

## Building Trust in Municipal Environmental Data Through Participatory Open Data Ecosystems

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### Abstract

*Trust is a fundamental precondition for effective governance in municipalities, enabling meaningful citizen participation and legitimate decision-making. Yet theoretical frameworks that systematically connect trust-building with participatory open data ecosystems remain scarce. Existing models tend to focus either on technical infrastructure or on governance mechanisms but rarely integrate both with community engagement in a comprehensive manner. This paper addresses this gap by asking: How can participatory open data ecosystems be designed and governed to build and sustain trust between municipalities and citizens in the domain of environmental data? Through a comparative theoretical analysis of municipal open data initiatives and drawing on insights from the Smart Transformation and Innovation Consortium Slovakia (STICS) project, we analyse three interconnected dimensions: technical infrastructure, governance mechanisms, and stakeholder engagement, and their relationship to different forms of trust. Building on the psychological literature on trust (particularly Mayer, Davis, and Schoorman, 1995; Lewicki and Bunker, 1996), the Trust-Centred Participatory Open Data Ecosystem (T-PODE) framework is proposed. The framework identifies three pillars of trust-building: data trust through technical transparency, institutional trust through participatory governance, and social trust through community co-creation. Contextualised within the STICS living laboratories operating in three Slovak regions, this paper contributes to the growing body of literature on open data ecosystems by explicitly positioning trust as both the central objective and the binding mechanism of participatory data governance at the municipal level.*

**Keywords---** open data ecosystems, trust-building, environmental data, stakeholder engagement, living laboratories, psychology of trust

### I. INTRODUCTION

When a municipality publishes environmental data on air quality or flood risk, the impact of that information depends less on its technical accuracy than on whether citizens believe it, act on it, and feel represented in how it was produced. Trust, in other words, is what makes data governance work. In the context of municipal environmental decision-making, the willingness of citizens, local authorities, and other stakeholders to rely on data, institutions, and each other determines whether governance processes achieve their intended outcomes (Grimmelikhuijsen and Meijer, 2014; Kim and Lee, 2012). From a psychological perspective, trust involves a readiness to accept vulnerability based on positive expectations about another party's ability, benevolence, and integrity (Mayer, Davis, and Schoorman, 1995). This readiness is not merely cognitive; it is also affective, shaped by emotional responses to past interactions, perceived fairness, and the sense of being heard (Lewicki and Bunker, 1996). Without it, even the most technically sophisticated data systems fail to generate the legitimacy needed for collective action on environmental challenges such as climate adaptation and sustainable urban development.

The proliferation of open government data (OGD) initiatives across Europe has created new opportunities for strengthening this trust. Open data ecosystems, understood as networks of actors, platforms, and governance arrangements that facilitate the production, sharing, and use of publicly accessible data (Harrison, Pardo, and Cook, 2012; Dawes, Vidiasova, and Parkhimovich, 2016), hold significant potential for transforming the relationship between municipalities and their citizens. When implemented effectively, these ecosystems can enhance transparency, enable evidence-based decision-making, and provide a foundation for meaningful civic participation (Janssen, Charalabidis, and Zuiderwijk, 2012; Ruijter, Grimmelikhuijsen, and Meijer, 2017).

However, realising this potential presents considerable challenges. European municipalities frequently struggle with fragmented environmental data, limited interoperability across sectors, and insufficient mechanisms for engaging communities in data governance processes (Lnenicka et al., 2024; ODECO, 2024). Crucially, the scholarly landscape on open data ecosystems reveals a persistent bifurcation. One stream of research concentrates on technical infrastructure, data quality standards, and platform architectures (Attard et al., 2015; Zuiderwijk and Janssen, 2014; Lnenicka et al., 2024), producing technically sophisticated models that nonetheless leave questions of governance legitimacy and community ownership largely unaddressed. A parallel stream focuses on governance models and institutional arrangements (Grimmelikhuijsen and Feeney, 2017; Meijer, 2009; Ostrom, 1990), offering important insights into accountability and participation rules yet often abstracting away from the technical realities of data systems. While both streams acknowledge the importance of trust, no existing framework integrates technical, governance, and community dimensions into a unified analytical model with trust as the central organising principle. Smart governance models (Vitálišová et al., 2022) emphasise institutional innovation but do not systematically incorporate data ecosystem architectures. Open data maturity models (Lnenicka et al., 2022) assess technical transparency without embedding participatory governance. Commons-based governance frameworks (Ruhaak et al., 2021) address collective action rules but lack specificity regarding data trust mechanisms. The result is a fragmented theoretical landscape in which practitioners must draw on multiple, disconnected models when designing participatory open data ecosystems.

This theoretical gap is particularly consequential for municipalities seeking to develop participatory open data ecosystems for environmental governance. As Schmidhuber et al. (2021) demonstrate, the relationship between government openness and public trust is mediated by democratic capacity, that is, the extent to which citizens can meaningfully engage with and influence decision-making processes. Simply making data available is insufficient; what matters is how data ecosystems are designed, governed, and embedded within community practices (Ruijter et al., 2020; Slobodova and Becker, 2020). Psychologically, this reflects a well-established finding: people judge the trustworthiness of institutions not only by the outcomes they deliver but also by the fairness of the processes they use (Tyler, 2006). When citizens feel that they have a genuine voice in how environmental data is collected and used, their trust in the resulting governance system deepens, even when specific decisions do not align with their individual preferences.

Against this background, the present paper addresses the following research question: **RQ: How can participatory open data ecosystems be designed and governed to build and sustain trust between municipalities and citizens in the domain of environmental data?**

In pursuing this question, we draw on insights from both the open data governance literature and the psychology of trust, recognising that trust

is not merely a technical or institutional outcome but a deeply human phenomenon rooted in perceptions of competence, goodwill, and fairness (Mayer, Davis, and Schoorman, 1995; Lewicki and Bunker, 1996). We adopt a multi-dimensional understanding of trust that distinguishes between data trust (confidence in information quality), institutional trust (confidence in governance arrangements), and social trust (mutual confidence among ecosystem actors), and we trace how each dimension is shaped by different aspects of open data ecosystem design.

To answer this question, we propose the Trust-Centred Participatory Open Data Ecosystem (T-PODE) framework, developed through a comparative theoretical analysis of existing models and enhanced by practical experience from the Smart Transformation and Innovation Consortium Slovakia (STICS) project. STICS operates three living laboratories in Slovakia -- in two municipalities, Kežmarok and Horné Srnie, and the Banská Bystrica Self-Governing Region. In these three territories, they integrate environmental sensors, spatial planning data, and citizen inputs across approximately 250 data sources. The consortium's practical experience provides a grounding context for our theoretical framework. The paper is structured as follows. Section 2 reviews the theoretical background on open data ecosystems, trust, and participatory governance. Section 3 describes our comparative analytical methodology. Section 4 presents the results of the comparative analysis, including a systematic examination of existing models and their limitations. Section 5 proposes and discusses the T-PODE framework, accompanied by a graphical representation (Figure 1). Section 6 offers concluding remarks.

## II. THEORETICAL BACKGROUND

### A. Open Data Ecosystems: From Technical Platforms to Socio-Technical Systems

The concept of data ecosystems has evolved significantly since its early formulations. Harrison, Pardo, and Cook (2012) proposed a research agenda for creating open government ecosystems that recognised the need to move beyond data portals towards networked environments supporting innovation. Dawes, Vidiasova, and Parkhimovich (2016) advanced this thinking by developing an ecosystem model for planning and designing OGD programmes. Using socio-technical systems theory, they addressed how governments can stimulate and support ecosystems of data producers, innovators, and users in diverse cultural settings.

More recently, Lnenicka et al. (2024) conducted a comprehensive platform theory-based analysis of sustainable open data ecosystems across 19 European smart cities. Their work identified 50 contextual patterns that influence and shape open data platform ecosystems, classifying them into socio-economic, political-institutional, and information-technological contexts. This research confirmed that sustainable open data ecosystems require the alignment of multiple stakeholder groups around shared data governance principles, rather than merely technical solutions.

The ODECO (Open Data ECOsystems) Marie Curie consortium has further elaborated the multi-dimensional nature of open data ecosystems, identifying nine categories of user needs: availability, accessibility, and findability; improved data quality; reliable data infrastructures; adequate funding; literacy; data ethics; licensing and privacy; governance principles; and communication frameworks (Di Staso et al., 2023; ODECO, 2024). This work emphasises the transition from linear producer-driven models to circular user-driven models, recognising the centrality of diverse actors and the multiple roles they play within the ecosystem.

In the municipal environmental context, projects such as AURORAL (Architecture for Unified Regional and Open digital ecosystems for Smart Communities) and VICINITY have demonstrated the potential and challenges of interoperable IoT-based data ecosystems. AURORAL, a Horizon 2020 project with 25 partners across 11 European countries, developed an open, API-based, federated IoT architecture for rural and semi-urban communities, demonstrating cross-domain applications across five European regions (European Commission, 2021). VICINITY similarly explored IoT interoperability across domains including energy, transport, and assisted living (VICINITY Consortium, 2016). Both projects highlight the critical importance of data sovereignty and privacy: in AURORAL's architecture, each user retains ownership of their data, with no access without explicit consent agreements.

### B. Trust as a Multi-Dimensional Construct in Open Governance

These developments illustrate an important conceptual shift in the understanding of open data initiatives. Early approaches treated open data primarily as a technical infrastructure centred on data portals and publication and transparency mechanisms. More recent approaches increasingly conceptualise open data initiatives as socio-technical ecosystems composed of interacting actors, institutions, technologies, and governance arrangements. European projects such as AURORAL and VICINITY demonstrate that technical interoperability alone is insufficient for sustainable data ecosystems. Successful implementations require the alignment of technological architectures with governance frameworks and stakeholder practices. This evolution confirms that open data ecosystems must be understood as socio-technical systems in which technological infrastructures, institutional arrangements, and human actors co-evolve. Trust has been extensively studied in the context of open government and e-governance, yet its operationalisation in the specific context of open data ecosystems remains underdeveloped. From a psychological standpoint, the most influential conceptualisation of trust is provided by Mayer, Davis, and Schoorman (1995), who define trust as the willingness to be vulnerable to the actions of another party based on the expectation that the other will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party. Their model identifies three antecedents of perceived trustworthiness: ability (the competence of the trustee in a relevant domain), benevolence (the extent to which the trustee is believed to want to do good to the trustor), and integrity (the trustor's perception that the trustee adheres to a set of principles that the trustor finds acceptable). These three dimensions translate naturally into the open data context. Citizens assess whether a municipality has the technical capacity to produce reliable data (ability), whether the municipality genuinely acts in the public interest (benevolence), and whether governance processes are fair and consistent (integrity). In practice, these assessments are rarely made through careful deliberation. They are often intuitive, shaped by prior experiences with institutions and by the psychological heuristics that people use when evaluating complex systems (Kahneman, 2011). A single experience of data inaccuracy or perceived institutional dishonesty can disproportionately undermine trust, while consistent, small acts of transparency and responsiveness can gradually build it.

Lewicki and Bunker (1996) offer a complementary developmental perspective, proposing that trust evolves through three stages: calculus-based trust (grounded in deterrence and rational calculation), knowledge-based trust (built through repeated interactions and growing familiarity), and identification-based trust (arising when parties share values and goals). This developmental model is particularly relevant for participatory open data ecosystems, where initial engagement may be motivated by instrumental concerns but can, over time, develop into deeper forms of trust as stakeholders co-create governance rules and share experiences in living laboratories.

In the public governance literature, Meijer (2009) established that modern transparency, enabled by information and communication technologies, has the potential to enhance government accountability and reduce corruption, though the relationship between transparency and trust is neither automatic nor straightforward. Grimmelikhuijsen and Meijer (2014) empirically demonstrated that the effects of transparency on trust depend on prior dispositions and contextual factors. Their subsequent work on open government adoption in local governments (Grimmelikhuijsen and Feeney, 2017) revealed that structural, cultural, and environmental variables all influence the adoption of accessibility, transparency, and participation dimensions. This underscores the multi-factorial nature of trust-building: transparency alone does not generate trust if citizens perceive that the governance culture behind it is insincere or unresponsive.

Wiencierz and Luenich (2022) specifically examined trust in open data applications, finding that transparency mechanisms must be carefully

designed to generate trust rather than confusion or scepticism. Mutambik et al. (2022) investigated factors influencing public trust in OGD, confirming that perceived data quality, system quality, and service quality all affect citizens' trust perceptions.

Drawing on Ostrom's (1990) seminal work on governing the commons, several scholars have begun to conceptualise open data as a commons resource requiring collective governance arrangements. The Mozilla Foundation (Ruhaak et al., 2021) has developed a practical framework applying Ostrom's eight design principles to data commons governance, emphasising that data governance must address not only the data itself but also the rules governing access, participation, and benefit-sharing. Calzati and van Loenen (2023) proposed a Data Republic model comprising public data trusts, local data communes, data stewards, and a board of data arbitrators, an institutional architecture that resonates strongly with trust-building objectives.

For the purpose of this paper, and drawing on both the psychological and governance literatures reviewed above, we distinguish three forms of trust that are particularly relevant for participatory open data ecosystems. Data trust refers to stakeholders' confidence in the quality, reliability, and verifiability of the data itself; it corresponds closely to Mayer et al.'s (1995) notion of perceived ability. Institutional trust denotes confidence in the governance arrangements, rules, and accountability mechanisms that structure the ecosystem; it relates to perceived integrity and the fairness of procedures. Social trust captures the mutual confidence among actors, including citizens, local authorities, businesses, and civil society organisations, that emerges through collaborative processes and shared experiences; it resonates with Lewicki and Bunker's (1996) identification-based trust and with Mayer et al.'s benevolence dimension. Importantly, these three forms of trust are not independent. A failure in one dimension (for example, a data breach undermining data trust) can rapidly erode trust across the other dimensions as well, because people tend to generalise negative experiences across related domains (Slovic, 1993).

### C. Participatory Governance and Stakeholder Engagement

Participatory approaches to data governance draw on a rich tradition of democratic innovation and co-creation in public administration. Kim and Lee (2012) demonstrated that e-participation and transparency jointly contribute to trust in local government, establishing that active involvement of citizens in governance processes is a distinct predictor of trust beyond mere information provision. Simonofski et al. (2017) proposed an evaluation framework for citizen participation in smart cities, identifying multiple levels of engagement from information sharing to co-decision-making.

Vitálišová et al. (2022, 2024) have examined smart governance principles in Slovak municipalities, finding that participatory mechanisms are critical for building legitimate and effective governance systems. Their model of optimal smart open governance (Vitálišová et al., 2025) identifies four foundational elements: the institutional framework, principles of open governance, tools and methods, and evaluation and feedback. While this model provides a comprehensive vision of smart open governance at the local level, and while it recognises open data and data-driven systems as important tools for smart and open governance, its primary orientation is towards governance processes and institutional arrangements rather than the detailed architecture of open data ecosystems.

Living laboratories have emerged as a particularly promising approach for testing and developing participatory data governance arrangements. Gascó (2017) analysed living labs as implementation mechanisms for open innovation in the public sector, while Ruijer and Meijer (2020) documented how living lab experiments can facilitate the innovation process of open government data. The iterative, low-pressure nature of living labs is also psychologically significant: by reducing perceived risks associated with participation, living labs lower the psychological barriers to engagement and create conditions in which trust can develop gradually through direct experience (Lewicki and Bunker, 1996). These findings are directly relevant to the STICS project, which employs three living laboratories as testing grounds for participatory approaches to environmental data governance.

### D. The Fragmentation of Existing Models: A Critical Assessment

Based on a qualitative comparative analysis of the scientific literature, we evaluated the models' coverage in three dimensions -- technical, governance, community -- with an emphasis on assessing the primary focus and analytical scope of each framework.

A review of the existing theoretical approaches reveals that models addressing the intersection of open data, trust, and participatory governance tend to be partial in scope, each illuminating one or two dimensions while leaving others underexplored. Table 1 summarises this fragmentation.

TABLE I. Scope of Selected Existing Models and Frameworks

Model / Framework	Technical	Governance	Community	Trust Treatment
Platform ecosystem model (Lnenicka et al., 2024)	✓✓✓	✓	✓	Implicit; transparency maturity assessed but trust not central
Open government adoption (Grimmelikhuisen & Feeney, 2017)	✓	✓✓✓	✓	Trust as dependent variable, not as organising principle
Commons governance (Ostrom, 1990; Ruhaak et al., 2021)	✓	✓✓✓	✓✓	Implied through collective choice; not operationalised for data
Smart open governance (Vitálišová et al., 2022, 2025)	✓	✓✓✓	✓✓	Trust as precondition; governance-oriented with technology and open data as tools, but without detailed data architecture
AURORAL federated IoT (EC, 2021)	✓✓✓	✓	✓	Data sovereignty as trust proxy; no explicit trust framework
OGD network model (Reggi & Dawes, 2022)	✓	✓✓	✓✓✓	Ecosystem relations mapped; trust dynamics not theorised
T-PODE (this paper)	✓✓✓	✓✓✓	✓✓✓	Trust as central organising principle across all three dimensions

Note: ✓ = peripheral coverage; ✓✓ = moderate coverage; ✓✓✓ = strong coverage. Source: Authors' own elaboration.

As Table 1 illustrates, no single existing model achieves strong coverage across all three dimensions while simultaneously treating trust as the central organising principle. Technically-oriented models excel at platform design and data quality but treat governance and community engagement as contextual factors. Governance-oriented models provide robust institutional analysis but abstract away from technical implementation realities. Community-oriented models map stakeholder networks but lack integration with technical architectures and formal governance mechanisms. This fragmentation motivates the development of an integrated framework that explicitly bridges all three dimensions through the unifying lens of trust.

### III. METHODOLOGY

This paper employs a comparative theoretical analysis to develop an integrated framework for trust-building in participatory open data ecosystems. The methodology combines two complementary approaches: (a) a structured comparative analysis of existing frameworks and models, and (b) contextualisation through the STICS project.

#### A. Comparative Analysis Design

The comparative analysis examines existing theoretical and empirical contributions to open data ecosystems, with particular attention to their treatment of trust, participation, and stakeholder engagement. We identified relevant literature through a targeted search across Scopus, Web of Science, and Google Scholar databases, using combinations of key terms including "open data ecosystem," "municipal trust," "participatory governance," "environmental data," and "smart city governance." These databases were selected for their comprehensive coverage of public administration, information systems, and urban governance research, in line with established practice in systematic comparative reviews of e-government and open data scholarship (Tranfield, Denyer, and Smart, 2003; Attard et al., 2015).

The analysis is organised around three analytical dimensions that emerged inductively from initial engagement with the literature, following the thematic synthesis approach described by Thomas and Harden (2008) and consistent with framework development methodology in the social sciences (Jabareen, 2009). These dimensions are: (1) Technical infrastructure -- how platforms, standards, and data quality mechanisms contribute to data trust; (2) Governance mechanisms -- how institutional rules, accountability structures, and decision-making processes build institutional trust; and (3) Community engagement -- how participatory practices, co-creation processes, and stakeholder relationships foster social trust.

#### B. STICS Project Context

The Smart Transformation and Innovation Consortium Slovakia (STICS) provides the practical context for our analysis. STICS operates three living laboratories: the Kežmarok municipality in the Prešov Region, the Horné Srnie municipality in the Trenčín Region, and the Banská Bystrica Self-Governing Region. These laboratories are designed to integrate diverse data sources, including climate sensors, spatial planning data, and citizen inputs, enabling cross-sectoral environmental monitoring and governance experimentation. Our involvement in STICS provides insider perspective on the practical challenges and opportunities of building participatory data ecosystems at the municipal level in Slovakia. Insights from STICS workshops, stakeholder consultations, and early implementation experiences inform the framework development, although the primary contribution of this paper is theoretical rather than empirical.

#### C. Framework Synthesis

The T-PODE framework is synthesised through an iterative process. First, we identify the strengths and limitations of existing approaches along each analytical dimension (summarised in Table 1). Second, we extract cross-cutting success factors for trust-building. Third, we integrate these findings into a coherent three-pillar model with trust as the central organising principle. Finally, we examine how the framework applies to the STICS context, using the consortium's experience to assess the model's practical relevance and to identify areas requiring further development.

### IV. RESULTS AND COMPARATIVE ANALYSIS

#### A. Technical Infrastructure and Data Trust

Our analysis of technical approaches reveals several patterns critical for building data trust. The AURORAL project's federated IoT architecture demonstrates that data sovereignty, meaning that each data provider retains ownership and control, is a fundamental technical precondition for trust in multi-stakeholder ecosystems (European Commission, 2021). Unlike centralised platforms that concentrate control, federated architectures distribute authority and thereby mitigate the concentration risks that often undermine trust.

Lnenicka et al. (2024) identify that sustainable open data ecosystems require platforms serving multiple functions: data disclosure, thematic visualisation, citizen reporting, and participation. The analysis of 19 European cities showed that cities with higher transparency maturity tend to implement multiple complementary platforms rather than relying on a single portal (Lnenicka et al., 2022). This finding suggests that data trust is built not through a single technical solution but through an ecosystem of tools that collectively enable verification, comprehension, and use of environmental data.

Data quality emerges as a pivotal mediator between technical infrastructure and trust. Mutambik et al. (2022) confirm that perceived data quality directly influences trust in OGD, while the ODECO consortium emphasises the importance of institutionalising FAIR principles (Findable, Accessible, Interoperable, Reusable) as a foundation for data quality governance (ODECO, 2024). Real-time data validation, clear metadata, and transparent provenance tracking are technical mechanisms that directly support data trust. From a psychological standpoint, these mechanisms function as trust signals: observable cues that allow individuals to form positive judgments about the reliability of a system without needing to understand its full technical complexity (Luhmann, 1979).

However, these technically-oriented models share a common limitation: they treat governance and community engagement as exogenous factors rather than as integral components of the trust-building process. AURORAL's federated architecture preserves data sovereignty but does not specify how collective governance rules should be established. Lnenicka et al.'s (2024) platform analysis identifies socio-economic and political-institutional contexts but does not model how these contexts interact with technical design to generate or erode trust.

#### B. Governance Mechanisms and Institutional Trust

Governance arrangements determine whether open data ecosystems generate institutional trust or institutional scepticism. Grimmelikhuijsen and Feeney (2017) demonstrate that open government adoption in local governments depends not only on organisational capacity but also on an innovative and participative climate within the institution. This finding underscores that governance for trust requires both structural arrangements and a cultural orientation towards openness.

The application of Ostrom's (1990) commons governance principles to data ecosystems provides particularly valuable insights. Ostrom's design principles, including clearly defined boundaries, proportional costs and benefits, collective-choice arrangements, monitoring, graduated sanctions, conflict resolution, and recognition of self-governance rights, translate directly into governance requirements for open data ecosystems (Ruhaak et al., 2021). In data commons, clearly defined boundaries mean establishing who has access to what data under what conditions. Collective-choice arrangements require that those affected by data governance rules participate in shaping them. Monitoring ensures compliance not through surveillance but through mutual accountability.

Vitálišová et al.'s (2022, 2025) model of optimal smart open governance provides a particularly relevant governance framework from the Central European context. Their model identifies four foundational elements: an institutional framework of governance bodies and stakeholders, principles of open governance (transparency, participation, accountability, integrity, and accessibility), tools and methods combining traditional and digital instruments, and evaluation and feedback mechanisms. While this model offers a comprehensive governance vision, and while it positions open data and data architecture as essential tools for data-driven and evidence-driven governance, its primary orientation is towards institutional arrangements and participatory processes within local self-government rather than towards the detailed technical architecture of open data ecosystems or the dynamics of trust-building across multiple dimensions.

Ruijter et al. (2020) reveal the political dimensions of open data governance, showing that organisational responses to transparency pressures vary based on the perceived legitimacy of openness demands and the organisational capacity to respond. This political perspective is critical for understanding institutional trust: governance arrangements must be seen as fair and responsive, not merely as compliance mechanisms imposed from above. In psychological terms, institutional trust grows when people perceive procedural justice, that is, when the processes through which decisions are made appear fair, consistent, and open to correction (Tyler, 2006).

The limitation of governance-oriented models lies in their abstraction from technical realities. Ostrom's principles, while powerful as design guidelines, do not address the technical mechanisms through which data quality is assured, provenance is tracked, or interoperability is achieved. Grimmelikhuijsen and Feeney's (2017) framework explains adoption patterns but does not model the feedback loops between technical design choices and governance outcomes.

### C. Community Engagement and Social Trust

Social trust, understood as the mutual confidence among diverse actors within an ecosystem, emerges through sustained interaction and shared experience. The comparative analysis identifies co-creation as a critical mechanism for building social trust. Reggi and Dawes (2022) demonstrate through social network analysis that government organisations play a central role as data providers and intermediaries in OGD ecosystems, but that effective ecosystems require active engagement of user communities, NGOs, and media actors. Moreover, co-location and shared geographic context significantly predict the formation of new ecosystem connections.

Living laboratories provide structured environments for fostering social trust through co-creation. Gascó (2017) and Ruijter and Meijer (2020) document how living lab approaches enable iterative learning and relationship-building among stakeholders who may initially have different interests and levels of digital competency. The experimental nature of living labs reduces the stakes of individual decisions while building the relational infrastructure needed for sustained collaboration (Vaňová, 2021). Psychologically, this resembles what Lewicki and Bunker (1996) described as the transition from calculus-based trust, where participation is driven by expected rewards, to knowledge-based trust, where repeated positive interactions create familiarity and predictability.

Vitálišová et al.'s (2025) findings from Slovak district cities are particularly relevant for the STICS context. Their research reveals that Slovak municipalities tend to rely on obligatory and offline participation tools, which limits the development of social trust in digital governance contexts. This gap between existing practice and the requirements of participatory open data ecosystems represents both a challenge and an opportunity: the introduction of new participatory mechanisms through projects like STICS can catalyse shifts in governance culture, but only if implemented with sensitivity to local conditions and existing relationships.

Capacity building emerges as an essential precondition for meaningful community engagement. The ODECO consortium highlights digital literacy as a critical user need, while Slobodova and Becker (2020) emphasise that open data platforms must be designed with attention to the actual capacities and interests of local actors, not just to technical possibilities. In the environmental domain, this means translating complex sensor data and spatial information into formats and narratives that citizens can engage with meaningfully. When people feel competent in their ability to understand and use data, their willingness to participate and trust the process increases (Bandura, 1997).

### D. Cross-Cutting Patterns: Success Factors for Trust-Building

Across the three analytical dimensions, our comparative analysis identifies five cross-cutting success factors for building trust in participatory open data ecosystems:

**First**, distributed authority rather than centralisation. Federated architectures (AURORAL), commons-based governance (Ostrom, 1990), and multi-stakeholder networks (Reggi and Dawes, 2022) all point to the importance of distributing power and control across ecosystem actors. Centralised systems may be technically efficient but tend to concentrate risk and undermine the trust of those excluded from decision-making.

**Second**, transparency as a design principle rather than an afterthought. Lnenicka et al. (2022) and Janssen et al. (2017) argue for "transparency-by-design," where data systems are constructed from the outset with transparency as a core requirement. This proactive approach generates more trust than reactive disclosure, because it signals genuine institutional commitment rather than reluctant compliance.

**Third**, iterative co-creation processes. Living laboratories, collaborative workshops, and participatory budgeting all demonstrate that trust is built through repeated, low-stakes interactions that gradually establish shared norms and mutual understanding (Gascó, 2017; Ruijter and Meijer, 2020). Trust cannot be engineered in a single event; it grows through accumulated experience.

**Fourth**, contextual sensitivity. Successful open data ecosystems are adapted to local conditions, including institutional cultures, digital capacities, and existing stakeholder relationships (Dawes et al., 2016; Vitálišová et al., 2025). Universal solutions imposed without local adaptation tend to fail because they disregard the relational and cultural substrates on which trust depends.

**Fifth**, reciprocal benefit. Ostrom's (1990) principle of proportional costs and benefits applies directly: ecosystem participants must perceive tangible value from their engagement. For municipalities, this means improved decision-making; for citizens, it means greater influence over environmental issues affecting their lives; for businesses, it means access to data that supports innovation. When the benefits of participation are visible and fairly distributed, the motivation to trust and to invest in the ecosystem grows accordingly.

## V. DISCUSSION: THE T-PODE FRAMEWORK

### A. Framework Architecture

Unlike existing frameworks that treat trust as an outcome variable, the T-PODE framework conceptualises trust as the structural principle around which the entire ecosystem is organised. Conceptually, the proposed framework is aligned with socio-technical systems theory, which emphasises the co-evolution of technological infrastructure, institutional arrangements, and human actors. Based on the comparative analysis, we propose the Trust-Centred Participatory Open Data Ecosystem (T-PODE) framework (Figure 1). The framework is designed to address the fragmentation identified in Section II.D and Table 1 by integrating all three dimensions (technical infrastructure, governance mechanisms, and community engagement) into a unified model with trust as the central organising principle. The framework is structured around three interconnected pillars, each generating a specific form of trust, with trust functioning simultaneously as the objective and the binding mechanism of the ecosystem:

**Pillar A: Technical Infrastructure → Data Trust.** This pillar encompasses the platforms, standards, data quality mechanisms, and interoperability solutions that enable stakeholders to access, verify, and use environmental data with confidence. Key components include: federated data architectures preserving data sovereignty; FAIR-compliant metadata and quality indicators; real-time environmental monitoring with transparent data provenance; interoperable APIs enabling cross-sectoral data integration; and accessible visualisation and communication tools that translate technical data into actionable information. Psychologically, these components serve to reduce the uncertainty that citizens face when evaluating municipal data, thereby lowering the threshold for trust (Mayer et al., 1995).

**Pillar B: Governance Mechanisms → Institutional Trust.** This pillar addresses the rules, accountability structures, and decision-making processes that govern the ecosystem. Drawing on Ostrom's (1990) commons governance principles and adapted for the open data context, key components include: clearly defined data access and sharing rules with explicit rights and obligations; collective-choice arrangements enabling stakeholder participation in rule-setting; monitoring and accountability mechanisms based on mutual transparency rather than surveillance;

conflict resolution procedures for data disputes; privacy protection mechanisms that balance openness with individual and community rights; and recognition by higher authorities of the ecosystem's self-governance capacity.

**Pillar C: Community Engagement → Social Trust.** This pillar concerns the participatory practices, capacity-building processes, and stakeholder relationships that generate mutual confidence. Key components include: living laboratory approaches for iterative co-creation and testing; multi-stakeholder workshops and deliberative forums; citizen science programmes for environmental data collection and validation; digital literacy and data skills programmes; feedback mechanisms ensuring responsiveness to community input; and social innovation initiatives that demonstrate the practical value of participatory data governance. By creating spaces where citizens and institutions interact as partners rather than as passive recipients and providers, this pillar cultivates the benevolence dimension of trust (Mayer et al., 1995) and supports the developmental progression from calculus-based to identification-based trust (Lewicki and Bunker, 1996).

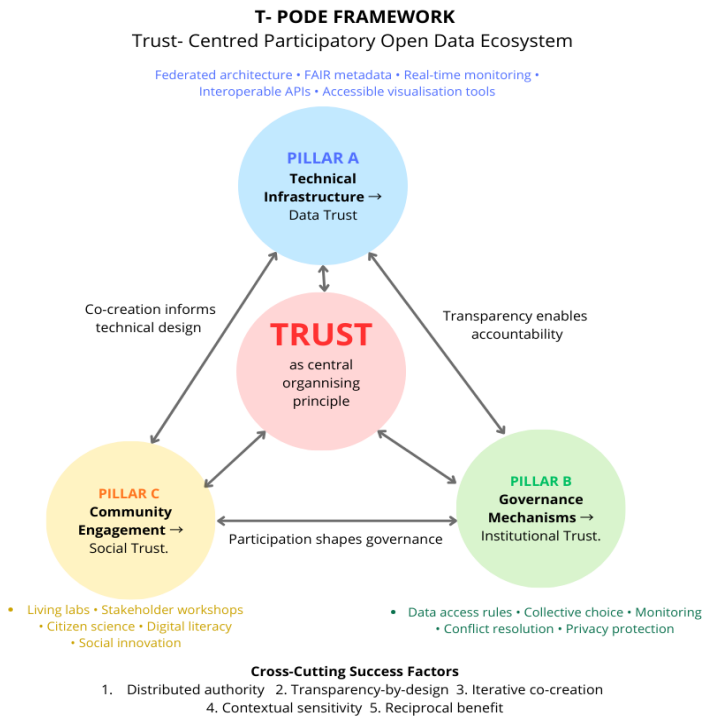


Fig. 1. The T-PODE Framework: Trust-Centred Participatory Open Data Ecosystem. Source: Authors' own elaboration.

### B. Interconnections and Dynamics

The three pillars of the T-PODE framework are not independent but mutually reinforcing, as illustrated by the connecting lines in Figure 1. These relationships are bidirectional: co-creation processes inform technical design choices, while technical infrastructure simultaneously enables and facilitates community co-creation and participatory governance. Technical infrastructure that is well-designed but governed without stakeholder input generates data trust while potentially undermining institutional and social trust. Conversely, highly participatory governance processes that lack adequate technical infrastructure cannot sustain data trust. The framework recognises these interdependencies and posits that sustainable trust requires simultaneous attention to all three pillars.

The dynamic relationships between pillars follow a virtuous cycle logic. When citizens participate in data governance (Pillar C) and see their input reflected in governance rules (Pillar B) and technical design (Pillar A), social trust increases. When governance rules are transparent and effectively enforced (Pillar B), both data trust (Pillar A) and social trust (Pillar C) are strengthened. When technical systems reliably provide verifiable data (Pillar A), they provide the evidential basis for both governance accountability (Pillar B) and community engagement (Pillar C). This virtuous cycle corresponds to Lewicki and Bunker's (1996) developmental model: early positive experiences across all three pillars create the conditions for deeper, more resilient forms of trust to emerge over time.

However, the framework also acknowledges potential tensions and vulnerabilities. Privacy requirements may limit data openness; technical complexity may constrain participation; and governance formalisation may reduce the flexibility needed for innovation. Moreover, trust is asymmetric in its dynamics: it is built slowly through consistent positive experiences but can be destroyed rapidly by a single negative event (Slovic, 1993). Designing for resilience, including clear procedures for responding to trust violations, transparent error correction, and mechanisms for rebuilding confidence after failures, is therefore an essential part of the framework's practical application.

### C. Application to the STICS Context

The STICS project provides an illustrative context for examining the T-PODE framework's practical implications. In the technical infrastructure pillar, STICS's integration of over 250 data sources, including climate sensors, spatial planning data, and citizen inputs across three living laboratories, represents a significant effort to create the technical conditions for data trust. The consortium's work on data interoperability addresses the fragmentation challenges identified in the comparative analysis.

In the governance mechanisms pillar, STICS's collaborative approach involving 24 partners from five EU countries provides experience with multi-stakeholder governance arrangements. The consortium's workshops serve as practical testing grounds for collective-choice mechanisms, while the living laboratory approach allows for iterative refinement of governance rules based on practical experience.

In the community engagement pillar, STICS's emphasis on social innovation and stakeholder engagement directly addresses the social trust deficit identified in Vitálišová et al.'s (2025) research on Slovak municipalities. The project's living laboratories in Kežmarok, Horné Srnie, and the Banská Bystrica Self-Governing Region create structured opportunities for community participation in environmental data governance, potentially catalysing the shift from offline, obligatory participation towards more dynamic and digitally enabled engagement.

The Slovak context also reveals specific challenges for the T-PODE framework. The relatively low maturity of open governance implementation in Slovak municipalities (Vitálišová et al., 2025) means that all three pillars must be developed simultaneously, rather than

building on existing foundations. This starting position, while challenging, also presents an opportunity: the framework can be implemented from the outset as an integrated system rather than retrofitted onto legacy arrangements.

#### D. Theoretical Contributions and Practical Implications

The T-PODE framework makes several contributions to the existing literature. First, it explicitly positions trust as the central organising principle of open data ecosystems, moving beyond models that treat trust as one variable among many (see Table 1). Second, it integrates three distinct forms of trust (data trust, institutional trust, and social trust) into a unified framework, recognising their interdependence while preserving analytical clarity. Third, it bridges the gap between technically-oriented models (Lnenicka et al., 2024; AURORAL) and governance-oriented models (Ostrom, 1990; Grimmeliikhuijsen and Feeney, 2017; Vitálišová et al., 2022) by incorporating community engagement as a co-equal pillar rather than as an auxiliary concern. Fourth, by grounding the framework in the psychology of trust, it provides a theoretically richer account of why certain design and governance choices matter for the people who ultimately use, contribute to, and depend on open data ecosystems.

For practitioners, the framework provides a diagnostic tool. Municipalities can assess their open data ecosystems against the three pillars, identifying which forms of trust are well-supported and which require development. The psychological perspective embedded in the framework also offers practical guidance: for example, recognising that trust develops in stages (Lewicki and Bunker, 1996) suggests that initial engagement efforts should focus on delivering tangible, visible benefits (to build calculus-based trust) before moving towards more demanding forms of participation that require deeper commitment. For policy-makers, the framework suggests that investment in open data ecosystems must be balanced across technical, governance, and community dimensions.

#### E. Limitations and Future Research

This paper has several limitations that suggest directions for future research. As a theoretical framework paper based on comparative analysis, the T-PODE model requires empirical validation through systematic case studies. The STICS project's living laboratories provide a natural setting for such validation, and future research will assess the framework's utility through longitudinal analysis of trust-building processes across the three Slovak regions.

Furthermore, the framework does not yet specify how to measure the different forms of trust or how to assess the maturity of each pillar. Development of trust indicators and maturity assessment instruments, potentially drawing on validated psychological scales for measuring trust (such as those based on Mayer et al., 1995), represents a necessary next step. The framework's applicability across different national and institutional contexts also requires examination; while the comparative analysis draws on diverse European cases, the specific challenges and opportunities in Central and Eastern European municipalities may differ from those in Western European settings (Safarov, 2020).

Finally, the framework's treatment of power dynamics and potential conflicts of interest among ecosystem actors could be further developed. Ruijter et al.'s (2020) political perspective on open data governance highlights that data ecosystems are arenas of strategic behaviour, not merely collaborative platforms. Future iterations of the T-PODE framework should more explicitly address questions of power, equity, and distributional justice within participatory data ecosystems, as well as the psychological mechanisms through which perceived injustice erodes trust (Tyler, 2006).

#### VI. CONCLUSION

Building trust in municipal environmental data is not primarily a technical challenge but a socio-technical and governance challenge that requires integrated approaches. As our comparative analysis has demonstrated, existing models address individual dimensions, such as technical infrastructure, governance mechanisms, or community engagement, but none provides a comprehensive framework that integrates all three with trust as the central organising principle (Table 1). This paper has proposed the Trust-Centred Participatory Open Data Ecosystem (T-PODE) framework as a contribution to addressing this fragmentation.

This paper contributes to both the theoretical and practical dimensions of the research question in three ways. First, it conceptualises trust as the central organising principle of participatory open data ecosystems. Second, it integrates technical, governance, and community perspectives that are typically analysed separately in the existing literature. Third, it proposes the Trust-Centred Participatory Open Data Ecosystem (T-PODE) framework and illustrates its relevance through insights from the STICS living laboratories in Slovakia. In response to our research question, the T-PODE framework offers a three-pillar answer. Data trust is built through transparent, high-quality technical infrastructure. Institutional trust is cultivated through fair, participatory governance mechanisms. Social trust emerges through sustained community engagement and co-creation. None of these pillars is sufficient on its own; it is their integration, with trust as the binding mechanism, that creates the conditions for effective and legitimate environmental data governance.

The psychological perspective woven throughout this analysis offers a reminder that trust is, at its core, a human phenomenon. It is shaped by perceptions, emotions, and experiences that cannot be fully captured by institutional design or technical specifications alone. People trust not only because systems are well-built and rules are fair, but also because they feel heard, respected, and included in processes that affect their lives (Mayer et al., 1995; Tyler, 2006). Designing open data ecosystems with this understanding in mind is essential for municipalities that aspire not just to be data-rich, but to be genuinely trusted by the communities they serve.

The five cross-cutting success factors identified in the analysis (distributed authority, transparency-by-design, iterative co-creation, contextual sensitivity, and reciprocal benefit) provide principles for practitioners seeking to build trusted participatory data ecosystems at the municipal level. The framework's application to the STICS context demonstrates both its analytical utility and the specific challenges facing Central European municipalities in developing participatory open data governance.

As municipalities across Europe face growing demands for evidence-based environmental governance and citizen participation, the need for integrated frameworks connecting data, governance, and community trust becomes increasingly pressing. The T-PODE framework offers a starting point for this integration, while recognising that its refinement will depend on sustained empirical research and practical experimentation in diverse municipal contexts.

#### ACKNOWLEDGEMENT

Funded by the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project Smart Transformation and Innovation Consortium Slovakia (STICS) No. 09102-03-V01-00011 and by VEGA 1/0362/26 Integrated innovations to change the quality of life of communities.

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