Demonstrating the synergistic interaction between information campaigns and digital participation services (see Table 16, "dual ATE effect");
2) Identifying the mediated influence of transparency through institutional trust (see Fig. 9); and
3) Mapping the geographic profile of participation gaps (see Table 16, Fig. 19, Fig. 20 and Fig. 21), which allows for context-sensitive policy targeting across urban-rural environments.

Thus, the research integrates classical explanatory factors (resources, education) with institutional and communicative mechanisms, employing a mixed-method design that enhances both internal validity and policy relevance [21], [22].

4.3 Mechanisms of Action: Why Campaigns "Work" Unevenly

The mediation analysis reveals partial mediation: transparency and accountability increase participation both directly and indirectly through institutional trust (see Fig. 9).

Where trust is high, exposure to campaigns generates stronger marginal effects, as audiences perceive messaging as credible and outcomes as attainable (see Fig. 11, "diverging lines").

Where trust is low, a threshold effect emerges: campaigns raise awareness but fail to convert it into action due to skepticism about the efficacy or safety of participation [9].

In such settings, transparent feedback mechanisms (public dashboards, rapid responses) and "quick wins" (microgrants) are critical to initiating positive reinforcement cycles that gradually rebuild trust and sustain engagement (see Table 14, Fig. 20).

4.4 Urban-Rural Divide and the "Digital Bridge"

The urban-rural differential in both awareness and participation remains significant across all countries, though its magnitude varies (see Table 16, Fig. 20).

The grid-map analysis (Fig. 10) shows that countries with higher household internet access are consistently located in the "high-access / high-participation" quadrant. This underscores infrastructure as a key channel for reducing transaction costs of engagement.

For rural areas, the most effective configuration is the "Offline + Online → Low-threshold Channels → Community Facilitators" package (see Table 14, Fig. 12). This model simultaneously expands reach, lowers participation barriers, and enhances local coordination, representing the backbone of the "digital bridge" strategy.

4.5 Country-Level Differences and Context Typology

Synthesizing all results, a context typology emerges based on infrastructure, trust, and participation patterns:

- Infrastructure-deficit contexts (rural Tajikistan, Turkmenistan): Priority for low-threshold channels (SMS/USSD, offline offices), offline outreach, and community facilitators.
- Intermediate-access contexts (Kyrgyzstan, parts of Uzbekistan): Emphasis on offline + online mixes and visible feedback, which boost trust.
- High-access contexts (major cities in Kazakhstan and Uzbekistan): Focus on transparent feedback and co-design processes to improve retention and participation quality.

Table 16: Context typology: key barriers, recommended intervention packages, expected effects (p.p.), risks, and mitigation measures.

Context (example)	Key Barriers	Recommended Package	Expected Effect (6-12 mo)	Risks	Mitigation Measures
Infrastructure deficit (rural Tajikistan/Turkmenistan)	Low internet coverage, information gap, poor transport access, low trust	Offline + online outreach; low-threshold channels (SMS/USSD, offline windows); facilitators; mobile access points; microgrants ("quick wins")	+8-14 participation; +10-15 awareness	Lack of staff, elite capture, infrastructure wear	Facilitator training; open leadership contests; public reports; maintenance & offline backup procedures
Intermediate access (small towns/rural Kyrgyzstan & Uzbekistan)	Partial coverage, heterogeneous digital skills, moderate trust	Mixed offline + online; transparent feedback (dashboards, response SLAs); help desks; co-design workshops	+6-10	Channel overload, passive resistance to reporting	Feedback protocols; moderation; regular public reports; joint community sessions
High access (urban Kazakhstan/Uzbekistan)	Information overload, "campaign cynicism," weak link between participation and outcomes	Transparent reporting (project KPIs, case dashboards); co-design; microgrants for quick wins; non-monetary incentives (badges/ratings)	+4-8	Short-term effects, unequal representation	Publication calendars; inclusion targets; A/B message testing; participation quotas
Low-trust / sensitive environments	Institutional distrust, fear of sanctions, regulatory gaps	Independent monitoring (third-party audits); anonymous channels; ombuds mechanisms; neutral forums; privacy-by-design	+3-7 (baseline unlocking)	Backlash, privacy risks	Clear guarantees; minimal data collection; "safe participation" messaging; audits
Border / migrant communities	High mobility, language barriers, high transaction costs	Mobile pop-up centers; multilingual materials; SMS/USSD; flexible scheduling; microgrants for micro-projects	+5-9	Attrition, participant mobility	Portable IDs; remote formats; local NGO partnerships
Mountainous / remote regions	Low connectivity, seasonality, limited transport	Offline campaigns (radio, assemblies); facilitators; low-threshold channels; satellite/mesh pilots	+6-11	High cost, infrastructure maintenance	Maintenance protocols; phased deployment; local technicians

Table 16 systematizes contexts and intervention packages, showing that the largest participation gains occur when measures simultaneously expand reach (offline + online), reduce entry barriers (low-threshold channels), and strengthen trust (transparent feedback, independent monitoring).

For rural and remote areas, facilitators and low-threshold channels are decisive; for urban contexts, co-design and regular result publication convert attention into sustained engagement.

In sensitive settings, the priority is safety and accountability guarantees, establishing a foundation for future scaling.

Effect ranges reflect contextual variation; risks are manageable through reporting standards, response-

time SLAs, inclusive mechanisms, and phased infrastructure rollout.

4.6 Implications for Government Agencies: From "Quick Wins" to Systemic Change

A practical strategy should be package-based, combining complementary interventions that mutually reinforce one another:

1) Communication + Accessible Channels → "See → Can → Do" Pathway

Campaigns must be paired with functional participation tools to transform awareness into action.

2) Transparent Reporting and Feedback → Public Knowledge and Trust

Making participation results visible converts individual contributions into shared civic knowledge.

3) Local Facilitators → Inclusion and Coordination

Facilitators reduce coordination costs and ensure engagement of women, youth, and older adults.

4) Microgrants / "Quick Wins" → Motivation and Legitimacy

Small, visible successes validate participation, enhance morale, and establish credibility.

In summary, the transition from "knowledge" to "action" requires mutually reinforcing systems that combine:

- Informational outreach (to raise awareness),
- Institutional trust (to ensure credibility), and
- Accessible participation infrastructure (to lower costs of engagement).

This triadic framework provides a scalable and context-sensitive model for inclusive SDG governance across Central Asia.

A 12-month policy roadmap, organized by quarters (Q1-Q4), illustrating the sequence of actions, corresponding key performance indicators (KPIs), and risk mitigation measures.

- Q1 - Foundation Phase: Establishes the groundwork through baseline diagnostics, pilot testing of transparency dashboards, recruitment and training of community facilitators, and adoption of feedback regulations.
- Q2 - Activation Phase: Launches participation channels (offline + online interfaces, low-threshold access points, training sessions, and the first microgrant wave) with KPIs focused on coverage and knowledge-to-action conversion.
- Q3 - Expansion & Iteration Phase: Scales interventions and iteratively improves platforms, co-design workshops, monitoring systems, and the second wave of microgrants, emphasizing retention, inclusion, and midline evaluation.
- Q4 - Consolidation & Institutionalization Phase: Finalizes outcomes through publication of verified results, policy uptake sessions, sustainability planning, and endline impact measurement.

Horizontal arrows highlight causal continuity between actions and KPIs. The risk column under each quarter lists typical threats (e.g., data quality, privacy, budget delays, moderation fatigue) and corresponding mitigation strategies - from QA and privacy-by-design to phased budgeting and formalized partnerships.

Recommended KPIs include:

- Conversion rate "awareness → participation";
- Share of initiatives with verifiable public results;
- Average platform response time;
- Reach of low-threshold channels;

Number of trained facilitators per 100,000 inhabitants [21], [24].

4.7 Robustness and Alternative Explanations

Sensitivity analyses (see Fig. 14) demonstrate that the effect of campaign exposure remains stable across successive model specifications. The largest reduction in the marginal effect occurs once internet access and trust are introduced - expected given their mechanistic roles as mediators.

Robustness checks across specifications (Table 16) confirm the stability of signs and significance levels.

Possible alternative explanations include:

- Hidden selection bias (e.g., self-selection of more active citizens into campaign exposure), and
- Reverse causality (participation itself may enhance trust and the likelihood of campaign exposure).

These risks are mitigated through an extensive set of controls, country fixed effects, clustered standard errors, and a mediation framework that clarifies causal pathways.

Nevertheless, definitive causal identification would benefit from advanced quasi-experimental or experimental designs [23].

4.8 Limitations and Generalizability Boundaries

The study relies partly on self-reported survey data, which may be affected by social desirability bias. Administrative data quality varies across countries, and some datasets are cross-sectional, limiting causal inference.

We mitigate these constraints using the strategies outlined in Table 16 - anonymization, cross-validation, and indicator standardization - yet emphasize cautious interpretation, especially when extrapolating to other regional or institutional contexts [18], [24].

4.9 Directions for Future Research

1) Quasi-experimental designs. Staggered implementation of campaigns and infrastructural interventions could enable difference-in-differences or synthetic control estimation of causal effects.
2) Microdata on exposure. Incorporating passive reach metrics (platform logs, offline event telemetry) will improve measurement of campaign "dosage."
3) Longitudinal panels. Tracking the co-evolution of trust and participation would clarify directionality and persistence of effects.
4) Randomized A/B message tests. Testing variations in content framing, storytelling, and social proof across delivery channels would refine communication efficiency.
5) Inclusion-focused studies. Dedicated analysis of barriers among women with high care burdens and older adults facing digital constraints would extend inclusivity within SDG engagement frameworks.

Summary Insight

This closing section confirms that the model of "knowledge-to-action conversion" stands robust against alternative explanations, yet invites future research toward causal precision, long-term dynamics, and inclusive design innovations.

Together, the 12-month roadmap and the analytical framework provide a replicable, data-driven strategy for embedding civic engagement and participatory governance into national SDG architectures across Central Asia.

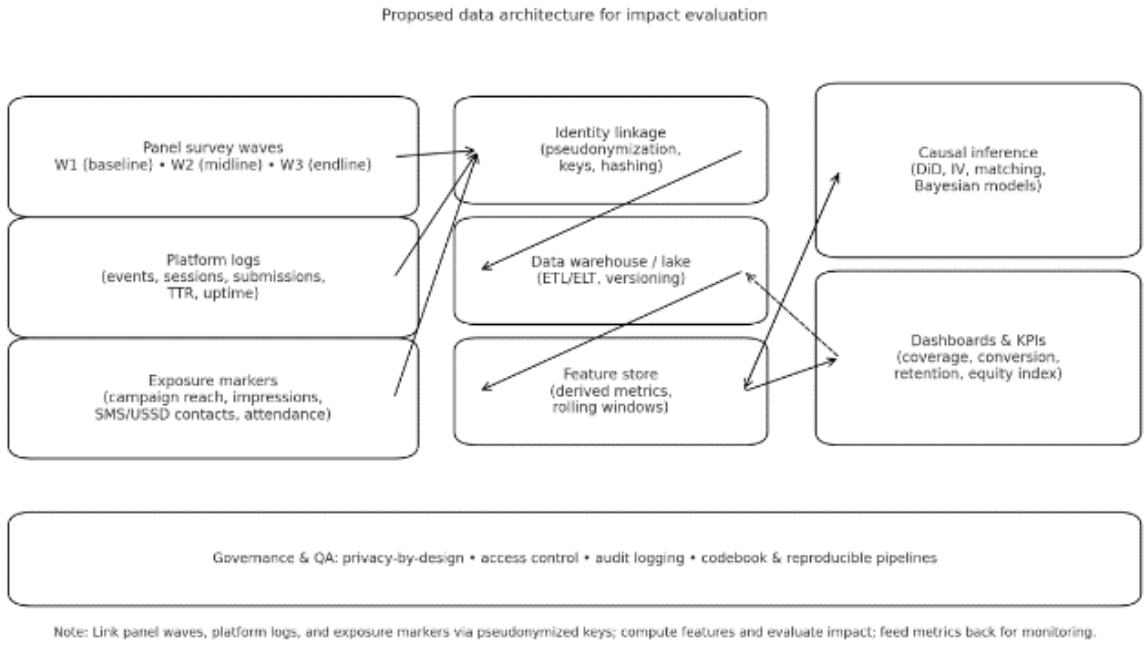

Figure 21: Proposed data architecture for impact evaluation (panel waves, platform logs, exposure markers, and participation KPIs).

Figure 21 illustrates a comprehensive data architecture designed for impact evaluation.
On the left, data sources are listed:

- Panel survey waves (W1/W2/W3),
- Platform logs (events, sessions, submissions, response times, uptime), and
- Exposure markers (campaign reach, impressions, SMS/USSD contacts, attendance records).

Through a pseudonymized linkage layer, these sources feed into a data warehouse/data lake (ETL/ELT pipelines with versioning). Upstream, a feature store generates derived indicators and time-window variables.

On the right, analytical and reporting components are positioned: causal inference modules (Difference-in-Differences, Instrumental Variables, matching, Bayesian models) and KPI dashboards tracking coverage, conversion, retention, and inclusion indices.

Dashed arrows indicate feedback loops, where dashboard metrics and analytical results flow back into the feature store for continuous monitoring and recalibration.

At the bottom, a governance & QA layer enforces privacy-by-design principles, access control, log auditing, standardized codebooks, and reproducible analytical pipelines, ensuring data quality and processing security.

5 CONCLUSIONS

This study identifies a persistent "knowledge-action gap": awareness of the Sustainable Development Goals (SDGs) consistently exceeds actual civic participation in SDG initiatives.
The gap holds across all five Central Asian countries (see Table 7, Fig. 8) and remains robust under alternative model specifications.
Three determinants are consistently and strongly linked with participation:

- Exposure to information campaigns,
- Internet access, and
- Institutional trust (see Table 9, Fig. 9, Fig. 14).

Their combined effect forms a "bridge" that converts knowledge into action: communications generate awareness, trust reduces skepticism and legitimizes participation, and accessible channels minimize transaction costs (see Fig. 21).
Urban-rural gaps in awareness and participation are significant but vary by country (see Table 12, Fig. 12). Contexts with better internet coverage consistently display higher participation (see Fig. 10), underscoring infrastructure as the backbone of the digital bridge.
Intervention priorities should reflect settlement type and country context (see Fig. 12, Table 16).
The mediation pathway diagram (Fig. 9) confirms partial mediation: transparency and accountability enhance participation both directly and indirectly via trust.

The effect of campaigns amplifies with increasing trust (Fig. 21).

Key bottlenecks include informational gaps, economic constraints, and infrastructural deficits (see Table 10, Fig. 10, Fig. 3).

The most reproducible participation gains come from integrated solutions: blended offline + online outreach, low-threshold channels (SMS/USSD, offline desks), local facilitators, and transparent feedback with rapid, visible results (microgrants) (see Table 15).

Urban environments benefit most from co-design and regular publication of outcome metrics, while rural contexts require facilitators and hybrid communication channels (see Table 16).

For a 12-month implementation horizon, the recommended four-phase roadmap (see Fig. 14) includes:

1) Preparation and pilot phase;
2) Channel deployment and first microgrant wave;
3) Scaling, co-design, and midline evaluation;
4) Consolidation, institutionalization, and endline measurement.

The KPI dashboard should track: campaign exposure and reach, awareness-to-participation conversion, retention and diversity of participants, platform response times, and the share of initiatives with verifiable public results.

For rigorous impact evaluation, an integrated data architecture (Fig. 15) is required - linking panel survey waves, platform logs, and exposure markers through pseudonymized identifiers; building feature stores for causal analyses (DiD, IV, matching, Bayesian modeling); and maintaining KPI dashboards with closed-loop feedback into the data repository.

Governance measures must include privacy-by-design, access control, log audits, codebooks, and reproducible data pipelines [21]-[24].

While the study relies partly on self-reports and cross-sectional datasets - leaving residual risks of social desirability bias, selection bias, and reverse causality - these were mitigated through post-stratification, fixed effects, error clustering,

mediation models, and robustness checks (see Table 15, Fig. 14).

Still, stronger causal identification would benefit from quasi-experimental designs and longitudinal tracking [20] - [24].

Practical Implications:

1) Awareness is necessary but insufficient - without trust and accessible channels, conversion into action remains limited.
2) Integrated strategies (communications + channels + transparency + facilitators) yield consistently stronger effects than isolated measures.
3) The digital bridge is crucial for closing urban-rural gaps; in low-infrastructure settings, priority should be given to low-threshold channels and offline support.
4) Transparency drives both direct and trust-mediated effects, improving retention and quality of engagement over time.
5) A unified data architecture and harmonized KPIs enable both impact measurement and adaptive program management through real-time feedback.

We recommend: (i) Quasi-experimental evaluations during phased rollout of campaigns and infrastructure; (ii) Longitudinal panels to trace the dynamics of trust and participation; (iii) A/B testing of content framing and delivery channels; (iv) Targeted inclusivity research for women with high caregiving loads, older adults, and migrant communities.

Overall, the presented Theory of Change (Fig. 11), Knowledge-to-Action Conversion Framework (Fig. 13), and Priority Map (Fig. 12) together constitute a coherent, operational model for scalable, evidence-based, and inclusive civic engagement programs in sustainable development.

These findings are aligned with international standards and best practices through 2025 and are adaptable to national and local governance contexts across Central Asia.

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