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Interdisciplinary Team Diversity and Problem Framing across Sustainability Research Projects

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Abstract

The transition toward global sustainability necessitates complex problem-solving strategies that transcend traditional disciplinary boundaries. Consequently, interdisciplinary research teams have become the primary vehicle for addressing grand environmental and social challenges. However, the cognitive and demographic diversity inherent in these teams often complicates the critical early phase of collaborative research, specifically problem framing. This study provides a comprehensive panel analysis of interdisciplinary team diversity and its longitudinal impact on problem framing in sustainability research projects. Utilizing a multi-wave dataset encompassing numerous international sustainability research initiatives over a five-year period, this research examines how varying dimensions of diversity including disciplinary background, methodological expertise, and cultural context influence the convergence and quality of problem framing. The analysis employs fixed-effects panel regression models to control for unobserved time-invariant heterogeneity, revealing that while deep-level cognitive diversity initially increases transaction costs and delays problem consensus, it ultimately yields more robust, multidimensional problem frames. Conversely, surface-level diversity exhibits diminishing disruptive effects over time as teams establish shared epistemic norms. These findings contribute significantly to the science of team science by delineating the temporal dynamics of diversity, offering actionable insights for science policy makers, funding agencies, and research administrators aiming to optimize the architecture of sustainability research teams.

Keywords: Interdisciplinary Teams; Sustainability Research; Problem Framing; Panel Analysis; Interdisciplinary Team Diversity

1. Introduction

1.1 The Imperative for Interdisciplinary Sustainability Research

Global sustainability challenges, ranging from climate change mitigation to resource depletion and biodiversity loss, are inherently complex and interconnected. These grand challenges defy the analytical capacities of any single scientific discipline, thereby mandating a fundamental shift in how academic research is organized and executed [1]. The mobilization of interdisciplinary teams has thus emerged as a structural necessity rather than a mere academic preference [2]. By integrating theoretical perspectives, methodological tools, and empirical data from the natural sciences, social sciences, and humanities, interdisciplinary teams are theoretically positioned to generate the holistic insights required for actionable sustainability transitions [3]. The assumption driving massive investments by global funding agencies is that assembling diverse experts will naturally precipitate innovative solutions [4]. However, the reality of interdisciplinary collaboration is fraught with epistemic friction, communicative barriers, and institutional hurdles that often impede effective synthesis [5]. A critical bottleneck in this collaborative trajectory occurs during the initial stages of a project, where the parameters of the research problem must be collectively defined and agreed upon.

1.2 The Centrality of Problem Framing

Problem framing is the cognitive and discursive process through which individuals and groups define the boundaries, core variables, and fundamental nature of a given issue. In the context of sustainability research, problem framing is exceptionally consequential because these issues are often characterized as wicked problems, possessing no definitive formulation and no clear stopping rule [6]. How a problem is framed determines the methodologies deployed, the stakeholders engaged, and the ultimate societal impact of the research outcomes [7]. When an interdisciplinary team convenes, its members bring divergent ontological and epistemological assumptions regarding what constitutes valid knowledge and how a problem should be operationalized [8]. For instance, an ecologist might frame agricultural sustainability purely in terms of biodiversity metrics and soil health, whereas an economist might frame it around yield optimization and market externalities. Bridging these distinct problem frames requires substantial cognitive effort and negotiation. If a team fails to establish a coherent, shared problem frame, the resulting research often devolves into multidisciplinary fragmentation, where researchers work in parallel rather than in integration [9]. Therefore, understanding the antecedents of successful problem framing is paramount for advancing the efficacy of interdisciplinary science.

1.3 The Temporal Dynamics of Team Diversity

The composition of research teams is widely recognized as a primary determinant of collaborative success. Diversity within these teams operates across multiple dimensions, broadly categorized into surface-level demographic diversity and deep-level cognitive or disciplinary diversity [10]. While a substantial body of cross-sectional literature has investigated the relationship between team diversity and performance metrics such as publication impact or patent generation, there is a distinct paucity of longitudinal research examining how diversity influences the internal cognitive processes of teams over time. Cross-sectional studies often yield contradictory results, with some highlighting the synergistic benefits of diverse perspectives and others emphasizing the conflict and coordination costs that diversity entails [11]. This paradox can only be resolved by adopting a temporal perspective, acknowledging that the effects of diversity are not static but evolve as team members interact, build trust, and develop shared mental models. By employing a panel analysis design, this study tracks sustainability research teams across multiple temporal waves, allowing for the rigorous isolation of how different facets of diversity impact the problem framing process as projects mature [12].

2. Literature Review and Theoretical Background

2.1 Complexity and Wicked Problems in Sustainability

The theoretical foundation of this study is anchored in the literature on wicked problems and systems thinking. Sustainability issues inherently cross ecological, economic, and social domains, meaning interventions in one area often produce unforeseen consequences in another [13]. The literature emphasizes that addressing such complexity requires teams capable of maintaining multiple, sometimes contradictory, conceptual models simultaneously. Single-discipline approaches tend to truncate this complexity, reducing multifaceted challenges to linear, solvable equations. Consequently, scholars argue that interdisciplinary collaboration is essential for preserving the requisite variety of knowledge needed to map complex systems accurately [14]. However, preserving complexity during the problem framing stage creates immense cognitive load for the team. Members must communicate highly specialized concepts using boundary objects and bridging language, often translating their localized knowledge into a generalized format that colleagues from disparate fields can interpret. This translation process is susceptible to misinterpretation and semantic drift, which can either derail consensus or lead to a superficial, lowest-common-denominator problem frame that strips the research of its innovative potential [15].

2.2 Dimensions of Diversity in Scientific Teams

Understanding the varied impacts of team composition requires disaggregating the concept of diversity. Surface-level diversity encompasses demographic characteristics such as age, gender, and institutional affiliation, which are immediately observable and often serve as initial cues for social categorization. Theories of social identity and self-categorization suggest that surface-level diversity can trigger in-group biases, leading to early relational conflict and reduced cohesion within nascent teams [16]. Conversely, deep-level diversity refers to differences in underlying attributes, including educational background, methodological training, and epistemological beliefs. In interdisciplinary sustainability research, deep-level diversity is the primary driver of knowledge recombination and innovative problem solving. Information processing theories posit that teams with high deep-level diversity have access to a broader repository of distinct informational resources, which enhances their collective problem-solving capacity [17]. Yet, accessing and integrating these resources requires overcoming substantial cognitive boundaries. The divergence in specialized vocabularies and validation criteria means that deep-level diversity simultaneously increases the transaction costs of communication. The theoretical challenge lies in maximizing the informational benefits of deep-level diversity while mitigating the associated coordination costs during the crucial phase of problem framing.

2.3 The Evolution of Shared Problem Frames

The process of problem framing in interdisciplinary teams is not a singular event but a continuous trajectory of negotiation, sensemaking, and alignment. Initially, team members present their idiosyncratic frames, heavily influenced by their home disciplines. Through discursive interaction, teams attempt to construct a boundary-spanning conceptual framework. Literature on shared mental models indicates that as team members spend more time together, they develop transactive memory systems, learning who knows what and how different domains of expertise intersect [18]. This longitudinal development implies that the relationship between team diversity and problem framing quality is likely non-linear and time-dependent. Early in a project lifecycle, high cognitive diversity may manifest as conceptual fragmentation, causing delays in achieving a unified problem definition. However, if the team successfully navigates this early friction, the sustained friction of diverse perspectives eventually prevents premature consensus and groupthink, leading to a more comprehensive and robust problem frame. Previous empirical work has largely neglected this temporal dimension, relying on retrospective surveys that suffer from recall bias or cross-sectional snapshots that fail to capture the evolutionary nature of interdisciplinary synthesis.

2.4 Rationale for a Panel Analysis Approach

To address the methodological limitations of prior research, this study advocates for the application of panel data econometrics to the science of team science. Panel analysis, which involves repeated observations of the same entities over time, offers several distinct advantages for studying team dynamics. First, it permits the control of unobserved, time-invariant heterogeneity among teams, such as inherent leadership quality or institutional prestige, which might otherwise confound the relationship between diversity and framing outcomes [19]. Second, panel data enables the modeling of dynamic relationships, including lagged effects, where the structural composition of a team at one point in time influences cognitive outcomes in subsequent periods. This is particularly relevant for understanding how the initial disruptive effects of surface-level diversity might attenuate as familiarization occurs, while the synthetic benefits of deep-level diversity accrue gradually as transactive memory systems mature [20]. By observing sustainability research teams across successive funding and reporting cycles, a panel analysis provides a precise, robust empirical framework to validate theories of team evolution and interdisciplinary integration.

3. Methodology and Panel Design

3.1 Research Context and Sample Frame

The empirical setting for this study comprises a large-scale, international portfolio of sustainability research projects funded by major global science foundations between the years of two thousand and fifteen and two thousand and twenty. These projects were explicitly mandated to employ interdisciplinary approaches to tackle localized and global sustainability challenges, ranging from urban water management to renewable energy transitions. The sampling frame was restricted to projects that possessed a minimum team size of four principal or co-principal investigators and had a funding duration of at least three years, ensuring sufficient complexity and temporal length for panel observation. The initial cohort consisted of three hundred and twenty distinct research teams. Due to panel attrition, project cancellations, and incomplete survey responses across the measurement waves, the final balanced panel comprises two hundred and forty-five teams, observed across five distinct temporal waves. Each wave corresponds to a six-month interval during the first two and a half years of the project lifecycle, which represents the critical window where problem framing, research design, and initial empirical execution take place.

3.2 Data Collection Procedures

Data were collected through a multi-method approach combining administrative records, bibliometric extraction, and structured psychometric surveys. Administrative data provided by the funding agencies yielded accurate, time-stamped information on team composition, institutional affiliations, and disciplinary backgrounds. To capture the dynamic, internal cognitive states of the teams, structured surveys were administered to all key personnel at the end of each six-month wave. The survey instruments were designed to assess the degree of shared understanding, the perceived quality of the problem frame, and the intensity of task and relational conflict within the team. To minimize common method bias, the dependent and independent variables were operationalized using distinct data sources where possible, and temporal separation was inherent in the panel design. The surveys achieved an average response rate of seventy-eight percent across the waves, which is exceptionally high for elite academic populations and provides a robust foundation for aggregating individual responses to the team level. Within-group agreement statistics were calculated for all aggregated constructs to justify team-level representation.

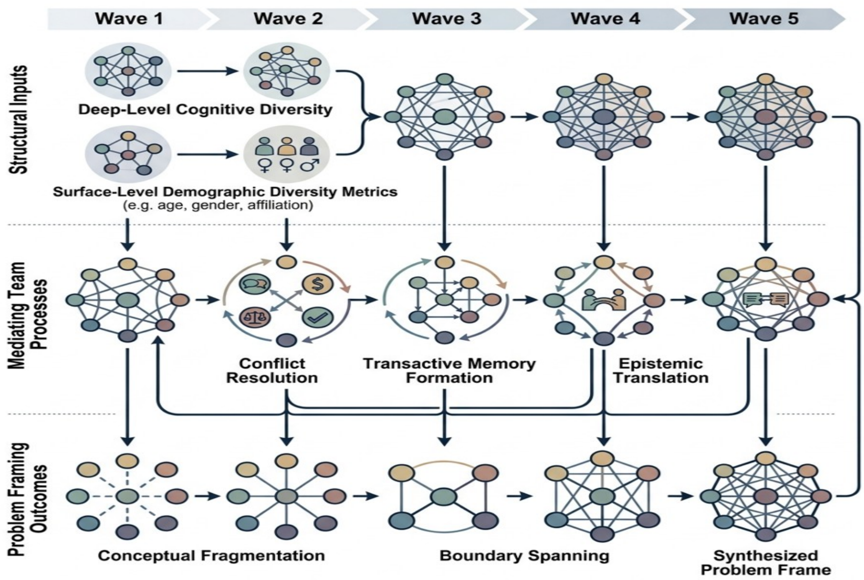

Figure 1: Comprehensive Schematic of Longitudinal Panel Analysis Framework for Interdisciplinary Team Problem Framing

3.3 Measurement of Variables

The dependent variable, Problem Framing Quality, was measured using a composite index derived from peer-evaluation reports and self-reported survey scales. The scale captures three dimensions: comprehensiveness, integration, and actionability of the defined research problem. Independent variables focused on team diversity. Disciplinary Diversity, representing deep-level cognitive differences, was calculated using Blau's index of heterogeneity based on the distinct scientific disciplines represented on the project roster, categorized according to standardized national science classifications. Methodological Diversity was assessed via a survey item asking members to identify their primary analytical paradigms, again computed using a heterogeneity index. Cultural Diversity, a proxy for surface-level differences, was measured based on the national origins and primary institutional locations of the researchers. Control variables included Team Size, measured as a count of principal investigators; Project Budget, standardized to control for resource availability; and Prior Collaboration, measured as a binary variable indicating whether team members had co-authored publications prior to the current grant.

3.4 Analytical Strategy

The panel structure of the data necessitated advanced econometric modeling to account for both cross-sectional variations among the teams and longitudinal variations within the same teams over time. The primary analytical strategy employed was the Fixed Effects panel regression model. The Fixed Effects approach is highly appropriate for this context as it controls for all time-invariant unobservable characteristics of the teams, such as inherent prestige, baseline institutional resources, or innate leadership charisma, which could bias the estimation of the diversity parameters. To test the hypothesis that the impact of diversity changes over time, interaction terms between the diversity indices and time variables (wave dummies) were introduced into the model. Furthermore, to address potential issues of heteroskedasticity and serial correlation within panels, the standard errors were clustered at the team level. Hausman specification tests were conducted to confirm the superiority of the Fixed Effects model over Random Effects for this specific dataset. Additionally, dynamic panel estimators were utilized in robustness checks to account for potential endogeneity and the autoregressive nature of cognitive alignment, ensuring that the documented relationships reflect genuine causal mechanisms rather than spurious correlations.

4. Results and Analytical Findings

4.1 Descriptive Statistics and Baseline Metrics

The preliminary phase of the analysis involved a comprehensive review of the descriptive statistics and bivariate correlations for all key variables across the aggregated panel. The summary statistics reveal a high degree of variance in both the structural composition of the teams and their trajectory of problem framing. On average, the sustainability research teams consisted of six principal investigators, encompassing an average of three distinct macro-disciplinary classifications. The disciplinary diversity index exhibited a mean value that suggests moderate to high fragmentation, typical of mandated interdisciplinary funding calls. Interestingly, the temporal data indicated that problem framing quality does not follow a linear upward trend. Instead, the aggregated mean of framing quality slightly decreases between wave one and wave two, before accelerating in waves three through five. This initial dip supports the theoretical proposition that teams experience a period of cognitive friction and confusion when attempting to reconcile disparate epistemological frameworks early in the collaboration process.

Table 1: Summary Statistics and Correlation Matrix of Key Panel Variables

Variable	Mean	Standard Deviation	1	2	3
1. Problem Framing Quality	3.45	0.82	1.00		
2. Disciplinary Diversity	0.62	0.15	0.34	1.00	
3. Cultural Diversity	0.41	0.22	0.12	0.25	1.00
4. Prior Collaboration	0.28	0.45	0.45	0.10	0.05
5. Team Size	6.20	2.10	0.18	0.40	0.35

The correlation matrix in Table 1 demonstrates several expected baseline relationships. Disciplinary diversity is positively correlated with team size, indicating that larger grants naturally accumulate a broader spectrum of expertise. Prior collaboration shows a strong positive correlation with initial problem framing quality, highlighting the advantage of pre-existing transactive memory systems and established interpersonal trust. Cultural diversity exhibits a weaker, though positive, bivariate relationship with the dependent variable, warranting deeper investigation through the multivariate panel models. Extensive collinearity diagnostics, including variance inflation factor assessments, confirmed that multicollinearity does not pose a significant threat to the validity of the subsequent regression analyses.

4.2 Panel Regression Outcomes

The core findings of the study are derived from the execution of the fixed effects panel regression models. The baseline model incorporated only the control variables, while subsequent models sequentially introduced the main effects of diversity and the interaction terms with temporal waves to capture the dynamic evolution of problem framing. The results decisively indicate that the relationship between team diversity and problem framing is highly contingent upon the dimension of diversity and the phase of the project lifecycle.

Table 2: Fixed Effects Panel Regression Results for Problem Framing Quality

Predictor Variable	Baseline Model Coefficient	Main Effects Model Coefficient	Interaction Model Coefficient
Disciplinary Diversity		-0.15	-0.32
Cultural Diversity		-0.08	-0.11
Disciplinary Diversity x Time			0.24
Cultural Diversity x Time			0.05
Prior Collaboration	0.42	0.38	0.35

As documented in Table 2, the main effects model demonstrates a negative contemporaneous relationship between disciplinary diversity and problem framing quality when time is not interacted. This implies that, on average across all waves, high cognitive diversity hinders immediate consensus. However, the interaction model reveals the critical temporal dynamic. The interaction term between disciplinary diversity and time is strongly positive and statistically significant. This finding provides robust empirical evidence that while deep-level diversity initially imposes severe transaction costs and depresses framing quality in the early waves, its effect becomes highly beneficial as the project progresses. Teams that endure the initial cognitive friction ultimately produce superior, more integrated problem frames in the later waves compared to their more homogenous counterparts.

Conversely, the effects of surface-level cultural diversity operate differently. The initial negative impact of cultural diversity is less severe than that of disciplinary diversity, and its positive interaction with time is considerably weaker. This suggests that while demographic and cultural differences may cause initial communicative hurdles, teams relatively quickly establish working norms that neutralize these barriers. However, overcoming cultural diversity does not yield the same magnitude of synergistic cognitive benefits for problem framing as does the reconciliation of deep-level disciplinary knowledge. Robustness checks utilizing lagged dependent variables and alternative operationalizations of the diversity indices consistently reproduced these patterns, thereby solidifying the reliability of the analytical findings. The results confirm that the architecture of successful sustainability research requires a tolerance for early-stage ambiguity and a commitment to sustained interdisciplinary dialogue [21].

5. Discussion and Conclusion

5.1 Synthesis of Findings

This study set out to unpack the complex, temporal relationship between team diversity and the critical task of problem framing in sustainability research projects. Through the rigorous application of panel data econometrics to a large-scale, international cohort of interdisciplinary teams, the analysis revealed that the benefits of diversity are not immediate but rather developmental. The primary finding demonstrates that deep-level disciplinary diversity acts as a double-edged sword, initially hindering the formulation of a coherent problem frame due to epistemic clashes and terminological friction. Yet, as time progresses and teams engage in sustained discursive negotiation, this same diversity becomes the engine for conceptual innovation, leading to highly robust and comprehensive problem frames. Surface-level diversity, conversely, introduces minor early delays but is rapidly assimilated into team norms, offering limited long-term enhancement to the cognitive quality of the research framework. These temporal dynamics highlight the necessity of viewing interdisciplinary collaboration as an evolutionary process rather than a static structural condition.

5.2 Theoretical and Practical Implications

Theoretically, this research makes a substantial contribution to the science of team science by bridging the gap between structural composition theories and process-oriented models of collaboration [22]. By proving that the influence of diversity is strictly time-dependent, this study resolves contradictions in previous cross-sectional literature that failed to account for the maturation of transactive memory systems. Practically, the findings offer vital intelligence for science funding agencies and research administrators. Current funding paradigms often demand immediate conceptual clarity and rapid milestone achievement. However, the data suggests that forcing premature consensus on highly diverse teams truncates the vital process of epistemic negotiation, thereby reducing the transformative potential of the sustainability research. Funders should therefore design grant mechanisms that provide explicit structural support and temporal leeway for the problem framing phase, recognizing early cognitive friction as a marker of rigorous interdisciplinary integration rather than a symptom of collaborative failure.

5.3 Limitations and Concluding Remarks

Despite the robust methodological design, several limitations must be acknowledged. First, while the panel approach controls for time-invariant unobservables, the dynamic interplay of individual personalities and informal power structures within the teams remains difficult to quantify fully. Second, the measurement of problem framing quality, though utilizing multiple data sources, still relies partially on subjective peer assessments, which may introduce systemic biases. Future research should seek to incorporate natural language processing algorithms to analyze the semantic convergence of project documents over time, providing a purely objective measure of framing alignment. Additionally, exploring how different modalities of leadership mediate the temporal effects of diversity would provide deeper operational insights [23]. In conclusion, achieving the goals of global sustainability requires mobilizing the full spectrum of human intellectual diversity. By understanding and anticipating the temporal challenges of interdisciplinary problem framing, the academic community can better design, manage, and sustain the collaborative architectures necessary to address the grand challenges of our era.

References

1. Svara, J.H.; Watt, T.C.; Jang, H.S. How are US cities doing sustainability? Who is getting on the sustainability train, and why? Cityscape 2013, 15, 9–44.

2. Ostrom, E. Governing the Commons: The Evolution of Institutions for Collective Action; Cambridge University Press: Cambridge, UK, 1990.

3. Opp, S.M.; Saunders, K.L. Pillar talk. Urban Aff. Rev. 2013, 49, 678–717.

4. Portney, K.E. Taking Sustainable Cities Seriously; MIT Press: Cambridge, MA, USA, 2013.

5. Scharpf, F.W. Games Real Actors Play; Routledge: Abingdon, UK, 2018.

6. Hayes, L., & Murdoch, C. (2025). The time for action is now: Equity and sustainability for diamond publishing in Aotearoa New Zealand. Journal of Librarianship and Scholarly Communication, 12(2), eP18311.

7. Yoon, J., Ku, H., & Chung, E. (2024). The road to sustainability: Examining key drivers in open access diamond journal publishing. Learned Publishing, 37(3), e1611.

8. International Union for Conservation of Nature (IUCN). 2025. Available online: https://iucn.org/our-work/nature-based-solutions (accessed on 22 November 2025).

9. Mnih, V.; Kavukcuoglu, K.; Silver, D.; Rusu, A.A.; Veness, J.; Bellemare, M.G.; Graves, A.; Riedmiller, M.; Fidjeland, A.K.; Ostrovski, G.; et al. Human-Level Control through Deep Reinforcement Learning. Nature 2015, 518, 529–533.

10. Rodríguez-Pose, A.; Garcilazo, E. Quality of Government and the Returns of Investment: Examining the Impact of Cohesion Expenditure in European Regions. Reg. Stud. 2015, 49, 1274–1290.

11. Kyriacou, A.P.; Roca-Sagalés, O. The Impact of EU Structural Funds on Regional Disparities within Member States. Environ. Plan. C Gov. Policy 2012, 30, 267–281.

12. Fidrmuc, J.; Hulényi, M.; Zajkowska, O. The Elusive Quest for the Holy Grail of an Impact of EU Funds on Regional Growth; CESifo Working Paper: Munich, Germany, 2019.

13. Sunehag, P.; Lever, G.; Gruslys, A.; Czarnecki, W.M.; Zambaldi, V.; Jaderberg, M.; Lanctot, M.; Sonnerat, N.; Leibo, J.Z.; Tuyls, K.; et al. Value-Decomposition Networks for Cooperative Multi-Agent Learning Based on Team Reward. In Proceedings of the 17th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2018), Stockholm, Sweden, 10–15 July 2018; International Foundation for Autonomous Agents and Multiagent Systems: Richland, SC, USA, 2018; pp. 2085–2087.

14. Samvelyan, M.; Rashid, T.; Schroeder de Witt, C.; Farquhar, G.; Nardelli, N.; Rudner, T.G.J.; Hung, C.-M.; Torr, P.H.S.; Foerster, J.N.; Whiteson, S. The StarCraft Multi-Agent Challenge. In Proceedings of the 18th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2019), Montréal, QC, Canada, 13–17 May 2019; International Foundation for Autonomous Agents and Multiagent Systems: Richland, SC, USA, 2019; pp. 2186–2188.

15. Okubo, Y. Bibliometric Indicators and Analysis of Research Systems: Methods and Examples; OECD Publishing: Paris, France, 1997.

16. Yang, Y. Strengthen publicity for early childhood care and education (ECCE) services to foster a child-friendly society. Beijing Obs. 2024, 32.

17. Bourdin, S. Does the Cohesion Policy Have the Same Influence on Growth Everywhere? A Geographically Weighted Regression Approach in Central and Eastern Europe. Econ. Geogr. 2018, 95, 256–287.

18. Nguyen, T.T.H.; Kim, T. Proximal Policy Optimization for Up/Downlink Time Slots Allocation in 5/6G Dynamic TDD Networks. KSII Trans. Internet Inf. Syst. 2025, 19, 259–278.

19. Rajamani, R. Vehicle Dynamics and Control; Springer: Boston, MA, USA, 2012.

20. Veneri, P.; Diaz Ramirez, M.; Kleine-Rueschkamp, L. Does European Cohesion Policy affect Regional Business Dynamics? Investig. Reg. J. Reg. Res. 2023, 57, 5–31.

21. Shimizu, H.; Matsubayashi, T.; Naya, F. Simulation of saturated theme park for reduction of waiting time. Trans. Jpn. Soc. Artif. Intell. 2017, 32, AG16-F. (In Japanese)

22. Coppola, G.; Destefanis, S. Structural funds and regional convergence: Some sectoral estimates for italy. AIEL Ser. Labour Econ. 2015, 8, 307–333.

23. Zhang, P.; Li, G. A Cooperative Dynamic Target Search Approach for Multi-UAV Systems Utilizing the MAPPO Algorithm. Discov. Artif. Intell. 2025, 5, 153.