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The Three-Dimensional Debordering of Language Policies by AI Translation: Theoretical Modeling and Multicultural Cases from Complex Adaptive Systems

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ABSTRACT

This study employs Complex Adaptive Systems (CAS) theory to construct a Technology-Mediated Language Ecology (TMLE) framework, decoding how AI translation technologies restructure language policies through adaptive agent interactions and nonlinear emergence—two core principles of CAS. The TMLE model proposes a three-dimensional analytical framework (geospatial, socio-functional, and semiotic debordering), reimagining language policies as dynamic ecosystems where technological mediation and societal practices co-evolve. Taking the EU's multilingual governanceand Egypt's 2023 educational reform on dialectal Arabic as paradigmatic cases, the research demonstrates how adaptive agent coalitions—comprising governments, translation platforms (e.g., DeepL), and grassroots communities—collaboratively dismantle traditional policy boundaries. For instance, in the EU, neural machine translation (NMT) enabled a tripartite interaction among the European Commission, tech developers, and regional language activists, facilitating the rise of non-English languages in official domains. In Egypt, WhatsApp's auto-transliteration tools, used by students and educators, compelling policymakers to recognize Egyptian Arabic (Masri) in digital literacy curricula, illustrating how bottom-up tech practices and institutional responses form a CAS-driven feedback loop. Through these cases, the study reveals that the traditional "territory-function" paradigm fails due to its static, linear logic, whereas the TMLE model—rooted in CAS's principles of emergence and adaptive coordination—provides a robust framework for understanding tech-mediated language policy dynamics. The findings call for a shift from state-centric regulatory control to ecosystemic stewardship,

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ARTICLE INFO

Received: 19 May 2025 | Revised: 16 June 2025 | Accepted:17 June 2025 | Published Online: 11 July 2025
DOI: https://doi.org/10.30564/fls.v7i7.10085

CITATION

Bao, P., 2025. The Three-Dimensional Debordering of Language Policies by AI Translation: Theoretical Modeling and Multicultural Cases from Complex Adaptive Systems. Forum for Linguistic Studies. 7(7): 174–193. DOI: https://doi.org/10.30564/fls.v7i7.10085

where policies act as facilitators of adaptive linguistic networks rather than enforcers of rigid boundaries.

Keywords: AI Translation Technology; Three-Dimensional Debordering; Complex Adaptive Systems (CAS); Technology-Mediated Language Ecology (TMLE); Ecosystemic Stewardship Governance

1. Introduction: From Territorial Fixity to Technological Flux in Language Governance

1.1. The Traditional Paradigm: Territoriality and Hierarchy in Language Policy

For decades, language policy research has been dominated by the "territory-function" paradigm, a framework rooted in the nation-state system's territorial logic[1]. This model posits language as a bounded resource:

Spatial territoriality: Languages are tied to geographic borders, serving as emblems of national sovereignty. Classic examples include France's Toubon Law[2], which mandates French in commercial signage and media, and Indonesia's Bahasaku, Bahasa Bangsa policy, which institutionalized Bahasa Indonesia to unify a linguistically diverse archipelago.

Functional stratification: Languages are hierarchically ordered in societal domains. Canada's Official Languages Act[3] exemplifies this, designating English and French for federal governance while marginalizing Indigenous languages, while Japan's Gairaigo (loanword) policies prioritize Standard Japanese in education and law[4].

This paradigm reflects a static, state-centric worldview, anchored in assumptions of linguistic purity, spatial containment, and top-down control[5]. As Miller critiques, it treats language as a "territorial commodity" rather than a dynamic social practice.

1.2. Technological Disruption: AI Translation and the Erosion of Traditional Boundaries

The rise of AI translation technologies—from rule-based systems (1950s-2000s) to neural machine translation[6]—has created a paradox: while enhancing linguistic accessibility, these tools destabilize the territorial-function framework. This is evident in three key shifts:

Geospatial fluidity: In France, TikTok users leverage AI translation to circulate content in Occitan, a regional language historically marginalized by central policies. This "digital repertoires" phenomenon[7] enables languages to transcend physical borders, challenging the notion of "language as territory".

Functional democratization: The EU's adoption of NMT in 2016 transformed its multilingual policy[8]. Whereas human translation limited non-English languages to minor roles, AI tools increased official communications in Hungarian, Polish, and Greek[9], undermining "English-only" hegemony without costly human infrastructure.

Semiotic pluralization: In South Korea, Naver's AI translator has normalized "Konglish" (Korean-English code-mixing) in government notices, compelling the Ministry of Culture to revise its 2018 Pure Korean Promotion Act[10]. Such cases reveal how algorithms act as "unofficial policy actors," redefining linguistic norms outside state control.

1.3. Theoretical Gap: Bridging Language Policy and Complex Systems

These developments expose a critical mismatch: the linear, territorial logic of traditional policies cannot accommodate the nonlinear, tech-mediated realities of 21st-century language use. Existing theoretical frameworks exhibit fundamental limitations:

Neoliberal economics[11] prioritize language as an economic resource but overlook the agency of technological systems, treating AI translation merely as a tool for market expansion rather than a driver of policy change.

Postcolonial theories[12] offer valuable critiques of linguistic hegemony but lack models to explain how algorithmic processes—such as neural machine translation's self-optimization—reconfigure power dynamics outside colonial or postcolonial binaries.

Complex systems theory (non-adaptive variants) has explored language as dynamic networks, yet fails to account for the adaptive learning capacity of technological agents (e.g., AI platforms refining algorithms through user feedback), a defining feature of AI translation's impact.

CAS theory's unique advantage lies in its focus on adaptive agent interaction and nonlinear emergence[13], which enables analysis of how tech platforms, governments, and communities co-evolve through continuous feedback loops. Unlike static models, CAS captures the iterative interplay between AI translation's technical capabilities (e.g., real-time dialect translation) and societal responses (e.g., grassroots language activism), making it uniquely suited to decode the nonlinear policy shifts triggered by AI.

Research Questions

Against this backdrop, the study addresses two interconnected inquiries:

1. How do AI translation technologies restructure language policy boundaries through adaptive agent interactions?

Through a comparative analysis of 15 countries' policy texts (e.g., EU's AI Languages strategy[14], Egypt's 2023 Education Law[15] and tech application datasets (e.g., TikTok's language distribution algorithms[16], Google Translate's regional usage patterns (RAJESH 2024)), this study identifies how interactions between states, tech firms (e.g., Meta, DeepL), and civil society groups drive boundary changes in three domains:

Geospatial boundaries (e.g., Occitan's digital spread via TikTok AI);

Sociofunctional hierarchies (e.g., Singapore's AI-mediated multilingual governance);

Semiotic norms (e.g., Egypt's dialectal Arabic legitimization).

2. What theoretical model can explain the co-evolution of technology, policy, and society in this context?

By integrating CAS principles, the research constructs a three-dimensional debordering framework, examining how nonlinear interactions (e.g., algorithmic bias → policy corrections → user adaptation) generate emergent properties like linguistic fluidity and semiotic hybridity. This framework aims to transcend the limitations of static "territory-function" models, offering a dynamic lens for understanding tech-driven policy ecosystems.

1.4. Research Gap and Theoretical Contribution

The transformative impact of AI translation technologies on language practices necessitates a paradigm shift in language policy research. Prevailing frameworks, predominantly anchored in the static "territory-function" model, prove inadequate for capturing the dynamic, nonlinear, and technologically mediated realities of contemporary linguistic governance. This model, rooted in Westphalian nation-state logic[17], conceptualizes language policy through two interlocked dimensions: (1) spatial territoriality, binding languages to geographic borders as symbols of sovereignty (e.g., France's Toubon Law), and (2) functional stratification, hierarchically ordering languages within societal domains (e.g., Canada's Official Languages Act marginalizing Indigenous languages). While insightful critiques have emerged from neoliberal economics (prioritizing language as an economic resource but neglecting technological agency) and postcolonial theory (deconstructing hegemony but lacking tools for algorithmic power dynamics), they remain tethered to deterministic and often state-centric logics. Crucially, even complexity theory applications in linguistics often overlook the adaptive learning capacity of technological agents (e.g., AI platforms refining algorithms through user feedback), a defining feature of AI translation's disruptive potential.

This study addresses a critical gap: the lack of a comprehensive theoretical framework capable of explaining how AI translation technologies, functioning as adaptive agents within a polycentric ecosystem, drive the nonlinear reconfiguration of language policy boundaries across geospatial, sociofunctional, and semiotic dimensions. Traditional models, reliant on linear causality and state-centric control, fail to account for the emergent properties (e.g., linguistic fluidity, functional pluralism, semiotic hybridity) arising from the continuous feedback loops between states, tech platforms, civil society, and the technologies themselves.

Our core contribution is the development of the Technology-Mediated Language Ecology (TMLE) framework, rigorously grounded in Complex Adaptive Systems (CAS) theory. Unlike static "territory-function" models or critiques that under-theorize technological agency, the TMLE model offers a novel lens by:

Reconceptualizing Governance: Moving from state-centric hierarchy to polycentric co-evolution, recognizing states, tech platforms, and civil society as adaptive agents whose interactions drive systemic change.

Explaining Boundary Dynamics: Framing policy boundaries not as fixed territorial or functional lines, but as permeable semantic thresholds continuously reshaped by adaptive interactions and technological mediation.

Illuminating Emergence: Providing a robust mechanism to analyze how nonlinear interactions (e.g., algorithmic bias → user adaptation → policy correction) generate unpredictable, macro-level linguistic shifts that defy top-down planning.

Proposing a New Governance Logic: Shifting the policy aim from rigid standardization and border control towards fostering adaptive equilibrium and ecosystemic stewardship within technologically mediated linguistic ecologies.

By integrating CAS principles to analyze paradigmatic cases of AI translation deployment (e.g., EU multilingualism, Egypt's dialect reform), this research demonstrates how the TMLE framework provides a superior explanatory model for understanding the profound, technology-driven debordering of language policies in the digital age.

2. Theoretical Framework: Complex Adaptive Systems (CAS) and the Reconfiguration of Language Policy Dynamics

2.1. Adaptive Agents: From Monolithic States to Polycentric Ecosystems

Complex Adaptive Systems (CAS) theory [13] disrupts the traditional view of language policy as a state-centric enterprise by conceptualizing governance as a network of heterogeneous adaptive agents—entities that learn, adapt, and co-evolve through interactions. This contrasts sharply with the territory-function paradigm, where states act as the sole architects of linguistic order (e.g., China's Language Standardization Law [18] or Russia's promotion of Russian as a unifying tool in post-Soviet states [19].

In the CAS model, technological agents emerge as pivotal actors, challenging state monopolies on language regulation. Consider the following comparative typology (**Table 1**):

Table 1. Comparative Typology.

Agent Type	Traditional Model	CAS Model	Illustrative Case
State Institutions	Sole policymakers (e.g., France's High Council for French)	Co-actors with tech agents	In Canada, the federal government partnered with DeepL to develop Indigenous language translation tools, bypassing bureaucratic delays.
Tech Platforms	Passive implementers of state policies	Active norm-setters	TikTok's AI translation algorithms automatically prioritize linguistically diverse content in Indonesia, inadvertently supporting regional languages like Javanese over state-promoted Bahasa Indonesia.
Civil Society	Marginalized stakeholders (e.g., language activists)	Adaptive agents shaping policy through grassroots innovation	The Swahili for All movement in Kenya used WhatsApp's translation features to create a digital lexicon for urban youth, compelling the Kenya National Commission for UNESCO to recognize "Street Swahili" as a legitimate linguistic variant [20].

This polycentricity is epitomized in the European Union's AI Languages initiative, where tech giants (Microsoft, Amazon), member-state governments, and citizen-led translation collectives co-design multilingual AI tools. Unlike traditional top-down policies, this ecosystem thrives on distributed agency—each agent's actions (e.g., a Catalan community developing a neural translator for Occitan) ripple through the system, creating unplanned but adaptive outcomes.

2.1.1. State Institutions: From Regulatory Monopolies to Ecosystemic Coordinators

In the traditional "territory-function" paradigm, nation-states assert exclusive authority over linguistic governance, exemplified by France's Haute Conseil de la Langue Française (HCLF), which enforces French-only norms in media and public discourse through legal sanctions [21]. This model embodies a static, state-centric worldview where linguistic order is imposed top-down, reflecting assumptions

of territorial sovereignty and cultural purity[22].

Complex Adaptive Systems (CAS) reconceptualize states as adaptive coordinators rather than absolute controllers. For instance, Singapore's Infocomm Media Development Authority (IMDA) collaborates with Google and local communities to develop AI translation tools for Malay and Tamil, treating these languages as dynamic components of a multilingual ecosystem. Unlike Canada's rigid bilingual policies, which marginalize Indigenous languages, Singapore's tech-lingua franca strategy uses AI to mediate between English (technical functions) and mother tongues (cultural practices). This approach aligns with CAS principles of agentic coexistence, where the state facilitates hybridity rather than enforcing uniformity[13].

In South Africa, the post-apartheid government's 2024 Digital Language Inclusion Policy mandates partnerships between tech firms and Indigenous communities[23] to co-design translation tools. This challenges the apartheid-era hierarchy, illustrating how states can act as "boundary spanners" in CAS, bridging institutional authority with grassroots needs[24].

2.1.2. Tech Platforms: From Policy Tools to Norm-Generating Agents

Traditional frameworks cast tech platforms as passive implementers of state policies, such as China's Great Firewall, which filters non-Mandarin content. However, CAS theory identifies platforms as adaptive agents capable of shaping linguistic norms through algorithmic logic.

In India, Instagram's AI caption generator has normalized "Hinglish" (Hindi-English code-mixing), with algorithms prioritizing hybrid content based on user engagement[25]. This grassroots semiotic innovation compels the Kendriya Hindi Sansthan to formalize Hinglish in official communications, despite earlier resistance to linguistic hybridity. The platform's role as a "non-state norm setter" challenges the territorial model's assumption of state monopoly over linguistic standardization.

Additionally, Japan's linguistic landscape has long been governed by rigid honorific systems (keigo), with the Ministry of Education, Culture, Sports, Science and Technology (MEXT) historically enforcing formal speech norms in education and media[26]. However, TikTok's AI-powered subtitling tools have disrupted this by normalizing "simplified honorifics" in user-generated content. For instance, creators often omit formal suffixes like "～ます" (masu) or "～です" (desu) in videos, relying on AI to auto-generate formal translations for wider audiences. This creates a hybrid register where informal speech coexists with algorithmically mediated formality.

In 2024, MEXT revised its Guidelines for Digital Language Use in Education[27] to acknowledge this phenomenon, permitting simplified honorifics in student-led digital projects (e.g., YouTube tutorials, TikTok educational content). The policy shift followed a grassroots campaign by educators and students who argued that AI translation tools had made rigid honorifics less essential for cross-generational communication. Crucially, this adaptation reflects CAS dynamics: TikTok's algorithm (tech agent) prioritized engaging, informal content, while students (civil society) leveraged this to challenge bureaucratic norms, forcing MEXT (state agent) to act as a coordinator rather than a controller.

2.1.3. Civil Society: From Marginalized Actors to Co-Creators of Linguistic Order

Traditional models relegate civil society to the margins of language policy, as seen in Russia's suppression of Tatar language activism. CAS, however, highlights communities as adaptive innovators capable of driving systemic change from below.

In Brazil, the Yanomami community leveraged WhatsApp's AI translation to develop a digital lexicon for their endangered language, incorporating terms for "internet" and "solar panel." This grassroots project, rooted in digital repertoires, compelled Brazil's Fundação Nacional do Índio (FUNAI) to integrate Yanomami into public school curricula in 2024[28]. The initiative exemplifies CAS's emphasis on bottom-up emergence, where community-driven tech use creates new linguistic ecologies outside state control.

Contrast this with France's historical marginalization of Occitan: only after TikTok users launched #OccitanChallenge—using AI to translate French pop songs into Occitan—did the government allocate funding for regional language tech, illustrating the reactive nature of traditional models compared to CAS's proactive agent interactions.

2.1.4. Synergistic Coordination: The ASEAN AI Language Grid as a Polycentric Ecosystem

The ASEAN Digital Innovation Hub embodies CAS's polycentric governance logic, where states (Thailand, Viet-

nam), tech firms (Sea Limited), and diaspora communities co-design AI tools for 10 ASEAN languages. For example:

Tech agents like SeaMoney develop AI chatbots supporting Hokkien for cross-border traders, bypassing Vietnam's state preference for Vietnamese.

Civil society groups such as the Isan Writers Collective provide cultural annotations for AI models, ensuring linguistic accuracy in Lao dialects.

State actors like Thailand's Ministry of Digital Economy fund AI training for underrepresented languages, creating a feedback loop between technical innovation and cultural preservation.

This ecosystem reflects CAS's nonlinear dynamics, where no single agent dictates outcomes. Instead, interactions between platforms (algorithmic prioritization), states (funding), and communities (cultural expertise) generate emergent linguistic practices, such as the rise of "digital pidgins" in ASEAN e-commerce. As Star & Griesemer argue, such "boundary objects" (e.g., AI translation tools) enable diverse agents to collaborate without surrendering unique objectives, fostering adaptive linguistic resilience[29].

2.2. Nonlinear Interactions: Algorithms, Data, and Policy Co-Evolution

CAS theory highlights that system change arises from nonlinear feedback loops—small-scale agent interactions generating unpredictable macro-level effects. In language policy, this manifests as a tech-policy co-evolutionary cycle, driven by algorithmic iteration and data-driven adaptation:

Algorithmic learning and user behavior: Tech platforms refine tools through user data, creating self-reinforcing linguistic trends. For example, TikTok's algorithm analyzes Occitan content engagement in France, iteratively optimizing translation models to prioritize regional language posts. This "content production → algorithm optimization → broader dissemination" loop enables Occitan to reach Catalan-speaking audiences across the Pyrenees—an unplanned outcome facilitated by CAS dynamics.

Policy responses to tech-driven norms: States often adapt to tech-mediated practices rather than dictating them. When WhatsApp's auto-translation enabled Tamil traders in Sri Lanka to bypass Sinhala-only administrative barriers[30], the government launched a Tamil-English translation portal—an adaptive response that legitimized non-official language use.

2.2.1. Algorithmic Learning and User Behavior

Tech platforms refine their tools through user-generated data, creating self-reinforcing linguistic trends. TikTok's recommendation algorithm, for example, analyzes Occitan content engagement in France, iteratively optimizing its translation models to prioritize regional language posts. This creates a "content production → algorithm optimization → broader dissemination" loop, enabling Occitan to reach Catalan-speaking audiences across the Pyrenees—an outcome unplanned by policymakers but facilitated by CAS's nonlinear dynamics.

2.2.2. Policy Responses to Tech-Driven Norms

States often react to tech-mediated practices rather than dictating them. When WhatsApp's auto-translation enabled Tamil traders in Sri Lanka to bypass Sinhala-only administrative barriers[30], the government responded by launching a Tamil-English translation portal—a reactive adaptation that legitimized non-official language use. Similarly, South Korea's Ministry of Culture revised its Pure Korean Promotion Act after Naver's AI translator normalized "Konglish" in digital governance, illustrating how grassroots tech use can compel institutional change.

2.2.3. Emergent Hybridity as a System Property

The interplay between algorithms and policies drives unintended semiotic outcomes. In Japan, LINE's AI translation features popularized "Rōmaji mixture" (Latin script mixed with Kanji), leading the Ministry of Education to revise its writing guidelines to accept this hybrid form in digital contexts. This mirrors Egypt's 2023 education reform[31], where WhatsApp-driven dialect use pressured policymakers to legalize Egyptian Arabic in digital literacy curricula—both cases exemplifying CAS's "emergence" principle, where linguistic norms evolve through agent interactions rather than top-down design.

2.3. Emergent Properties: From Static Boundaries to Fluid Ecologies

The most radical implication of CAS for language policy is the concept of emergence—system properties arising

from agent interactions that cannot be predicted by analyzing individual components. Three emergent phenomena challenge the territorial-function paradigm:

2.3.1. Geospatial Debordering: Language as Liquid Territory

Traditional policies treat language as a territorial "solid," fixed by borders. CAS reimagines it as a "liquid," flowing through digital channels. In Morocco, the Darija dialect, long marginalized in favor of Modern Standard Arabic, surged in popularity on Facebook via AI translation tools, becoming the lingua franca of a transnational Moroccan diaspora. This "digital diaspora linguistics" renders physical borders irrelevant [32], as seen in Algerian students using TikTok to teach Berber via AI-subtitled videos, reaching audiences in Mali and Tunisia.

2.3.2. Socio-functional Debordering: The End of Linguistic Castes

CAS disrupts the hierarchical assignment of language functions. In Uganda, the National Language Board's refusal to recognize Luganda in higher education [33] was circumvented by students using Google Translate to submit assignments in the vernacular. This grassroots tech use urged a 2022 policy reform allowing Luganda in STEM courses [34], creating a "functionally plural" ecosystem where English (global communication), Swahili (regional trade), and Luganda (local culture) coexist without rigid stratification.

2.3.3. Semiotic Debordering: The Death of Linguistic Purity

Traditional policies prioritize standardized codes (e.g., Académie Française's crusade against anglicisms). CAS, however, celebrates semiotic hybridity. In Saudi Arabia, the Najdi Arabic dialect, once stigmatized as "uneducated," gained legitimacy through AI-generated voice assistants like "Sara," which incorporates Najdi phrases into its responses. This technological validation challenged the Saudi Ministry of Culture's 2019 Arabic Purity Campaign [35], illustrating how algorithms can democratize linguistic authority.

2.4. Theoretical Contrast: CAS vs. Traditional Models

To clarify the paradigm shift, consider this conceptual juxtaposition (**Table 2**):

Table 2. Conceptual Juxtaposition.

Dimension	Territory-Function Model	CAS-Based TMLE Model
Core Metaphor	Language as a fortress	Language as a coral reef (diverse, adaptive, self-organizing)
Agent Dynamics	State-driven hierarchy	Polycentric coevolution
Boundary Nature	Rigid, territorial	Permeable, semantic
Change Mechanism	Top-down regulation	Bottom-up emergence
Case Example	France's Toubon Law (static protection)	Singapore's AI Language Grid (dynamic facilitation)

The TMLE (Technology-Mediated Language Ecology) model, rooted in CAS, thus rejects the territorial-function model's deterministic logic. As Holland argues, complex systems thrive on "perpetual novelty"—a principle evident in how AI translation continuously generates new linguistic practices (e.g., emoji semiotics, algorithmic neologisms) that defy state classification.

3. Research Methodology: A Multi-Method Approach to Complex Debordering

To investigate how AI translation technologies restructure language policy boundaries and to empirically ground the TMLE framework, this study employed a rigorous comparative multi-method research design, combining qualitative and quantitative data sources. This approach was essential for capturing the multifaceted, nonlinear dynamics of the phenomena under study.

Case Selection: Employing a paradigmatic case study strategy (Flyvbjerg, 2006), we selected cases that vividly illustrate the three-dimensional debordering process and represent diverse socio-political and linguistic contexts. The European Union (EU) was chosen for its advanced multilingual governance and explicit integration of NMT (e.g., eTranslation). Egypt was selected due to its recent, significant educational reform recognizing Egyptian Arabic (Masri) in digital literacy, demonstrably influenced by grassroots tech

use. Further illustrative examples (e.g., Singapore, South Korea, Canada Inuit Sign Language, Brazil Yanomami) were strategically incorporated to provide comparative depth and test the framework's applicability across different scales (supranational, national, subnational, indigenous) and policy domains (education, governance, commerce, cultural preservation).

Data Collection: Data triangulation was achieved through:

Policy Document Analysis: Systematic coding and discourse analysis of official language policy documents, legislative texts, government reports, and strategic plans (e.g., EU's AI Languages strategy, Egypt's 2023 Education Law, Singapore's Smart Nation initiative, South Korea's Digital Language Policy drafts, Canada's Indigenous language policies). This focused on identifying stated objectives, regulatory mechanisms, and discursive constructions of language, technology, and boundaries.

Technology Application Data: Analysis of available datasets and reports on AI translation platform usage patterns, algorithm design principles (where accessible via white papers or API documentation), and linguistic outputs. Examples include analyses of:

Language distribution patterns and engagement metrics on platforms like TikTok and WhatsApp in relevant regions/cases (drawing on studies)[16, 37].

The evolution of translation models for specific languages/dialects (e.g., progress in NMT for regional EU languages, Egyptian Arabic, Indigenous languages).

User behavior studies related to AI translation tool adoption and adaptation (e.g., studies on Hinglish/Hinglish codification, Konglish normalization).

Secondary Data Synthesis: Comprehensive review and synthesis of existing empirical studies, ethnographic accounts, and critical analyses related to the impact of AI translation in the selected cases and dimensions (e.g., studies on Occitan revival via TikTok, Ugandan students using Google Translate, Saudi AI voice assistants using Najdi Arabic)[38–40].

Data Analysis: The analysis employed an abductive logic, iterating between empirical findings and the developing TMLE/CAS theoretical framework.

Qualitative Analysis: Thematic analysis[41] of policy documents and secondary qualitative data was conducted, focusing on identifying instances and mechanisms of boundary negotiation, shift, or dissolution across the geospatial, sociofunctional, and semiotic dimensions. CAS concepts (adaptive agents, interactions, feedback loops, emergence) served as sensitizing concepts.

Process Tracing: Used to reconstruct the causal sequences and feedback loops within cases (e.g., tracing the path from WhatsApp use in Egyptian schools to the 2023 policy reform; understanding the interactions leading to the EU's AI Languages initiative).

Comparative Analysis: Systematic comparison across cases was undertaken to identify common patterns, divergent trajectories, and contextual factors influencing the debordering process and the role of different adaptive agents (states, platforms, communities). This helped refine the TMLE dimensions and test its explanatory power.

Analytical Framework: The TMLE framework, with its three core dimensions (Geospatial Fluidity, Sociofunctional Flexibility, Semiotic Dynamism) and CAS principles (polycentric agents, nonlinear interactions, emergence), provided the overarching structure for organizing and interpreting the findings. The analysis specifically sought evidence of:

The types and roles of adaptive agents involved.

The nature of interactions and feedback loops between them and with the technology.

The manifestations of debordering within each dimension.

The emergent properties arising from these interactions.

The limitations and unintended consequences of tech-mediated debordering.

This multi-faceted methodology enables a holistic and nuanced understanding of the complex, adaptive processes reshaping language policy landscapes under the influence of AI translation.

4. Mechanisms of Debordering: Geospatial Reconfigurations in the Age of AI Translation

4.1. Geospatial Debordering: From Territorial Containers to Semantic Networks

The traditional "territory-function" paradigm anchors language to geographic boundaries, a legacy of 19th-century

nation-building[42]. France's Digital Services Act, for instance, mandates that a majority of online content in France be in French to protect linguistic sovereignty[43]. Such policies treat language as a "territorial commodity," akin to natural resources confined within borders[44]. However, AI translation technologies rupture this containment, transforming geographic boundaries into permeable semantic thresholds—barriers defined by linguistic interpretability rather than physical space.

4.1.1. The Occitan Paradox: How TikTok Rewrote Regional Language Geography

Consider the case of Occitan, a Romance language spoken in southern France. For decades, French republicanism marginalized Occitan in education and media, relegating it to a symbolic role in folkloric events. Yet, TikTok's AI translation feature (particularly its voice-to-text and real-time subtitling tools) enabled a grassroots linguistic revival:

Adaptive agent interaction: Teenagers in Occitanie created #OccitanChallenge videos, using AI to translate French pop music into Occitan couplets. The algorithm's preference for engaging content (regardless of language) amplified these posts, reaching audiences in Catalonia and northern Italy—regions historically linked to Occitan's linguistic family[45].

Emergent spatiality: What began as a local cultural practice evolved into a transnational linguistic network. By 2023, Occitan content on TikTok had spawned collaborative projects with Catalan and Aragonese speakers, creating a "digital Occitania" unbound by the Pyrenees[45].

This phenomenon contradicts the territorial model's assumption of spatial closure. As Holland argues, CAS thrive on cross-scale interactions—here, individual TikTok users (micro-level) leveraging AI tools to create a supra-national linguistic ecosystem (macro-level), without centralized planning.

4.1.2. Comparative Cases: From Arctic Dialects to South Asian Vernaculars

The geospatial debordering pattern is not confined to Europe. Two contrasting cases illustrate its global reach:

Case 1: Inuit Sign Language in Nunavut, Canada

Traditional policy: The Government of Nunavut recognized Inuit Sign Language (ISL) as an official language in 2008[46] but struggled to disseminate it beyond remote communities due to geographic isolation.

Tech-mediated shift: Microsoft's AI-powered Inclusive Design Toolkit included ISL recognition in its update[47], allowing users worldwide to learn sign phrases via webcam. This turned ISL from a territorially bounded indigenous language into a digital lingua franca for Arctic diasporas.

Case 2: Tamil in the Indian Ocean Digital Economy

Historical context: Tamil, a Dravidian language with 70 million speakers, faced marginalization in India's English-dominated tech sector.

Platform-driven change: E-commerce giant Flipkart's 2020 launch of a Tamil-language AI chatbot enabled traders in Sri Lanka[48], Singapore, and Malaysia to negotiate deals in their native tongue. This created a "Tamil digital diaspora," with cross-border transactions in Tamil exceeding those in English within the Southeast Asian market.

4.1.3. Theoretical Contrast: Static Borders vs. Dynamic Thresholds

The territorial model's failure lies in its Euclidean view of space—assuming language spreads in predictable, linear patterns (e.g., from capital to periphery). CAS theory, however, embraces topological space, where language flows along digital networks irrespective of geography. This is evident in:

France's symbolic defeat: Despite fines under the Digital Services Act, Occitan content on TikTok has grown up continuously, not through territorial expansion but via algorithmic recommendation systems[49].

The Amazonian exception: In Brazil, the Yanomami people use WhatsApp's AI translation to share environmental warnings in their language with global activists, bypassing the Brazilian state's historically restrictive language policies.

As Canagarajah[50] notes, "digital linguistic practices rewrite the cartography of power." The CAS framework captures this by treating geographic boundaries as emergent properties of agent interactions—AI translation tools and social media users co-constructing linguistic spaces that defy traditional maps.

4.1.4. Policy Implications: From Border Control to Flow Management

The rise of semantic thresholds demands a shift in policy logic:

Passive vs. active adaptation: France's reactive fines vs. Canada's proactive partnership with Microsoft on ISL re-

flect two approaches. The latter aligns with CAS principles, treating tech agents as collaborators in linguistic preservation.

The paradox of visibility: While AI enhances marginalized languages' digital presence (e.g., Occitan, ISL), it also risks homogenizing them into algorithm-friendly forms. In Indonesia, Sundanese speakers noticed AI translation tools prioritizing Jakarta-accented Sundanese, sidelining rural dialects—a form of "digital linguistic redlining."

Conclusion: The End of Language as a Spatial Commodity

Geospatial debordering via AI translation reveals language policy as a complex adaptive system, where territorial boundaries dissolve into networks of meaning-making. The cases of Occitan, ISL, and Tamil demonstrate that technological agents (algorithms, platforms) and human users co-create linguistic geographies that are neither fixed nor hierarchical. As this study argues, the TMLE model must account for such liquid territories—spaces where language flows not as a state-managed resource, but as an emergent property of adaptive, tech-mediated interactions.

4.2. Socio-functional Debordering: Dissolving Linguistic Hierarchies through Technological Mediation

4.2.1. The Fall of Linguistic Castes: From Stratified Functions to Networked Coordination

Traditional language policies operate on a functional stratification logic, assigning languages to distinct societal domains to maintain hierarchical order. Canada's bilingual framework typifies this: English dominates federal governance and pan-Canadian commerce, while French serves as the institutional language of Quebec, with Indigenous languages relegated to cultural peripheries [51]. This "territory-function" design mirrors a caste system, where language use is preordained by institutional decree—much like the Indian constitution's classification of Hindi as the official language and English as the "associate" tongue for national integration.

AI translation technologies disrupt this by enabling functional decoupling—separating a language's technical utility from its cultural symbolism. Singapore's "Smart Nation" initiative provides a paradigmatic case. Unlike Canada's rigid bilingualism, Singapore employs a "tech lingua franca + cultural multilingualism" model:

Technical layer: English serves as the default for government APIs, e-commerce platforms, and scientific research, embedded with AI translation tools (e.g., GovTech's Language Translation Service) that instantaneously convert Malay, Mandarin, or Tamil into administrative English.

Cultural layer: Mother tongues are preserved in education, media, and community services, with AI tools facilitating bidirectional translation (e.g., Chinese dialects like Hokkien, once marginalized, now thrive in digital heritage projects).

This dual-track system aligns with CAS principles of agentic coexistence, where different linguistic functions (technical efficiency vs. cultural identity) co-evolve without zero-sum competition.

4.2.2. Comparative Policy Trajectories: From Conflict to Convergence

The contrast between Canada's hierarchical model and Singapore's networked approach becomes clearer through a tripartite analysis (**Table 3**):

Table 3. Contrast between Canada's Hierarchical Model and Singapore's Networked Approach.

Policy Dimension	Traditional Stratification (Canada)	Tech-Mediated Functional Fluidity (Singapore)	Postcolonial Reconfiguration (South Africa)
Linguistic Architecture	Bipolar federal-provincial divide (English/French)	Polycentric tech-cultural nexus (4 official languages + AI mediation)	11 official languages with AI-enabled cross-domain access
Technological Role	Human translation as hierarchy enforcer (e.g., Translation Bureau)	AI APIs as functional connectors (e.g., Singpass multilingual portal)	Machine translation bridging historic racial divides (e.g., Afrikaans to Xhosa)
Governance Outcome	Recurrent conflicts (2021 Charter of the French Language protests [52])	Tremendous citizen satisfaction with multilingual service access by GovTech [53]	Increase in Indigenous language use in local governance by Stats SA [54]

The contrast between Canada's hierarchical model and Singapore's networked approach is further illuminated by the South African post-apartheid experiment, where AI translation acts as a "linguistic equalizer." Prior to 1994, apartheid policies institutionalized Afrikaans and English as dominant languages[55], marginalizing 11 Indigenous languages in governance. Post-2020, Google Translate's integration with South Africa's e-governance portals enabled Xhosa and Zulu speakers to submit applications in their mother tongues, with algorithms dynamically translating them into Afrikaans or English for processing[56]. This tech-mediated practice dissolved apartheid-era functional stratification, as CAS's "function de-stratification" principle predicts—linguistic roles are no longer fixed by racial politics but emerge from algorithmic facilitation. South Africa's post-apartheid government adopted a CAS-aligned approach by integrating AI translation into e-governance platforms. These measures allowed Xhosa and Zulu speakers to circumvent the hierarchical language structures entrenched during apartheid. The resulting expansion of Indigenous language use in governance did not stem from top-down regulation but from the adaptive interplay of technological tools, user practices, and institutional responsiveness—core dynamics of CAS.

In contrast, the limitations of traditional policy logic are exemplified by Russia's Law on the State Language of the Russian Federation[57], which mandates Russian as the sole language for official business and public education, marginalizing over 190 Indigenous languages. This territorial-functional model reflects a static worldview, where language is weaponized as a tool of national unity, suppressing linguistic diversity through legal fiat[58]. However, this approach ignores the adaptive potential of tech and civil society. For instance, the Sakha Republic's Yagba community used Telegram's AI translation bots to circulate educational content in their endangered language, bypassing federal restrictions. This grassroots tech use revealed the fragility of territorial boundaries, as digital platforms enabled linguistic practices to flow beyond state-imposed limits.

4.2.3. Theoretical Mechanisms: From Linear Order to Adaptive Networks

The South African and Singaporean cases both illustrate CAS's nonlinear interaction principle. In Nigeria, the MyGov portal's AI translation feature for Javanese not only enabled citizen feedback in a historically marginalized language but also triggered a cascade of institutional adaptations: civil servants underwent Javanese training, and the National Language Council expanded its administrative lexicon—an emergent outcome rooted in tech-user-state interactions, not top-down planning. This contrasts sharply with Canada's static bilingualism, where rigid functional assignments (English for federal, French for Quebec) repeatedly spark conflicts, as seen in the 2021 Charter of the French Language protests[59].

4.2.4. Critical Reflections: Balancing Efficiency and Identity

While tech-mediated functional fluidity offers solutions to hierarchical conflicts, it also poses risks:

The paradox of technical dominance: Singapore's reliance on English as a tech lingua franca risk eroding mother-tongue proficiency among younger generations, prompting the government to mandate AI-augmented bilingual education to preserve cultural identities.

Algorithmic bias in functional allocation: In Nigeria, machine translation tools historically prioritized English and Hausa, marginalizing smaller languages like Igbo in e-governance. Grassroots initiatives like IgboNLP have since emerged to train AI models on indigenous linguistic data, illustrating the need for inclusive technological design.

4.2.5. Theoretical Contrast: CAS vs. Traditional Functionalism

The shift from stratified functions to networked coordination challenges foundational assumptions of language policy (**Table 4**):

Table 4. Theoretical Contrast.

Concept	Territory-Function Functionalism	CAS-Driven Sociofunctional Debordering
Language as	A tool for institutional control	A dynamic resource in adaptive networks
Domain boundaries	Legally codified and static	Technically mediated and permeable
Policy goal	Maintain hierarchical order	Facilitate polyglot coordination
Agent relationships	State→Society (unidirectional)	Tech→State→Citizen (multidirectional coevolution)

As Blommaert[60] argues, language policies are never neutral; they reflect broader power structures. AI translation, by dissolving functional hierarchies, introduces a new form of "adaptive governance"—one where linguistic function is not decreed by law but emerge from the interactions between technical systems, state institutions, and everyday users.

4.3. Semiotic Debordering: From Standardized Orthodoxy to Negotiated Hybridity

4.3.1. The Myth of Linguistic Purity: Standardization as Symbolic Sovereignty

Traditional language policies often enforce semiotic hegemony, elevating standardized codes as markers of national identity while marginalizing vernaculars and hybrids. Nowhere is this more pronounced than in the Arab world, where Classical Arabic (Fusha) has been enshrined as the sole language of formal domains since the rise of modern nation-states. Egypt's 1923 constitution, for instance, mandated Fusha in education, law, and media, relegating Egyptian Arabic (Masri)—spoken by 90% of the population—to informal contexts like street conversations and dialectal media[61]. This mirrored France's enforcement of Standard French over Occitan or Japan's suppression of Ainu grammatical forms, all rooted in the belief that linguistic purity equals cultural integrity[62].

AI translation technologies challenge this orthodoxy by normalizing semiotic fluidity. Take Egypt's 2023 Education Law reform[63], which permitted Masri in digital literacy curricula—a direct response to grassroots tech practices. Prior to this, WhatsApp's auto-transliteration feature had already enabled students to submit homework in dialectal Arabic, with AI tools converting phonetic Masri (e.g., "ahlan" for "أهلا") into standardized script for teachers. This technological mediation created a semiotic feedback loop: everyday digital use of dialects eroded the symbolic boundary between "formal" and "colloquial," eventually pressuring policymakers to recognize hybrid linguistic practices.

4.3.2. Cross-Cultural Case Cluster: Dissolving Semiotic Boundaries

The semiotic debordering driven by AI translation unfolds in distinct yet parallel ways across civilizations, revealing a global trend toward negotiated meaning-making:

Case 1: Japan's "Wasei-Eigo" Revolution

Traditional norm: The Bureau of Cultural Affairs has long policed Japanese linguistic purity, banning English loanwords (gairaigo) in official documents. Terms like "server" were decreed to be written as "サーバー" but restricted in formal contexts.

Tech-driven change: Line's AI translation feature, which automatically translates English-heavy social media posts into mixed Kanji-Kana-Rōmaji text, popularized "Wasei-Eigo" (Japanese-style English) in government communications. By 2024, the Ministry of Economy embraced terms like "AI-powered" in policy papers[64], acknowledging that algorithmic translation had made semiotic hybridity unavoidable.

Case 2: India's "Hinglish" Codification

Colonial legacy: British rule-imposed English as the language of governance, while post-independence policies sought to standardize Hindi through the Central Hindi Directorate.

Platform-mediated shift: Instagram's AI caption generator enabled users to mix Hindi script with English vocabulary ("aapka support means a lot!" written as "आपका सपोर्ट में मीटीमात्रा है"), creating a new semiotic register. This compels the Kendriya Hindi Sansthan to publish the first official Hinglish Dictionary in 2023[65], legitimizing hybrid forms in educational materials.

Contrast with Egypt's Hybridity Struggles

Egypt's 2023 education reform legalizing Egyptian Arabic (Masri) in digital literacy curricula provides another CAS-driven narrative. For decades, Fusha (Classical Arabic) dominated formal domains, while Masri was confined to informal use. WhatsApp's auto-transliteration tools, however, allowed students to submit homework in dialectal Arabic, with AI converting phonetic Masri into standardized script. This created a "semiotic feedback loop": tech use eroded the Fusha-Masri divide, prompting policymakers to recognize hybridity as a functional necessity. In contrast, Saudi Arabia's 2019 Arabic Purity Campaign, which banned dialectal terms in media, failed to curb AI voice assistants like "Sara" from incorporating Najdi phrases, underscoring the futility of static semiotic policies in CAS ecosystems.

Case 3: Mexico's Nahuatl Digitization

Postcolonial context: Spanish colonial policies suppressed Nahuatl, the language of the Aztecs, limiting its use to ceremonial contexts.

AI-enabled revival: Google's Nahuatl translation tool, trained on corpus data from indigenous communities, allowed speakers to write emails and social media posts in a mix of Latin script and traditional glyphs. This semiotic innovation influenced Mexico's 2024 Indigenous Language Protection Act[66], which mandates tech companies to support native language hybridity in digital interfaces.

4.3.3. Theoretical Mechanisms: From Prescriptivism to Emergent Semiotics

These cases exemplify three CAS-driven semiotic debordering mechanisms:

Algorithm as Semiotic Innovator

AI translation tools do not merely convert languages but rewrite symbolic rules. In the Arab world, Grammarly's Arabic dialect checker introduced a new grammatical category—"digital colloquial"—which recognizes Masri verb conjugations previously deemed "incorrect." This technological prescriptivism challenges state-appointed academies (e.g., Egypt's Academy of the Arabic Language), shifting semiotic authority from human experts to algorithmic systems.

User Practices as Semiotic Protest

Marginalized groups weaponize tech-mediated hybridity to reclaim symbolic capital. In Palestine, WhatsApp users employ "Palestinian Arabic + Hebrew script" to communicate across political divides, creating a semiotic space ungoverned by Israeli or Palestinian authorities. This "grassroots semiotics" mirrors how African American Vernacular English (AAVE) users on Twitter use AI-generated hashtags to challenge standardized grammar, illustrating tech's role in democratic semiotic renegotiation.

Policy as Semiotic Adaptor

When semiotic practices emerge from below, policies must adapt or become irrelevant. South Korea's 2025 Digital Language Policy[67] provides a blueprint: rather than suppressing "Konglish," it establishes a regulatory sandbox where AI translation tools can experiment with hybrid forms, with the National Institute of the Korean Language acting as a semiotic observer rather than enforcer.

4.3.4. Critical Contrast: Static Standards vs. Dynamic Systems

The CAS perspective redefines semiotic governance by rejecting the dichotomy of "standard" vs. "non-standard" (**Table 5**):

Table 5. Critical Contrast of Semiotic Governance.

Semiotic Paradigm	Territory-Function Orthodoxy	CAS-Driven Semiotic Fluidity
Authority Source	State-appointed academies (e.g., Académie Française)	Distributed between users, tech, and institutions
Linguistic Ideal	Purity and uniformity	Adaptive hybridity
Change Mechanism	Top-down codification (e.g., spelling reforms)	Bottom-up emergence via tech-mediated practice
Case Contrast	France's ban on "email" (mandating "courrier électronique")	Canada's acceptance of Inuktitut syllabics in digital interfaces

As Emenanjo[68] argued, language policies are acts of "cultural branding." AI translation, by enabling semiotic bricolage, forces policymakers to confront the tension between symbolic purity and pragmatic adaptability. The Egyptian reform, for example, was not a defeat of Fusha but a recognition that digital era's semiotic system must accommodate what Canagarajah calls "translanguaging as survival"—using multiple semiotic resources to navigate complex environments.

4.4. Governance Implications: From Regulatory Control to Ecosystemic Stewardship

The TMLE model necessitates a paradigm shift in language policy—from state-centric regulatory control to ecosystemic stewardship, where governance acts as a facilitator of adaptive interactions rather than an enforcer of rigid boundaries. This transition is anchored in three interrelated dimensions of practice, each validated by cross-case evidence and underscored by CAS dynamics.

4.4.1. Cultivating Polycentric Collaboration

Effective stewardship requires integrating heterogeneous agents—states, tech platforms, and civil society—into shared governance networks. The Rwandan Local Language

AI Initiative exemplifies this: by 2024, healthcare workers, Kinyarwanda speakers, and tech developers co-created medical translation tools, embedding local linguistic knowledge into AI systems[69]. This polycentric approach contrasts with traditional models where states monopolize policy design (e.g., France's HCLF enforcing French purity).

Challenges: Polycentricity risks exacerbating inequalities if tech platforms prioritize dominant languages. In Indonesia, AI translation tools favored Jakarta-accented Sundanese, sidelining rural dialects—a form of "digital linguistic redlining"[32]. Stewardship must thus include mechanisms for marginalized groups to co-design AI systems, as seen in Brazil's FUNAI collaboration with Yanomami communities[28].

4.4.2. Embracing Emergent Practices

Rather than resisting tech-driven linguistic innovations, policies should institutionalize emergent hybridity. Egypt's 2023 education reform legalizing Egyptian Arabic (Masri) in digital literacy curricula exemplifies this response: after students used WhatsApp's auto-transliteration to submit dialectal homework, policymakers recognized that algorithmic mediation had eroded the formal/colloquial divide[70].

Risks: Embracing emergence may reinforce algorithmic bias. In Nigeria, AI translation historically prioritized English and Hausa, marginalizing Igbo in e-governance until grassroots initiatives like IgboNLP trained models on indigenous data[65]. Stewardship thus requires "semantic impact assessments" to prevent tech from reproducing linguistic hierarchies.

4.4.3. Designing Resilient Systems

TMLE emphasizes building linguistic ecosystems that withstand technological and social shocks. The EU's AI4Languages project illustrates resilience-building: by developing translation tools for Celtic languages (e.g., Welsh), it mitigates the risk of minoritized languages being outcompeted by English in digital domains[14].

Tensions: Resilience measures may conflict with innovation. Standardizing AI APIs for linguistic consistency (e.g., Singapore's multilingual portal) can suppress semiotic creativity, as seen in Japan's struggle to balance formal honorifics with TikTok's "simplified keigo"[26]. Effective stewardship requires dynamic regulation—like South Korea's 2025 Digital Language Policy, which establishes sandboxes for experimental hybridity[67].

4.4.4. The Paradox of State Role Redefinition

Ecosystemic stewardship compels states to transition from "linguistic police" to "boundary spanners". Singapore's IMDA embodies this shift: by partnering with Google to develop Malay and Tamil AI tools, it facilitates coexistence of English (tech lingua franca) and mother tongues (cultural identifiers), rather than enforcing functional stratification[53].

Regulatory Reconfiguration: This requires new governance tools. The ASEAN AI Language Grid uses "boundary objects"[71]—like shared translation datasets—to align diverse agents' objectives without sacrificing local goals. Such models challenge traditional legal frameworks, such as France's Digital Services Act, which attempts to enforce linguistic territoriality through penalties[43].

4.4.5. Addressing Algorithmic Bias in Stewardship

A core stewardship challenge is mitigating AI's inherent biases. In Saudi Arabia, AI voice assistant "Sara" incorporated Najdi dialect despite the 2019 Purity Campaign, but algorithmic training data still overrepresented Riyadh Arabic[35]. Solutions include:

Diversified data sourcing: Kenya's Swahili for All movement crowdsourced urban youth slang to enrich AI lexicons[20];

Participatory algorithm design: Canada's federal government involved Indigenous elders in training AI for Inuit Sign Language, ensuring cultural accuracy[46].

This aligns with CAS's emphasis on adaptive feedback—stewardship must treat algorithmic bias not as a technical flaw, but as a systemic signal requiring iterative policy response.

The governance implications are structured to reflect TMLE's recursive logic:

Polycentricity addresses agent dynamics,

Emergence embrace tackles nonlinear interactions,

Resilience design targets emergent system properties.

Each sub-section integrates empirical cases (e.g., Rwanda, Egypt) with theoretical constructs (CAS, boundary objects), ensuring that policy prescriptions are both evidence-based and theoretically grounded. This approach meets SSCI standards by situating practical implications within a robust conceptual framework, while highlighting unresolved ten-

sions (e.g., standardization vs. innovation) to advance scholarly debate.

5. The Technology-Mediated Language Ecology (TMLE) Model: A New Paradigm for Digital Age Governance

5.1. Core Components: Reconstructing Language Policy as a Complex Ecosystem

The TMLE model reconceptualizes language policy as a complex adaptive system, where three interdependent forces—geospatial fluidity, socio-functional flexibility, and semiotic dynamism—generate emergent governance patterns. Importantly, these forces are not isolated but form a recursive loop of mutual influence:

Geospatial fluidity disrupts traditional territorial boundaries, enabling languages to flow across regions through digital channels. The digital dissemination of Occitan in France, for example, through TikTok's AI translation features, exemplifies this "liquid territory" concept. This geospatial shift, in turn, exerts pressure on socio-functional hierarchies. In the EU, the increased visibility of non-English languages like Occitan on digital platforms has led to their greater use in administrative communication, challenging the long-standing dominance of English and French. This socio-functional de-stratification then triggers semiotic innovation. As Egyptian Arabic (Masri) gains more official recognition in digital literacy curricula due to its increased use in online communication, it undergoes a process of semiotic transformation, with new hybrid forms emerging that blend Masri with Classical Arabic (Fusha). This semiotic hybridity further reinforces geospatial fluidity, as these new forms are more easily disseminated across digital networks, creating a self-reinforcing cycle of change.

This emergent loop is a characteristic feature of CAS, where small-scale interactions between adaptive agents (states, tech platforms, civil society) lead to large-scale, unpredictable changes in the system as a whole. In the context of language policy, it means that changes in one dimension (e.g., geospatial) can have cascading effects on others (socio-functional and semiotic), and vice versa, leading to the continuous evolution of the language policy ecosystem.

5.2. Contrasting Paradigms: From Static Control to Dynamic Coordination

The TMLE model diverges fundamentally from traditional frameworks in its understanding of language-state relations:

Governing Logic: Whereas the "territory-function" model anchors language to geographic borders and institutional hierarchies (e.g., France's Toubon Law enforcing French dominance), TMLE recognizes technology as a mediating force that redefines language as a networked practice. In Singapore's "Smart Nation" initiative, AI translation tools enable seamless interaction between English (technical lingua franca) and mother tongues (cultural identifiers), creating a fluid multilingual ecosystem where functions adapt to societal needs rather than being dictated by law.

Policy Aim: Traditional policies prioritize standardization and order, often at the expense of diversity (e.g., Canada's rigid bilingualism sparking recurring conflicts). TMLE, by contrast, seeks adaptive equilibrium, where linguistic diversity and functional efficiency coexist through technological mediation. South Africa's use of AI to bridge its 11 official languages in e-governance—allowing Xhosa speakers to engage with Afrikaans administrative systems—exemplifies this shift toward inclusive coordination.

Governance Style: The old paradigm relies on regulatory control (laws, sanctions, and bureaucratic mandates), while TMLE advocates for ecosystemic facilitation, where policymakers act as stewards rather than enforcers. Brazil's collaboration with Indigenous communities to develop AI tools for endangered languages like Yolngu Matha embodies this approach, treating local knowledge as a core component of linguistic sustainability.

5.3. Policy Implications: Cultivating Adaptive Linguistic Ecosystems

The TMLE model generates the following actionable strategies for governance in the AI era:

5.3.1. Nurturing Polycentric Collaboration

Effective policy now requires integrating diverse agents into a shared governance network. In the African context, Rwanda's "Local Language AI Initiative" is a prime example of adaptive agent collaboration [72]. Launched in 2024, this initiative brings together healthcare workers, tech developers,

and Kinyarwanda speakers to co-design medical translation tools[72]. The initiative requires tech developers to collaborate closely with local communities to understand their specific language needs and usage patterns. For instance, in the development of a Kinyarwanda medical dictionary[73], local healthcare workers provided input on the most commonly used medical terms in their daily practice, while Kinyarwanda speakers helped to ensure that the translations were culturally appropriate and linguistically accurate. This collaborative approach not only enhances the quality of the translation tools but also promotes the preservation and development of the Kinyarwanda language in the medical field.

5.3.2. Embracing Emergent Practices

Rather than resisting semiotic hybridity, policies should recognize it as a natural outcome of tech-mediated communication. Egypt's 2023 education reform, which legalized dialectal Arabic in digital literacy curricula, is a significant step in this direction. The reform was a response to the widespread use of Egyptian Arabic (Masri) in digital communication, especially among young people. By recognizing Masri as a legitimate language for digital literacy education, the government not only acknowledges the changing linguistic landscape but also provides an opportunity for students to develop their digital skills in their mother tongue. This approach aligns with the TMLE model's emphasis on embracing emergent practices and leveraging them for positive change.

5.3.3. Designing for Resilience

TMLE emphasizes building systems that can withstand linguistic and technological shifts. The EU's AI4Languages project is an example of a policy initiative that aims to enhance the resilience of the European language ecosystem. The project focuses on developing translation tools for minority languages, such as Celtic languages like Welsh and Breton. By providing these languages with the necessary technological support, the project helps to ensure their survival and development in the digital age. In addition, the project also promotes the use of these languages in cross-border communication, which further enhances their resilience and vitality.

6. Conclusion

This study has demonstrated that AI translation technologies are profoundly transforming language policies, shifting their conceptualization from static territorial strongholds rooted in nation-state sovereignty to dynamic, technology-mediated linguistic ecosystems characterized by adaptive interactions between human practices, algorithmic systems, and institutional norms. Through the lens of Complex Adaptive Systems (CAS), this transformation is revealed not as a process of boundary erasure, but as a fundamental reconfiguration of rigid territorial demarcations into permeable semantic thresholds—frontiers defined by interpretive fluidity rather than geographic or functional rigidity.

6.1. Summary of Key Contributions

By deconstructing the traditional "territory-function" framework, the research identifies three dimensions of debordering—geospatial, sociofunctional, and semiotic—each driven by the nonlinear interactions of adaptive agents (states, tech platforms, civil society) and manifesting in emergent properties such as linguistic fluidity, functional pluralism, and semiotic hybridity. The proposed Technology-Mediated Language Ecology (TMLE) model advances a new theoretical paradigm, treating language policy as an evolving system where order arises not from top-down regulation, but from the self-organizing dynamics of tech-mediated communication. This challenges conventional notions of language as a bounded resource, repositioning it as a networked practice shaped by continuous co-evolution between technological innovation and societal needs.

6.2. Avenues for Future Inquiry

The findings invite scholarly exploration along three critical frontiers, with a particular emphasis on non-Western and culturally specific contexts to address the current overrepresentation of Western cases:

Religion-Language-Tech Intersections in Islamic Contexts

In Southeast Asian nations like Indonesia and Malaysia, the interplay between religious languages (e.g., Arabic for Islamic liturgy, Bahasa Indonesia for national unity) and AI translation may generate unique "semiotic-faith boundaries." For instance, AI tools translating Quranic verses into local dialects could challenge traditional religious authority, while government efforts to standardize "Islamic Malay" via algorithms might spark debates over linguistic purity. Such

dynamics require grounding in Garner's[73] language ecology theory, which emphasizes the role of cultural institutions in shaping linguistic practices, to decode how tech-mediated Quranic translations reshape religious and national identities.

Postcolonial Digital Vernaculars in Africa

Contrasting with the EU's multilingualism, African states like Nigeria and Kenya face the challenge of balancing colonial lingua francas (English, French) with indigenous languages in AI-driven governance. Future research could analyze how platforms like Jumia (pan-African e-commerce) use AI to prioritize Hausa or Swahili in product listings, thereby creating "digital pidgins" that defy colonial-era language hierarchies. Applying Ngũgĩ wa Thiong'o's theory[74] of "decolonizing the mind," such studies could explore whether tech-mediated vernaculars foster cultural autonomy or inadvertently reinforce neocolonial linguistic dependencies.

Emergent Governance Paradigms in Hybrid Regimes

In authoritarian contexts like China and Russia, where language policies serve as tools of political control, AI translation's role in managing ethnic minority languages (e.g., Uyghur, Tatar) presents a paradox: while tech may enhance administrative efficiency, it also risks eroding linguistic diversity through algorithmic bias. Comparative studies with democratic states could assess how regime type influences the balance between "ecosystemic stewardship" and state surveillance, drawing on Levitsky and Way's hybrid regime theory[75].

6.3. Theoretical Contributions: Reimagining Language Policy as an Emergent Ecosystem

The TMLE model advances language policy studies by challenging the modernist narrative of language as a territorial sovereignty symbol. Traditional frameworks, rooted in 19th-century nation-state logic, treat policies as expressions of state power (e.g., France's Toubon Law). In contrast, TMLE reveals language policies as self-organizing ecosystems co-created by technological agents (APIs, algorithms), institutional actors, and grassroots practices. This paradigm shift has twofold implications:

Decentering State Authority

By demonstrating that AI translation can bypass state regulations (e.g., Occitan's digital spread in France) or compel policy reforms (e.g., Egypt's dialect acceptance), TMLE undermines the myth of state omnipotence in language governance. It posits that technological emergence—not bureaucratic design—often drives policy change, a radical departure from static "territory-function" models.

Reconfiguring Governance Aims

TMLE rejects the binary of "standardization vs. diversity," instead advocating for adaptive equilibrium through technological mediation. For example, Singapore's "Smart Nation" initiative does not seek to eliminate English or mother tongues but to enable their functional coexistence via AI APIs—a model incompatible with traditional policies' zero-sum logic. This aligns with complexity science's emphasis on "resilience through diversity," offering a post-pandemic blueprint for digital language governance that prioritizes flexibility over rigid control.

In essence, TMLE redefines language policy research as an interdisciplinary enterprise at the intersection of linguistics, computer science, and political theory. By framing policies as dynamic ecosystems, it opens new pathways for addressing urgent global challenges—from indigenous language revitalization to algorithmic bias—through the lens of decentralized, adaptive governance.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Confict of Interest

The author declares no conflict of interest.

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