Acta Sci. Pol.
Silv. Colendar. Ratio Ind. Lignar. 25(2) 2026, 203–215
ACTA FORESTRY
www.forestry.actapol.net pISSN 1644-0722 eISSN 2450-7997 https://doi.org/10.17306/J.AFW.2026.2.14

ORIGINAL PAPER

Received: 02.11.2026
Accepted: 12.11.2026

UTILISATION OF TRADITIONAL FOREST BY-PRODUCTS (POTARCH) IN SUSTAINABLE RURAL DEVELOPMENT: A SCENARIO APPROACH

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ABSTRACT

Traditional forest by-products, including potash, tar, resin, and charcoal (PoTaRCh), represent an underutilised category of forest resources with potential relevance for the circular bioeconomy and sustainable rural development. This study explores alternative pathways for their future utilisation through a qualitative, literature-informed, scenario-based foresight approach. Drawing on academic literature and relevant policy frameworks, seven interconnected drivers were identified across ecological, socio-economic, technological, and governance dimensions. Their alternative configurations informed the construction of four illustrative scenarios: Conservation-Oriented, Bioeconomy Integration, Community-Based Rural Development, and Hybrid Models. A qualitative comparative framework was used to examine potential trade-offs related to technological innovation, market orientation, community participation, and sustainability risks. The analysis suggests that greater commercialisation may create economic opportunities while introducing additional ecological pressures, whereas community-oriented approaches may support traditional knowledge and local livelihoods but face limitations in scalability. Diversified utilisation strategies may offer opportunities to integrate economic, environmental, and socio-cultural objectives, although their feasibility depends on product-specific characteristics, local resource conditions, and institutional capacity. The proposed scenarios represent exploratory conceptual pathways rather than empirically validated outcomes, providing a framework for future research and context-sensitive forest management planning.

Keywords: PoTaRCh (forest by-products), forest management scenarios, circular bioeconomy, rural resilience; multifunctional forest management

INTRODUCTION

Forests provide a wide range of ecosystem services that extend beyond timber production, including biodiversity conservation, climate regulation, and the provision of non-timber forest products (NTFPs) that support rural livelihoods and cultural practices (Hun and Sarun, 2025; Truffer et al., 2025). In recent years, the concept of the forest-based bioeconomy has gained increasing importance, emphasising the sustainable use of biological resources to foster economic development while maintaining ecological integrity (Piplani and Smith-Hall, 2021; Luhas and Mikkilä, 2025). Within this framework, renewed attention has been directed toward underutilised forest resources and traditional practices that can contribute to multifunctional forest management and rural resilience. Traditional forest by-products such as potash, tar, resin, and charcoal (PoTaRCh) represent a specific category of NTFPs that historically played a significant role in

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local economies and everyday life in forest-dependent regions (Zborowska et al., 2024). These products were closely linked to traditional ecological knowledge and low-impact production systems adapted to local environmental conditions. However, processes of industrialisation and socio-economic transformation have led to the marginalisation or abandonment of many of these practices, resulting in a decline in both their economic relevance and cultural transmission (Shanley et al., 2016; Kim et al., 2017).

Despite their shared historical significance, potash, tar, resin, and charcoal differ considerably in terms of raw materials, production processes, technological requirements, market applications, and potential environmental impacts. Potash was traditionally obtained through the processing of wood ash, involving leaching and evaporation to recover potassium-rich compounds. In contrast, wood tar was produced through the thermal decomposition of woody materials, particularly resin-rich wood, and historically used for preservation and protective treatments. Resin production, in contrast, primarily involves the tapping of resin-producing trees, particularly conifers, and provides raw materials for products such as adhesives, coatings, varnishes, and other bio-based chemicals. Charcoal is produced through the carbonisation of woody biomass under oxygen-limited conditions and has traditionally been used as a fuel and in metallurgical processes. These differences also influence their environmental implications. While resin tapping may allow repeated harvesting without tree felling, inappropriate extraction practices can damage trees and affect forest health. Similarly, charcoal and tar production may generate atmospheric emissions and increase pressure on forest biomass resources, while potash production may involve substantial biomass consumption, energy requirements, and waste generation. Consequently, traditional or small-scale production should not automatically be regarded as environmentally sustainable, as its impacts depend on resource sourcing, production efficiency, extraction intensity, and management practices. In this study, PoTaRCh resources are considered collectively to develop a general conceptual framework for exploring alternative utilisation pathways, rather than to provide product-specific assessments of their technological, economic, or environmental performance.

At the same time, contemporary policy and research agendas, particularly within the European context, highlight the importance of circular economy principles, low-carbon development, and the revitalisation of rural areas (D'Amato et al., 2017; OECD, 2020). Forest-based bioeconomy strategies increasingly recognise the potential of NTFPs to diversify forest-based income, enhance value chains, and support sustainable development. Nevertheless, existing studies have predominantly focused on timber production or modern bio-based industries, while traditional forest by-products remain insufficiently explored as components of future-oriented forest management systems (Lovrić et al., 2020; Boyapati and Muthukumarappan, 2025). Moreover, the majority of research addressing PoTaRCh-related practices is oriented toward historical, ethnographic, or conservation perspectives (Zborowska et al., 2024; Martinho and Bróz-dowski, 2025). While these contributions are valuable, they often do not examine how such practices could be adapted, transformed, or reintegrated into contemporary socio-economic systems. In particular, there is a lack of forward-looking approaches that consider the role of uncertainty, innovation, policy dynamics, and market changes in shaping the future use of these resources.

In this context, scenario-based foresight approaches offer a useful tool for exploring alternative development pathways under conditions of complexity and uncertainty (Wiebe et al., 2018). By identifying key drivers of change and examining their interactions, such approaches enable the systematic exploration of possible futures and support strategic planning in resource management. Although scenario methods have been applied in forestry and environmental planning, their use in relation to traditional forest by-products and NTFPs remains limited.

This paper addresses this gap by examining how PoTaRCh resources could be integrated into future forest-based bioeconomy and rural development strategies. The main research question guiding the study is: *How could traditional forest by-products (PoTaRCh) be utilised under different future conditions of ecological, socio-economic, technological, and policy change?* By combining insights from the literature on NTFPs, forest bioeconomy, and traditional knowledge with a qualitative scenario development approach, the

study aims to identify potential pathways for the sustainable utilisation of these resources. In doing so, it contributes to a better understanding of how heritage-based practices can be reinterpreted within contemporary forest management frameworks.

METHODOLOGY

Research design and analytical approach

This study adopts a qualitative, literature-informed scenario-based foresight approach to explore alternative future pathways for the utilisation of traditional forest by-products (PoTaRCh) within the context of sustainable forest management, the circular bioeconomy, and rural development. Scenario planning was selected because the future utilisation of these resources depends on the interaction of multiple ecological, economic, technological, and institutional factors whose development cannot be predicted with certainty. The methodological approach was informed by the principles of exploratory scenario development described by Wiebe et al. (2018), emphasising the identification of influential drivers, consideration of critical uncertainties, and construction of internally coherent alternative futures. Rather than estimating the probability of particular outcomes, the study examines how different combinations of conditions may shape future resource utilisation strategies.

Identification and selection of key drivers

The identification of potential drivers was informed by a review of academic literature and relevant policy-oriented publications addressing non-timber forest products, forest-based bioeconomy development, traditional ecological knowledge, sustainable forest management, and rural livelihoods. The reviewed literature provided the conceptual foundation for identifying factors that could influence the future availability, production, commercialisation, and governance of PoTaRCh resources. Particular attention was given to research examining forest ecosystem services, bioeconomy development, traditional resource management practices, innovation, and the socio-economic challenges facing forest-dependent communities. The identified factors were organised into four interconnected analytical dimensions: (1) ecological conditions, (2) socio-economic dynamics, (3) technological development, and (4) governance and institutional support. This classification provided a framework for distinguishing the principal types of influences shaping potential future development pathways. The relative importance of the identified drivers was considered using three qualitative criteria:

1. Potential impact: the extent to which a driver could influence the ecological sustainability, economic viability, or socio-cultural relevance of PoTaRCh utilisation.
2. Future uncertainty: the extent to which the future direction or intensity of a driver could vary under different environmental, economic, technological, or policy conditions.
3. Relevance to PoTaRCh utilisation: the extent to which the driver directly or indirectly affects the feasibility of maintaining, adapting, or expanding traditional forest by-product activities.

The assessment was conceptual and interpretative rather than statistical. No numerical weighting or probabilistic ranking was applied. Instead, the drivers were considered in relation to the mechanisms described in the reviewed literature and their potential implications for alternative forest utilisation pathways. Six interconnected drivers were retained as particularly relevant: forest ecosystem health, demand for locally sourced and sustainable products, rural depopulation, innovation in processing techniques, policy support for small enterprises, and integration into bioeconomy strategies. These drivers represent the ecological resource base, market and demographic conditions, technological opportunities, and institutional environment influencing the future utilisation of PoTaRCh resources. To enhance the transparency of the driver identification and selection process, Table 1 summarises the six key drivers identified through the literature-informed analysis, together with their supporting academic sources, potential impacts on PoTaRCh utilisation, and principal sources of future uncertainty. This overview provides the analytical foundation for understanding how ecological, socio-economic, technological, and governance-related factors may influence alternative development pathways and informs the subsequent construction of the four scenarios.

Table 1. Literature-informed identification and qualitative assessment of drivers influencing PoTaRCh utilisation
Tabela 1. Identyfikacja i jakościowa ocena czynników wpływających na wykorzystanie PoTaRCh na podstawie analizy literatury

Driver	Supporting literature	Potential impact	Main source of uncertainty
Forest ecosystem health	Truffer et al. (2025); Hun and Sarun (2025)	Determines resource availability and ecological limits	Climate impacts, ecosystem degradation, conservation effectiveness
Demand for local and sustainable products	Boyapati and Muthukumarappan (2025); Piplani and Smith-Hall (2021)	Influences commercialisation and market opportunities	Consumer preferences and market development
Rural depopulation	OECD (2020); Shanley et al. (2016)	Influences labour availability and knowledge transmission	Demographic change and rural economic opportunities
Innovation in processing techniques	D'Amato et al. (2017); Lovrić et al. (2020)	Enables product diversification and value creation	Technological accessibility, investment, and adoption
Policy support for small enterprises	OECD (2020); Luhas and Mikkilä (2025)	Influences business viability and local participation	Future policy priorities and financial support
Integration into bioeconomy strategies	Piplani and Smith-Hall (2021); Lovrić et al. (2020)	Determines strategic recognition and development opportunities	Institutional commitment and policy implementation

Construction of alternative scenarios

The scenarios were developed through the qualitative exploration of alternative configurations of the identified drivers. The scenario-building process involved three analytical steps. First, the selected drivers were interpreted in terms of their potential influence on forest resource utilisation, including their implications for ecological pressure, market development, production technologies, institutional support, and local livelihoods. Second, alternative development conditions were considered by examining how various levels of market demand, technological innovation, government support, and community engagement could interact with ecological constraints. These conditions were treated as interconnected rather than independent factors, recognising that changes in one dimension may reinforce or constrain developments in others. Third, four contrasting but plausible configurations were synthesised into distinct forest utilisation models: (1) a Conservation-Oriented Model, characterised by limited commercialisation and an emphasis on ecological and cultural preservation; (2) a Bioeconomy Integration Model, characterised by strong technological development, market expansion, and institutional support; (3) a Community-Based Rural Development Model, emphasising local participation, traditional knowledge, and small-scale production; and (4) a Hybrid Model, combining diversified economic activities, technological adaptation, community participation, and multifunctional forest management.

The scenarios were constructed to illustrate different strategic orientations rather than mutually exclusive or exhaustive future outcomes. Their internal coherence was considered by examining whether the assumed combinations of drivers were consistent with the characteristics of each development model. Finally, the four scenarios were compared qualitatively in terms of innovation, market orientation, community participation, and sustainability risks. This comparative assessment was intended to identify potential trade-offs and strategic implications rather than establish an empirically validated ranking of the scenarios. It is important to emphasise that the four scenarios represent illustrative, literature-informed exploratory scenarios developed through qualitative synthesis and interpretation of the identified drivers. They were not derived from a formal quantitative foresight model or a probabilistic forecasting procedure. Instead, the scenario framework was designed to explore contrasting but plausible development pathways and to examine how alternative combinations of ecological, socio-economic, technological, and institutional conditions may influence PoTaRCh

utilisation. Consequently, the scenarios should be interpreted as conceptual analytical tools supporting strategic reflection and the identification of potential sustainability trade-offs, rather than empirically validated predictions of future forest resource utilisation.

Qualitative comparative assessment of scenarios

To facilitate a systematic comparison of the four alternative PoTaRCh utilisation scenarios, a qualitative evaluation framework was developed around four analytical dimensions: technological innovation, market orientation, community participation, and sustainability risk. These dimensions were selected because they reflect the principal differences between the scenarios and capture important economic, social, technological, and environmental implications of alternative forest resource utilisation pathways. Each scenario was assessed using an ordinal qualitative scale consisting of low, medium, and high levels. Intermediate categories (low–medium and medium–high) were used where scenario characteristics suggested a transitional position between two categories. The ratings were based on the defining assumptions and expected characteristics of each scenario, rather than on empirical measurements or quantitative indicators. Technological innovation refers to the extent to which new or improved processing techniques, product development, and technological adaptations are incorporated into PoTaRCh utilisation. A low rating indicates reliance on traditional methods with minimal technological change; a medium rating reflects selective or incremental innovation; and a high rating indicates substantial technological adaptation and diversification of production processes. Market orientation describes the extent to which PoTaRCh activities are directed toward commercial production and integration into broader value chains. Low market orientation indicates primarily non-commercial, educational, or conservation-related uses; medium orientation refers to localised commercial activities and small-scale market participation; and high orientation reflects extensive commercialisation and access to regional or international markets.

Community participation refers to the degree of local involvement in resource management, production activities, decision-making, and the transmission of traditional knowledge. A low rating indicates limited participation or primarily symbolic involvement; a medium rating reflects partial involvement in production or management; and a high rating represents substantial community ownership, active decision-making, and the integration of local knowledge into resource utilisation strategies. Sustainability risk refers to the potential for adverse ecological and socio-economic consequences arising from the implementation of each scenario. A low rating indicates relatively limited resource extraction and low expected environmental pressure; a medium rating reflects manageable but context-dependent risks associated with resource use and institutional coordination; and a high rating indicates greater potential for ecological degradation, resource overexploitation, or socio-economic imbalances in the absence of effective safeguards. The qualitative ratings were used as descriptive analytical categories to highlight differences and potential trade-offs among the scenarios. They do not represent empirically validated performance measures, and the evaluation dimensions were not aggregated into a composite sustainability score. Consequently, the comparative assessment does not establish a definitive ranking of the scenarios but provides a structured basis for discussing their potential advantages, limitations, and context-dependent suitability.

RESULTS: SCENARIO DEVELOPMENT OF POTARCH UTILISATION PATHWAYS

Based on the identified drivers of change and their interactions, four possible scenarios were developed to illustrate alternative pathways for the future utilisation of traditional forest by-products (PoTaRCh). These scenarios reflect different combinations of governance support, technological innovation, market demand, and community engagement, and are interpreted as distinct models of forest resource utilisation within the bioeconomy context. The analysis identified several critical drivers shaping the future of PoTaRCh utilisation. These drivers were grouped into four dimensions: ecological, socio-economic, technological, and governance-related (Table 2).

To clarify the relationship between the identified drivers and the development of alternative PoTaRCh utilisation pathways, Table 3 presents the qualitative configurations underlying the four scenarios. Each scenario represents a distinct combination of ecological

Table 2. Key drivers influencing PoTaRCh utilisation
Tabela 2. Kluczowe czynniki wpływające na wykorzystanie PoTaRCh

Dimension	Driver	Expected influence
Ecological	Forest ecosystem health	Resource availability
Socio-economic	Demand for local/sustainable products	Market expansion
Socio-economic	Rural depopulation	Labour constraints
Socio-economic	Community participation and traditional knowledge transmission	Influences local ownership, knowledge preservation, and continuity of traditional production
Technological	Innovation in processing techniques	Value-added products
Governance	Policy support for small enterprises	Business viability
Governance	Integration into bioeconomy strategies	Strategic importance

Source: authors.
Źródło: opracowanie własne.

conditions, socio-economic dynamics, technological development, and governance arrangements. Particular attention is given to differences in market demand, community participation, technological innovation, and institutional support, as these factors influence the extent to which traditional forest by-products may be

Table 3. Qualitative configurations of key drivers across the four PoTaRCh utilisation scenarios
Tabela 3. Jakościowe konfiguracje kluczowych czynników w czterech scenariuszach wykorzystania PoTaRCh

Driver	Conservation-oriented	Bioeconomy integration	Community-based	Hybrid
Forest ecosystem health	Stable; strict protection	Managed; potential extraction pressure	Locally managed; low-intensity use	Managed through multifunctional practices
Demand for local/sustainable products	Low	High	Moderate–high	Moderate–high
Rural depopulation	Continued demographic pressure	Potential employment-driven stabilisation	Potential stabilisation through local livelihoods	Potential stabilisation through diversified opportunities
Community participation and knowledge transmission	Limited; heritage-focused	Moderate; commercially oriented	High; traditional knowledge central	High; traditional and modern knowledge integrated
Innovation in processing techniques	Low	High	Moderate; incremental innovation	High; sustainability-oriented innovation
Policy support for small enterprises	Moderate; conservation-focused	Strong; commercialisation-focused	Moderate; locally targeted	Strong; integrated support
Integration into bioeconomy strategies	Limited	High	Partial; locally oriented	High; multifunctional integration

Note: The configurations represent qualitative assumptions derived from the conceptual characteristics of each scenario, rather than empirically measured conditions. The demographic entries describe possible implications rather than established future outcomes.
Uwaga: Przedstawione konfiguracje odzwierciedlają założenia jakościowe wynikające z koncepcyjnej charakterystyki poszczególnych scenariuszy, a nie warunki określone na podstawie pomiarów empirycznych. Zapisy dotyczące uwarunkowań demograficznych opisują możliwe konsekwencje, a nie ustalone przyszłe rezultaty.

preserved, commercialised, or integrated into diversified rural development strategies. The configurations are illustrative and conceptually derived rather than empirically observed or quantitatively estimated.

Scenario 1: Conservation-Oriented Model

This scenario is characterised by low market demand and limited technological innovation, combined with relatively stable ecological conditions and moderate institutional support focused primarily on conservation. In this context, PoTaRCh resources are treated predominantly as elements of natural and cultural heritage rather than as economically active forest products. Forest management practices emphasise strict sustainability principles, often within protected areas or regulated forest zones. The use of PoTaRCh is limited to demonstration purposes, educational programs, and heritage preservation initiatives, such as open-air museums or interpretative trails. Knowledge related to traditional production techniques is documented and occasionally transmitted through workshops or cultural events, but it is not widely applied in economic activities. The principal environmental advantage of this model is its limited intensity of resource utilisation and emphasis on controlled management practices, which may reduce pressures on forest ecosystems. Nevertheless, low extraction intensity does not necessarily eliminate environmental impacts, particularly in activities involving biomass combustion, thermal processing, or potentially harmful extraction techniques. However, the economic contribution to rural communities remains weak, and there is a risk of "museumisation", where traditional practices lose their functional relevance and become symbolic representations detached from everyday life. Over time, this may lead to further erosion of practical knowledge and reduced community engagement.

Scenario 2: Bioeconomy Integration Model

In this scenario, PoTaRCh resources are fully integrated into modern forest-based bioeconomy systems, driven by strong policy support, technological innovation, and growing market demand for sustainable and bio-based products. Advances in processing technologies enable the transformation of traditional by-products into high-value goods, such as natural chemicals, eco-materials, or energy-related products. Forest management becomes increasingly production-oriented, yet remains sustainability-regulated, with an emphasis on optimising resource use and developing efficient value chains. Small and medium enterprises, as well as larger industrial actors, play a key role in scaling production and connecting forest resources to regional and global markets. This model offers significant economic benefits, including job creation, diversification of forest-based income, and increased competitiveness of rural regions. However, it also introduces potential sustainability risks, particularly if resource extraction intensifies beyond ecological limits. Without adequate governance and monitoring, there is a danger of overexploitation, loss of biodiversity, or simplification of forest ecosystems. Additionally, while traditional knowledge may serve as an initial inspiration, it can become technologically transformed or partially detached from its original cultural context, raising questions about authenticity and heritage preservation.

Scenario 3: Community-Based Rural Development Model

This scenario is based on strong local engagement, moderate policy support, and growing societal demand for locally produced, sustainable goods. PoTaRCh resources are utilised primarily through small-scale, community-driven initiatives, including cooperatives, family businesses, and informal networks. Production processes rely heavily on traditional ecological knowledge, often combined with incremental innovations that improve efficiency without fundamentally altering traditional methods. Forest use is closely aligned with local ecological conditions, and resource extraction remains low-intensity and adaptive. The key strength of this model lies in its contribution to rural livelihoods, social cohesion, and cultural continuity. By embedding economic activities within local communities, it supports the preservation of knowledge and reinforces local identity. From an environmental perspective, small-scale and locally managed production may facilitate more adaptive resource management and closer monitoring of extraction activities. However, environmental performance depends on the specific production process, biomass sourcing, harvesting intensity, and application of appropriate safeguards. Traditional or community-based practices should therefore not

automatically be regarded as environmentally sustainable, particularly where inefficient combustion technologies, excessive resource extraction, or inadequate emission controls are involved. This model faces limitations in terms of economic scalability and market access. Limited financial resources, lack of infrastructure, and weak integration into broader value chains may constrain growth. As a result, while the model is socially and environmentally sustainable, its broader economic impact may remain localised.

Scenario 4: Hybrid model with diversified use

The hybrid scenario represents a balanced and integrative approach, combining elements of technological innovation, policy support, and strong community participation. In this model, PoTaRCh resources are utilised through diversified pathways, including bioeconomy applications, small-scale production, and complementary activities such as education, cultural interpretation, and tourism. Forest systems are managed as multifunctional landscapes, where economic, ecological, and cultural values are simultaneously considered. Traditional knowledge is not only preserved but also adapted and reinterpreted, often through collaboration between local communities, researchers, and entrepreneurs. Innovation occurs in ways that respect ecological limits and cultural authenticity. This scenario offers the highest level of system resilience and adaptability, as it does not depend on a single development pathway. It enables multiple value streams, reduces risks associated with market fluctuations, and enhances the overall sustainability of forest use. However, the implementation of this model requires complex governance structures, coordination among diverse stakeholders, and supportive institutional frameworks. Challenges include aligning different interests, ensuring equitable benefit distribution, and maintaining long-term ecological balance.

Product-specific applicability of the scenarios

Although the four scenarios provide a common conceptual framework for exploring future PoTaRCh utilisation pathways, their applicability may differ across potash, tar, resin, and charcoal due to variations in resource requirements, production technologies, market conditions, and environmental impacts. The scenarios should therefore be interpreted as alternative strategic orientations rather than standardised development models that can be applied uniformly to all four products. The Conservation-Oriented Model may be particularly relevant for preserving historically significant production techniques through educational demonstrations, cultural interpretation, and heritage-based activities. However, even small-scale demonstrations of traditional charcoal, tar, or potash production require appropriate environmental safeguards, particularly where combustion, emissions, or biomass consumption are involved.

The Bioeconomy Integration Model may offer opportunities for resin-based chemicals, technologically improved charcoal production, and selected specialised applications of potash and tar. Nevertheless, the feasibility of commercial expansion depends on product-specific technological requirements, market demand, resource availability, and environmental regulations. In particular, increased production intensity may create additional ecological pressures if biomass sourcing, extraction practices, and emissions are not adequately managed. The Community-Based Rural Development Model may support small-scale production, traditional knowledge transmission, and locally embedded value chains. However, the environmental sustainability of community-based activities cannot be assumed solely on the basis of their traditional character or limited production scale. Appropriate harvesting practices, resource monitoring, emission controls, and sustainable biomass management remain essential.

The Hybrid Model may provide opportunities to combine selected commercial applications with heritage preservation, education, tourism, and community-based initiatives. Its practical implementation would nevertheless require differentiated management approaches reflecting the ecological and technological characteristics of each product. For example, resin-based activities may emphasise sustainable tapping and tree health monitoring, whereas charcoal and tar production may require particular attention to biomass sourcing, processing efficiency, and emission reduction. The proposed scenarios represent general conceptual pathways whose environmental and socio-economic performance must be evaluated in relation to specific products, production systems, and regional conditions. Their applicability should not be interpreted as evidence that any particular scenario is inherently sustainable across all PoTaRCh resources.

Comparative analysis of scenarios

The qualitative comparison of the four PoTaRCh utilisation scenarios highlights several trade-offs between economic opportunities, ecological sustainability, community participation, and institutional requirements (Table 4). Rather than representing alternative pathways with universally predictable outcomes, the scenarios illustrate how different configurations of technological innovation, market orientation, and governance arrangements may influence the balance between resource utilisation and sustainability objectives.

A central trade-off concerns the relationship between economic diversification and ecological pressure. Greater commercialisation and technological development may create opportunities for value addition and market expansion, but these benefits may be accompanied by increased demand for forest resources, higher processing intensity, and additional environmental management requirements. Conversely, approaches prioritizing conservation and limited resource extraction may reduce certain ecological pressures while providing fewer opportunities for direct economic development. The extent of these trade-offs is likely to vary across individual PoTaRCh products and production systems. A second trade-off concerns the relationship between local participation and economic scalability. Community-based utilisation may strengthen the continuity of traditional knowledge, local decision-making, and the retention of economic benefits within rural areas. However, its potential contribution to broader regional development may be constrained by limited investment, technological capacity, and market accessibility. More commercially oriented approaches may overcome some of these limitations but could also increase dependence on external investors and reduce local control over resource utilisation.

The comparison further suggests that governance capacity represents a critical condition influencing the feasibility of all four scenarios. While relatively specialised management arrangements may support conservation-oriented or locally embedded activities, diversified utilisation pathways require coordination across multiple actors, economic activities, and environmental objectives. In this respect, the Hybrid Model may offer opportunities for balancing competing priorities, although its implementation could involve greater institutional complexity and coordination costs. Overall, the comparative assessment does not establish a definitive hierarchy among the scenarios.

Table 4. Comparative evaluation of PoTaRCh scenarios across key dimensions
Tabela 4. Ocena porównawcza scenariuszy wykorzystania PoTaRCh w odniesieniu do kluczowych wymiarów analiz

Scenario	Technological innovation	Market orientation	Community participation	Sustainability risk
Conservation-oriented	Low	Low	Low	Low
Bioeconomy Integration	High	High	Medium	Medium-High
Community-Based	Medium	Medium	High	Low-Medium
Hybrid Model	High	Medium-High	High	Medium

Note: Ratings represent conceptual assessments derived from the assumed characteristics of each scenario. Low, medium, and high indicate relative differences according to the qualitative criteria described in the Methodology section. Intermediate ratings indicate characteristics falling between adjacent categories. Sustainability risk refers to potential adverse ecological and socio-economic consequences, not to the probability of scenario occurrence. Ratings are illustrative and should not be interpreted as empirically validated outcomes.
Uwaga: Oceny mają charakter koncepcyjny i wynikają z przyjętych założeń dotyczących charakterystyki poszczególnych scenariuszy. Kategorie „niski", „średni" i „wysoki" wskazują na względne różnice określone na podstawie kryteriów jakościowych opisanych w sekcji „Metodyka". Oceny pośrednie odnoszą się do cech sytuujących się pomiędzy sąsiadującymi kategoriami. Ryzyko dla zrównoważonego rozwoju oznacza potencjalne negatywne konsekwencje ekologiczne i społeczno-ekonomiczne, a nie prawdopodobieństwo wystąpienia danego scenariusza. Przedstawione oceny mają charakter ilustracyjny i nie należy ich interpretować jako wyników zweryfikowanych empirycznie.

Instead, it identifies potential advantages, limitations, and trade-offs associated with different strategic orientations. The qualitative ratings presented in Table 3 reflect the assumed characteristics of the scenarios rather than empirically measured performance. Consequently, the relative suitability of each pathway must be evaluated in relation to local ecological conditions, socio-economic characteristics, institutional capacity, and forest management priorities.

DISCUSSION AND CONCLUSION

Context-dependent suitability of alternative PoTaRCh utilisation pathways

The proposed scenario framework contributes to discussions on sustainable forest management and the circular bioeconomy by examining how traditional forest by-products may be incorporated into alternative development pathways. Rather than treating PoTaRCh utilisation as a uniform development opportunity, the scenarios illustrate how different combinations of ecological conditions, technological capabilities, market opportunities, and institutional arrangements may shape the feasibility of future resource use. This perspective complements existing research on forest-based bioeconomy development and the multifunctionality of forest resources (Piplani and Smith-Hall, 2021; Lovrić et al., 2020), while drawing attention to traditional production practices that have received comparatively limited consideration in forward-looking forest management discussions. An important implication is that the suitability of individual scenarios depends on the characteristics and development priorities of specific forest-dependent regions. Conservation-oriented approaches may be particularly appropriate in ecologically sensitive areas, protected landscapes, or regions where safeguarding traditional knowledge and cultural heritage represents a primary management objective. In such contexts, the potential value of PoTaRCh resources may lie less in commercial production and more in education, cultural interpretation, and the preservation of historical practices. However, conservation-oriented strategies may offer limited direct economic opportunities unless complemented by other rural development activities.

Bioeconomy integration may be more feasible in regions characterised by established processing infrastructure, technological capabilities, access to investment, and demand for bio-based products. Under these conditions, traditional forest by-products could potentially contribute to product diversification and the development of specialised value chains. Nevertheless, commercial expansion would require careful consideration of ecological limits, sustainable biomass sourcing, production-related emissions, and regulatory requirements. The economic opportunities associated with technological modernisation should therefore be assessed alongside their environmental and social implications. Community-based approaches may be particularly relevant in rural regions where traditional ecological knowledge remains accessible and local organisations have the capacity to participate in resource management and production activities. Such approaches could support livelihood diversification, cultural continuity, and locally retained economic benefits. However, their feasibility depends on access to financial resources, organisational capacity, market connections, and the willingness of community members to participate. Furthermore, traditional or small-scale production should not automatically be considered environmentally sustainable, as its impacts depend on the specific resource, production technology, and management practices.

The Hybrid Model represents a potentially useful conceptual option where local institutions can coordinate multiple resource utilisation activities and balance commercial, ecological, and socio-cultural objectives. By combining selected bioeconomy applications with heritage preservation, community participation, and complementary activities such as education and tourism, this approach could offer opportunities for diversification and adaptive management. However, such benefits remain hypothetical and may be offset by coordination costs, institutional complexity, and competing stakeholder interests. Accordingly, the Hybrid Model should not be interpreted as universally preferable, but as one possible development pathway whose suitability depends on local governance capacity and the availability of appropriate resources.

Implications for forest planning and policy

Although the proposed scenarios provide a conceptual basis for exploring alternative PoTaRCh utilisation pathways, their application in practical forest planning

would require additional context-specific information. First, reliable assessments of forest resource availability, ecosystem condition, and sustainable harvesting limits would be necessary to determine whether specific production activities could be supported without compromising ecological integrity. Such assessments should consider differences among potash, tar, resin, and charcoal, particularly regarding biomass requirements, extraction methods, processing technologies, and potential environmental impacts. Second, economic feasibility assessments would be required to examine production costs, technological requirements, market demand, infrastructure availability, and opportunities for value-chain development. These considerations are particularly relevant when evaluating whether traditional production activities can be adapted to contemporary bioeconomy systems or remain primarily suitable for small-scale and heritage-oriented applications.

Third, the social and institutional context should be examined through stakeholder engagement and the assessment of local governance capacity. Understanding community interests, traditional knowledge availability, ownership arrangements, access to forest resources, and potential conflicts among stakeholders would be essential for identifying socially acceptable development pathways. Participatory approaches could also help determine which objectives local communities and forest managers consider most important, including biodiversity conservation, income diversification, employment, and cultural heritage preservation. Finally, environmental assessments should address the potential impacts of individual PoTaRCh production systems rather than assuming that traditional practices are inherently sustainable. Depending on the product and production process, relevant considerations may include harvesting intensity, tree health, biomass consumption, energy efficiency, atmospheric emissions, and waste generation. Integrating these assessments into forest management planning would help identify the safeguards necessary for implementing different utilisation pathways.

From a policy perspective, the proposed framework suggests that support for traditional forest by-products should be differentiated according to regional conditions and development objectives. Rather than promoting a single model of resource utilisation, policy instruments could facilitate locally appropriate combinations of conservation measures, technological support, market development, and community participation. This approach is consistent with broader perspectives on multifunctional forest management and rural well-being, which emphasise the need to consider economic, ecological, and social objectives together (OECD, 2020; Piplani and Smith-Hall, 2021).

Methodological limitations and future research

Several limitations should be acknowledged when interpreting the proposed scenario framework. First, the study adopts an exploratory, literature-informed qualitative approach, and the four scenarios represent conceptual constructions rather than empirically observed or statistically forecast development trajectories. The assumed relationships between drivers and scenario characteristics have not been independently validated through empirical testing or formal expert elicitation. Consequently, the scenarios should be understood as analytical tools for exploring possible futures rather than predictions of likely outcomes. Second, the qualitative comparison of scenarios relies on interpretative ratings reflecting their assumed characteristics. Although explicit evaluation criteria improve transparency, these ratings do not constitute independently measured indicators of economic performance, ecological sustainability, social outcomes, or resilience. The analysis therefore does not establish the relative effectiveness or overall superiority of any particular scenario. Different evaluation criteria or policy priorities could lead to different interpretations of their suitability. Third, the study considers PoTaRCh resources at an aggregated level despite substantial differences among potash, tar, resin, and charcoal in terms of production processes, technological requirements, market opportunities, and environmental impacts. This generalisation is appropriate for developing an initial conceptual framework but limits the direct applicability of the scenarios to specific products and locations.

Fourth, the framework does not incorporate detailed spatial, economic, or institutional data that would be necessary for operational forest planning. Factors such as local resource availability, infrastructure, market accessibility, land tenure arrangements, community capacity, and regulatory conditions may substantially influence the feasibility of individual pathways. Future research could address these

limitations through comparative regional case studies, stakeholder-based scenario workshops, and product-specific environmental and economic assessments. Participatory foresight methods, including Delphi studies or structured expert consultations, could help refine the identified drivers and evaluate the plausibility of alternative scenario configurations. In addition, multi-criteria decision analysis could support more systematic comparisons of development options under different policy priorities. Life cycle assessment and economic feasibility studies could provide evidence regarding the environmental and commercial implications of specific PoTaRCh production systems. Such approaches would contribute to transforming the proposed conceptual framework into a more operational decision-support instrument for sustainable forest management and rural development.

ACKNOWLEDGEMENTS

This research was supported by the grant Cost Action 22155- EU-PoTaRCh: Network for Forest By-products (Charcoal, Resin, Tar, Potash). The findings of this study were presented through oral presentation at the Third General meeting in Brașov, Romania held from 17 to 19 February 2026.

DECLARATIONS

Data statement

All data supporting this study has been included in this manuscript.

Ethical approval

Not applicable.

Competing interests

The authors declare that they have no conflicts of interest.

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WYKORZYSTANIE TRADYCYJNYCH PRODUKTÓW UBOCZNYCH GOSPODARKI LEŚNEJ (POTARCH) W ZRÓWNOWAŻONYM ROZWOJU OBSZARÓW WIEJSKICH: PODEJŚCIE SCENARIUSZOWE

ABSTRAKT

Tradycyjne produkty uboczne gospodarki leśnej, w tym potaż, dziegieć, żywica i węgiel drzewny (PoTaRCh), stanowią kategorię niedostatecznie wykorzystywanych zasobów leśnych, które mogą odgrywać istotną rolę w rozwoju biogospodarki o obiegu zamkniętym oraz zrównoważonym rozwoju obszarów wiejskich. Celem niniejszego badania jest analiza alternatywnych kierunków ich przyszłego wykorzystania z zastosowaniem jakościowego podejścia prognostycznego opartego na analizie literatury i scenariuszy rozwoju. Na podstawie literatury naukowej oraz odpowiednich ram politycznych zidentyfikowano siedem wzajemnie powiązanych czynników determinujących przyszłe kierunki rozwoju, obejmujących aspekty ekologiczne, społeczno-ekonomiczne, technologiczne i instytucjonalne. Ich alternatywne konfiguracje posłużyły do opracowania czterech przykładowych scenariuszy: zorientowanego na ochronę zasobów, integracji z biogospodarką, rozwoju obszarów wiejskich opartego na społecznościach lokalnych oraz modeli hybrydowych. Zastosowano jakościowe ramy analizy porównawczej w celu zbadania potencjalnych kompromisów i zależności pomiędzy innowacjami technologicznymi, orientacją rynkową, udziałem społeczności lokalnych a zagrożeniami dla zrównoważonego rozwoju. Wyniki analizy wskazują, że zwiększona komercjalizacja może stwarzać nowe możliwości gospodarcze, jednocześnie prowadząc do wzrostu presji na środowisko przyrodnicze. Z kolei podejścia ukierunkowane na społeczności lokalne mogą sprzyjać zachowaniu tradycyjnej wiedzy i wspierać lokalne źródła utrzymania, jednak ich możliwości rozwoju na większą skalę mogą być ograniczone. Zróżnicowane strategie wykorzystania tych produktów mogą umożliwiać łączenie celów gospodarczych, środowiskowych i społeczno-kulturowych, choć ich wykonalność zależy od specyfiki poszczególnych produktów, lokalnych uwarunkowań zasobowych oraz potencjału instytucjonalnego. Zaproponowane scenariusze przedstawiają eksploracyjne, koncepcyjne ścieżki rozwoju, a nie rezultaty zweryfikowane empirycznie. Stanowią one ramy analityczne dla przyszłych badań oraz planowania gospodarki leśnej uwzględniającego specyfikę lokalnych uwarunkowań.

Słowa kluczowe: PoTaRCh (produkty uboczne gospodarki leśnej), scenariusze gospodarki leśnej, biogospodarka o obiegu zamkniętym, odporność obszarów wiejskich, wielofunkcyjna gospodarka leśna