Journal of Environmental Management 417 (2026) 130872



Contents lists available at ScienceDirect

Journal of Environmental Management

journal homepage: www.elsevier.com/locate/jenvman



Research article

Combining present suitability and future probability to identify forest rewilding opportunities in Europe

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ARTICLE INFO

Keywords:
Rewilding
Land-use scenarios
Suitability mapping
Forests
Nature restoration

ABSTRACT

Forests cover over 40% of EU land and provide critical carbon and biodiversity services, yet the vast majority remain under active management. While rewilding assessments have identified ecologically promising areas across Europe, they rarely distinguish forest rewilding (i.e., halting management in existing forests, allowing forests to develop toward naturally regulated states) from afforestation or abandonment-driven reforestation, and seldom test whether identified opportunities are consistent with plausible future land-use trajectories. Here, we develop a European-scale framework that jointly maps present-day suitability and future probability of forest rewilding. Suitability is assessed via a multi-criteria analysis aggregating spatial metrics representing elements of ecological value, feasibility, threat exposure. Probability is estimated by combining different scenario outcomes (2020–2050), spanning IPCC Shared Socio-economic Pathways and IPBES Nature Futures, into a cross-scenario agreement index. We estimated that high suitability areas cover 26.2% of Europe's forest and mosaic domain, clustering in mountain and upland systems. Although ~595,000 km^2 shows rewilding in at least one scenario, cross-scenario agreement is rare, revealing that most outcomes depend on governance choices rather than emerging spontaneously. Integrating both layers isolates priority areas where high suitability and probability coincide and broader landscapes where targeted policy could unlock opportunities for more natural and wild forests. These distinctions support the differentiated spatial targeting needed under the EU Biodiversity Strategy for 2030 and the Nature Restoration Regulation, helping identify where rewilding is best supported across divergent futures, where intervention could tip the balance, and where ecological constraints warrant caution.

1. Introduction

Covering 43.5% of the EU's land area (European Commission, 2021), forests act as the continent's largest carbon sink, annually offsetting around 10% of EU greenhouse-gas emissions via biomass storage (Migliavacca et al., 2025). Additionally, they are important biodiversity reservoirs; several threatened species depend on forest habitats, with old-growth and structurally complex forests supporting some of the richest assemblages (Berglund et al., 2021; O'Brien et al., 2021). Yet, 76.6% of European forests are classified as “forest available for wood supply” (FAWS), indicating ongoing active or potential management, leaving only a small fraction in old-growth or near-natural conditions (Forest Europe, 2020).

Rewilding has emerged as a strategy to restore self-sustaining ecosystems by reducing human pressures and allowing the re-establishment of natural processes and ecological networks (Perino et al., 2019). In Europe, the concept has evolved from large-scale wilderness recovery to context-sensitive applications, focusing on restoring predator–prey networks and fostering biodiversity-rich dynamic mosaics on abandoned land (Carver et al., 2025; Jepson et al., 2018). Rewilding is increasingly recognized in policy as a nature-based approach to deliver biodiversity and climate targets (Schmitz et al., 2023), supporting the Paris Agreement, the EU Green Deal, the EU Biodiversity Strategy for 2030, which targets land protection with emphasis on old-growth forests (European Commission, 2020), and the Nature Restoration Law, which introduces binding targets for forest structural diversity, deadwood, and natural regeneration (European Parliament and Council of the European Union, 2024). At the same time, rewilding initiatives can generate social controversy regarding land-use change and perceived loss of traditional landscapes (Faure et al., 2024; Mikołajczak et al., 2022), underscoring the need for transparent, spatially explicit information on where specific pathways are ecologically and socially feasible.

Forest rewilding and restoration pathways range from *reforestation* and *afforestation*, involving planting on cleared or previously non-

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https://doi.org/10.1016/j.jenvman.2026.130872
Received 1 May 2026; Received in revised form 13 August 2026; Accepted 31 August 2026
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forested land (Bozzano et al., 2014; FAO, 2020), to *proforestation*, which emphasizes management de-intensification of existing forests (Stanturf et al., 2024; Vizzarri, 2024), allowing them to mature, accumulate biomass, and develop structural complexity to maximise carbon and biodiversity benefits (Luyssaert et al., 2008; Moomaw et al., 2019). Among these, proforestation aligns most closely with the rewilding concept, as it prioritises the recovery of self-regulating natural processes over the attainment of a fixed reference state. As our assessment aims to capture a wider range of rewilding possibilities for forests, from spontaneous abandonment to planned de-intensification, we embrace forest rewilding as our guiding concept throughout, with proforestation standing as its most precise and closely matching expression.

Because suitable land is finite and multiple competing pressures (e.g., timber demand, agricultural use) constrain where rewilding is ecologically viable and practically achievable, spatial prioritisation is crucial. Two major gaps limit current assessments. First, studies identifying rewilding potential based on ecological conditions or large mammal recovery (Araújo and Alagador, 2024; Bergin et al., 2024; Kloibhofer et al., 2025) rarely distinguish forest rewilding from agricultural abandonment-driven reforestation, treating rewilding typologies generically (Ceauşu et al., 2015; Perpiña Castillo et al., 2021), despite evidence that halting forest management yields larger, more durable carbon and biodiversity gains than new plantations (Moomaw et al., 2019; Paillet et al., 2010). Second, rewilding mapping remains largely static (Araújo and Alagador, 2024; Bergin et al., 2024; Kloibhofer et al., 2025; Navarro and Pereira, 2012), and when scenarios are used they rely on single storylines or treat rewilding as an option rather than an objective (Ceauşu et al., 2015; Fayet and Verburg, 2023; Brown et al., 2024), whereas land-use trajectories are shaped by interacting drivers that vary by region and future (Levers et al., 2018; Ustaoglu and Collier, 2018).

Here, we aim to identify regions where current conditions across Europe's existing forested land may favour forest rewilding, allowing the dynamism of self-regulating natural processes to establish and persist. In parallel, we explore where future scenarios point to recurring transitions towards reduced-management regimes, creating opportunities for this process to emerge. Taken together, these regions can offer a more grounded picture of where forest rewilding could be readily achievable, as well as where it likely remains contingent on deliberate policy intervention. To this end, we develop a European-scale assessment combining multi-criteria suitability analysis with land-use scenario modelling, supporting conservation organisations, forest managers and policy-makers in targeting efforts under the EU Biodiversity Strategy for 2030, the Nature Restoration Law, and climate-mitigation goals.

2. Materials and methods

Our approach (Fig. 1, more detailed version in Fig. S1b) relies on the combination of two complementary methodological components: (i) a rewilding suitability assessment based on a multi-criteria analysis (MCA) of 13 metrics aggregated into a composite index, following the general approach adopted in previous studies on rewilding potential (Araújo and Alagador, 2024; Kloibhofer et al., 2025; Bergin et al., 2024), and (ii) dynamic land-use change modelling using an ensemble of exploratory scenarios to identify where forest management deintensification transitions recur across structurally different

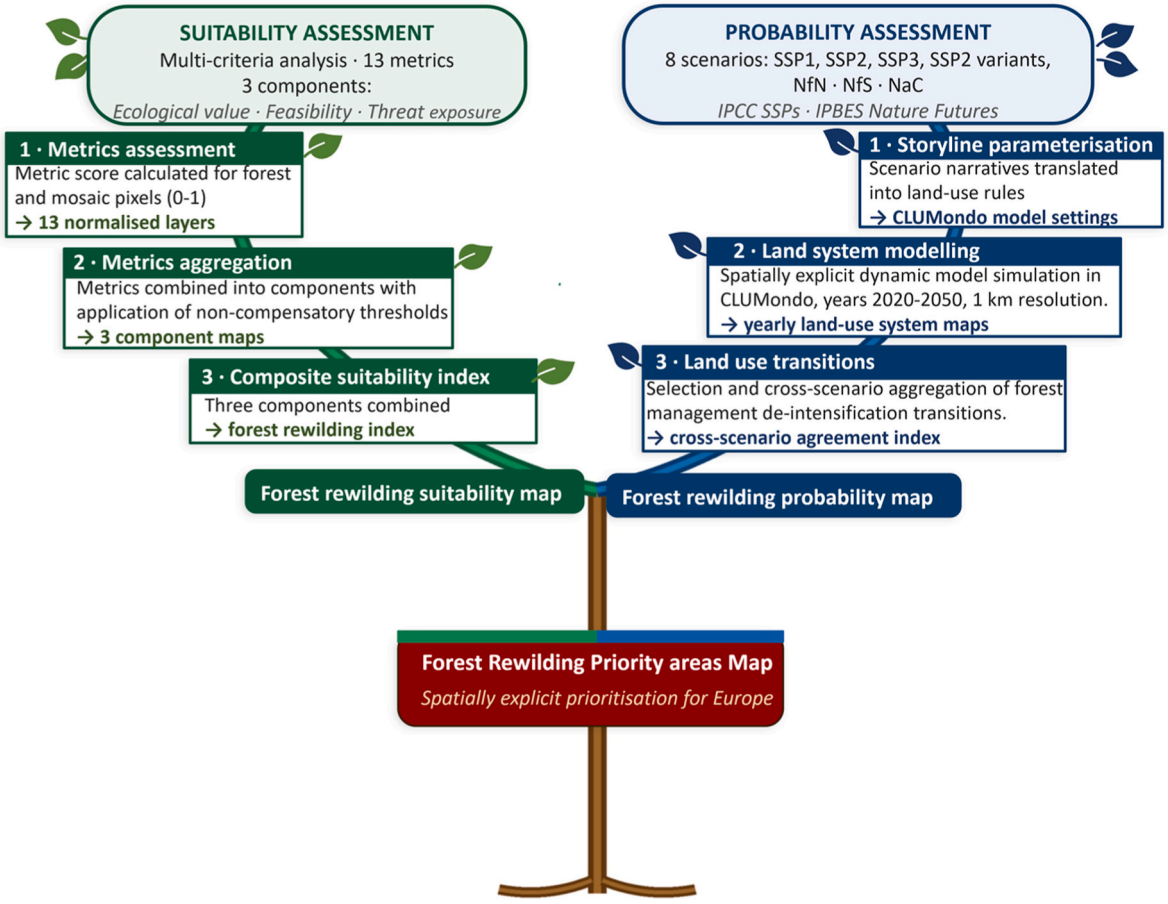


Fig. 1. Schematic flowchart reporting the main steps of the methodological approach. On the left side, the forest rewilding suitability assessment; on the right side, the land use change modelling process for the forest rewilding probability estimation. Acronyms: SSP-Shared socio-economic pathways; NfN-Nature for Nature; NfS-Nature for Society; NaC-Nature as Culture.

socio-economic futures, with cross-scenario agreement used as a qualitative indicator of probability, grounded in the uncertainty emerging from differences between the scenarios. The two layers were then integrated to identify forest rewilding priority areas.

The study area covers EU-27 (excluding Cyprus due to incomplete data coverage for several metrics), plus the United Kingdom, Norway, Switzerland and the Western Balkans (Serbia, Kosovo, North Macedonia, Albania, Montenegro, Bosnia and Herzegovina). The produced maps are at 1 km^2 resolution, projected to EPSG 3035 – ETRS89 extended LAEA Europa and aligned with the European reference grid.

2.1. Forest rewilding suitability

The forest rewilding suitability was mapped using a multi-criteria analysis of thirteen spatial metrics designed to identify where this process is both ecologically desirable and practically achievable, while accounting for key pressures. The individual metrics are normalised to a 0–1 scale, combined into three main components and finally aggregated into a composite suitability index. The Ecological value component captures the inherent ecological richness and heterogeneity of an area, identifying where forest rewilding would generate the highest conservation returns. The Feasibility component assesses whether rewilding is practically achievable under current landscape conditions, reflecting the structural and functional capacity of the landscape to support self-sustaining rewilding. The Threat exposure component highlights where external pressures may compromise long-term rewilding success, accounting for risks that could undermine forest recovery particularly during vulnerable early phases when restored systems are least resilient.

Our set of metrics (Table 1) was derived from European case-study documentation of implemented forest restoration and rewilding interventions (Rewilding Europe, 2019, 2020, 2023; Segar et al., 2022), following a structured mapping exercise that linked intervention types to component assignment and validated the final grouping against forest ecology and restoration literature (Fig. S1a; Table S1). Multicollinearity was assessed by Pearson correlations across normalised rasters (Table S2).

Table 1
Description of the metrics for assessing forest rewilding suitability. Details on sources and how each metric is calculated are reported in the Supplementary Information (Table S4), as well as full rationales for metrics choice and validation (Section S1.6).

Component	Metric	Description
Feasibility	Area	Size of continuous forest–mosaic patches.
	Elevation	Elevation range (max–min) within each 1 km cell.
	Slope	Slope class distribution per 1 km cell, favouring gentle to moderate slopes.
	Connectivity	Structural connectivity of forest–mosaic pixels at local (1 km) and broader (5 km) scales.
	Seed bank availability	Natural regeneration potential based on soil seed density/diversity and proximity to natural forest.
	Cover of buildup areas	Built-up/impervious surface cover as a negative pressure on rewilding.
	Road density	Road infrastructure density (m km^{-2}) as a proxy for disturbance pressure.
Ecological value	Diversity soil types	Shannon Diversity of soil types within 1 km buffer, reflecting edaphic heterogeneity.
	Diversity habitat types	Shannon Diversity of forest or mosaics habitat types within 1 km buffer.
	Potential for RedListed species	Potential presence of forest-specific IUCN Red Listed species.
	Presence large fauna	Presence of large-bodied fauna (>5 kg) as a proxy for trophic complexity.
Threat exposure	Wildfire regime	Combined fire danger and vulnerability indicating wildfire relevance for rewilding.
	Invasive species pressure	Pressure from forest and shrubland invasive alien species on natural regeneration and native biodiversity.

Sensitivity analysis: Because several components of the analysis rely on assumptions that introduce uncertainty into the final prioritisation, we conducted three complementary sensitivity analyses (analyses were carried out in Python v. 3.12). These tested metric thresholds and deal-breaker/enhancing-factor thresholds via Monte Carlo simulation, and the relative weighting of the three suitability components via alternative weighting schemes, in each case varying one parameter at a time while holding all others constant. Outputs from the three analyses were combined into a single uncertainty layer summarising cumulative sensitivity across the final priority map. Full methods, parameter settings, and results are reported in the Supplementary Information (Section S3).

Metrics aggregation and spatial analysis: Standard linear-additive MCA risks allowing high performance on some metrics to substitute for poor performance on others, potentially masking ecological trade-offs (Esmail and Geneletti, 2018; Steele et al., 2009). To reduce this risk, metrics were first aggregated separately within each component (ecological value, feasibility, and threat exposure) rather than pooled into a single score, limiting substitution across fundamentally different dimensions of suitability. Both within and across-component averaging was further constrained by explicit non-compensatory thresholds for conditions such as extreme fragmentation or infrastructure density, going beyond standard additive approaches (Esmail and Geneletti, 2018; Kiker et al., 2005) by treating non-compensability as a structuring principle rather than an afterthought.

Implemented in Python (v. 3.12), all 13 metrics were normalised to 0–1 (min–max), with pressure metrics inverted so high scores reflect low threat exposure. Equal-weight averaging within each component produced three component maps, subsequently averaged into a final composite index reclassified into low (0–0.50), moderate (0.51–0.75), and high (0.76–1.00) suitability classes for visualisation. Equal weighting was adopted at both levels (within components and across them), because no empirical basis exists for ranking the relative contribution of individual metrics or of the three components at continental scale, and differential weighting would embed context-specific normative judgements about which dimension should dominate. Alternative schemes are tested in the sensitivity analysis (Fig. S5–S6).

This MCA-informed decision tree structure served as the foundation to build a broader heuristic prioritisation framework, extended by a set of ecologically grounded rules to better account for aspects of practical and ecological complexity that metric averaging alone cannot capture. We integrated in our decision-tree: 1) Deal-breaker: pixels in forests or mosaics patches <10 km^2 (Sandström et al., 2023), with very high road density (≥1000 m km^{-2}; Meijer et al., 2018), or high impervious cover (≥25%; EEA, 2018) were set to zero, reflecting practical infeasibility despite other favourable scores. 2) Enhancing factor: co-occurrence of ≥1 large herbivore and ≥1 large carnivore applies a +10% adjustment, following the minimal trophic complexity criterion of Araújo and Alagador (2024), considered an adequate starting point for passive rewilding. The magnitude is kept intentionally small so it refines rather than dominates the composite score, limiting penalties where keystone species are naturally absent due to restricted ranges (e.g., *Alces alces*). As a binary threshold, it does not account for richness or composition, a simplification chosen to limit overlap with two existing metrics that already capture the species richness and diversity dimensions regardless of functional role: potential for Red-Listed species, and presence of large fauna. Threshold rationales are reported in the Supplementary Information (Table S3).

2.2. Forest rewilding probability

Future land-use trajectories were simulated with the CLUMondo land-system model, a dynamic, spatially explicit allocation framework representing land as discrete land-system types (e.g. forest management intensities, croplands, grasslands, mosaics, urban; see technical

documentation in Tita et al. (2025) for full class list). At each time step, CLUMondo allocates transitions to meet exogenously defined regional demands for agricultural products, livestock, wood, and urban land, constrained by biophysical suitability, spatial context and permitted conversion pathways (Eitelberg et al., 2015; Schulze et al., 2021; Van Asselen and Verburg, 2012, 2013). All eight scenarios were simulated at 1 km resolution for 2020–2050, using the 2020 land-system map as baseline (Sandström et al., 2023) and demand trajectories derived from the outputs of the GLOBIOM and CAPRI global economic and agro-economic land use models.

Scenarios implementation: We implemented eight scenarios capturing a spectrum of socio-economic developments, policy ambition and value perspectives on nature. Full scenario narratives and parametrisation details are reported in Penna et al. (2025). We modelled three SSP scenarios used in IPCC assessments (O'Neill et al., 2017; Riahi et al., 2017), translating the narratives into land-use rules, alongside two variants of the SSP2 baseline, and three Nature Futures Framework (NFF) scenarios (Nature for Nature, Nature for Society, Nature as Culture) developed in IPBES assessments. We have anchored these NFF scenarios in the SSP1 macro-context to achieve a consistent scenario framework. NFF scenarios differ in the relative value assigned to different facets of nature (IPBES, 2023; Pereira et al., 2020) (Table 2). These narratives are operationalised through targeted changes in protection strength, restoration targets and conversion preferences for thirteen different land use classes.

Deriving forest management de-intensification transitions and the consensus metric: Scenario outputs were processed in QGIS (v. 3.36.3) and Python (v. 3.12). For each scenario, 2020–2050 land-system trajectories were post-processed to detect forest rewilding-relevant transitions. We selected pixels where managed forests (intensive, very intensive, combined-objective) and partially forested mosaics (forest–shrub–grassland; forest–shrub–agriculture) transitioned to low intensity management close-to-nature forest. Forest rewilding probability was then approximated by summing the frequency of transitions across scenarios, yielding a consensus map (0–8). Scores were classified as low (0–2), moderate (3–4), or high (5–8): high scores indicate consistently modelled transitions across divergent futures, while low scores reflect stronger dependence on specific scenario assumptions. We define probability here in a specific sense: while individual scenario outputs are produced by a land-use model (CLUMondo) embedding empirically grounded probabilistic allocation (Van Asselen and Verburg, 2013), the scenarios themselves are exploratory rather than forecasts, so agreement across them does not imply greater forecasting capability. It does, however, constrain the uncertainty arising from scenario-specific assumptions, since regions where rewilding recurs across structurally divergent futures depend less on any single set of assumptions. Thus, we use probability here to mean likelihood grounded in low scenario uncertainty.

Integrated forest rewilding priority areas: To integrate the forest rewilding suitability with scenario-based probability outputs, the two reclassified layers (low, medium, high) were overlayed obtaining nine unique suitability–probability combinations. The resulting map identifies priority areas where high suitability coincides with high scenario agreement.

Table 2
List of the modelled scenarios with their narratives and main characteristics. RCP: Representative concentration pathway.

Scenario	Abbreviation	RCP	Core land-use narratives
SSP1– Sustainability	SSP1	2.6	Strong environmental regulation; strict protection of natural systems; compact urban development; intensification over expansion.
SSP2– Middle of the road	SSP2	4.5	Business-as-usual; moderate protection; continued agricultural intensification on existing land.
SSP3 – Regional rivalry	SSP3	7.0	Weak governance; relaxed protection; higher land-use pressure; easier conversion of natural systems; limitations brought by increased aridity.
SSP2–Technological innovation	SSP2-Tech	4.5	Yield improvements reduce land demand, opening scope for abandonment.
SSP2–Planned rewilding	SSP2-P.R	4.5	Abandonment and transitions toward low intensity and unmanaged forest favoured inside high rewilding suitability areas (from MCA).
Nature for Nature	NfN	2.6	Strict protection and large restoration areas; human-dominated land preferentially converted to low intensity and unmanaged forests and wetlands (land-sparing logic).
Nature for Society	NfS	2.6	Multifunctional, service-oriented landscapes; intensive agriculture shifted toward low-intensity uses, combined-objective forests, and mosaics.
Nature as Culture	NaC	2.6	Biocultural values prioritised; mosaic-dominated landscapes promoted; modified land steered toward low-intensity forest–agriculture systems.

3. Results

3.1. Forest rewilding suitability in Europe

Across Europe, high forest rewilding suitability covers 696,630 km^2 (26.2% of European forest and mosaic area; Fig. 2), concentrating in major upland forest systems: the Scandinavian mountain range, Finnish boreal forests, the Carpathians, Dinaric Alps, Pyrenees, Cantabrian Mountains, Scottish Highlands, and the Balkans. Moderate suitability (1,323,412 km^2; 49.8%) forms discontinuous belts around these cores, spanning temperate mixed forests of central Europe, the Baltic hemiboreal zone, and forested uplands of the Iberian interior and Apennines. Low suitability (635,555 km^2; 23.9%) dominates intensively used lowlands and agricultural plains such as the Po Valley, North European Plain, Paris Basin, and farmed lowlands of Poland and the Czech Republic, constrained by low ecological value, reduced feasibility from heavy infrastructure presence, and locally higher threat exposure.

Regional drivers differ markedly. High suitability across Scandinavian and Finnish boreal forests is driven primarily by strong feasibility in large continuous patches, with ecological value constrained by widespread intensive management. In the Baltic states and parts of Poland, high biodiversity value in mixed and broadleaf forests of the temperate-boreal transition zone is often offset by lower feasibility and more variable pressure conditions. Along the Atlantic and northern Iberian coast, mild humid conditions support structurally complex, well-connected forests with consistently high feasibility and moderate-to-high ecological value, though wildfire risk increases coastward, pointing to a more pronounced gradient in Mediterranean coastal ecosystems. The diverse montane forest communities in the Carpathians, Alps, and Dinaric mountains show the greatest internal coherence, scoring high across all three components simultaneously across temperate and continental climates. Across central European lowlands, intensive management and fragmentation drive uniformly low suitability under our non-compensatory rules. Regional patterns and spatial agreement across criteria are further illustrated in Fig. S2 and quantified in Table S5.

3.2. Forest rewilding probability in Europe

The probability map reveals a rather asymmetrical pattern across different European forest rewilding prospects: transitions are

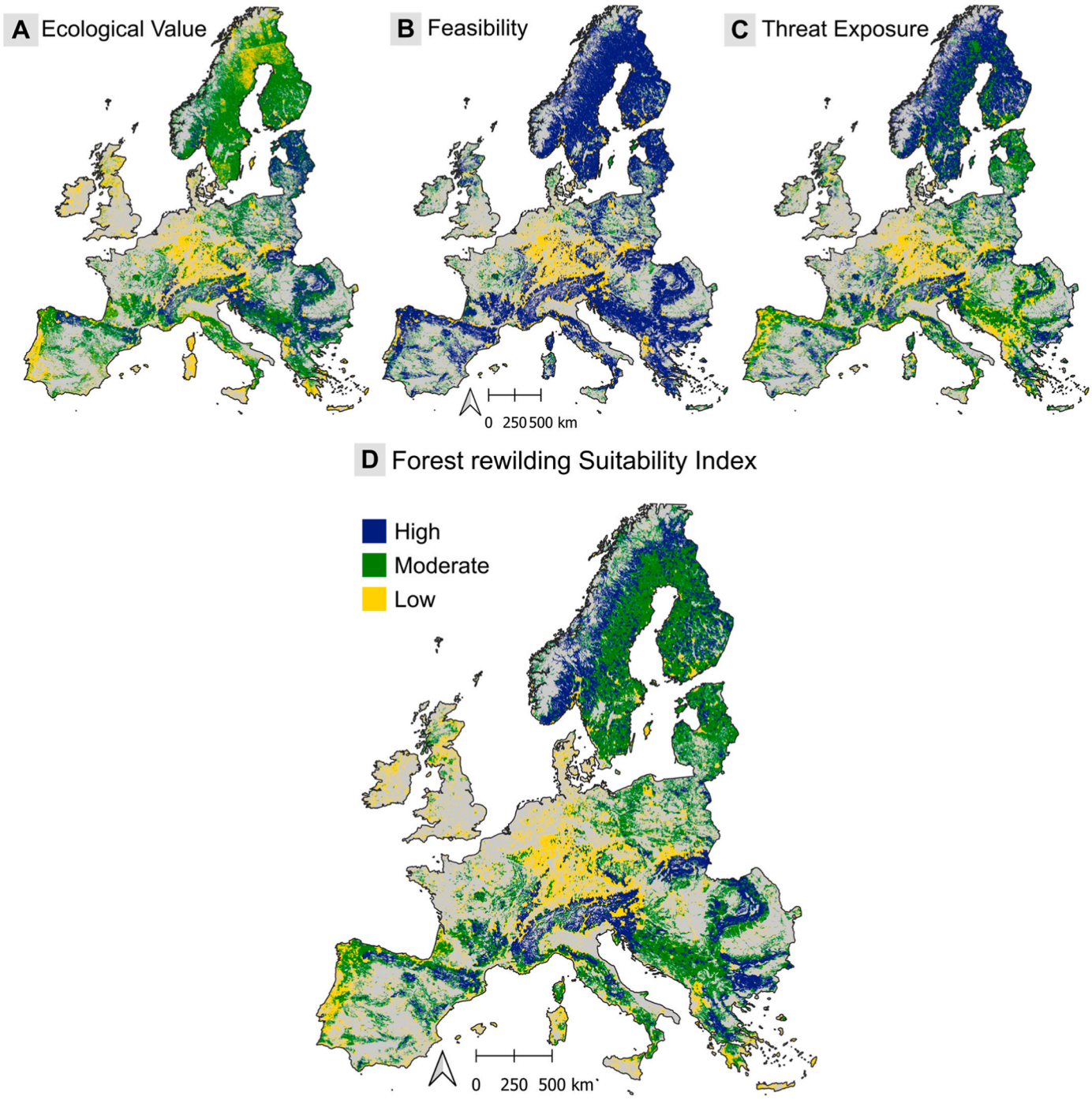


Fig. 2. Composite forest rewilding suitability index in Europe (d), based on Ecological value (a), Feasibility (b) and Threat exposure (c).

geographically widespread but high consistency across scenarios is rare (Fig. 3A). Forest rewilding probability is highest across Europe's main mountain systems, with the clearest concentrations in the alpine ecoregion along the Alps and Carpathian range, extending south-eastward through the Dinaric, Rhodope and Balkan ranges, and across Mediterranean systems including the Central Meseta, Sistema Ibérico, Apennines, and Greek uplands. In Atlantic and continental regions, high probability clusters around the Cantabrian ranges, Vosges, and uplands of central-southwestern Germany, where multifunctional and intensively managed forests are projected to undergo extensification, particularly near existing low-intensity stands. Lowland plains and boreal northern Europe show predominantly low agreement, reflecting consistent barriers from agricultural production and timber harvest pressures respectively. Despite ranking among the highest suitability areas for forest rewilding, Scandinavian boreal forests remain under intensive management in most scenarios, with moderate probability emerging only under strong environmental policy (e.g., Nature for Nature) or relatively low timber demand (e.g., SSP3). Further north, scattered high-probability regions in Sweden and Finland indicate where management abandonment generates fewer competing land-use conflicts across scenarios. In total, while ~22% of the forest and mosaic domain shows forest rewilding in at least one scenario, this share collapses to under 1% at high consensus, with full agreement found in only 1559 km^2.

Across scenarios, the balance between forest rewilding, forest gain, and forest loss varies markedly (Fig. 3B), reflecting how different

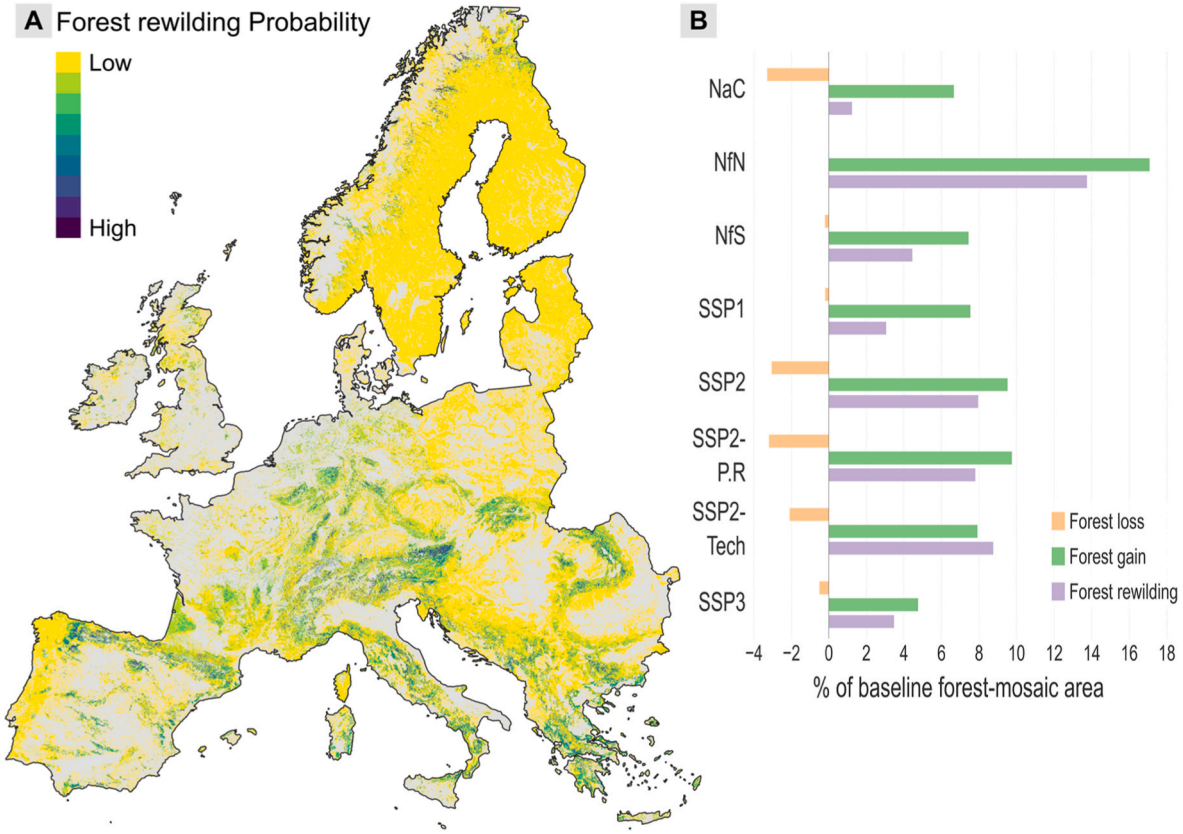


Fig. 3. Forest rewilding probability is displayed as A) Map of the level of agreement across scenarios. The more scenarios projected a transition to low intensity or unmanaged forest, the higher the probability, grounded in low cross-scenario uncertainty. Non-forest areas (outside the scope of the analysis) are shown in neutral beige. B) Land-use dynamics in European forests (2020–2050): forest loss, forest gain, and forest rewilding across scenarios (refer to Table 2 for full scenarios names). Diverging stacked bars report the percentage (%) of forest loss (forest → non-forest, shown as negative values; orange), forest gain (non-forest → forest; green) and forest rewilding (managed forest or forest–mosaic → low intensity or unmanaged forest; purple) for each scenario, relative to existing forests and mosaics area (total of 2,724,817 km^2, representing 10.91% of European land).

combinations of land demand pressure, protection strength, and spatial targeting produce divergent forest trajectories.

Despite sharing the same macro-economic context and sustainability ambition, the three Nature Futures scenarios differ considerably in forest rewilding outcomes, from ~14% under Nature for Nature to ~4.5% and ~1.2% under Nature for Society and Nature as Culture, reflecting how the same broad targets translate into fundamentally different land-use priorities depending on the value assigned to nature. The SSP scenarios, by contrast, diverge primarily in the level of pressure exerted on forests from multiple sources. SSP2 and its variants reach 7.9–8.8% rewilding alongside higher forest loss (2.1–3.0%) showing continued forest dynamism, driven by conflicting timber and crop demands under less restrictive conservation rules. SSP1 balances restoration effort across multiple objectives (e.g., nature restoration and protection, multifunctional landscapes) while maintaining relatively high wood demand, resulting in limited rewilding (3.1%) but very stable existing forests (0.2% loss). Finally, SSP3 and Nature as Culture occupy the lower end at 3.4% and 1.2% rewilding respectively, with the latter also recording the highest forest loss (3.3%), pointing to landscape reallocation rather than a directional shift toward management deintensification.

3.3. *Integrated forest rewilding priority locations*

Through the integrated representation of forest rewilding probability and suitability (Fig. 4), the most compelling priority regions are identified. Most of the high priority areas (represented by the co-occurrence of high probability and high suitability) exist as spatially concentrated pockets (dark green). The most coherent and large high priority clusters are located in the Austrian Alps, central Switzerland, eastern Italian Alps and Rhodopes mountains in Bulgaria, with additional more scattered regions along parts of the Apennines and southern Italy, the Vosges mountains in north-eastern France, Greek uplands and northern Iberia (Cantabrian mountains and Pyrenees). Smaller, more isolated high priority patches are also visible in sections of the Alps, Romanian Carpathians, Central Germany, Slovakia and northern Sweden. Conversely, the limited extent of high probability regions restricts high priority areas in most of Scandinavia, the Baltic states, and parts of the Carpathians, where suitability would otherwise be promising.

Notably, these high–high priority regions are embedded within much larger surrounding belts of high suitability with moderate probability regions (dark purple), which represent similarly promising opportunity areas: they share the strongest underlying suitability signal, while also showing a non-negligible tendency toward conversion across different futures. These belts are most evident in the surroundings of high-high regions, with additional widespread but scattered hotspots in the Spanish Pyrenees, the Massif Central in France, Slovakia, Slovenia and Romanian Carpathians, thereby outlining a broader set of landscapes where targeted local investigations could clarify how policy instruments, such as targeted subsidies or protected-area designation, might enable rewilding conversions.

Sensitivity testing indicates the prioritisation is broadly robust to the assumptions underlying the suitability layer. Half the forest and mosaic domain (49.8%) shows no directional shift, and elsewhere changes are limited: locations change class in only 7% of tested variants on average, never under all of them, and most frequently by a single class at the mid-

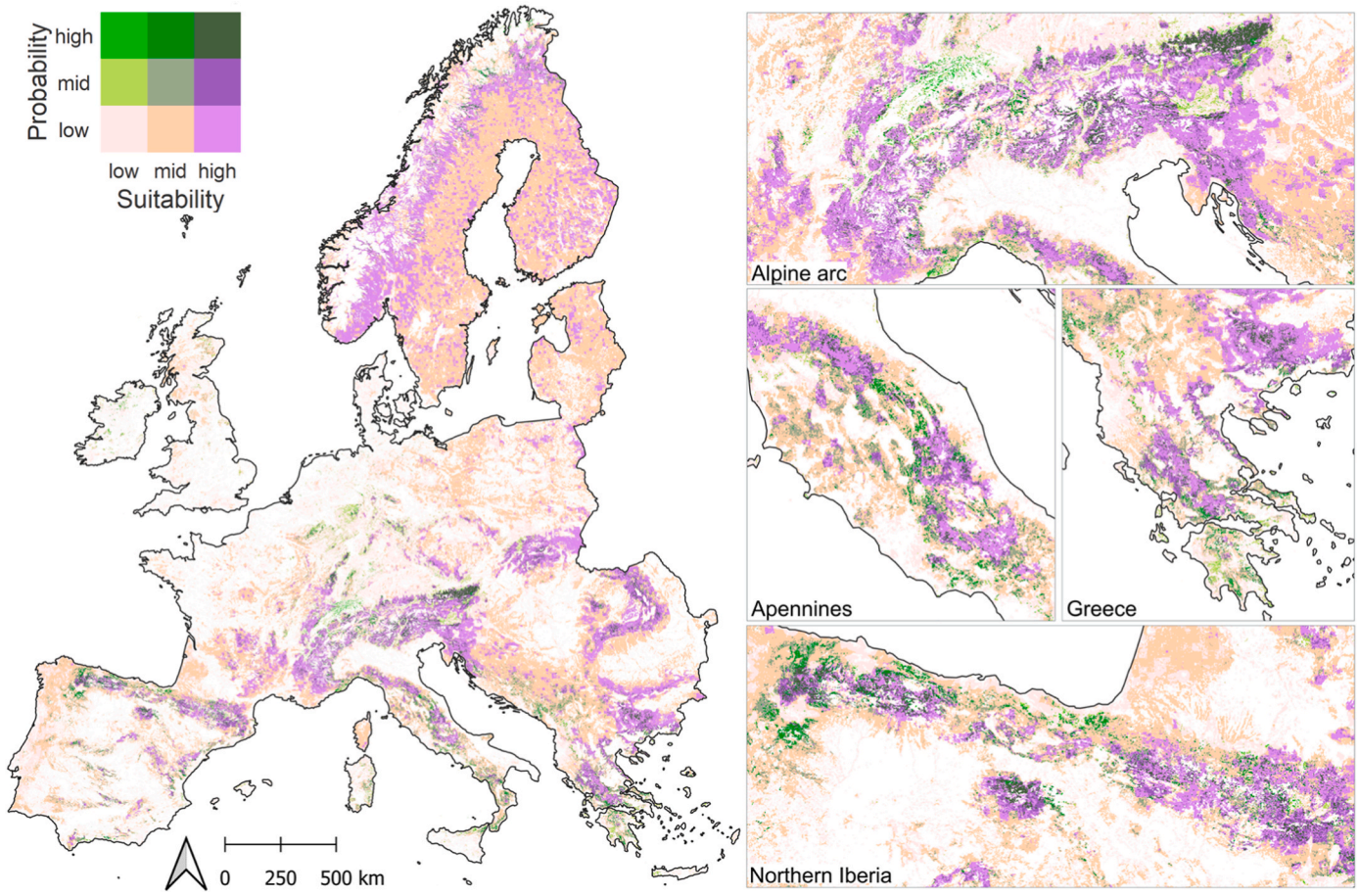


Fig. 4. Bivariate map integrating suitability and probability of forest rewilding. Non-forest areas (outside the scope of the analysis) are shown in neutral white. Details of the regions where significant high forest rewilding priority is concentrated are provided on the right: Alpine arc, The Apennines, Greece, northern Iberia.

high suitability boundary. High-probability, high-suitability areas are the most stable, with residual uncertainty falling mainly on intermediate-suitability classes (Fig. S3–S6).

4. Discussion

Our results show that suitability and probability of forest rewilding have strong spatial variations across Europe. At the same time, high suitability and high probability do not often overlap, indicating that, in the absence of guidance, forest rewilding may concentrate in areas without optimal conditions for long-term success.

High forest rewilding priority clusters in mountain and upland systems, where remoteness, lower land-use profitability, and reduced anthropogenic pressure (Dax et al., 2021; Navarro and Pereira, 2012) have allowed broadly continuous semi-natural stands with high biodiversity potential to develop (Anselmetto et al., 2024; Estreguil et al., 2012; Lasanta et al., 2017; Zlatanov et al., 2013). Here, passive forest rewilding could be triggered by management de-intensification or abandonment alone, achieving biodiversity and carbon gains at relatively low implementation cost (Faure et al., 2024).

The sharp decline from 26.2% high suitability to 0.9% high consensus probability, the latter indicating areas where rewilding transitions are more robust to varying scenario assumptions, highlights fundamental differences between the processes shaping each dimension, and their integration enriches our understanding of forest rewilding opportunities. Where both align (e.g., Austrian Alps, Rhodopes mountains), the case for prioritisation is well-supported; where they diverge, each reveals complementary information about constraints limiting long term success.

The Scandinavian boreal forests represent an extreme case of this divergence: despite high suitability, intensive timber production consistently suppresses rewilding across scenarios (Scherpenhuijzen et al., 2025), illustrating the broader continental pattern whereby, without active policy, forest transitions concentrate where production pressures are lowest rather than where suitability is highest. Forest rewilding outcomes depend not simply on overall sustainability ambition but on how that ambition translates into land-use priorities. This is most visible across the Nature Futures scenarios, which share the same macro-economic context yet produce markedly different forest rewilding geographies depending on the value assigned to nature, with rewilding aligning most closely with high-suitability areas under Nature for Nature (35% overlap), narrowing the gap between environmentally optimal and socio-economically plausible outcomes.

The concentration of priority areas in mountain systems is consistent with existing European rewilding assessments (Araújo and Alagador, 2024; Kloibhofer et al., 2025), which capture dimensions methodologically close to our suitability component. However, incorporating probability refines these hotspot maps: areas identified as highly suitable in prior studies, including Scandinavia, the UK, and the Baltic states, lose prominence once land-use dynamics are considered, suggesting that suitability-only assessments may overestimate passive rewilding's contribution to restoration ambitions. This is consistent with Brown et al. (2024), whose UK scenario simulations show very limited forest rewilding under baseline dynamics, with unmanaged forests emerging mainly as a land-sparing outcome.

Forest gains and rewilding remain concentrated in historically abandoned mountain and border regions even under less sustainability-oriented futures (Keenleyside and Tucker, 2010; MacDonald et al.,

2000), with SSP3 still showing a 3.48% expansion of low-intensity forests by 2050. What our forest rewilding lens adds is a perspective on the relaxation of forest management itself, a process that has received far less explicit attention than agricultural abandonment despite being an equally important and already occurring creator of rewilding opportunity, documented locally but lacking continental-scale mapping (Schnitzler, 2014; Mikołajczak et al., 2022; Navarro and Pereira, 2012), and one whose ecological potential for carbon and biodiversity gains surpasses that of newly afforested land (Moomaw et al., 2019; Wang et al., 2025).

European policy currently sends mixed signals for forest rewilding (Wang et al., 2025): the CAP and bioeconomy-oriented forest strategies favour timber mobilisation (Cuadros-Casanova et al., 2023; Pe'er et al., 2020; Winkel et al., 2022), while the Nature Restoration Regulation, EU Biodiversity Strategy, and LULUCF targets increasingly favour old-growth forest development (European Parliament and Council of the European Union, 2024; European Commission, 2020, 2021). Spatially explicit prioritisation is particularly valuable here, identifying where existing instruments already support forest rewilding and where adjustments are needed. High-suitability but moderate-probability areas are the most policy-relevant opportunity landscapes, where modest incentive or governance shifts could unlock disproportionate gains in carbon storage, and habitat quality (Erdozain et al., 2025; Martín-Forés et al., 2020; Wang et al., 2025). By contrast, high-probability but low-suitability areas, such as wildfire-exposed forests in parts of Greece or infrastructure-fragmented landscapes across central Europe, require policy focused on safeguarding and guiding the transition rather than actively promoting it. High-suitability areas with low probability conversely signal missed opportunities constrained by governance or market conditions, where spatially targeted instruments could tip the balance. Together, these distinctions can support strategic prioritisation under current EU nature restoration policies, by indicating where rewilding is ecologically grounded, delivers co-benefits, and can be spatially targeted. Our findings should be treated as decision support rather than prescription. At continental resolution, mapped classes are best used to prioritise where further regional diagnostics, stakeholder processes, and site-level evidence are most needed.

In addition, both methodological components carry choices that shape results. The MCA follows established conservation prioritisation practice (Esmail and Geneletti, 2018; Geneletti, 2007; Strassburg et al., 2020), with component-wise aggregation and non-compensatory thresholds reducing substitution risk (Esmail and Geneletti, 2018; Steele et al., 2009). These literature-derived thresholds carry their own uncertainty, but by design exclude only clearly unsuitable locations. The enhancing factor's binary co-occurrence design carries a related simplification: interpreted as a minimal trophic functionality condition, it does not distinguish richness or composition, so pixels with markedly different trophic complexity overall can receive comparable adjustments (see Methods, section 2.1). Nonetheless, sensitivity testing confirmed high-suitability geography is unaffected by threshold choice, with residual sensitivity confined to forest edges and lowland mosaics (Table S7; Fig. S4). Equal weighting within and across components implies equivalent importance of ecological value, feasibility, and threat exposure; alternative weighting schemes could shift spatial patterns (Huang et al., 2011). Testing this directly, the high-priority clusters proved broadly stable regardless of which component was weighted more heavily, with reclassification concentrated at the mid/high suitability boundary and largely confined to Fennoscandia. Most reweighting shifted pixels upward rather than downward, suggesting the equal-weight baseline is, if anything, conservative (Fig. S5–S6).

Given rising compound disturbances across European forests (Dudney et al., 2025; Mohr et al., 2025), the threat-exposure component incorporates current wildfire regime and invasive species pressure but not pest outbreaks, drought-induced mortality, or windthrow. Though European-scale vulnerability data exist for these disturbance (Forzieri et al., 2021), their relevance as threats to rewilding is unclear: windthrow can initiate rewilding-compatible succession, and structural complexity from rewilding itself is thought to buffer drought stress (Moomaw et al., 2019; Watson et al., 2018). Pest outbreaks are the clearest gap, since invasive insects are only partly captured (Polce et al., 2023) and native pests such as the spruce bark beetle are not. Social-acceptance and conflict metrics were also excluded, as their strongly context-specific nature risks false precision at continental scale (Jeanroy et al., 2026; Mikołajczak et al., 2022; Faure et al., 2024).

The use of eight scenarios is aimed at capturing uncertainty in plausible futures (Prestele et al., 2016; Hewitt et al., 2022). This reduces but does not remove uncertainty from scenario-specific assumptions: scenarios are treated as equally informative rather than equally likely, so high agreement reflects robustness in the locations subject to rewilding under differen scenario conditions rather than greater forecasting capability. In fact, many unforeseen drivers may lead to deviations from this range of futures. Specifically, the scenario ensemble does not include extreme or disruptive futures, and key disturbance drivers such as climate extremes and pests are not explicitly represented in the land-system model (Langenbacher et al., 2025). In addition, the EU-wide policy parametrisation in the model does not completely reflect national and local institutional contexts. Land-use model performance is inherently difficult to validate given the unpredictability of human decision-making and policy change (Gao et al., 2022). Consequently, the results should be used as a screening tool to inform regional assessment, stakeholder co-design, and on-the-ground validation, rather than as prescriptive policy guidance.

5. Conclusions

Across Europe's forest and mosaic domain, core areas with high suitability and high probability of forest rewilding are spatially concentrated in montane areas (e.g., Austrian Alps, the Vosges, central Switzerland, northern Spain and Greek uplands). The sharp decline from widespread suitability to rare cross-scenario consensus reveals that most rewilding outcomes in Europe are contingent on governance choices rather than structurally inevitable, underscoring the need for spatially targeted policy rather than blanket restoration ambitions. Near-term rewilding opportunities lie primarily in allowing existing managed forests to mature rather than expanding forest cover onto new land, a pathway that avoids direct competition with agricultural production and is more compatible with existing policy frameworks. In a European context where rewilding is often perceived as threatening productive landscapes, this distinction matters. At the same time, the frequent suitability-probability divergence shows that environmental opportunity alone does not translate automatically into land-use change. Read together, the two layers indicate not only where forest rewilding would be environmentally sound, but what each area may need: whether safeguarding a trajectory that converges across possible futures, or creating the conditions for one to emerge. Spatially targeted instruments under the EU Biodiversity Strategy and Nature Restoration Regulation can be further developed around this distinction.

CRediT authorship contribution statement

Margherita Penna: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Natalie Davis:** Writing – review & editing, Supervision, Conceptualization. **Peter H. Verburg:** Writing – review & editing, Supervision, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Diana Lucero Ramirez Mejia, Federico Riva, and Juan Antonio Hernández Agüero for expert input on conceptualisation, Tom Xaver Hackbarth for IPBES scenario parametrisation, and Davide Tita, Camille Venier-Cambron, and Niek Scherpenhuijzen for their work on scenario simulations. We also thank WILDCARD project coordinator Giorgio Alberti (University of Udine) for feedback on simulated scenario outputs. This research was funded by the European Union Horizon Europe programme under Grant Agreement no. 101081177 (WILDCARD Project).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2026.130872.

Data availability

Our results for the forest rewilding maps (both Suitability and Probability) are available through the DataverseNL repository (https://doi.org/10.34894/SXTT6U). In the same repository, the final and initial year (2020-2050) simulation results for the SSP2-Planned Rewilding scenario results are available. Individual scenario outputs for all the other scenarios, in the form of yearly land use system maps, are available at https://doi.org/10.34894/GBDS5T and https://doi.org/10.5281/zenodo.18833293. Code developed for the analysis will be shared upon request.

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