Code Ecologies: Operationalising Symbolic Codes for Legitimacy in Sustainability Transitions

Abstract

A persistent challenge in sustainability transitions is the uneven uptake of interventions such as renewable energy projects, conservation measures and rewilding initiatives. These often encounter resistance that cannot be explained by economics, technical feasibility or governance arrangements alone. Instead, they hinge on questions of legitimacy and cultural alignment. Existing frameworks, including socio-ecological systems and cultural ecosystem services, recognise human dimensions but lack tools to identify the symbolic dynamics through which interventions are interpreted, accepted or contested. This paper advances the concept of *Code Ecologies*, where sustainability transitions are understood as a co-evolution of cultural, ecological and technological change. It contributes the Symbolic Ecology Framework, which integrates symbolic codes into socio-ecological analysis. Symbolic codes are defined as patterned systems of meaning expressed through aesthetics, aspirational values and common practices. They filter legitimacy and shape whether interventions are embraced, negotiated or resisted. The framework specifies six attributes – salience, valence, resonance, legitimacy, diachronic status, and place-binding – by which codes can be systematically assessed. These attributes are aggregated into a Symbolic Alignment Index, with results visualised as cultural alignment maps. An application to renewable energy siting illustrates how the framework can be applied to identify potential misalignments and support culturally resonant intervention design.

Keywords: Symbolic codes; Socio-ecological systems; Cultural legitimacy; Sustainability transitions

1. Introduction

Despite decades of innovation, the uptake of sustainability interventions – from renewable energy and conservation to rewilding and circular practices – remains uneven and contested, despite the remarkable sophistication in modelling ecological processes, socio-economic drivers and governance arrangements. Frameworks such as social–ecological systems (SES) have broadened the scope of analysis beyond the biophysical, enabling research to treat human institutions and behaviours as integral to sustainability (Ostrom, 2009; McGinnis & Ostrom, 2014). Ecosystem services approaches have likewise acknowledged the cultural and spiritual dimensions of human–nature relations (Daniel et al., 2012; Fish et al., 2016; IPBES, 2018). Yet despite these advances, persistent difficulties in uptake reveal a critical blind spot.

An important factor in whether interventions succeed is the extent to which they fit the socio-symbolic logics of the communities in which they are introduced. When the symbolic framing of an intervention clashes with local codes of meaning, legitimacy is withheld and uptake falters. Renewable energy projects, for example, are often delayed not by technical design or cost, but by

disputes over how turbines alter valued landscapes and identities (Devine-Wright, 2009). Similarly, rewilding initiatives can provoke contestation when they disrupt established narratives of belonging and stewardship (Lorimer et al., 2015).

These symbolic dimensions are not always visible. They consist largely of unspoken beliefs, assumptions and shared understandings that bind people together and define identity and belonging. Crucially, they also vary from context to context: what secures legitimacy in one community may provoke resistance in another. For outsiders – whether policymakers, scientists or developers – these symbolic codes are therefore difficult to detect and easy to overlook. The challenge, then, is how to systematically identify such tacit, context-specific codes and account for them in the design of sustainability interventions. Addressing this challenge requires interdisciplinary approaches that can integrate cultural analysis into environmental science. Semiotics, as the study of codes and meaning systems, provides a powerful basis for this integration.

Global corporations routinely invest heavily in semiotic research – often branded as 'cultural deep dives' – to ensure products resonate with local markets (Oswald, 2020). To illustrate this claim, in one well-known case, cultural analysis revealed that square headlights on the Jeep Wrangler clashed with the deep cultural code in the United States, where it was positioned as symbol of freedom and power. Sales surged after semiotics insights – the vehicle was reframed as a technological successor to the horse, the headlights redesigned to resemble 'round eyes' to give it resonance with rural familiarity. In Europe, the same vehicle carried a different cultural code – 'liberator' – evoking wartime memories of Allied forces, and campaigns were reframed accordingly. If such symbolic cues can determine uptake in consumer markets, overlooking symbolic codes in sustainability interventions risks even greater consequences.

This article builds on previous methodological work in design semiotics that has operationalised cultural codes for sustainability transitions (Author et al., 2016; Author, 2023). While that research demonstrated how codes can be identified and curated in innovation contexts, here the approach is extended into environmental science by proposing symbolic codes as ecological variables in socio-ecological analysis.

The paper proceeds in four steps. Section 2 reviews relevant literatures in environmental science and semiotics, and identifying the methodological gap. Section 3 sets out the premises of the Symbolic Ecology Framework (SEF) and details its attributes and conceptual tools. Section 4 illustrates its application to renewable energy siting, demonstrating how symbolic codes can be mapped, assessed and used strategically to align interventions. Section 5 discusses the broader implications of SEF for environmental research, policy and practice, and concludes by outlining directions for integrating symbolic variables into socio-ecological analysis.

2. Literature Review

This section reviews how environmental science has addressed human dimensions of ecological systems, what remains under-theorised, and how semiotic perspectives offer conceptual tools for filling this gap.

2.1 Environmental science approaches to human dimensions, and the cultural blind spot

Over the past two decades, environmental science has steadily integrated human and institutional variables into ecological models. The SES framework provided a structure for including governance and collective-choice arrangements in ecological analysis (Ostrom, 2009; Partelow, 2018). Research on cultural ecosystem services (CES) acknowledged that landscapes are not only biophysical systems but carry identity, heritage and spiritual significance (Daniel et al., 2012; Fish et al., 2016). While these frameworks keep expanding the scope of socio-ecological modelling (Manyani et al., 2024), the symbolic systems through which intervention legitimacy and meaning are constructed remain largely unexamined – a gap noted in earlier reviews (Fish et al., 2016; Schäfer & O'Neill, 2017; Partelow, 2018). Consequently, sustainability transitions uptake challenges persist across sectors and geographies.

The social–ecological systems (SES) framework gave environmental science a common diagnostic language to integrate humans into ecological modelling. In Ostrom's formulation, subsystems (resource system, resource units, governance system, users) and second-tier variables (e.g., rules-in-use, social capital, leadership, knowledge of the SES) explain interactions and outcomes (Ostrom, 2009; McGinnis & Ostrom, 2014; Partelow, 2018). Culture appears here, but indirectly – as *norms*, *shared strategies*, *trust*, and *institutional arrangements* embedded in communities and governance. This lens is powerful for analysing rule configurations and collective action, yet it tends to focus on cultural factors as behavioural or institutional properties, without going as deep into the symbolic systems that confer or withdraw legitimacy.

Cultural ecosystem services (CES) explicitly recognise symbolic and relational dimensions of human–nature relations – identity, heritage, spirituality, sense of place (Daniel et al., 2012; Fish et al., 2016; IPBES, 2018). CES work has broadened what 'benefits' mean and introduced methods for eliciting values (e.g., deliberative valuation, participatory mapping). However, operationalisation often rests on preference metrics and static classifications. These surface *what* people value, but rarely model how symbolic codes evolve, compete, and move between centre and periphery over time, nor *how* such dynamics translate into legitimacy for concrete interventions.

Adoption, framing and legitimacy

Science and technology studies (STS) emphasise co-production – technologies and social orders co-evolve, so artefacts cannot be understood outside their institutional and cultural contexts (Hackett et al., 2007). Work on boundary organisations has further shown that knowledge uptake depends on perceptions of credibility, salience and legitimacy (Cash et al., 2003; White et al., 2010). These literatures converge on a central insight: meaning matters for uptake. Yet they remain methodologically decoupled from SES diagnostics and ecological modelling.

Uneven uptake across geographies underscores the gap. Renewable energy programmes are resisted where they clash with symbolic landscapes and place identities (Devine-Wright, 2009); protected areas meet opposition when they undermine existing cultural practices (Büscher & Fletcher, 2020); rewilding ignites contestation around belonging and stewardship (Lorimer et al., 2015).

A smaller set of applied studies shows the *inverse*: when interventions are embedded in local symbolic logics, trust and uptake increase. A smaller body of applied studies demonstrates how interventions gain traction when embedded in cultural and social logics. In Samoa, the blending of seasonal climate forecasts with traditional ecological indicators increased trust and adoption among farmers by aligning scientific information with established cultural codes (McNamara & Prasad, 2014). In Porto Torres, Sardinia, a participatory plan that involved schools, associations, and trusted local media succeeded in building legitimacy around environmental health interventions by anchoring them in familiar community practices (De Marchi et al., 2023). In Belgium, randomized controlled trials in social housing demonstrated that uptake of retrofit technologies increased significantly when messages were framed through local social norms—highlighting neighbours' behaviours and peer comparisons (Bielig, Kacperski & Kutzner, 2024). These cases illustrate that symbolic alignment can decisively shape outcomes – yet they remain fragmented and lack a unifying framework.

Most studies in socio-cultural and symbolic factors that shape decision-making have focused on barriers, documenting obstacles to public engagement, polarisation and resistance (Cox, 2010; Schäfer & O'Neill, 2017). But there is also strong evidence that symbolic alignment can enable successful interventions. Related literature in sustainable product–service systems adoption has shown how cultural codes shape the framing and positioning of sustainable offerings (Author et al., 2016). Research on the circular economy points to user practices and symbolic dimensions as critical to adoption and legitimacy (Pieroni et al., 2019). In studies of sustainable business models, value propositions have been shown to embed cultural meanings and user practices that shape uptake and interpretation. As Baldassarre et al. (2017, p. 177) argue, by integrating a user focus, tools for business model innovation can support companies in 'overcoming the pitfall of directing their sustainable development efforts exclusively on technological advancements and production efficiency.' Evidence accumulates, but tools remain ad hoc.

The cultural blind spot, clarified

Across SES and CES, and adjacent adoption literatures, four limitations persist:

1. **Unit of analysis** – Culture is proxied as *norms/values/preferences* rather than codes (aesthetics, narratives, moral values, cultural logics) that mediate legitimacy.
2. **Temporality** – Valuation is often static; there is little modelling of diachronic movement (residual–dominant–emergent) or centre–periphery shifts that determine what becomes legitimate.
3. **Spatial integration** – Place attachment is measured, yet symbolic variables are not integrated spatially with ecological or technical layers to guide siting and design.

4. **Design diagnostics** – SES excels at diagnosing governance fit; CES elicits values; communication tests frames, but the field lacks a systematic method to *identify, score, and align* symbolic systems with interventions so that uptake can be anticipated rather than retro-explained.

An important factor in whether interventions succeed is fit with the socio-symbolic logics of the communities where they land. Those logics are tacit and context-specific, making them hard to see from outside and easy to miss in planning. What is missing is a framework that treats symbolic systems as variables – measurable, comparable, and mappable – that can sit alongside governance, biophysical and behavioural variables in SES analysis.

2.2 Semiotics and Sociocultural Change

If SES and CES show where culture is recognised but under-theorised, semiotics offers conceptual tools to address this gap. In this section, we first present systemic perspectives in semiotics that connect culture and ecology, and the role of codes as the infrastructure of meaning. We then examine how codes can be treated as variables within socio-ecological analysis, with particular attention to their political dimensions and ethics of use.

Semiotics and codes: Definitions

Semiotics is the study of sign systems – the patterned conventions through which humans interpret the world and organise collective life (Nöth, 1990). At its core lies the concept of the code: socially agreed conventions that link signs to meanings. Some codes are obvious – such as traffic lights (red = stop; green = go) – while others are tacit and deeply embedded in culture, such as colour–gender associations (pink for girls, blue for boys) or rituals of status and belonging. These unspoken conventions shape identity, group cohesion and the legitimacy of practices.

Symbolic codes play a big role in the construction of social realities, reflecting class differentiation, identity and belonging (Nöth, 1990). Codes that signal legitimacy and belonging are expressed through aesthetics (the visual and material signs that signal what is familiar or desirable), aspirational values (the orientations that guide what people strive for), and common practices (the routines and rituals that embody belonging) (Author, 2023). These codes structure narratives, preferences, attitudes and behaviours, and signal what is normalised, desirable or misaligned in a given cultural context (Nöth, 1990; Kress, 2010).

Symbolic codes therefore matter for sustainability uptake. They are the filters through which interventions are interpreted, accepted or resisted. For example, the recycling symbol condenses a complex system of waste management into a simple sign, guiding behaviour when it resonates with people's beliefs and aspirations (Benford & Snow, 2000; Alexander, 2004). If it does not, the sign is ignored, however well designed. The same principle applies to sustainability transitions: their success depends not only on technical design or governance, but on alignment with the symbolic codes that underpin identity, belonging and trust (Kress, 2010). Marketing

semiotics has long recognised this dynamic, demonstrating how brands succeed when they embed themselves within cultural codes (Oswald, 2020).

Semiotic perspectives on ecology

Crucially for sustainability, semiotics understands meaning-making as a systemic property, where interrelated codes form dynamic ecologies (Lotman, 1990). Gregory Bateson (1972) first advanced the idea that the unit of survival is not the isolated organism but the ecology of mind: the circuits of information and relationship in which organisms live. In this view, errors of thought – for example, hubristic premises of separation from nature – are not trivial, but ecological in consequence when reinforced by thousands of everyday cultural details, for example, overconsumption. Yuri Lotman (1990) extended this systems view, conceptualising culture as a *semiosphere*: a dynamic ecology of signs in which meanings constantly evolve. More recently, Barbieri's (2003) theory of *code biology* reinforced this systemic understanding by showing that codes are not only cultural constructs but fundamental to life itself. In biology, codes mediate between information and function – most famously, the genetic code that links nucleotides to amino acids. This perspective has grown into the field of biosemiotics, which studies sign and code processes across living systems, highlighting that semiosis is as intrinsic to life as energy and matter (Barbieri, 2015).

Dynamics of change

Raymond Williams (1977) showed that cultural forms coexist as residual, dominant and emergent. This temporality explains why old traditions persist, dominant codes stabilise legitimacy, and new meanings struggle for recognition – all at once. Lotman (1990) also observes that meanings compete for position and legitimacy: codes in the periphery may migrate to the centre and reshape what is legitimate, while dominant codes can lose resonance and drift outward. Hall (1980) further emphasised that even dominant codes are never passively absorbed: audiences decode them in dominant, negotiated or oppositional ways. As Mouffe (2000) argued, politics is not about eliminating antagonism but managing it through agonistic struggle. These perspectives highlight why adoption is never a simple matter of exposure to information. It is a process of negotiation within an ecology of codes – some entrenched, some contested, some emerging – that collectively shape legitimacy.

Plastics illustrates this dynamic well: *Reuse and thrift* re-emerge as residual codes, *disposability and convenience* remain dominant yet contested, while *circularity* and *closed-loop design* struggle as emergent codes, showing how residual, dominant and emergent codes coexist, clash and migrate, reshaping the symbolic terrain of everyday practice.

Code Ecologies as co-evolution

Building on Bateson's and Lotman's conceptualisations, Bruni (2011) proposed a triadic ontology of the *biosphere* (ecological systems of life), *technosphere* (human infrastructures and technologies), and *semiosphere* (cultural-symbolic systems of meaning). These spheres are

interdependent, he argued, and sustainability can only be achieved through the interrelated co-evolution of technological, biological and cultural change. For example, the spread of electric vehicles involves mobilising the technological resources (e.g. batteries and charging grids), the biological resources (from reduced tailpipe emissions to increased demand for mineral extraction), and symbolic resources (such as whether EVs are framed as luxury commodities, green necessities, or transitional technologies). Therefore, working with codes is not 'soft communication' but systemic leverage.

A Code Ecologies perspective, therefore, treats cultural-symbolic systems as legitimate ecological variables alongside biophysical and technological ones.

Implications for adoption

Societies are hierarchical and contested, and codes reflect this condition. Peripheral codes often need to move inward for survival, a process that entails conflict and negotiation. As Damasio (2018) observed, cultural systems, like biological ones, evolve through drives toward homeostasis. Symbolic codes echo these ecological logics: they compete, adapt and reorganise, sustaining or undermining systemic balance. Adoption of sustainability interventions is therefore not a neutral transfer of information but a semiotic process of alignment, contestation and reframing to establish legitimacy. Sustainability transitions are always mediated by the interpretive work of the code ecologies they inhabit.

2.3 Gap: from recognition to operationalisation

Across SES, CES and adjacent literatures, there is widespread recognition that cultural and symbolic dimensions matter for sustainability transitions. SES research acknowledges norms, trust and institutions; CES highlights heritage, identity and spirituality; adoption and communication studies demonstrate framing effects and worldviews. Together, these literatures provide strong evidence that interventions succeed or fail in part because of their symbolic alignment.

Yet three persistent limitations remain:

1. **Descriptive treatment of culture:** Culture is recognised but typically proxied as values, attitudes or preferences. These elicit what people care about but not how symbolic systems structure legitimacy or shift over time.
2. **Lack of temporal and spatial integration:** While ecological and technical variables are modelled diachronically and spatially, symbolic dimensions are rarely integrated in ways that can trace residual, dominant and emergent codes, or map where cultural alignment supports or undermines interventions.
3. **Absence of design diagnostics:** Current approaches document barriers or report successful cases after the fact. What is missing is a systematic, ex-ante method to identify, score and align symbolic systems with interventions, enabling uptake to be anticipated and strategically shaped rather than retroactively explained.

Important precedents suggest the operationalisation of symbolic codes is possible. Semiotics has long examined the differential weight of codes: Kress and van Leeuwen (2001) proposed visual grammars to measure salience and modality in multimodal texts; Hall's (1980) encoding/decoding model classified interpretive positions as dominant, negotiated or oppositional. Communication studies have shown how moral, economic or security frames alter legitimacy and uptake of climate messages (Nisbet, 2009; Wolsko et al., 2016). Ecosystem services research has formalised relational values through classification and weighting methods (Daniel et al., 2012; Chan et al., 2016; Fish et al., 2016).

Meanwhile, marketing and brand strategy have long operationalised semiotics with enormous effect. Corporations invest heavily in 'cultural deep dives' to identify which codes resonate across markets and reframe products accordingly (Oswald, 2022; Rapaille, 2007). A car, a food brand, or a financial service succeeds internationally not because of technical superiority but because it is encoded in ways that fit the symbolic logics of its target culture. Sustainability science, despite being equally dependent on uptake, has yet to apply the same tools. The contrast is striking: while corporations spend millions to decode cultural logics for product legitimacy, sustainability interventions – arguably more consequential – still treat symbolic alignment as peripheral.

Early efforts to connect semiotics and ecology include Nielsen's (2007) proposal for an 'ecosystem semiotics' programme. And in sustainable design, cultural codes have been operationalised to mainstream sustainable product–service systems by embedding aesthetics, practices and values into value propositions (Author et al., 2016). What is missing is a coherent framework that integrates disparate strands and treats symbolic codes as variables in their own right: analysable, comparable and alignable alongside biophysical, governance and behavioural dimensions. If codes are hierarchical, contested and constitutive of legitimacy, then adoption cannot be left to chance or relegated to communication afterthoughts. The challenge is not to prove that codes matter – that much is already evident – but to develop systematic ways of analysing and operationalising them. This paper addresses that gap by proposing the Symbolic Ecology Framework (SEF), which embeds codes into socio-ecological analysis and practice.

3. Theoretical Framework – Towards Operationalising Code Ecologies

Frameworks such as SES and CES have expanded environmental research by incorporating governance, institutions, values and behaviours alongside ecological processes. This article proposes the Symbolic Ecology Framework (SEF). SEF extends SES by operationalising symbolic codes as system-level variables that can be identified, scored and aligned, providing a structured way to anticipate contestation, reduce resistance and design culturally resonant interventions (Figure 1).

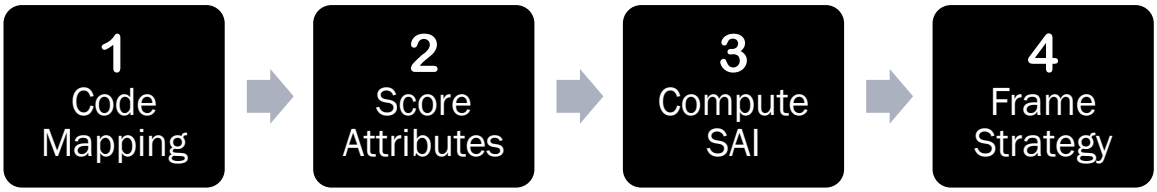

Figure 1. SEF Framework – four-step operationalisation process

1. **Code Mapping:** Identify symbolic codes in the contextual semiosphere (media, narratives, ethnography, participatory workshops). Group in three categories: aesthetic, aspirational values, common practices.

2. **Score Attributes:** Assess codes on salience, valence, resonance, legitimacy, diachronic status, place-binding (e.g. using score scale 0–5).

3. **Compute SAI:** Aggregate scores into the Symbolic Alignment Index to diagnose alignment/misalignment.

4. **Frame intervention and strategy:** Select codes with high alignment potential to frame the intervention strategically (e.g. heritage-compatible stewardship, local sovereignty), and design communication/participation strategies accordingly.

This model functions like an extension to SES frameworks – where governance, behaviour, and values are recognised but remain under-theorised, symbolic codes provide a systematic, quantifiable, and spatially mappable layer that connects interventions with societal responses.

3.1 Categories for Code Mapping

A previously published design semiotics model (Author, 2020; Author, 2023), developed through applied research in design for sustainability, provides the methodological foundation for SEF. The model distinguishes three categories of codes that strongly influence the uptake of interventions:

- **Aesthetic Codes**: The visual and material signs that indicate what is desirable, familiar, or modern within a culture. Examples to source these codes include styles of dress, architecture, cars, and artefacts. These codes provide cues for how communities perceive harmony, appropriateness or modernity, shaping whether an intervention appears legitimate or alien.

- **Aspirational Values**: The orientations and collective imaginaries that motivate what people strive for in life. Examples might be ‘my children receive a good education,’ ‘family remains united,’ or ‘we can eat well.’ These values anchor long-term visions of

the future and condition how sustainability is justified and pursued.

- **Common Practices**: The everyday routines and social rituals that embody belonging – what 'people like us do.' Examples include going for a pint after work, rising early for agricultural labour, or helping neighbours. These practices reflect collective norms that determine what feels natural, trustworthy and socially legitimate.

These categories provide a comprehensive, structured way to map the cultural-symbolic logics of a given context, highlighting the tacit codes that filter legitimacy and shape whether interventions are resisted, negotiated or embraced. Once mapped, these codes can then be analysed through the attributes (Section 3.3) and subsequently aggregated within the Symbolic Alignment Index (SAI) (Section 3.4).

3.2 Variables and Attributes

To operationalise symbolic codes within socio-ecological analysis, they must be described and assessed in systematic ways. We propose six core attributes that capture how codes shape legitimacy and uptake. These attributes function as diagnostic variables: they can be observed, scored, and compared across contexts, providing the basis for integration into models of intervention adoption:

1. **Salience** – the frequency and visibility of a code in public discourse, media, or practice. In semiotics, salience refers to the degree to which elements attract attention within a composition (Kress & van Leeuwen, 2001). In political science, 'issue salience' captures how strongly a topic features in collective agendas (McCombs & Shaw, 1972).
2. **Valence** – the positive or negative orientation attributed to a code in collective meaning-making, ranging from antagonistic to aspirational. In psychology, affective valence denotes the emotional charge of experiences (Frijda, 1986). In communication studies, valence framing influences whether issues are embraced or resisted (de Vreese & Boomgaarden, 2003).
3. **Resonance** – the depth of alignment between a code and collective identities, values, and affective orientations. In social movement theory, frame resonance explains why some frames mobilise while others fail (Benford & Snow, 2000). In cultural sociology, resonance is the symbolic 'fit' with wider imaginaries (Alexander, 2004).

4. **Legitimacy –** The extent to which a symbolic code is recognised as valid, fair and authoritative within a given context, shaping whether interventions are accepted as just and appropriate. In sustainability research, legitimacy is a key criterion for effective knowledge systems, alongside salience and credibility (Cash et al., 2003).
5. **Diachronic Status (Residual, Dominant, Emergent)** – the temporal positioning of a code. Williams (1977) distinguished between residual forms (inherited from the past but still active), dominant forms (prevailing in the present), and emergent forms (new and not yet fully institutionalised). This dimension highlights cultural shifts over time.

6. **Place-binding** – the anchoring of codes to specific landscapes or places. Environmental psychology shows how place attachment and identity shape acceptance (Devine-Wright, 2009; Lewicka, 2011). Cultural ecosystem services research similarly highlights symbolic ties between places and meanings (Chan et al., 2016).

The attributes provide a vocabulary for measuring symbolic dynamics in ways comparable to other socio-ecological variables. They are the building blocks for the Symbolic Alignment Index. Table 1 summarises them for easy access.

Table 1. Attributes for operationalising symbolic codes in socio-ecological analysis

Attribute	Definition (short)	Illustrative example	Reference(s)
Salience	Visibility/frequency of a code in discourse or practice	Recycling symbol present on packaging and bins	Kress & van Leeuwen (2001); McCombs & Shaw (1972)
Valence	Positive/negative orientation of a code	Wind turbines framed as 'green progress' vs 'industrial blight'	Frijda (1986); de Vreese & Boomgaarden (2003)
Resonance	Depth of alignment with identities and values	'Family farming' resonating with rural traditions	Benford & Snow (2000); Alexander (2004)
Legitimacy	Recognition of a code as fair and authoritative	Indigenous stewardship narratives gaining official recognition	Cash et al. (2003)
Diachronic Status	Temporal positioning: residual, dominant, emergent	Revival of residual folk practices in modern rewilding	Williams (1977)

Place-binding	Anchoring of codes to landscapes/places	Opposition to dams tied to cultural river identity	Devine-Wright (2009); Lewicka (2011); Chan et al. (2016)

3.3 Symbolic Alignment Index (SAI)

The Symbolic Alignment Index (SAI) integrates symbolic codes attributes into a composite measure of how well an intervention aligns with the codes of a given community.

- **High SAI values** indicate strong symbolic legitimacy and smoother uptake.
- **Low or negative values** signal symbolic conflict, pointing to likely resistance or contestation.

By spatialising SAI outputs, researchers can generate *Cultural Alignment Maps* that overlay symbolic codes onto ecological and technical data. These maps reveal where interventions are more likely to encounter legitimacy barriers or resonance, offering a diagnostic tool that complements assessments such as environmental impact studies.

At this stage, the SAI is presented as a conceptual tool. The quantitative specification and weighting of attributes remain a direction for future empirical and modelling work, but the framework already provides a systematic pathway for integrating symbolic codes into environmental research and practice. The following section illustrates how these concepts can be applied in practice.

4. Application: Renewable Energy Siting

The siting of renewable energy infrastructure illustrates how symbolic codes shape societal responses to interventions. Although wind and solar projects are technically feasible and aligned with climate targets, they frequently encounter opposition that delays or blocks implementation. Research in energy geographies has shown that such conflicts cannot be reduced to ‘NIMBY’ effects or narrow attitudinal factors; they are shaped by deeper cultural-symbolic meanings attached to landscapes and technologies (Wolsink, 2007; Devine-Wright, 2009; Pasqualetti, 2011; Batel & Devine-Wright, 2015).

4.1 Codes as acceptance variables

For the purpose of modelling, four recurrent themes from this literature can be reframed as symbolic codes. The perception of wind turbines as ‘industrial imposition’ reflects a logic of intrusion into rural spaces (Jobert et al., 2007). The notion of ‘sacred skylines’ highlights the cultural-symbolic significance of heritage vistas (Pasqualetti, 2011). Codes of ‘working land’ foreground stewardship and agricultural legitimacy (Batel & Devine-Wright, 2015). Finally,

‘local sovereignty’ emerges in contexts where community ownership or co-benefits strengthen legitimacy (Walker & Devine-Wright, 2008; Bauwens, 2016).

In conventional research, these are often approached as attitudes or acceptance factors. Within the Symbolic Ecology Framework, however, they are treated as *cultural codes*: structured, contextual and diachronic. They are not individual opinions but patterned logics embedded in communities and landscapes. Their salience, valence, legitimacy, resonance, RDE status and place-binding can be systematically assessed and aggregated into a Symbolic Alignment Index (SAI). Tables 2–4 illustrate how baseline SAI scores for a wind project can be calculated, and how reframing strategies such as community ownership or landscape-sensitive design shift symbolic alignment and predicted uptake.

4.2 Illustrative Modelling

Let’s take, for example, a proposed wind farm in Southern Italy to illustrate how codes operate in practice. While technically aligned with European climate goals, the project was widely read through codes of intrusion and heritage violation: turbines appeared as industrial ‘scars’ against olive groves, archaeological sites and traditional masserie. Here the ‘sacred skyline’ code resonated strongly with local identity, while the ‘industrial imposition’ code carried high salience and negative valence, producing low legitimacy. Yet the same Cultural Alignment Map also contained favourable codes: youth activists framed the project through ‘energy sovereignty’ and intergenerational justice, while farmers recognised continuities with ‘working land’ stewardship. By engaging these codes through place-sensitive design (hedgerow planting, participatory ownership schemes) and symbolic practices (artists reimagining landscapes, schoolchildren narrating turbines as ‘new giants’), the intervention could be re-encoded within the context, shifting its alignment profile. The resulting change in SAI scores demonstrates not only diagnostic capacity but also the possibility of designing interventions in symbolic as well as technical alignment.

Table 2 illustrates how symbolic codes surrounding a proposed wind project can be systematically described through the attributes of the Symbolic Ecology Framework. At baseline, codes such as ‘working land’ and ‘local sovereignty’ offer partial support, while ‘sacred skyline’ and ‘industrial imposition’ introduce negative orientations. The resulting Symbolic Alignment Index (SAI) baseline SAI of 0.55 (on a 0–1 scale) signals a field of contested legitimacy: support is partial, but opposition is strong enough to threaten uptake.

Table 2. Symbolic code attributes and baseline alignment for a proposed wind project

Code	Salience	Valence	Legitimacy	RDE Status	Place-binding	Alignment (A_k)

Working land (stewardship)	High	Positive	Moderate	Dominant	Strong	0.62
Sacred skyline (heritage vistas)	Moderate	Negative	Moderate	Residual	Strong	0.38
Industrial imposition	High	Negative	Low	Dominant	Moderate	0.41
Local sovereignty (co-ownership)	Moderate	Neutral	Moderate	Emergent	Strong	0.55

Note: Alignment (A_k) is calculated by combining attribute scores (0–1 scale).

Table 3 shows how targeted interventions can shift symbolic alignment. Community ownership schemes increase the positive valence and legitimacy of the 'local sovereignty' code, while landscape-sensitive siting and hedgerow planting reduce the salience of 'industrial imposition' and strengthen associations with stewardship. The aggregated effect is a higher SAI of 0.66, signalling stronger cultural alignment and reduced symbolic conflict.

Table 3. Change in symbolic alignment after reframing and design interventions

Intervention	Effect on Codes	SAI (Symbolic Alignment Index)	Predicted Societal Response
Baseline (no interventions)	—	0.55	Low-moderate legitimacy; likely contestation

Community ownership scheme	↑ Valence & legitimacy of 'Local sovereignty'	0.61	Improved acceptance, sense of agency
Landscape-sensitive siting & hedgerow planting	↓ Salience of 'Industrial imposition'; ↑ legitimacy of 'Working land'	0.66	Higher legitimacy; reduced symbolic conflict

Table 4 summarises the implications by linking SAI to predicted uptake probability (illustrative, not empirical) showing how the integration of symbolic variables could feed into modelling. While the technical and policy baseline remains constant, the integration of symbolic variables demonstrates a measurable improvement in expected societal response. This suggests that interventions designed with symbolic alignment in mind are more likely to gain legitimacy, reduce resistance and accelerate transitions.

Table 4. Summary: impact of interventions on symbolic alignment and uptake

Scenario	Symbolic Alignment Index (SAI)	Predicted Uptake Probability*
Baseline	0.55	0.63
After interventions	0.66	0.68

**Predicted uptake probability derived by combining SAI with technical/policy baseline scores.*

4.3 Designing and framing interventions with the SAI

The value of the Symbolic Ecology Framework lies not only in diagnosing potential legitimacy conflicts but in guiding the design and framing of interventions. By consulting the SAI, planners can identify which symbolic codes carry the greatest weight in shaping responses to a proposed intervention. For instance, if the index reveals that 'sacred skyline' codes are both salient and negatively valenced, the intervention can be re-framed through design choices that reduce visual intrusion or foreground heritage-sensitive narratives. Conversely, if 'local sovereignty' is identified as an emergent but under-leveraged code, strategies such as community ownership, co-benefit schemes, or participatory governance can be prioritised to enhance legitimacy. In this way, the SAI functions as a decision-support tool: it provides a structured assessment that allows interventions to be *designed into alignment* with cultural logics, rather than imposed in ways that generate resistance. Over time, repeated application across cases could generate comparative insights into how symbolic codes evolve, enabling adaptive governance that integrates cultural legitimacy as a standard component of environmental planning.

Table 5 compares how the intervention looks when framed purely technocratically vs. when it is informed by SAI.

Table 5. Wind farm intervention before & after SAI encoding.

Category	Before (Alien Frame)	After (Encoded Frame)
Aesthetic Codes	Turbines framed as *industrial infrastructure*; clash with heritage landscapes.	Turbines embedded in local imagery; artists paint future landscapes; symbols drawn from olive groves, masserie, heritage.
Aspirational Values	Project framed as EU policy/targets, abstract economic efficiency.	Framed as *energy sovereignty* ('keeping wealth local'), *heritage stewardship*, and *for our children's future*. Children build mini-turbines to tell parents the story of the 'new giants.'

Common Practices	Consultation in municipal offices or churches, detached from everyday life.	Engagement in pubs, piazzas, schools, and festivals; codes align with local rituals and daily practices.
Salience	High: dominates local debates and visible in landscape.	High: but reframed positively through participatory art, youth activism, and heritage-based symbolism.
Valence	Negative: coded as intrusion, exploitation, aesthetic ruin.	Positive: coded as local pride, empowerment, climate responsibility.
Resonance	Strong, but against the project (landscape beauty, outsider exploitation).	Strong and for the project (heritage stewardship, intergenerational justice).
Legitimacy	Low: decisions seen as top-down, procedural, extractive.	Higher: co-created frames, participatory processes, reciprocity (local benefits).
Diachronic Status	Residual: stewardship, suspicion of outsiders. Dominant: development/modernisation. Emergent: youth activism, climate justice.	Residual reframed (stewardship = renewables), emergent codes amplified (justice, sovereignty) to shift dominant frame.
Place-binding	Strong: heritage sites and landscapes used to reject turbines.	Strong: same heritage/landscape reframed as symbols of renewable guardianship.

In essence, from a Code Ecologies lens, the case study demonstrates how to leverage the cultural-symbolic field through which wind farms are made meaningful: in myths, aesthetics, narratives, cultural logics and symbolic anchors, to advance technological change that supports ecological balance. The task is not merely to install turbines (technosphere), or to justify them with CO_2 savings (biosphere), but to translate them into the symbolic ecologies (semiosphere) of the people who will live with them. Meaning is not imposed from above; it is co-created with

communities through symbols and language they already trust and love. This is what transforms a project from alien to familiar, from resisted to embraced. And it is this translational function that makes SEF more than 'communication': it is a systemic reframing of sustainability as cultural–ecological translation.

5. Implications

The Symbolic Ecology Framework (SEF) offers implications across science, theory, methodology and practice. By treating symbolic codes as ecological variables, it enables legitimacy and cultural alignment to be integrated systematically into sustainability research and governance.

5.1 Implications for Environmental Science

SES and CES frameworks have expanded the scope of environmental research to include governance, institutions and values. Yet symbolic dynamics remain under-theorised. SEF provides a way to integrate meaning as a measurable component of socio-ecological systems, complementing biophysical and institutional variables. This extends explanatory capacity: interventions can be evaluated not only for ecological performance or economic trade-offs, but also for symbolic legitimacy.

5.2 Theoretical Contribution

SEF bridges semiotic theory and environmental science, placing the semiosphere alongside the biosphere and technosphere as a co-evolving driver of socio-ecological transitions. It unites insights from applied semiotics and cultural theory with sustainability science, extending SES and CES into a more dynamic, code-based and standardised vocabulary and method for cultural alignment analysis.

5.3 Methodological Contribution

The Symbolic Alignment Index (SAI) and Cultural Alignment Maps provide decision-support tools for diagnosing and comparing symbolic dynamics. These tools build directly on earlier methodological contributions (Author, 2016, 2023), where cultural codes were first operationalised qualitatively for product–service systems and social innovation uptake. SEF generalises and scales these methods for socio-ecological analysis, combining qualitative and quantitative methods, enabling sensitivity to cultural nuance while allowing cross-case comparison. Repeated application could generate comparative databases of symbolic codes, advancing the modelling of cultural dynamics in sustainability transitions.

5.4 Policy and Practice

For policymakers and practitioners, SEF provides a structured way to anticipate resistance and design culturally resonant interventions. By assessing symbolic alignment early, interventions can be framed with community codes rather than imposed against them. This not only increases

uptake but strengthens social resilience by respecting the symbolic systems underpinning identity and belonging. Incorporating SEF into planning processes could help deliver global commitments, including the Kunming–Montreal Global Biodiversity Framework, by ensuring interventions resonate across ecological, technological and cultural domains.

5.5 Future Research Directions

The Symbolic Ecology Framework opens new pathways for interdisciplinary, empirical and comparative research:

1. **Interdisciplinarity to develop SAI indicators.** The next logical step is to co-develop the Symbolic Alignment Index (SAI) with quantitative expertise, enabling attributes to be statistically specified and integrated into socio-ecological models. This aligns with global calls for more robust indicators in the *IPBES Transformative Change Assessment* (2024), which emphasises shifts in systems of values, governance and practice.

2. **SEF and adaptive SES across cultures.** Comparative case studies across cultural and geographic contexts are vital to assess how symbolic codes vary, and which persist or converge. Such work could advance the development of archetypes of social–ecological interactions within SES (Partelow, 2018), while ensuring that models remain adaptive to cultural nuance. This direction also responds to IPBES's emphasis on integrating diversity and just transitions into biodiversity governance.

3. **Intersectionality with resilience and justice.** Future research should explore how symbolic codes interact with resilience, equity and justice – ensuring that interventions not only achieve uptake, but also reinforce identity, well-being and fairness. This direction aligns with the emerging policy discourse on *just transitions* (IPCC, 2023), which centres equitable outcomes and inclusive processes

6. Conclusion

Legitimacy remains one of the least unpredictable dimensions of sustainability transitions. Projects succeed or fail not only on technical, economic, or institutional grounds, but on whether they resonate with the symbolic codes through which communities interpret interventions. Recognising these dynamics is not an optional add-on but central to governing socio-ecological change.

This article has advanced a way to treat codes as ecological variables, reframing sustainability science to incorporate meaning as a constitutive force. Rather than displacing frameworks such as SES or CES, the Symbolic Ecology Framework extends them, making explicit what has long remained implicit that cultural-symbolic systems shape adoption and resistance as powerfully as biophysical or governance factors.

The Symbolic Ecology Framework opens dialogue between semiotics, environmental science and policy. In this sense, it advances a line of methodological work I have previously developed in applied semiotics, now adapted to the challenges of environmental science. Its promise lies not only in providing tools for diagnosis and design, but in reorienting transitions as cultural–ecological translations as much as technical ones.

Sustainability is not only about flows of energy and matter, but also about flows of meaning. Then, we must learn to work with the codes people live. Until these are recognised, ecological models will remain incomplete. The framework presented here formalises the role of meaning as a dynamic driver of ecological transitions.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used ChatGPT (OpenAI) to refine language and improve clarity of expression. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the published article.

References

Alexander, J. C. (2004). Cultural pragmatics: Social performance between ritual and strategy. *Sociological Theory, 22*(4), 527–573. https://doi.org/10.1111/j.0735-2751.2004.00233.x

Baldassarre, B., Calabretta, G., Bocken, N. M. P., & Jaskiewicz, T. (2017). Bridging sustainable business model innovation and user-driven innovation: A process for sustainable value proposition design. *Journal of Cleaner Production, 147,* 175–186. https://doi.org/10.1016/j.jclepro.2017.01.081

Barbieri, M. (2003). *The Organic Codes: An introduction to semantic biology.* Cambridge University Press.

Barbieri, M. (2015). *Code Biology: A new science of life.* Springer.

Bateson, G. (1972). *Steps to an ecology of mind.* Chandler.

Batel, S., & Devine-Wright, P. (2015). Towards a better understanding of people's responses to renewable energy technologies: Insights from Social Representations Theory. *Public Understanding of Science, 24*(3), 311–325. https://doi.org/10.1177/0963662513514165

Bauwens, T. (2016). Explaining the diversity of motivations behind community renewable energy. *Energy Policy, 93,* 278–290. https://doi.org/10.1016/j.enpol.2016.03.017

Benford, R. D., & Snow, D. A. (2000). Framing processes and social movements: An overview and assessment. *Annual Review of Sociology, 26,* 611–639. https://doi.org/10.1146/annurev.soc.26.1.611

Bielig, M., Kacperski, C., & Kutzner, F. (2024). Increasing retrofit device adoption in social housing: Evidence from two field experiments in Belgium. *Journal of Environmental Psychology, 95*(6), Article 102284. https://doi.org/10.1016/j.jenvp.2024.102284

Bruni, L. E. (2011). Cognitive sustainability in the age of digital culture. *tripleC: Communication, Capitalism & Critique, 9*(2), 473–482. https://doi.org/10.31269/triplec.v9i2.301

Büscher, B., & Fletcher, R. (2020). *The conservation revolution: Radical ideas for saving nature beyond the Anthropocene.* Verso.

Cash, D. W., Clark, W. C., Alcock, F., Dickson, N. M., Eckley, N., & Jäger, J. (2003). Salience, credibility, legitimacy and boundaries: Linking research, assessment and decision making. *KSG Working Paper Series, RWP03-045*. Harvard University. https://doi.org/10.2139/ssrn.372280

Chan, K. M. A., Balvanera, P., Benessaiah, K., Chapman, M., Díaz, S., Gómez-Baggethun, E., … Turner, N. (2016). Why protect nature? Rethinking values and the environment. *Proceedings of the National Academy of Sciences, 113*(6), 1462–1465. https://doi.org/10.1073/pnas.1525002113

Cox, R. (2010). *Environmental communication and the public sphere* (2nd ed.). Sage.

Damasio, A. (2018). *The strange order of things: Life, feeling, and the making of cultures.* Pantheon Books.

Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M. A., … von der Dunk, A. (2012). Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences, 109*(23), 8812–8819. https://doi.org/10.1073/pnas.1114773109

De Marchi, B., Scolobig, A., & Pellegrini, C. (2023). Environmental health communication in a contaminated site: The case of Porto Torres, Italy. *Frontiers in Communication, 8,* 1217427. https://doi.org/10.3389/fcomm.2023.1217427

de Vreese, C. H., & Boomgaarden, H. G. (2003). Valenced news frames and public support for the EU. *Communications, 28*(4), 361–381. https://doi.org/10.1515/comm.2003.024

Devine-Wright, P. (2009). Rethinking NIMBYism: The role of place attachment and place identity in explaining place-protective action. *Journal of Community & Applied Social Psychology, 19*(6), 426–441. https://doi.org/10.1002/casp.1004

Douglas, M., & Wildavsky, A. (1982). *Risk and culture: An essay on the selection of technical and environmental dangers.* University of California Press.

Fish, R., Church, A., & Winter, M. (2016). Conceptualising cultural ecosystem services: A novel framework for research and critical engagement. *Ecosystem Services, 21,* 208–217. https://doi.org/10.1016/j.ecoser.2016.09.002

Frijda, N. H. (1986). *The emotions.* Cambridge University Press.

Hackett, E. J., Amsterdamska, O., Lynch, M., & Wajcman, J. (Eds.). (2007). *The handbook of science and technology studies* (3rd ed.). MIT Press.

Hall, S. (1980). Encoding/decoding. In S. Hall, D. Hobson, A. Lowe, & P. Willis (Eds.), *Culture, media, language* (pp. 128–138). Hutchinson.

IPBES. (2024). *Summary for policymakers of the assessment of transformative change.* Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. https://ipbes.net

IPCC. (2023). *Climate change 2023: Synthesis report.* Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Jobert, A., Laborgne, P., & Mimler, S. (2007). Local acceptance of wind energy: Factors of success identified in French and German case studies. *Energy Policy, 35*(5), 2751–2760. https://doi.org/10.1016/j.enpol.2006.12.005

Kahan, D. M., Jenkins-Smith, H., & Braman, D. (2011). Cultural cognition of scientific consensus. *Journal of Risk Research, 14*(2), 147–174. https://doi.org/10.1080/13669877.2010.511246

Kress, G. (2010). *Multimodality: A social semiotic approach to contemporary communication.* Routledge.

Kress, G., & van Leeuwen, T. (2001). *Multimodal discourse: The modes and media of contemporary communication.* Arnold.

Lewicka, M. (2011). Place attachment: How far have we come in the last 40 years? *Journal of Environmental Psychology, 31*(3), 207–230. https://doi.org/10.1016/j.jenvp.2010.10.001

Lorimer, J., Sandom, C., Jepson, P., Doughty, C., Barua, M., & Kirby, K. J. (2015). Rewilding: Science, practice, and politics. *Annual Review of Environment and Resources, 40,* 39–62. https://doi.org/10.1146/annurev-environ-102014-021406

Lotman, Y. (1990). *Universe of the mind: A semiotic theory of culture.* I.B. Tauris.

Manyani, A., Nsengiyumva, A., & Kizito, F. (2024). Mapping the evolution and trends of social-ecological systems research: A bibliometric review. *Ecology and Society*, 29(1), 33. https://doi.org/10.5751/ES-14694-290133

McCombs, M. E., & Shaw, D. L. (1972). The agenda-setting function of mass media. *Public Opinion Quarterly, 36*(2), 176–187. https://doi.org/10.1086/267990

McGinnis, M. D., & Ostrom, E. (2014). Social-ecological system framework: Initial changes and continuing challenges. *Ecology and Society, 19*(2), 30. https://doi.org/10.5751/ES-06387-190230

McNamara, K. E., & Prasad, S. S. (2014). Coping with extreme weather: Communities in Samoa and Fiji. *Regional Environmental Change, 14*(3), 1293–1304. https://doi.org/10.1007/s10584-013-1047-2

Mouffe, C. (2000). *The democratic paradox.* Verso.

Nisbet, M. C. (2009). Communicating climate change: Why frames matter for public engagement. *Environment: Science and Policy for Sustainable Development, 51*(2), 12–23. https://doi.org/10.3200/ENVT.51.2.12-23

Nöth, W. (1990). *Handbook of semiotics.* Indiana University Press.

Ostrom, E. (2009). A general framework for analyzing sustainability of social-ecological systems. *Science, 325*(5939), 419–422. https://doi.org/10.1126/science.1172133

Oswald, L. R. (2020). *Doing semiotics: A research guide for marketers at the edge of culture.* Oxford University Press.

Partelow, S. (2018). A review of the social-ecological systems framework: Applications, methods, modifications, and challenges. *Ecology and Society, 23*(4), 36. https://doi.org/10.5751/ES-10594-230436

Pasqualetti, M. J. (2011). Social barriers to renewable energy landscapes. *Geographical Review, 101*(2), 201–223. https://doi.org/10.1111/j.1931-0846.2011.00087.x

Pieroni, M. P. P., McAloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability: A review. *Sustainable Production and Consumption, 20,* 1–23. https://doi.org/10.1016/j.jclepro.2019.01.036

Rapaille, C. (2007). *The culture code: An ingenious way to understand why people around the world live and buy as they do.* Broadway Books.

Schäfer, M. S., & O'Neill, S. (2017). Frame analysis in climate change communication. In M. C. Nisbet & E. Markowitz (Eds.), *Oxford research encyclopedia of climate science.* Oxford University Press. https://doi.org/10.1093/acrefore/9780190228620.013.487

Walker, G., & Devine-Wright, P. (2008). Community renewable energy: What should it mean? *Energy Policy, 36*(2), 497–500. https://doi.org/10.1016/j.enpol.2007.10.019

White, D. D., Wutich, A., Larson, K. L., Gober, P., Lant, T., & Senneville, C. (2010). Credibility, salience, and legitimacy of boundary objects: Water managers' assessment of a simulation model in an immersive decision theater. *Science and Public Policy*, 37(3), 219–232. https://doi.org/10.3152/030234210X497726

Williams, R. (1977). *Marxism and literature.* Oxford University Press.

Wolsink, M. (2007). Wind power implementation: The nature of public attitudes and acceptance. *Energy Policy, 35*(5), 2705–2716. https://doi.org/10.1016/j.enpol.2006.12.004

Wolsko, C., Ariceaga, H., & Seiden, J. (2016). Red, white, and blue enough to be green: Effects of moral framing on climate change attitudes and conservation behaviors. *Journal of Experimental Social Psychology, 65,* 7–19. https://doi.org/10.1016/j.jesp.2016.02.005