Science for the Carpathians (S4C) Research Agenda 2030



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[1] You can find all previous versions of the S4C Research Agenda here: https://carpathianscience.uj.edu.pl/research-agenda

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Introduction: (Re)shaping a common vision on the future of Carpathian research

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Context and rationale

The Carpathians are one of Europe's largest continuous mountain systems, spanning seven countries—the Czech Republic, Hungary, Poland, Romania, Serbia, Slovakia, and Ukraine.[2] They form a transboundary socio-ecological region of exceptional biodiversity, extensive forests, semi-natural grasslands and freshwater ecosystems, together with culturally diverse landscapes shaped by centuries of human use. These ecosystems provide essential services, including water regulation, soil protection, carbon storage and climate regulation, while supporting the livelihoods and cultural heritage of mountain communities. At the same time, the region faces interconnected pressures from climate change, land use change and abandonment, habitat fragmentation, infrastructure development, demographic and economic disparities, and the direct and indirect impacts of the Russian military aggression against Ukraine (Mitrofanenko et al., 2024; Melnykovych et al., 2026b). The transboundary and interconnected nature of these challenges makes coordinated regional action essential. The Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention, 2003), adopted by the seven Carpathian countries in 2003, provides the treaty basis for such regional cooperation.

Science for the Carpathians (S4C) is a regional interdisciplinary network and science–policy–practice platform that brings together researchers, practitioners and policymakers working on sustainable development in the Carpathian region. The S4C network, established in 2008, aims at defining research priorities for the Carpathian region and linking research, policy, and practice (Ostapowicz & Sitko, 2009; Kozak et al., 2011; Björnsen Gurung, 2013). Through its Steering and Executive Committees, the network promotes knowledge exchange, collaboration and joint priority-setting across countries, disciplines and sectors. A central role of S4C is to strengthen the connection between scientific knowledge and the needs of policy and practice in addressing complex and interconnected challenges facing the Carpathians. Continuous dialogue within the S4C community and across the science–policy–practice interface has shown that a key challenge for sustainable development in the Carpathians is not simply a lack of research. Rather, there is a need for stronger interdisciplinary and transdisciplinary approaches that systematically address interactions among environmental change, governance, socio-economic transformations and evolving geopolitical realities, while supporting the co-production of actionable knowledge relevant to policy and practice.

Since its establishment, S4C has worked closely with the Carpathian Convention and its institutional bodies. Drawing in particular on the outcomes of the **Forum Carpaticum** conferences (see the following section) and other S4C activities, the network provides scientific input and recommendations to the Convention Secretariat,

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[2] According to certain delineations, the geographical extent of the Carpathian ecoregion encompasses parts of Austria (Björnsen Gurung et al., 2009; Kozak et al., 2013)

its Working Groups, the Carpathian Convention Implementation Committee (CCIC) and the Conference of the Parties (COP) (e.g. Mitrofanenko et al., 2025). This collaboration provides an important mechanism for linking regional research priorities with policy development and implementation across the Carpathian region (Mitrofanenko et al., 2024).

Science for the Carpathians (S4C) Research Agenda

The Science for the Carpathians (S4C) Research Agenda 2030 (the "Agenda") provides a Science–policy–practice framework and outlines important research questions and topics to advance sustainable development in the Carpathian region and support implementation of the Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention, 2003). Building on the S4C Research Agenda 2022–2030 (Cudlín et al., 2022), this updated Agenda identifies priority knowledge needs, promotes research on interdisciplinary and transdisciplinary collaboration, and aims to strengthen the contribution of research to evidence-informed policy development and implementation. This Agenda intends to provide a shared reference for researchers, policymakers, practitioners, funding organisations, civil-society actors and local communities working across the Carpathian region. The S4C role is to link research, policy and practice by providing scientific input to the Convention Secretariat, its Working Groups, the Carpathian Convention Implementation Committee and the Conference of the Parties (Science for the Carpathians, 2012).

This Agenda responds to the current period of accelerating, interconnected environmental, socioeconomic, institutional and geopolitical change. Climate change, biodiversity loss, changes in water regimes and natural hazards, forest disturbance, land-use transitions, demographic decline, unequal access to services, energy and infrastructure development, and the consequences of the Russian war against Ukraine increasingly interact across sectors, borders and governance levels (Melnykovych et al., 2026a Melnykovych et al., 2026b). These pressures can generate compound and cascading risks that cannot be adequately understood or addressed through isolated research projects or sector-specific policy responses. The updated Agenda therefore adopts a systems perspective, while recognising the considerable diversity of national, subregional and local socio-ecological contexts across the Carpathians.

This document is designed not only as a catalogue of scientific topics and research questions, but also and even more so as a **Science–policy–practice research agenda** that connects knowledge production with policy needs, institutional learning and action. The purpose of the Agenda is to guide future research initiatives and to strengthen regional cooperation by outlining important topics, inform funding priorities in support of the implementation of the Carpathian Convention and its Protocols, and to encourage co-production of knowledge among researchers, policymakers, practitioners and communities.

This updated S4C Research Agenda 2030 retains the broad thematic foundation established by the S4C Research Agenda 2022–2030, while incorporating scientific advances, emerging policy priorities and recommendations developed by recent Forum Carpaticum processes (see Mitrofanenko et al., 2024 and the following section) and through cooperation with the Carpathian Convention. Forum Carpaticum 2023 brought increased attention to critical transitions, uncertainty, resilience, the consequences of the war against Ukraine on the

entire region and needs for post-war recovery initiatives and cooperation (Wojtowichz et al., 2023). Forum Carpaticum 2025 further strengthened the focus on empowering communities to act for change via partnerships and adaptive governance and generated interdisciplinary recommendations for the Carpathian Convention (Csabay et al., 2025; Mitrofanenko et al., 2025). The updated Agenda consequently places greater emphasis on vulnerability, adaptive governance, resilience, social innovation, knowledge co-production and empowerment, institutional capacity and stronger science–policy–practice interfaces.

The S4C Research Agenda 2030 encompasses **22 thematic research domains** addressing the environmental, social, economic, cultural and institutional dimensions of sustainable mountain development in its dedicated chapters : climate change; water resources and management; natural hazards and risks; land-use and land-cover change; integrated landscape management and governance; forest systems; conservation and biodiversity; ecosystem services and human wellbeing; urban and rural development; green energy and energy efficiency; tourism and human–nature interactions; cultural heritage and traditional knowledge; pastoralism; education for sustainable development; participatory research and knowledge co-production; social innovation; addressing vulnerability; data management; mapping; legal dimensions of governance; support of a green recovery of Ukraine and cross-cutting priorities for implementing the Agenda.

Together, these domains provide a comprehensive knowledge framework for supporting sustainable development in the Carpathian region, which cannot be advanced by addressing individual sectors in isolation. Climate change influences forests, water, biodiversity, hazards, livelihoods and health. Land-use decisions affect ecological connectivity, ecosystem services and cultural landscapes. Demographic change interacts with institutional capacity, service provision, local knowledge and economic opportunity. Energy, tourism and infrastructure development can create benefits while also generating new pressures on ecosystems, landscapes and communities. Research should therefore examine interactions, trade-offs, feedback and cumulative effects across these domains (Björnsen Gurung et al., 2009; Kozak et al., 2013; Melnykovych et al., 2018; Melnykovych et al., 2026a). The Agenda chapters illustrate interlinkages between these areas, both in the main text and in the Research Topics and Suggested Research Questions sections. The latter do not aim to provide an exhaustive set of topics and questions, but rather to outline a variety of relevant inter- and transdisciplinary dimensions and suggest directions for further research and Science–policy–practice work. The concluding chapter in the Agenda outlines cross-cutting priorities for implementing the S4C Research Agenda.

The Agenda takes a regional perspective given the aims and scope of the S4C and in recognition of the fact that many environmental processes, socioeconomic dynamics, and policy challenges transcend national borders and therefore require coordination across countries and territories. However, a regional approach does not imply a uniform response across the region. Research and implementation should remain place-based and context-sensitive, taking account of differences in environmental conditions, institutional capacities, socioeconomic circumstances, community needs, and the experiences of different social groups (as seen in Zimmer et al., 2026).

The S4C Research Agenda 2030 is conceived as a living framework that will be periodically reviewed in response to advances in scientific knowledge, evolving policy priorities, and emerging regional challenges. The implementation of the Agenda is expected to strengthen the shared evidence base, transboundary cooperation, research capacity, and the integration of research into the implementation of the Carpathian Convention.

Ultimately, the Agenda aims to contribute to a resilient, socially inclusive, and ecologically connected Carpathian region by strengthening collaboration across science, policy, and practice.

Forum Carpaticum 2010–2025: Developing and institutionalising science–policy–practice interfaces

Forum Carpaticum is an inter- and transdisciplinary conference, organised biennially by the S4C, in close collaboration with the Carpathian Convention Secretariat. It serves as a meeting point for scientists, practitioners, and policymakers dedicated to integrating knowledge across sectors to address the challenges of the Carpathian region. The Forum provides the basis for evidence-based, cross-sectoral recommendations to the Carpathian Convention Secretariat and its Parties.

The **1st Forum Carpaticum** (2010, Kraków, Poland) was dedicated to the integration of nature and society towards sustainability and identified the need for better information on data generation, availability, and accessibility in the Carpathians region (Ostapowicz & Kozak, 2010). The conference programme of the **2nd FC Forum Carpaticum** (2012, Stará Lesná, Slovakia) discussed the data–knowledge–action circle in three overarching and overlapping themes: 1) abiotic environment, 2) biodiversity and ecosystems and 3) human dimensions (Boltižiar, 2012). **The 3rd Forum Carpaticum** (2014, Lviv, Ukraine) considered topics related to but not limited to the policy priorities of the Europe 2020 Strategy, focusing on major challenges affecting the Carpathian ecoregion (Kruhlov & Prots, 2014).

Since its creation, but particularly in the last several years, the S4C has made efforts to strengthen interdisciplinary and transdisciplinary research and to promote these approaches among its members and young scientists from the Carpathian countries. At the **4th Forum Carpaticum** (2016, Bucharest, Romania) an emerging theme in the Carpathian area was education for sustainability (Verga and Manea, 2016). Most sessions and keynote speeches of the **5th Forum Carpaticum** (2018, Eger, Hungary) addressed interdisciplinary and intersectoral linkages such as climate change vulnerability assessments and adaptation, potential for social innovation in the Carpathian area, green energy innovations, and education for sustainable development (Mázsa, 2018; Mitrofanenko et al., 2020).

During the **6th Forum Carpaticum**, "Linking the Environmental, Political and Societal Aspects for Carpathian Sustainability", which took place virtually in June 2021 (Cudlín & Plch, 2021), a Plenary was devoted to discussion about how to enhance the role of Carpathian scientists and transdisciplinary approaches for sustainable development of the region. Furthermore, a broad participatory approach, initiated by the S4C, resulted in collecting recommendations from all conference participants for the Research Agenda for the Carpathians, and for the implementation of the Carpathian Convention (Zawiejska & Mitrofanenko, 2021).

The 7th Forum Carpaticum (2023 in Kraków, Poland) "Carpathian Futures – Critical Transitions" took place at a time of unprecedented crisis – the war in Ukraine – and addressed uncertainties and needs for resilience and post-war recovery and provided a timely platform to discuss "Future of the Carpathians in a Time of Critical Transition" (Wojtowichz et al., 2023). The Forum provided the basis for evidence-based recommendations

towards the implementation of the Carpathian Biodiversity Framework (Convention on Biological Diversity, 2023; Carpathian Convention, 2023a) for institutionalizing the Carpathian ESD Expert Network (Mitrofanenko et al., 2020), as well as integrating inputs on energy and plastic pollution for the attention of the Carpathian Convention bodies. The Forum also contributed to advancing Carpathian Convention action on Ukraine, following up on the Ministerial Declaration of the Carpathian Convention on Ukraine (Carpathian Convention, 2022) and contributing to the discussion on measures to address the environmental consequences of the Russian military aggression in Ukraine on the Carpathians (Carpathian Convention, 2023c). Following the Forum, a transition period of the S4C Network led to an expansion of its membership and partnerships.

The 8th Forum Carpaticum (2025 in Bratislava, Slovakia) "Taking stock and building partnerships for sustainable development of mountain and rural areas" tested the boundaries of the Network – as it was organised for the first time by a social science institution – and introduced a new angle to addressing socio-ecological transitions in the Carpathian region: that of vulnerable groups and territories (e.g., Roma communities, pastoralists and communities impacted by the Russian military aggression in Ukraine) (Csabay et al., 2025). The Forum served as the basis for detailed multi- and interdisciplinary recommendations for the Carpathian Convention, addressing COP Decisions (Mitrofanenko et al., 2025).

Taken together, the Forum Carpaticum series shows a gradual evolution from identifying data and knowledge gaps towards interdisciplinary and transdisciplinary research, stronger science–policy–practice collaboration, anticipatory approaches, and more explicit attention to resilience, justice, vulnerability, and implementation (see Mitrofanenko et al., 2024).

What enables knowledge leads to action: Cross-cutting priorities

Close collaboration between the Carpathian Convention and S4C has steadily strengthened and broadened, as reflected in co-organised events and joint publications (Mitrofanenko et al., 2024; Melnykovych et al., 2026b), the engagement of the Convention Secretariat in co-organising sessions at Forum Carpaticum, and joint efforts to co-create an evidence-based knowledge base for policymaking. This collaboration has also been reflected in the inclusion of a Decision on "Strengthening science–policy–practice interface and cooperation with scientific networks" in the official Decision document of the 7th Meeting of the Conference of the Parties to the Carpathian Convention (Carpathian Convention, 2023b).

Given the evolving thematic research domains addressed by the S4C and with the aim to continue strengthening the societal relevance of S4C work, this Agenda is anchored in four cross-cutting priorities that enable research to inform policy and practice. These priorities are built on recent S4C and Carpathian Convention processes, synthesised in Melnykovych et al. (2026a) and focused on four recurrent constraints: weak knowledge uptake, fragmented governance, uneven access to finance, and limited institutional and human capacities:

1. **Strengthening knowledge–policy–practice integration** through coordinated monitoring, interoperable data, shared indicators, regional assessments and better integration of scientific, local, traditional and practice-based knowledge.
2. **Advancing transboundary, multi-level and cross-sectoral governance** by improving co

ordination across countries, sectors and administrative levels, particularly for challenges such as climate adaptation, biodiversity, water, hazards, transport, tourism and energy.

3. **Mobilising and aligning financial resources** to support long-term research, monitoring, restoration, adaptation and implementation, including resilient and socially inclusive recovery and reconstruction in Ukraine.
4. **Strengthening institutional and human capacities** by supporting municipalities, protected areas, civil society, researchers and local actors, while promoting inclusion, participation, learn ing and enabling environment for social innovation.

Together, these priorities provide the enabling conditions for translating research into coordinated regional action (see Chapter 22 on cross-cutting priorities for further details).

From vision to action: A roadmap for the Carpathian Research Agenda 2030

The Agenda should guide research, funding, policy development and implementation through closer cooperation between S4C and the Carpathian Convention bodies, governments, research institutions, protected areas, civil society and local communities. Priority actions include regional monitoring and data sharing, regular science–policy–practice dialogue, transboundary research, support for early-career researchers, and monitoring of how scientific recommendations are taken up in policy and practice.

As we continue our efforts towards co-creating the knowledge base for implementing Agenda 2030 in the Carpathian Region and co-developing scenarios for the future of the region beyond 2030, we envision:

Strengthening the S4C–Carpathian Convention interface. Continued engagement of the S4C in Carpathian Convention activities and close collaboration between S4C and the Convention Secretariat, Focal Points, Working Groups, (WG) and other partners including:

- Representation of S4C colleagues at the WG and Carpathian Convention Implementation committee (CCIC) meetings;
- Engagement of the S4C Executive Board and Steering Committee as focal points for communication and collaboration with convention Parties and Partners;
- Acknowledgement, integration and follow up of S4C recommendations in legal frameworks, sectoral and cross-sectoral strategies and action plans, funding decisions and activities from the local to the regional levels;
- Collaboration among S4C and the Carpathian Convention Secretariat, its Parties and Partners on a monitoring mechanism to assess the state of implementation of evidence-based recommendations provided by science to the Carpathian Convention Parties; and
- Consideration of establishment of a Rapid Expertise Facility by S4C and the Carpathian Convention Secretariat, its Parties and Partners to provide rapid expert interventions on urgent socio-ecological risks in the Carpathian Region.

Expansion of regional and cross-regional research cooperation and stronger collaborations with other mountain research networks, such as the Scientific Network for the Caucasus Mountain Region (SNC-mt), the International Scientific Committee on Research in the Alps (ISCAR), and the Mountain Research Initiative (MRI).
In 2021, S4C and SNC-mt signed an MoU to strengthen cross-regional collaboration, followed by the co-organisation of several exchanges with representatives of regional scientific networks to explore prospects for meaningful collaboration. Our vision in this respect includes:

- Exchanges of information and knowledge;
- Support for collaboration between individual network members, including research visits and, co-supervision of early-career researchers and cooperation during regional conferences;
- Development, financing, and implementation of joint activities, aimed at building research capacities and fostering dialogue between research, policy and practice, to link research to the needs of sustainable development and environmental protection of both ecoregions; and
- Cross-regional exchange and learning, addressing socio-ecological challenges and facilitating sustainability transformations of mountainous regions.

Building the next generation of Carpathian researchers and strengthening active and sustained engagement of younger and early career scientists in the S4C, as well as providing them opportunities for training and exchange. Our vision includes:

- Support for participation of young and early-career researchers from the Carpathian countries in the Forum Carpaticum conferences; and
- Regular training and exchange opportunities for young and early-career researchers from the Carpathian countries and beyond, to create a better understanding of the complex challenges faced by the Carpathian region and to apply inter- and transdisciplinary approaches to address these challenges effectively in close collaboration with stakeholders from across the Carpathian region.

References

Björnsen Gurung A., Bokwa A., Chełmicki W., Elbakidze M., Hirschmugl M., Hostert P., Ibisch P., Kozak J., Kuemmerle T., Matei E., Ostapowicz K., Pociask-Karteczka J., Schmidt L., van der Linden S., & Zebisch M. (2009). Global Change Research in the Carpathian Mountain Region, Mountain Research and Development, 29(3), 282–288. https://doi.org/10.1659/mrd.1105
Björnsen Gurung, A. (2013). Science for the Carpathians: Using regional capacity to cope with global change. In Kozak J, Ostapowicz K, Bytnerowicz A, & Wyżga B. (Eds). The Carpathians: Integrating Nature and Society Towards Sustainability. Environmental Science and Engineering. Springer, 13–21. https://doi.org/10.1007/978-3-642-12725-0_2.

Boltižiar, M. (Ed.). (2012). From Data to Knowledge, from Knowledge to Action. Conference Abstracts of the 2nd Forum Carpaticum. ISBN: 978-80-968901-9-4 https://www.uj.edu.pl/documents/155564840/158097349/FC2012_Conference_Abstracts/403048c2-d064-417c-b842-c9394ab5b00a

Carpathian Convention. (2003). Framework Convention on the Protection and Sustainable Development of the Carpathians. http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/01%20The%20Convention/1.1.1.1_CarpathianConvention.pdf
Carpathian Convention. (2022). Ministerial Declaration of the Carpathian Convention on the impact of war on the environment in Ukraine and the need for cooperation and assistance. Adopted in Rzeszów, Poland, 22 November 2022, on the occasion of the Carpathian Ministerial Conference
http://www.carpathianconvention.org/2023/09/22/4impact-of-war-on-natural-environment-of-the-carpathians-in-ukraine/

Carpathian Convention (2023a). Carpathian Biodiversity Framework. Belgrade: UNEP Vienna Programme Office – Secretariat of the Carpathian Convention. https://www.carpathianconvention.org/cop7/docs/officialdocuments/CC%20COP7%20DOC7_Carpathian%20Biodiversity%20Framework_ADOPTED.pdf

Carpathian Convention (2023b). Decisions adopted at COP7 of the Framework Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention). Belgrade: UNEP Vienna Programme Office – Secretariat of the Carpathian Convention. https://www.carpathianconvention.org/cop7/docs/officialdocuments/CC_COP7_DOC3_COP7%20DECISIONS_ADOPTED.pdf

Carpathian Convention. (2023c). Set of measures to address the environmental consequences of the direct and indirect impacts of the war in Ukraine on the Carpathians. CC/COP7/DOC11_FINAL. Seventh Meeting of the Conference of the Parties to the Framework Convention on the Protection and Sustainable Development of the Carpathians. http://www.carpathianconvention.org/cop7/docs/officialdocuments/CC%20COP7%20DOC11%20%E2%80%93%20Set%20of%20measures%20-%20support%20to%20Ukraine%20within%20CC.pdf

Convention on Biological Diversity (CBD). (2023). Carpathian Biodiversity Framework. Convention on Biological Diversity. https://www.cbd.int/article/carpathian-biodiversity-framework

Csabay, J., Figulová, A., Grejtáková, K., & Škovira, R. (2025). 8th Forum Carpaticum: 2025. Taking stock and building partnership for sustainable development of the mountain and rural areas. Book of Abstracts and Conference Proceedings. Comenius University.

Cudlín, P., & Plch, R. (2021). Linking the Environmental, Political and Societal Aspects for Carpathian Sustainability. Book of Abstracts. International scientific conference 6th Forum Carpaticum: Global Change Research Institute of the Czech Academy of Sciences (CAS). Brno, Czechia. http://www.carpathianconvention.org/cop7/docs/officialdocuments/CC%20COP7%20DOC11%20%E2%80%93%20Set%20of%20measures%20-%20support%20to%20Ukraine%20within%20CC.pdf

Cudlín P, Zawiejska J, Mitrofanenko T, Mazsa K, & Melnykovych M. (Eds.). (2022). S4C Research Agenda 2022–2030. Science for the Carpathians (S4C) and Global Change Research Institute of the Czech Academy of Sciences (CAS), Brno, Czechia and Krakow, Poland.

Kozak, J., Björnsen Gurung, A., & Ostapowicz K. (Eds.). (2018). Research Agenda for the Carpathians: 2010–2015. (2011). Kraków, Poland.

Kozak, J., Ostapowicz, K., Bytnerowicz, A., & Wyżga, B. (Eds.). (2013). The Carpathians: Integrating Nature and Society towards Sustainability, Springer, ISBN 978-3-642-12724-3, 720 pp.

Kruhlov, I. & Prots, B. (Eds.). (2014). Local Responses to Global Challenges: Proceedings of Forum Carpaticum 2014. Ukrayinskyy Bestseller, Lviv. 120 pp.
https://www.uj.edu.pl/documents/155564840/158097349/FC2014_proceedings/457e6409-3d48-486d-abe5-4c1d9af0ca47

Mázsa, K. (Ed.). (2018) 5th Forum Carpaticum: Adapting to Environmental and Social Risk in the Carpathian Mountain Region. MTA Ökológiai Kutatóközpont, Tihany. ISBN 978-615-5270-48-2
http://real.mtak.hu/93241/1/MazsaK_szerk_Forum_Carpaticum_2018-book-of-abstracts.pdf

Melnykovych, M., Nijnik, M., Soloviy, I., Nijnik, A., Sarkki, S. & Bihun, Y. (2018). Social-ecological innovation in remote mountain areas: Adaptive responses of forest-dependent communities to the challenges of a changing world. Science of the Total Environment, 613, 894-906. http://doi.org/10.1016/j.scitotenv.2017.07.065

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkalakova, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvankova, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy. I., Waeber, P. O. & Zawiejska, J. (2026a). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda. Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Melnykovych, M., Nijnik, M., Soshenskyi, Zibtsev, S., Lobchenko, G., Sarkki, S., Voloshyna, N., Soloviy, I., Kravets, P., Khan, Y., Yaroshchuk, R., Keeton, W. S., Rosset, C., Pauli, B., Garcia C. A., & Waeber, P. O. (2026b). Pathways for Ukraine's post-war nature recovery: Focus on forest socio-ecological systems. Ambio 55, 817–843. 10.1007/s13280-025-02263-0

Mitrofanenko, T., Varga, A., & Zawiejska, J. (2020). Towards stronger integration of ESD into the Carpathian Convention activities: A reflection on the process to-date and on the outlook. Mountain Research and Development 40(4), A1-A14.

Mitrofanenko, T., Melnykovych, M., Kubal-Czerwińska, M., Kuras, K., Vetier, M., Halada, L., Zawiejska, J., & Nijnik, M. (2024). Science–policy–practice collaborations towards sustainable development in the Carpathian Region. In Safeguarding Mountain Social-Ecological Systems, Vol 2: Building Transformative Resilience in Mountain Regions Worldwide (pp. 207–217). S. Schneiderbauer, J. Szarzynski, J. Shroder, P. F. Pisa (Eds.). Elsevier's Hazards and Disasters Series. Elsevier. https://doi.org/10.1016/B978-0-443-32824-4.00006-7
.
Mitrofanenko, T., Škovira, R., Kholiavchuk, D., Csabay, J., Keeton, W., Zawiejska, J., Matei, E. & Melnykovych, M. (Eds.). (2025). Key Messages and Recommendations from Science for the Carpathians for the Carpathian Convention Implementation Committee: Based on Forum Carpaticum 2025 "Taking stock and building partnership for sustainable development of the mountain and rural areas", Bratislava, Slovakia, 9–11 September 2025. Science for the Carpathians (S4C). http://www.carpathianconvention.org/wp-content/uploads/2025/11/S4C-Recommendations-2025-to-CCIC_by-COP7-Decisions.pdf

Ostapowicz K., & Kozak J. (Eds.). (2010). Conference Proceedings of the 1st Forum Carpaticum: Integrating Nature and Society Towards Sustainability.
https://www.uj.edu.pl/documents/155564840/158097349/Ostapowicz+%26+Kozak%2C+2010/a4a70e7e-7067-40e9-9242-5bf67c8fab15

Ostapowicz K., & Sitko I. (Eds.). (2009). Science for the Carpathians. Strategy Development and Networking Workshop, Jagiellonian University, Kraków, Poland, 27–28 May 2008. Workshop Report. Bern, Switzerland. Ihttps://www.uj.edu.pl/documents/155564840/158097349/S4C_Workshop_report/967132c1-2dbb-4fb5-979a-f7c778d1e7b5

Science for the Carpathians (S4C). (2012). Science for the Carpathians (S4C) An interdisciplinary research network for the Carpathian Mountains. Memorandum of the S4C Scientific Steering Committee. Stará Lesná, Slovakia. https://www.uj.edu.pl/documents/155564840/158032522/Memorandum+2012/79006528-2315-456e-a426-0512ff56acdb

Verga M., & Manea G. (Eds.). (2016). Forum Carpaticum 2016: Future of the Carpathians: Smart, Sustainable, Inclusive. Conference Abstracts. September 28–30, 2016, Bucharest, Romania. https://www.uj.edu.pl/documents/155564840/158097349/FC2016_Abstract_Conference_book/d23e24ad-1421-41fd-800a-13351f490a4d

Wojtowicz, P., Kaim, D., Kubal-Czerwińska., M., Musielok, L., Wypych, A., Zawiejska, J. (Eds.). (2023). Carpathian Futures – Critical Transitions. 7th Forum Carpaticum. Book of Abstracts. Krakow.
https://www.uj.edu.pl/documents/155564840/158097349/FC2023_abstracts/611d7937-bf7e-455b-8cd5-616c939cf2e2

Zawiejska, J., & Mitrofanenko, T. (Eds.). (2021). Recommendations to the Carpathian Convention from the Science for the Carpathians (S4C) Network. Based on the inputs of participants of the 6th Forum Carpaticum "Linking the Environmental, Political and Societal Aspects for Carpathian Sustainability", 21–25 June 2021. Secretariat of the Carpathian Convention.

Zimmer, A., Grêt-Regamey, A., Palomo, I., Adler, C., Aakairi, M., Anière, M., Anthelme, F., Baruffa, C., Bele, B., Clark, V. R., et al. (2026). A research agenda for mountain futures. Cell Reports Sustainability,100775. https://doi.org/10.1016/j.crsus.2026.100775



1 Climate Change

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Climate change has intensified in the Carpathian region over recent decades, becoming a dominant driver of environmental and socio-economic transformation. Mean annual air temperature in the Carpathians has increased by 1.3°C to 2.1°C since the mid-twentieth century, with pronounced warming in the Western Carpathians – about +2.1°C in the Low Tatras compared with approximately +1.2°C in the Southern and Eastern Carpathians (Spinoni et al., 2015; Micu et al., 2021). The strongest changes have generally occurred in winter and summer with non-uniform altitudinal patterns: in the Western Carpathians, summer warming has been pronounced in the foothills, whereas winter warming has been stronger at the highest elevations (Wypych et al., 2018; Lukasová et al., 2021). Precipitation patterns have shown seasonal redistribution rather than a consistent change throughout the region. Winter precipitation has increased, primarily as rain at low- to mid-elevations, while summer precipitation has declined episodically (Onderka & Pecho, 2023; Kholiavchuk et al., 2024). Changes in precipitation intensity, timing and phase, together with altered snow accumulation and melt, may modify runoff seasonality, low flows and flood generation, thereby reorganising the regional water cycle (Wypych & Ustrnul, 2024).



Torrential summer rain (Marmaros Mountains, Ukraine). Credit: Dariia Kholiavchuk

Combined with rising evapotranspiration, these changes are driving more frequent, severe summer droughts, particularly in the southern and eastern Carpathians and within inner mountain basins (Spinoni et al., 2018; Cebulska & Kholiavchuk, 2022). EURO-CORDEX models project additional warming of roughly 2°C by mid-century under intermediate scenarios, with higher summer temperatures (+4.3°C on average by the end of the twenty-first century) and intensifying heatwaves, thereby reducing the frequency of indices related to minimum temperature expected throughout the twenty-first century, and increasing growing degree days (Torma & Kis, 2022; Simon et al., 2023). Historical warming shifted selected vertical climatic zones upslope by approximately 350 m while future projections indicate a further average upward displacement of about 300 m under RCP 4.5 and 500 m under RCP 8.5 by 2100, although the magnitude varies among climatic boundaries (Wypych et al., 2018). Together with paleoclimatic evidence of regional differences in the timing of past changes, these projections highlight the pronounced spatial heterogeneity of climate impacts and ecosystem responses across the Carpathians, making one-size-fits-all adaptation approaches inappropriate.

All these changes drive systematic bioclimatic reorganisation. Cold-adapted zones contract and fragment while thermophilous conditions expand upslope, destabilising ecotones with profound implications for landscape connectivity, biodiversity, and ecosystem service provisioning. These dynamics undermine assumptions of climatic stationarity (or "equilibrium") that still underpin many land use and conservation strategies. In other words, the distribution of vegetation is unlikely to be in equilibrium with current and rapidly changing climatic conditions.



Spruce forest in winter (High Tatra Mountains, Slovakia). Credit: William Keeton

Forest ecosystems, which dominate much of the Carpathian region, are among the most climate-sensitive systems. Forests demonstrate sensitivity through multiple mechanisms, including phenological shifts, altitudinal migration, and alterations in disturbance regimes. Climate change acts as a threat multiplier, superimposing additional stresses on already vulnerable forest systems. Stress and rates of change are accelerated both through the direct physiological impacts of climate change on organisms and indirect effects mediated by disturbances, including drought, insect and disease outbreaks, windstorms, forest fires, and flood events (Keeton et al., 2025). While warming may locally enhance growth at higher elevations or in mixed stands, these potential benefits are increasingly offset by water stress, compound disturbance interactions, and threshold effects that may trigger rapid state transitions in forest composition and function.

Climate impacts interact with socio-economic pressures, producing uneven vulnerability across the region. Mountain agriculture faces increasing risks from drought, heat stress, and phenological shifts, while water resources are affected by declining snowpack and altered runoff seasonality. Southern regions will be most affected, with significant risks of deterioration in agricultural production and forest growth (EEA, 2019).

Climate change in the Carpathians constitutes a systemic challenge requiring integrated, transboundary responses, harmonised data infrastructures and regionally differentiated strategies that account for substantial climatic and ecosystem heterogeneity. A network of representative transboundary mountain catchment observatories, integrating long-term monitoring of climate, snow, river flow, ecosystems and land use across regional and elevational gradients, would support the detection and attribution of change, model validation and adaptation planning.

Recommended topics

- High-resolution climate downscaling and ensemble analysis across Carpathian subregions with uncertainty quantification
- Establishment of pre-industrial baselines and distinguish natural climate variability via paleoclimatic reconstructions with implications for regionally differentiated climate projections and ecosystem responses
- Impact of changing climatic conditions on major ecosystems and ecosystem service providers through envelope models
- Social aspects of climate change mitigation measures
- Resilience of ecosystem services and land-use practices to climate change
- Identification of bioclimatic thresholds and tipping points
- Ecosystem and land-use resilience and adaptation limits and maladaptation risks
- Ecosystem service vulnerability, including compound extremes, cascade disturbances, bioclimatic thresholds, and tipping points
- Changing hydroclimatic regimes and extremes across the annual cycle: interactions among precipitation, snow accumulation and melt, river flow, floods, low flows and drought
- Transboundary mountain catchment observatories
- Transboundary coordination: harmonised monitoring protocols, adaptive management strategies, and policy integration across seven countries

Recommended research questions

- Which climate change mitigation measures are relevant and socially acceptable in the Carpathi an region?
- Which groups of ecosystem services are the most affected by the impacts of climate change in the Carpathian region, and what measures can be implemented to prevent their further degradation?
- Are there any practices (i.e., forest management, farming methods) in the Carpathian region that are resilient to climate change?
- What are the most appropriate climate change mitigation and adaptation measures in the Carpathians, considering their complexity and mutual positive and negative effects in terms of expected future developments?
- How rapidly and heterogeneously are bioclimatic zones shifting across Carpathian subregions?
- How are changes in the hydrological cycle altering the seasonality, magnitude and spatial distribution of floods, low flows and droughts across Carpathian subregions?
- How do paleoclimatic reconstructions inform natural climate variability patterns across different Carpathian regions?
- How should regional heterogeneities shape differentiated climate projections and adaptation strategies?
- What high-resolution spatial datasets (climate, soil, forests, paleoclimatic proxies) are needed to improve climate model accuracy, given geographical and temporal variability?
- Which harmonised variables, monitoring protocols, spatial and temporal resolutions, and data--sharing standards are required to detect and attribute changes in Carpathian hydroclimatic regimes and extremes?
- Which ecosystems and land-use systems are approaching critical climate thresholds?
- Which management practices enhance resilience under combined warming and drying trends?
- Where are the ecological and social limits to adaptation in mountain regions?
- How can coordinated transnational research better support climate risk reduction in the Carpathians?
- How can paleoclimatic evidence of past extreme events and ecosystem responses contribute to robust long-term conservation strategies that account for both natural variability and anthropogenic trends?

References

Cebulska, M., & Kholiavchuk, D. (2022). Variability of meteorological droughts in the Polish and the Ukrainian Carpathians, 1984–2015. Meteorology and Atmospheric Physics, 134(17). https://doi.org/10.1007/s00703-021-00853-7

European Environment Agency (EEA). (2019). Climate change (Chapter 7). In The European environment – state and outlook 2020: Knowledge for transition to a sustainable Europe (pp. 182–213). Publications Office of the European Union. https://www.eea.europa.eu/en/analysis/publications/soer-2020

Kholiavchuk, D., Gurgiser, W., & Mayr, S. (2024). Carpathian forests: Past and recent developments. Forests, 15(1). https://doi.org/10.3390/f15010065

Keeton, W. S., McCallum, S., Kuraś, K., Fischer, E., & Egerer, H. (2025). Assessment of climate risks and adaptation options for Carpathian forest ecosystems and their services. Secretariat of the Carpathian Convention. Vienna, Austria.

Lukasová, V., Škvareninová, J., Bičárová, S., Sitárová, Z., Hlavatá, H., Borsányi, P., & Škvarenina, J. (2021). Regional and altitudinal aspects in summer heatwave intensification in the Western Carpathians. Theoretical and Applied Climatology, 146(3–4), 1111–1125. https://doi.org/10.1007/s00704-021-03789-5

Micu, D. M., Dumitrescu, A., Cheval, S., Nita, I.-A., & Birsan, M.-V. (2021). Temperature changes and elevation-warming relationships in the Carpathian Mountains. International Journal of Climatology, 41(3), 2154–2172. https://doi.org/10.1002/joc.6952

Onderka, M., & Pecho, J. (2023). On how precipitation–temperature coupling affects drought severity in the western Carpathians and the adjacent northern part of the Pannonian Plain. Theoretical and Applied Climatology, 152(1–2), 681–692. https://doi.org/10.1007/s00704-023-04395-3

Simon, C., Kis, A., & Torma, C. Z. (2023). Temperature characteristics over the Carpathian Basin—Projected changes of climate indices at regional and local scale based on bias-adjusted CORDEX simulations. International Journal of Climatology, 43(8), 3552–3569. https://doi.org/10.1002/joc.8045

Spinoni, J., Naumann, G., & Vogt, J. V. (2018). Will drought events become more frequent and severe in Europe? International Journal of Climatology, 38(4), 1718–1736. https://doi.org/10.1002/joc.5291

Spinoni, J., Szalai, S., Szentimrey, T., Lakatos, M., Bihari, Z., Nagy, A., Németh, Á., Kovács, T., Mihic, D., Dacic, M., Petrovic, P., Kržič, A., Hiebl, J., Auer, I., Milkovic, J., Štepánek, P., Zahradníček, P., Kilar, P., Limanowka, D., … Antolovic, I. (2015). Climate of the Carpathian Region in the period 1961–2010: Climatologies and trends of 10 variables. International Journal of Climatology, 35(7), 1322–1341. https://doi.org/10.1002/joc.4059

Torma, C. Z., & Kis, A. (2022). Bias-adjustment of high-resolution temperature CORDEX data over the Carpathian region: Expected changes including the number of summer and frost days. International Journal of Climatology, 42(12), 6631–6646. https://doi.org/10.1002/joc.7654

Wypych, A., & Ustrnul, Z. (2024). Precipitation and hydrological extremes during the warm season in response to climate change: the example from the Polish Carpathians. Regional Environmental Change, 24, 90. https://doi.org/10.1007/s10113-024-02252-1

Wypych, A., Ustrnul, Z., & Schmatz, D.R. (2018). Long-term variability of air temperature and precipitation conditions in the Polish Carpathians. Journal of Mountain Science, 15, 237–253. https://doi.org/10.1007/s11629-017-4374-3



2 Water resources and management

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Ongoing climate change may affect multiple flow characteristics of Carpathian rivers, such as flow amount, seasonality of extremes and temperature regime (Kędra, 2017; Gîrbea et al., 2026) depending on river location in the Carpathian arc. Such concerns have been documented in the Polish and Romanian Carpathians, for example, where recent studies indicate increasing hydroclimatic variability, more frequent hydrological extremes, and growing pressures on water resources associated with changing precipitation regimes and rising temperatures (Bîrsan et al., 2014; Cheval et al., 2014; Kundzewicz et al. 2016; Micu et al., 2016; Micu et al., 2021). Evidence from Carpathian river archives highlights the combined influence of regional climate variability, Carpathian topographic controls, and land-cover changes on long-term flood regimes and fluvial dynamics, emphasising the importance of integrating climatic and catchment-scale drivers in understanding hydrogeomorphic evolution (Gębica, 2013; Moroșanu et al., 2017; Rădoane et al., 2019; Niță et al., 2025). Conventional engineering management of mountain streams was shown to exert negative impacts on all dimensions of sediment connectivity and, thus, on hydromorphological stream quality (Wyżga et al., 2012; Moroșanu, 2020). Therefore, there is a need to define and apply more environment-friendly approaches to the management of mountain streams and rivers (Galia, 2021). Decades of channel regulation, bank reinforcement, hydropower development, and gravel extraction have similarly altered river continuity, sediment transport, and habitat diversity, highlighting the importance of restoring more natural hydromorphological processes (Rădoane et al., 2003; Zaharia et al., 2018; Moroșanu & Ioana-Toroimac, 2022). The onset of restoration projects in Carpathian streams and rivers raises the question of suitability and effectiveness of applied restoration measures. Scientific monitoring of river restoration projects is thus required to promote a wider use of innovative, cost-effective restoration measures aimed to improve the functioning of degraded mountain ecosystems (Wyżga et al., 2021). Recent Romanian restoration initiatives further emphasise the importance of establishing long-term hydromorphological and ecological monitoring frameworks capable of evaluating restoration success and supporting adaptive river management (Ioana-Toroimac & Zaharia, 2014; Moroșanu & Ioana-Toroimac, 2022; Ioana-Toroimac et al., 2024).

In the twentieth century, valleys of Polish Carpathian rivers experienced considerable expansion of floodplain forest which has had important impacts on riverine ecosystems and flood hazard (Hajdukiewicz & Wyżga, 2019); however, more recent forest development trends may differ among Carpathian countries. Trees fallen to river channels were recognised as beneficially influencing ecological processes in rivers, but mobility of in-channel wood during floods may pose hazard risks to property and infrastructure on valley floors. Sustainable management of in-channel wood requires knowledge of its mobility, which can differ considerably between mountain channels of different sizes (Ruiz-Villanueva et al., 2016; Mikuś & Wyżga, 2020). Recent studies emphasise the need to protect native riparian vegetation and implement river management strategies in the Carpathians that prioritise restoring natural hydrological conditions, reducing channelisation, and allowing for seasonal flooding, which supports biodiversity and ecosystem resilience. Systematic remote-sensing techniques can be employed to monitor and control invasive species and guide targeted management actions, ensuring the long-term sustainability of riparian ecosystems under changing climate conditions. Similar approaches should be increasingly promoted in Carpathian mountain catchments, where the conservation and

restoration of riparian corridors are recognised as key nature-based solutions for enhancing flood resilience, improving ecological connectivity, and supporting the implementation of European Union Nature Restoration Regulation.

It is now widely recognised that plastic is ubiquitous in different forms in mountain environments at all elevations and thus, that there is an urgent need for research into plastic occurrence and potential impacts to aid development of adequate short- and long-term management strategies. While numerous studies have explored the pollution of the environment with microplastic, pollution of riverine environment with plastic debris (macro-, micro- and nanoplastic) has only recently been recognised. Consequently, further research is needed to identify sources of plastic delivery, mechanisms and rates of plastic storage, transport, and redeposition in rivers (Liro et al., 2025). Due to the dynamic nature of mountain rivers, particular attention should be focused on the fate of macroplastic because of its potential fragmentation into hazardous microplastic during fluvial transport and storage. Importantly, these issues require complex studies of flood hydrology, hydromorphological characteristics, wood and sediment fluxes and deposition patterns to aid sustainable plastic-waste-removal solutions. Multiple, plastic-related knowledge gaps exist throughout the Carpathians despite increasing evidence of plastic accumulation in the river systems following flood events (e.g., Rădoane et al., 2013; Ștefănescu et al., 2025).

Flash floods are phenomena that have been increasingly responsible for property damage and sudden transformation of mountain catchments and are especially hazardous in settled but ungauged catchments. While there is a growing body of research linking the physical properties of the catchments with flash flood hazards, there is an urgent need to develop flash flood hazard identification tools for small catchments to inform warning systems. Research efforts should also be focused on delineation of flash flood hazard zones in small catchments and supporting collaborative, inter- and transdisciplinary work to develop adaptation strategies aimed at risk reduction, including housing design for affected areas. Recent examples from Polish and Romanian Carpathians that have experienced several recent catastrophic flash floods exposed the vulnerability of small mountain catchments and highlighted the need for integrated hydro-meteorological monitoring, high-resolution hazard mapping, and improved early-warning systems (Zaharia et al., 2015; Popa et al., 2020; Popescu & Ștefan, 2021; Albulescu, 2022). In addition, recent national assessments have emphasised the importance of integrating hydrological, geomorphological, and socio-economic information to better understand flood impacts and strengthen climate adaptation strategies in mountain regions (Costache & Bui, 2020; Dragomir et al., 2020; Oniga et al., 2020; Costache et al., 2022).

Recommended topics

- Pollution of mountain watercourses with micro- and macroplastic including storage and redeposition of plastic in the river sediments
- Recent trends of development or decline of riparian forests along mountain rivers in Carpathian countries and their impact on changes of the quality of riverine and riparian ecosystems and flood hazard
- Impacts of climate change on the amount and variability of river flow, including the frequency and seasonality of extreme events (floods and droughts), and thermal regime of river waters
- Changes in sediment connectivity in Carpathian rivers resulting from various engineering mea

sures (i.e., channelisation structures, dams, check-dams) and channel incision
- Evaluation of immediate and long-term effects of river restoration projects
- Continued studies of water and sediment management, especially in anthropogenically affected and/or upstream river reaches
- Support of free data sharing of Carpathian rivers to enable collaborative management of trans boundary rivers



A morphologically diverse reach of the Czarny Dunajec River, Polish Carpathians, representing high ecological status conditions. Credit: Joanna Zawiejska

Recommended research questions

- What are the sources, types, amounts and fate (flux, deposition, disintegration) of macroplastics entering mountain rivers in the Carpathians and what are their interactions with biotic and abiotic elements of the river environment? What are the potential hazards associated with macroplastics pollution and how can waste management strategies be informed and adapted to minimise impacts on the environment and human health?
- How are the hydromorphological status and human pressures affecting Carpathian rivers assessed and regulated across the Carpathian countries, and how could monitoring methods, assessment protocols, and river basin management practices be better harmonised and shared at the trans-Carpathian level?
- How can scientific research and grey literature on the hydromorphological impacts of anthro

pogenic interventions (particularly old dams, large hydropower infrastructure and long river embankments) be systematically compiled and integrated to improve understanding of the cumulative effects on Carpathian river dynamics, including in transboundary river systems?

- What are the main drivers of recent changes in the extent, distribution and regeneration of riparian forests in Carpathian river valleys? How do these changes interact with river dynamics, land use and flood risk and what are effects on the ecological status of rivers
- How does the mobility of in-channel wood differ between mountain watercourses of different sizes and geomorphological features, and how do these differences affect flood hazard in the valleys and functioning of river ecosystems?
- What opportunities and approaches exist for developing and implementing river restoration and river connectivity measures in the Carpathian region, and how can their ecological and hydro-morphological effects be better documented, monitored and evaluated over time?
- How do river restoration projects modify abiotic and biotic characteristics of degraded mountain watercourses during the time span of these projects and in the long term?



GNSS survey of riverbed deformations in the Cheremosh River Valley (Bukovynian Carpathians, Ukraine). Credit: Mykola Pasichnyk

References

Albulescu, A. C. (2022). Flood hazard and vulnerability-related research in Romania. The Gordian knot of conceptual and operational overlapping. GeoPatterns, 7(1), 34. https://doi.org/https://doi.org/10.5719/GeoP.7/3

Bîrsan, M. V., Dumitrescu, A., Micu, D. M., & Cheval, S. (2014). Changes in annual temperature extremes in the Carpathians since AD 1961. Natural Hazards, 74(3), 1899–1910. DOI:10.1007/s11069-014-1290-5

Cheval, S., Birsan, M. V., & Dumitrescu, A. (2014). Climate variability in the Carpathian Mountains Region over 1961–2010. Global and Planetary Change, 118, 85–96. https://doi.org/10.1016/j.gloplacha.2014.04.005

Costache, R., & Bui, D. T. (2020). Identification of areas prone to flash-flood phenomena using multiple-criteria decision-making, bivariate statistics, machine learning and their ensembles. Science of the Total Environment, 712, 136492. 10.1016/j.scitotenv.2019.136492

Costache, R., Pham, Q. B., Arabameri, A., Diaconu, D. C., Costache, I., Crăciun, A., ... & Avand, M. (2022). Flash-flood propagation susceptibility estimation using weights of evidence and their novel ensembles with multicriteria decision making and machine learning. Geocarto International, 37(25), 8361–8393. https://doi.org/10.1080/10106049.2021.2001580

Dragomir, A., Tudorache, A. V., & Romulus, C. (2020). Assessment of flash-flood susceptibility in small river basins. Present Environment and Sustainable Development, 14(1), 119–130. https://doi.org/10.15551/pesd2020141010

Galia, T. (2021). Legacy of human impact on geomorphic processes in mountain headwater streams in the perspective of European cultural landscapes. Geosciences, 11(6), 253. https://doi.org/10.3390/geosciences11060253

Gębica, P. (2013). Geomorphological records of human activity reflected in fluvial sediments in the Carpathians and their foreland. Landform Analysis, 22, 21–31. http://dx.doi.org/10.12657/landfana.022.003

Gîrbea, E., Zaharia, L., Ioana-Toroimac, G., Borcan, M., & Moise, M. (2026). Changes in flood characteristics and maximum streamflow in the Carpathians and Subcarpathians (1961–2020): A case study of the upper Ialomița River catchment, Romania. International Journal of River Basin Management, 1–23.

Hajdukiewicz, H., & Wyżga, B. (2019). Aerial photo-based analysis of the hydromorphological changes of a mountain river over the last six decades: The Czarny Dunajec, Polish Carpathians. Science of the Total Environment, 648, 1598–1613.

Ioana-Toroimac, G., & Zaharia, L. (2014). Hydromorphological priorities of river restoration projects in Romania. In 3rd International Conference Water Resources and Wetlands, 8–10 September 2016 Tulcea (Romania). https://www.limnology.ro/wrw2016/proceedings/2_Ioana-Toroimac.pdf

Ioana-Toroimac, G., Neculau, G., Stoica, C., Șandor, I. A., Constantin, D. M., & Moroșanu, G. A. (2024). Demonstrating the effectiveness of open-water wetlandscape restoration: Lessons learned from South-Eastern Europe. Restoration Ecology, 32(5), e14147.

Kędra, M. (2017). Long-term trends in river flow: A case study of the Soła River (Polish Carpathians). In E3S Web of Conferences 19, p. 02012. EDP Sciences.

Kundzewicz, Z. W., Stoffel, M., Niedźwiedź, T., & Wyżga, B. (Eds.). (2016). Flood risk in the upper Vistula basin. Springer International Publishing.

Liro, M., Mikuś, P., & Zielonka, A. (2025). Field experiment confirms high macroplastic trapping efficiency of wood jams in a mountain river channel. Scientific Reports, 15(1), 2933.

Micu, D. M., Amihaesei, V. A., Milian, N., & Cheval, S. (2021). Recent changes in temperature and precipitation indices in the Southern Carpathians, Romania (1961–2018). Theoretical and Applied Climatology, 144(1), 691–710. https://doi.org/10.1007/s00704-021-03560-w

Micu, D. M., Dumitrescu, A., Cheval, S., & Birsan, M. V. (2016). Climate of the Romanian Carpathians. Springer.

Mikuś, P., & Wyżga, B. (2020). Long-term monitoring of the recruitment and dynamics of large wood in Kamienica Stream, Polish Carpathians. Journal of Mountain Science, 17(6), 1281–1293.

Moroșanu, G.A., Zaharia, L., & Ioana-Toroimac, G. (2017). Changes in forest and water management in the upper Jiu River catchment (Romania): Possible effects on the hydro-sedimentary dynamics. In Proceedings of the 17th International Conference SGEM 2017, Planetary and Geo Sciences, 17 (32), 749–756, Albena. DOI:10.5593/sgem2017/32/S14.097

Moroșanu, G. A. (2020). La dynamique hydro-sédimentaire du bassin de la rivière Jiu. Approche systémique et multiéchelle [in French], Universitară Editing House, Bucharest, ISBN: 978-606-28-1203-4

Moroșanu G. A., & Ioana-Toroimac, G. (2022). Changements hydromorphologiques induits par les gravières et les travaux de gestion. Études de cas sur les rivières roumaines [Evidence of hydromorphological alteration under present-day sand mining and management works. Case studies on Romanian rivers]. 4th International Conference I.S. Rivers Proceedings – Integrative Sciences and Sustainable Development of Rivers.

Niță, M. D., Suarez, J. D., & Nicolae, I. A. (2025). Morphological evolution and land cover changes in the Mureș River riparian area over a century of anthropogenic pressure. Environmental Monitoring and Assessment, 197(7), 796.

Oniga, V. E., Crenganiş, L., Diac, M., & Chiripa, C. (2020). Overview on remote sensing methods and data sources for floods and landslides management. Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura, 66(4), 59–70.

Popa, M. C., Simion, A. G., Peptenatu, D., Dima, C., Draghici, C. C., Florescu, M. S., ... & Diaconu, D. C. (2020). Spatial assessment of flash-flood vulnerability in the Moldova river catchment (N Romania) using the FFPI. Journal of Flood Risk Management, 13(4), e12624.

Popescu, C., & Ștefan, D. C. (2021). Study of Susceptibility to Flash Floods in the Vărbilău River Catchment. Ovidius University Annals of Constanta-Series Civil Engineering, 23(1), 69–76.

Rădoane, M., Chiriloaei, F., Sava, T., Nechita, C., Rădoane, N., & Gâza, O. (2019). Holocene fluvial history of Romanian Carpathian rivers. Quaternary International, 527, 113–129.

Rădoane, M., Obreja, F., Cristea, I., & Mihailă, D. (2013). Changes in the channel-bed level of the eastern Carpathian rivers: Climatic vs. human control over the last 50 years. Geomorphology, 193, 91–111.

Rădoane, M., Rădoane, N., & Dumitriu, D. (2003). Geomorphological evolution of longitudinal river profiles in the Carpathians. Geomorphology, 50(4), 293–306.

Ruiz-Villanueva, V., Wyżga, B., Zawiejska, J., Hajdukiewicz, M., & Stoffel, M. (2016). Factors controlling large-wood transport in a mountain river. Geomorphology, 272, 21–31.

Ștefănescu, L., Alexandrescu, F., & Meltzer, M. (2025). Embedded environmental activism in the Apuseni Mountains of Romania: The case of deficient local waste management. Eurasian Geography and Economics, 1–27.

Wyżga, B., Zawiejska, J., Radecki-Pawlik, A., & Hajdukiewicz, H. (2012). Environmental change, hydromorphological reference conditions and the restoration of Polish Carpathian rivers, Earth Surface Processes and Landforms 31(11), 1213–1226

Wyżga, B., Amirowicz, A., Bednarska, A., Bylak, A., Hajdukiewicz, H., Kędzior, R., & Zawiejska, J. (2021). Scientific monitoring of immediate and long-term effects of river restoration projects in the Polish Carpathians. Ecohydrology & Hydrobiology, 21(2), 244–255.

Zaharia, L., Costache, R., Prăvălie, R., & Minea, G. (2015). Assessment and mapping of flood potential in the Slănic catchment in Romania. Journal of Earth System Science, 124, 1311–1324. https://doi.org/10.1007/s12040-015-0608-3

Zaharia, L., Perju, R., & Ioana-Toroimac, G. (2018). Climate Changes and Effects on River Flow in the Romanian Carpathians. Aerul si Apa Componente ale Mediului [Air & Water Components of the Environment] [Conference], 211–218. DOI:10.24193/AWC2018_25

3 Natural hazards and risks

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Mountainous areas in the Carpathians and throughout the world are among the environments most prone to natural hazards. The complexity of present-day geomorphic processes and their high intensities, frequencies, and magnitudes enhance the exposure of mountain residents to such risks, increasing their vulnerability compared with lowland populations. Climate change and the increasing intensity of extreme events mean that such risks must be included in spatial development plans in the Carpathians. Improper spatial development may increase the negative effects of these processes on humans and their communities. A respect for nature, adaptation of human interventions to natural processes, a careful assessment of ecosystem services, and the transfer of scientific knowledge to local decision-making, are the most effective ways to reduce risk (Ćwik, 2024).

Over the last centuries, shifting human land-use regimes – progressive deforestation, pastoral expansion, and, more recently, industrial and infrastructural development – have repeatedly reconfigured Carpathian landscapes, amplifying slope instability, sediment transfer, and flood activity, particularly during phases of intensified settlement and resource extraction. These anthropogenic pressures interacted with climatic fluctuations, during which alternating warm–wet and cold–humid intervals increased the frequency of floods, landslides, and erosional episodes, triggering cascading hazard responses in already transformed catchments (Kholiavchuk et al., 2024).





Flooding of the Prut River and its impact on the main market in Chernivtsi City in 2008 (Bukovynian Mountains foreland, Ukraine). Credit: Bogdan Ridush

The impact of very fast onset hazards like rock falls on the Transcarpathian roads network in 2010 (Curvature Carpathians, Romania). Credit: Mihai Micu

Landslides are prevalent in flysch formations, among the most common geological structures in the Outer Carpathians (Kroh et al., 2021) and are also an immediate natural hazard in seismic areas (e.g., in the Curvature Carpathians) (Micu et al., 2023). In the high mountain areas of the range, rock avalanches and debris flows occur very frequently, while rockfalls pose a danger in many areas with exposed rock outcrops. Channel modifications and floodplain development exacerbate flooding, including flash flooding that extends across the Carpathian countries (Kundzewicz et al., 2012). Avalanches threaten expanding ski resorts, while droughts intensify, exacerbated by irrigation expansion and declining forest cover, which have increased water deficits (Spinoni et al., 2018). Windstorms cause extensive damage in monodominant spruce plantations and initiate cascading disturbances through bark beetle outbreaks (Mezei et al., 2017).





A deep-seated complex landslide greatly impacted a reservoir in 2006 (Curvature Carpathians, Romania). Credit: Mihai Micu

Erosion and debris flow in the Southern Carpathians (Parang Mountains, Romania). Credit: Mihai Micu

Critical knowledge gaps constrain effective management. This statement aligns with the position paper of the Board of the European Federation of Geologists, in which the authors highlight the urgent need for the European Union to develop a Landslide Directive (Board of the European Federation of Geologists, 2026). High resolution mapping is available for fragmented areas of the Carpathians but rarely incorporates land use scenarios. Hazard prevalence changes are attributed to climate but also can implicate deforestation, infrastructure, or agricultural practices; the question remains unresolved (Gariano & Guzzetti, 2016). Nature based solutions lack systematic evaluation and inclusion despite their potential. Early warning coverage is incomplete and disconnected from land use planning, which continues to expand exposure. Natural risk analysis, evaluation, and management must be considered, in light of the increasing intensity of extreme events, to enhance the resilience of inhabitants of the Carpathians.

Recommended topics

- Living with hazards: Social and economic development with respect to natural processes
- Hazard and risk assessment for the main natural hazards in the Carpathians (i.e., landslides, floods, flash floods, local droughts, strong winds, avalanches)
- Natural hazard impact on safety
- Implementation of natural hazard research results in spatial planning
- Prediction of natural hazard occurrence and rates in the climate change context, for example:
    - precipitation change vs. landsliding hazard
    - snow cover and rainfall vs. flash floods hazard
    - local droughts vs. local flora or agriculture susceptibility
    - transboundary research and risk management: integration of natural hazards and risk

management research results between neighbouring countries and regions, especially when natural systems (i.e., catchment areas) are shared by two countries

- Multi-hazard mapping integrating climate projections and land-use change scenarios
- Transboundary early warning linked to spatial planning, preventing exposure expansion
- Quantifying climate change versus land-use contributions to observed hazard trends

Recommended research questions

- How to develop in a sustainable way with respect for natural resources and processes?
- How spatially uniform and widely understood is the knowledge of natural hazards in terms of occurrence and potential impacts?
- How do land-use trajectories interact with climate change to modify hazard-triggering thresholds?
- How can spatial planning integrate hazard projections to reduce exposure expansion while supporting sustainable development?
- What governance mechanisms in forest management, agricultural techniques, and infrastructure designs minimise cascading hazards under climate change?
- How will climate change affect the intensity of natural processes and susceptibility for the frequency and magnitude of natural hazards?
- How to standardise GIS-based risk mapping and integrate hazard knowledge into planning in the transboundary Carpathian context?
- How to build societal sustainability with respect for natural evolution cycles and resources?

References

Board of the European Federation of Geologists (EFG) (2026, February). Europe Needs a Landslide Directive: A Lesson from Niscemi. [Position Paper]. https://eurogeologists.eu/wp-content/uploads/2026/02/2026_Niscemi_EFG.pdf

Ćwik, A. (2024). Can spatial planning in the Polish Carpathians be enforced? How spatial chaos indicators depict a gap between scientific knowledge and practice. Journal of Mountain Science 21(11): 3871–5875. https://doi.org/10.1007/s11629-024-8810-x

Gariano, S. L., & Guzzetti, F. (2016). Landslides in a changing climate. Earth-Science Reviews, 162, 227–252. https://doi.org/10.1016/j.earscirev.2016.08.011

Kholiavchuk, D., Gurgiser, W., & Mayr, S. (2024). Carpathian forests: Past and recent developments. Forests, 15(1), 65. https://doi.org/10.3390/f15010065

Kroh, P., & Pawlik, Ł. (2021). Recent advances on geomorphology of the Gorce Mountains: The outer western Carpathians state-of-the-art and future perspectives. Geographia Polonica, 94(1). DOI:10.7163/GPol.0193

Kundzewicz, Z. W. (Ed.). (2012). Changes in Flood Risk in Europe. Special Publication No. 10, IAHS Press.

Mezei, P., Jakuš, R., Pennerstorfer, J., Havašová, M., Škvarenina, J., Ferenčík, J., Slivinský, J., Bičárová, S., Bilčík, D., Blaženec, M., & Netherer, S. (2017). Storms, temperature maxima and the Eurasian spruce bark beetle: An infernal trio in Norway spruce forests of the Central European High Tatra Mountains. Agricultural and Forest Meteorology, 242, 85–95. https://doi.org/10.1016/j.agrformet.2017.04.004

Micu, M., Micu, D., & Havenith, H. B. (2023). Earthquake-induced landslide hazard assessment in the Vrancea Seismic Region (Eastern

Carpathians, Romania): Constraints and perspectives. Geomorphology, 427, 108635. https://doi.org/10.1016/j.geomorph.2023.108635

Spinoni, J., Vogt, J. V., Naumann, G., Barbosa, P., & Dosio, A. (2018). Will drought events become more frequent and severe in Europe? International Journal of Climatology, 38(4), 1718–1736. https://doi.org/10.1002/joc.5291



4 Land use and land cover change

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Dominant land-use change processes observed in the Carpathian region include land abandonment leading to forest cover increase (Pazur et al., 2014; Kolecka et al., 2017; Săvulescu et al., 2019; Kholiavchuk et al., 2024) and settlement development (Kaim, 2017; Pazur & Bolliger, 2017). Both processes impact biodiversity and land fragmentation. While abandonment of agricultural land can support wildlife or reduce soil erosion (Kijowska-Strugała et al., 2025), it negatively impacts habitats that rely on human inputs such as grassland extent and the associated increase in forest cover, which further alters valley geosystem functioning by promoting river incision (Ortyl et al., 2018). The Carpathian grasslands are among the most biodiversity-rich in Europe (Janišová et al., 2024). Critical drivers for land use change are both natural and socio-economical (Bucała-Hrabia, 2024) and include climate change, demographic processes, policy and institutional interventions (e.g., Common Agricultural Policy, Biodiversity Strategy 2030). Settlement pressure, including urban sprawl and building dispersion in the region results in strong impacts on biodiversity and ecosystems including land fragmentation, movement barriers, light and noise pollution, human–wildlife interactions, increasing landslide threat and loss of landscape values. At the same time, traditional land management approaches have been preserved throughout the Carpathian region, especially in peripheral areas (e.g., at the junction of the Carpathian and Pannonian regions). Protection of these peripheral areas is vital as their management practises often support biodiversity and they tend to form a buffer between intensively used agrarian landscapes on the foothills and other landscapes in the mountains.



Landscape transition in the former Lemko village Wołtuszowa (Beskid Niski Mountains, Poland). Credit: Agata Ćwik



Secondary grasslands with Orchidaceae and Bulbocodium versicolor species in the National Natural Park Vyzhnytskyi (Bukovynian Mountains, Ukraine). Credit: Dariia Kholiavchuk

Recommended topics

- Multi-disciplinary research of rural areas, especially in context of their depopulation, including the causes and consequences of this trend
- Research to facilitate ecological restoration of Carpathians grasslands
- Understanding, mapping and supporting traditional land management approaches in the Carpathian region
- Land abandonment and its consequences in the Carpathians
- Land use scenarios of settlements and tourist infrastructure development
- Environmental, social and economic consequences of land use change
- Long-term land use legacies in the region
- Scenarios of the future land use changes regarding demography and climate change in the region
- Impact of landscape dynamics on different fauna and flora species and their connectivity

Recommended research questions

- What are the primary causes and consequences of land-use change?
- How will land-use change in the Carpathians affect biodiversity and ecosystem services in future?
- How will land use be affected in future by the critical drivers, which are climate change, demographic processes, policy and institutional interventions (i.e., Common Agricultural Policy, Biodiversity Strategy 2030)?
- What kind of spatial planning tools should be adopted to mitigate unfavourable phenomena resulting from land use change?

References

Bucała-Hrabia, A. (2024). Reflections on land use and land cover change under different socio-economic regimes in the Polish Western Carpathians. Regional Environmental Change 24(28). https://doi.org/10.1007/s10113-024-02187-7

Janišová, M., Magnes, M., Bojko, I., Borsukevych, L. M., Budzhak, V. V., Chorney, I., Iuga, A., Ivașcu, C.M., Kish, R., Kuzemko, A. & Palpurina, S. (2024). Agricultural legacy shapes plant diversity patterns in mountain grasslands of Maramureș and Bukovina: A cross-border perspective (Ukraine, Romania). People and Nature, 6(6), 2283–2299.

Kaim, D. (2017). Land cover changes in the Polish Carpathians based on repeat photography. Carpathian Journal of Earth and Environmental Sciences, 12(2).

Kijowska-Strugała, M., Demczuk, P., & Bucała-Hrabia, A. (2025). What are the impacts of land use change and cover-management factors on soil erosion modelling studies? Catena, 258. https://doi.org/10.1016/j.catena.2025.109240

Kolecka, N., Kozak, J., Kaim, D., Dobosz, M., Ostafin, K., Ostapowicz, K., ... & Price, B. (2017). Understanding farmland abandonment in the Polish Carpathians. Applied Geography, 88, 62–72.

Kholiavchuk, D., Gurgiser, W., & Mayr, S. (2024). Carpathian forests: Past and recent developments. Forests, 15(1), 65. https://doi.org/10.3390/f15010065

Ortyl, B., Ćwik, A. & Kasprzyk I. (2018). What happens in a Carpathian catchment after the sudden abandonment of cultivation? Catena 166, 158–170.

Pazúr, R., Lieskovský, J., Feranec, J., & Oťahel', J. (2014). Spatial determinants of abandonment of large-scale arable lands and managed grasslands in Slovakia during the periods of post-socialist transition and European Union accession. Applied Geography, 54, 118–128.

Pazúr, R., & Bolliger, J. (2017). Land changes in Slovakia: Past processes and future directions. Applied Geography, 85, 163–175.

Săvulescu, I., Mihai, B. A., Virghileanu, M., Nistor, C., & Olariu, B. (2019). Mountain arable land abandonment (1968–2018) in the Romanian Carpathians: Environmental conflicts and sustainability issues. Sustainability, 11(23), 6679.



Secondary grasslands with Orchidaceae and Bulbocodium versicolor species in the National Natural Park Vyzhnytskyi (Bukovynian Mountains, Ukraine). Credit: Dariia Kholiavchuk



5 Integrated landscape management and governance

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Carpathian landscapes are shaped by long-term interactions among forests, grasslands, agricultural land, settlements, water systems, infrastructure and local communities. Their sustainable development therefore requires governance approaches that extend beyond individual sectors and administrative boundaries. Decisions concerning forestry, agriculture, biodiversity conservation, tourism, energy, transport and spatial development frequently affect the same landscapes and may generate synergies, trade-offs and cumulative impacts (Melnykovych et al., 2026). A landscape approach provides an appropriate framework for addressing these interactions by integrating ecological, socioeconomic and governance dimensions across spatial scales and sectors. Landscapes are recognised as multifunctional social–ecological systems in which conservation, production, livelihoods and development objectives need to be considered together. Integrated landscape management and governance should therefore be based on inclusive decision-making, collaboration among stakeholders, coordination across sectors and governance levels, and nature-based approaches to land use and natural-resource management.



The Bran-Moeciu socio-ecological buffer zone between the Bucegi and Piatra Craiului nature reserves (Bucegi and Piatra Craiului Mountains, Romania). Credit: Claudiu Paduroiu

Integrated landscape approaches can contribute to reducing degradation of forests, grasslands, soils and water resources, maintaining ecological connectivity, supporting ecosystem restoration and conserving biodiversity while simultaneously addressing regional development needs. A key research challenge is to understand how these objectives can be reconciled under conditions of environmental change, demographic transition and uneven socioeconomic development.

Rural depopulation, outmigration and changing agricultural systems are contributing to land abandonment and the gradual erosion of traditional landscape-management knowledge in parts of the Carpathians (Smaliychuk et al., 2016; Molnár & Berkes, 2018; Bezáková, & Bezák, 2022). The consequences of abandonment are context-dependent (European Commission, 2020). Natural succession may support forest regeneration and some ecosystem functions, while the cessation of extensive management can also contribute to the loss of species-rich grasslands, biocultural diversity and characteristic cultural landscapes. Landscape governance should therefore consider alternative trajectories – including continued extensive management, restoration, natural succession and new livelihood models – rather than treating abandonment as inherently beneficial or detrimental.

Traditional and local ecological knowledge remains important for maintaining multifunctional cultural landscapes. However, demographic change, livelihood transformation and agricultural restructuring increasingly challenge its continuity. Research should therefore examine not only how such knowledge can be documented and maintained, but also how relevant practices can evolve and be combined with contemporary scientific knowledge, technologies and governance arrangements (Špaček et al., 2022). Social innovation may support this process by enabling new forms of collective action, cooperation and sustainable natural-resource governance (Kozová et al., 2017; Kluvánková et al., 2018; Nijnik et al., 2022).

Governance across the Carpathians remains fragmented, while ecological processes and landscape functions frequently extend beyond municipal, regional and national boundaries. Differences in legislation, institutional capacity, access to finance, monitoring systems and implementation capacities further constrain coordination. Stronger multi-level, cross-sectoral and transboundary governance is therefore needed to connect scientific knowledge, policy, planning and local implementation.

Attention should be given to transboundary landscapes – including river basins (see Chapter 2 on water), ecological networks, forest landscapes and other social-ecological systems whose processes do not correspond to administrative boundaries. Research is needed to determine the appropriate spatial scales and institutional arrangements for governing such landscapes and to identify mechanisms that enable coordination among authorities, land managers, civil society, businesses and local communities.

Spatial planning is a central instrument for translating landscape knowledge into regional-development policy. Its effectiveness depends not only on the availability of environmental and socioeconomic information, but also on institutional capacity, implementation and enforcement (Ćwik, 2024). Research should therefore examine how spatial planning can more effectively integrate ecological connectivity, water resources, ecosystem services, natural-hazard exposure, demographic trends and development needs into land-use decisions.

A central challenge for landscape governance is the management of trade-offs among competing land uses

and development objectives. Biodiversity conservation, forestry, agriculture, tourism, renewable-energy development, transport infrastructure and settlement expansion may pursue legitimate but conflicting objectives within the same landscape. Research should therefore move beyond sectoral and project-specific assessments towards landscape-scale evaluation of synergies, trade-offs, cumulative impacts and alternative development pathways. Such analysis should address not only the environmental effects of development but also questions of scale, intensity, location and distribution. The relevant governance challenge is to determine where activities are most appropriate, under which environmental and institutional conditions, and how benefits and costs are distributed among affected actors. This is particularly important in mountain regions, where development opportunities are spatially constrained and ecological sensitivity is often high.

Ecological connectivity represents another major landscape-governance challenge. Infrastructure development, settlement expansion and intensive land use can fragment habitats and reduce landscape permeability. Maintaining and restoring connectivity therefore requires stronger integration of ecological networks and green-blue infrastructure into spatial planning, transport, energy, forestry, agriculture and regional development policies. Research should focus on both the ecological effectiveness of connectivity measures and the governance arrangements required for their implementation across jurisdictions.

Climate change adds further complexity because impacts on forests, water systems, aquatic and riparian habitats, biodiversity, natural hazards and socioeconomic activities are interconnected. These interactions are still frequently assessed and governed separately. Integrated landscape research should therefore address compound and cascading impacts, cross-sectoral and cross-border adaptation options and governance responses across ecological and socioeconomic systems. More territorially balanced research and monitoring are also needed to reduce geographical disparities in knowledge across the Carpathian region.

Energy transitions similarly require a landscape perspective. Renewable-energy development can contribute to decarbonisation, regional investment and community development, but may also affect biodiversity, ecosystem services, ecological connectivity and landscape character. Research should therefore examine renewable-energy systems as part of integrated landscape and regional-development strategies rather than as isolated sectoral interventions. Experience with wood-energy innovation in the Carpathians illustrates the need to assess both socioeconomic opportunities and environmental risks (Soloviy et al., 2019).

Inclusive and participatory governance is essential because landscape decisions involve actors with different interests, capacities, knowledge systems and levels of influence. Collaborative governance and knowledge co-production can strengthen legitimacy, local agency and institutional learning, but require supportive institutions, sustained financing and meaningful opportunities for participation (Kusters et al., 2020).

Finally, integrated landscape governance should explicitly consider procedural and distributive dimensions of regional development. Conservation, restoration, infrastructure, tourism and energy development can generate benefits at one spatial scale while concentrating environmental impacts or restrictions at another (Żemła-Siesicka & Sobala, 2024). Research is therefore needed to understand how costs, benefits and decision-making power are distributed and how governance arrangements can support more legitimate, equitable and durable pathways for integrated landscape management and governance.

Recommended topics

- Green infrastructure planning and ecological connectivity
- Sustainable renewable-energy provision based on participatory and inclusive approaches, in cluding citizen energy communities and protection of natural heritage
- Landscape-scale conservation and restoration of areas where natural processes and ecological dynamics remain functional
- Inclusive natural-resource governance, including cross-border cooperation
- Integrated governance of abandoned agricultural land, supported by remote sensing and regular landscape monitoring
- Governance of competing land uses, including cumulative impacts of tourism, settlements, transport and energy infrastructure
- Integration of traditional and local ecological knowledge into contemporary landscape governance
- Knowledge co-creation integrating ecological, social and human dimensions of forest and landscape sustainability
- Integrated assessment and governance of climate-change impacts across forests, aquatic systems and socioeconomic sectors
- More territorially balanced and methodologically coordinated research across the Carpathians
- Landscape-scale assessment of trade-offs and cumulative impacts among conservation, development and infrastructure objectives
- Stronger integration of spatial planning with EIA/SEA, including assessment of alternatives and ecological connectivity for major infrastructure and development projects

Recommended research questions

- How can multi-level, cross-sectoral and transboundary governance support integrated landscape management and sustainable regional development in the Carpathians?
- How can interactions among actors and their networks foster knowledge co-production, social innovation and the adaptation of traditional land-management practices?
- How can landscape planning identify and manage trade-offs, synergies and cumulative impacts among conservation, agriculture, forestry, tourism, settlements, transport and energy development?
- Which financial incentives, governance arrangements and policy-harmonisation mechanisms can best support ecological networks, landscape connectivity and restoration?
- How can participatory landscape governance address agricultural abandonment while enhancing biodiversity, ecosystem services, cultural landscapes and rural livelihoods?
- How can traditional and local ecological knowledge be maintained, adapted and integrated with scientific knowledge under changing environmental and socioeconomic conditions?
- How can integrated interdisciplinary approaches capture interactions among forests, aquatic-ecosystems, climate change and socioeconomic sectors to support adaptive landscape governance?

- Which forms of participatory governance and co-created knowledge improve the design, implementation and social acceptance of landscape-management and climate-adaptation policies?
- How can bio- and circular-economy approaches contribute to integrated resource management and sustainable regional development in the Carpathians?
- What coordinated research and monitoring frameworks are needed to reduce geographical disparities in knowledge and to support place-based landscape governance across the Carpathian region?

References

Bezáková, M., & Bezák, P. (2022). Which sustainability objectives are difficult to achieve? The mid-term evaluation of predicted scenarios in remote mountain agricultural landscapes in Slovakia. Land Use Policy, 115, 106020. https://doi.org/10.1016/j.landusepol.2022.106020

Ćwik, A. (2024). Can spatial planning in the Polish Carpathians be enforced? How spatial chaos indicators depict a gap between scientific knowledge and practice. Journal of Mountain Science, 21, 3871–3885. https://doi.org/10.1007/s11629-024-8810-x

European Commission. (2020). Agricultural land abandonment in the EU by 2030. Knowledge for Policy, European Commission, Joint Research Centre. The 2020 EC resource draws on the JRC assessment of agricultural land abandonment in the EU for 2015–2030. https://publications.jrc.ec.europa.eu/repository/handle/JRC113718

Kluvánková, T., Brnkaľáková, S., Špaček, M., Slee, B., Nijnik, M., Valero, D., Miller, D. Bryce, R., Kozová, M., Polman, N., Szabo, T., & Gežík, V. (2018). Understanding social innovation for the well-being of forest-dependent communities: A preliminary theoretical framework. Forest Policy and Economics 97, 163–174. https://doi.org/10.1016/j.forpol.2018.09.016

Kozová, M., Pauditšová, E., Kluvánková, T., & Brnkaľáková, S. (2017). Social innovation for maintaining biocultural heritage in rural areas: UNESCO Vlkolínec site in Slovakia. In European Landscape Ecology Congress of the International Association for Landscape Ecology: From Pattern and Process to People and Action. Ghent, Belgium, 12–15 September 2017.

Kusters, K., De Graaf, M., Buck, L., Galido, K., Maindo, A., Mendoza, H., Nghi, T. H., Purwanto, E., & Zagt, R. (2020). Inclusive Landscape Governance for Sustainable Development: Assessment Methodology and Lessons for Civil Society Organizations. Land, 9(4), 128. https://doi.org/10.3390/land9040128

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkaľáková, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvánková, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy, I., Waeber, P. O. & Zawiejska, J. (2026). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda, Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Molnár, Zs., & Berkes, F. (2018). Role of traditional ecological knowledge in linking cultural and natural capital in cultural landscapes. In M. L. Paracchini, P. C. Zingari, & C. Blasi, (Eds.). Reconnecting Natural and Cultural Capital: Contributions from Science and Policy (pp. 183–194). Publications Office of the European Union, Luxembourg.

Nijnik, M., Kluvánková, T., & Melnykovych, M. (2022). Social innovation to steer sustainable governance of nature. Environmental Policy and Governance, Special Issue.

Smaliychuk, A., Müller, D., Prishchepov, A. V., Levers, C., Kruhlov, I., & Kuemmerle, T. (2016). Recultivation of abandoned agricultural lands in Ukraine: Patterns and drivers. Global Environmental Change, 38, 70–81. https://doi.org/10.1016/j.gloenvcha.2016.02.009

Soloviy, I., Melnykovych, M., Björnsen Gurung, A., Hewitt, R. J., Ustych, R., Maksymiv, L., Brang, P., Meessen, H., & Kaflyk, M. (2019). Innovation in the use of wood energy in the Ukrainian Carpathians: Opportunities and threats for rural communities. Forest Policy and Economics, 104, 160–169. https://doi.org/10.1016/j.forpol.2019.05.001

Špaček, M., Melnykovych, M., Kozová, M., Pauditšová, E., & Kluvánková, T. (2022). The role of knowledge in supporting the revitalisation

of traditional landscape governance through social innovation in Slovakia. In Social innovation to steer sustainable governance of nature [Special Issue]. Environmental Policy and Governance, 32(6), 560–574. https://doi.org/10.1002/eet.2026

Żemła-Siesicka, A., & Sobala, M. (2024). How does tourist development influence traditional mountain landscapes? A case study from the Western Beskids, Poland. Science of the Total Environment, 951, 175376. https://doi.org/10.1016/j.scitotenv.2024.175376



6 Carpathian forest ecosystems and resources

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Since publication of the previous edition of the Carpathian Research Agenda, concern over the priority topics identified then has only increased. This is particularly true regarding the continuing symptoms of global change expressed through altered forest disturbance dynamics, exacerbated within the region by climate extremes including floods and unprecedented drought. Recent pan-European papers have shown that disturbance risks are both increasing and fundamentally changing forests systems, redirecting succession and forest composition in novel ways. Formerly less pervasive disturbances such as forest fires are now of more widespread concern (Zymaroieva et al., 2026). The services provided by forested landscapes are likely to change accordingly, for example through impaired economic opportunities, diminished climate regulation, and shifts in the mix and distribution of habitats for biodiversity (Kruhlov et al., 2018; Thom et al., 2019). At the same time, the war in Ukraine has focused attention on impacts to the forest sector as well as anticipation of recovery opportunities in the eastern Carpathians (Melnykovych et al., 2026).

Forest ecosystems in the Carpathians will continue to change into the future as compounded stresses from climate disruption, alteration of disturbance regimes, invasive species, land use pressures, and other factors increase. Forest scientists and practitioners are challenged to integrate knowledge from multiple disciplines in addressing questions of climate change. Our research agenda will continue to address the multiple ecological, social, and economic dimensions of global change as it pertains to the forest sector (see Chapter 1 on climate change). We will address critical topics identified by regional assessments, such as the Assessment of Climate Risks and Adaptation Options for Carpathian Forest Ecosystems and their Services (Keeton et al., 2025), as well as pan-European initiatives, including the European Union 2030 Biodiversity Strategy and the 2024 Nature Restoration Law.

Forests in the Carpathians, as in the rest of the world, are increasingly valued as Natural Climate Solutions (NCS) (Griscom et al., 2017). Yet alterations of natural disturbance
regimes, such as increases in the frequency and severity of disturbances, such as bark beetle outbreaks, forest fire, and wind events, may limit NCS solutions through reduced carbon storage capacity in European forests (Seidl et al., 2014; Kowalski et al., 2026). Thus, forest managers face major challenges as they seek adaptive forest management approaches. Research on all aspects of forest resilience will be particularly relevant to the Carpathian region – from flood control and hydrologic regulation to forest road design and from assisted tree migration and future-adapted plantings to silviculture for plant functional trait diversity.

Research on disturbance risks and adaptation

Like much of Europe, Carpathian forest ecosystems and resources are increasingly vulnerable to disturbance risks associated with climate change, historic land use, and past forest management practices (Seidl et al., 2017). These risks include forest fires, windthrow events, insect outbreaks, spread of pathogens, and both drought and floods (Senf & Seidl, 2021). Mitigating and adapting to disturbance risks has assumed top priority among many forest managers and policy makers, yet research is often lacking on management and adaptation options, as is information on disturbance risks of sufficiently fine resolution to enable accurate forecasting and

site-specific adaptations. Many climate impacts (e.g., changes in temperature and precipitation) and disturbance risks are expressed variability throughout the region, requiring high-resolution, spatially explicit empirical research, modeling, and mapping. Research needs to focus as much on the role of natural disturbances as structuring agents (Mikoláš et al., 2021) –controlling the temporal and spatial distribution of habitats and ecosystem processes – as on opportunities to restore landscape conditions that are more resilient and adaptive to shifting disturbance regimes (Aszalós et al., 2022).

Scientists engaged with the S4C network are uniquely positioned to form collaborative sub-regional and regional scale projects to address these research needs. A preliminary list of relevant topics based on a qualitative assessment of priorities expressed by regional experts is shown here (see Table 1). Greater participation in pan-European assessments and research initiatives by scientists based in Carpathian countries would also bring valuable predictive models and spatial data to the region.

Table 1. Ranked climate risks and adaptation options for Carpathian forests, based on a synthesis of survey responses from regional experts

Risk Rankings	**Risk Category**	**Potential Impacts**
Top ranked	Disturbances	Reduced carbon storage, growth increment, and climate regulation. Accelerated shifts in species distributions. Accelerated spread of invasive species
Second ranked	Drought	Forest decline, dieback, and reduced productivity. Shifts in species distributions, exacerbation of insect and fire risks, and diminished ecosystem services
Third ranked and other	Flooding, invasive species, land use pressure	Interactions across a range of ecosystem services and habitat provisioning, including carbon sequestration, hydrologic regulation, connectivity, and wood production as well as biodiversity
Adaptation Ranking	**Adaptation Themes**	**Recommended Actions**
Top ranked	Forest restoration	Need for restoration and climate-adapted forest regeneration practices; restoration of connected habitats and High Conservation Value Forests
Second ranked	Sustainable management, including broader use of close-to-nature silviculture and continuous-cover forestry	Need for broader use of multifunctional management practices, including close-to-nature and other types of ecological silviculture
Third ranked and other	Landscape heterogeneity to increase resilience to disturbance and drought	Need to address altered disturbance regimes, promote future-adapted forest composition, increase landscape heterogeneity and complexity, and reduce spread of invasive species

Source: Table modified with permission from Keeton et al. (2025).



Spruce forest dieback (Chorniy Dil, Ukraine). Credit: Yana Popiuk

Other critical research topics needed to inform climate smart forestry and adaptive forest management include (extracted from Keeton et al., 2025):

- Improved regional-scale forest monitoring: harmonizing monitoring programmes and sharing data across borders to facilitate coordinated adaptation;
- Monitoring physiological and phenological responses of trees to climate change over time, as well as the interactions between species and their environment as baselines for adaptive capacity assessments;
- Investigating the role of genetic diversity in forest ecosystems for adaptation (e.g., assessing the adaptive potential of different genetic lineages, and effects of genetic diversity on ecosystem resilience);
- Assessing the effectiveness of adaptive silviculture practices in Carpathian forests; long-term monitoring of adaptive practices will also be important to continuously (re-)evaluate their success;
- Assessing the economic viability and costs associated with different adaptation approaches; and
- Understanding social acceptability and equity implications and considering the impacts of adaptation on local communities and livelihoods.

Research supporting conservation of forest biodiversity

Also of concern is conservation of rare and under-represented forested communities
and seral stages, including intact floodplain and riverine systems, as well as primary and old-growth forests

(Sabatini et al., 2018). Research is needed to identify both protection priorities (Sabatini et al., 2020) as well as vulnerabilities in the face of climate change or invasive species. Research investigating the role that natural disturbances play in shaping landscape patterns, beta diversity in habitat and species distributions, and ecosystem service provisioning will be central to our agenda (Mikoláš et al., 2021).



Caption: Rare black pine stand on a rocky outcrop (Piatra Craiului Mountains, Romania). Credit: William Keeton

At the 2025 Forum Carpaticum, participants identified a need for better integration of connectivity into forest management planning. Research on the efficacy of connectivity approaches, such as discrete corridors, riparian buffers, and silvicultural retention practices that maintain dispersal habitats (e.g., partial to fully closed canopies) will be critical in this context. Proper design of biodiversity monitoring systems would complement such research, with Forum participants having identified a particular need for monitoring of large carnivore populations. Integrating forest ecosystem service assessment and valuation into biodiversity and connectivity research would also help clarify trade-offs and synergies among conservation, timber production, carbon storage, water regulation, and recreation, and could strengthen the evidence base for prioritising management interventions.

Research on old-growth, riparian, and other high conservation value forests

A high priority for conservation in the Carpathian Mountain is the forest condition variability termed virgin, quasi-virgin, primeval, primary, old-growth, or natural. In essence, these are old forests exhibiting a high degree of structural complexity and less evidence of recent human disturbance as compared to managed forests. They provide late-successional or late-seral habitats for biodiversity and other functions (Kozák et al., 2023) such as exceptional hydrologic regulation and carbon storage (Markuljaková et al., 2025). It is important to note that primary forest landscapes may contain a mix of seral conditions, both early (young) and late (old), with patch mosaics driven by natural disturbances, ecological succession, and edaphic variability. Here we refer collectively to these systems as "old growth" for consistency with the international scientific literature.

Scientific understanding of old-growth structure, function, and dynamics in the Carpathian region has improved in recent decades, and several mapping efforts have been completed both for portions of the Carpathians specifically and for Europe generally. However, comprehensive, high-resolution, spatially explicit data on old-growth distribution and status remains incomplete, despite efforts by the Carpathian Convention Working Group on Sustainable Forest Management to compile nationally reported point data on "quasi-virgin" forests as in Mancosu (2023) and other pan-European mapping efforts (Sabatini et al., 2018; Barredo et al., 2021). This topic persists, therefore, as a critical research need to guide conservation planning and national compliance with old-growth forest protection commitments. Continued research on old-growth forest processes should remain a priority, such as investigations of carbon dynamics under climate-induced stress, adaptive properties (e.g., plant functional trait diversity, genetic, microclimate regulation), biodiversity relationships, and responses to disturbances.

Recent and current research is also exploring other types of high conservation value forests (HCVFs). These include areas that have remained in continuous forest cover since the mid- to late nineteenth century, as evidenced by historical maps, yet likely have been subject to various human disturbances, including partial harvests. Termed "persistent forests" by Grabska et al. (2024), these include significant areas of riparian (or streamside) forests (Grabska & Keeton, 2026), the latter recognised as critically important for watershed functioning (Hajdukiewicz et al., 2019). Research on the complex forest-stream interactions occurring in riparian areas, as well as their role in flood control, must be a priority for the Carpathian region. Better understanding of other HCVFs, such as rare plant communities, is also needed to inform management and conservation planning.

Research on multifunctional and climate-smart forest management

Sustaining multifunctional forests in the Carpathians requires management approaches that jointly addres climate mitigation and adaptation, biodiversity conservation, ecosystem services, and local livelihoods. Climate-smart forestry provides one such framework by enhancing forest resilience, maintaining productivity, and strengthening carbon sequestration under changing climatic conditions. However, these objectives can generate trade-offs among forest functions and between individual and collective interests, making governance arrangements as important as silvicultural measures. Research in European mountain regions shows that locally based organisations can support the transition towards climate-smart forestry by facilitating cooperation and balancing private and common interests (Brnkaľáková et al., 2022). This will be a fruitful area for continued research.

For the Carpathians specifically, research is needed to better understand how to link multifunctional forest management with restoration and adaptive governance. Research should focus, therefore, not only on forest science oriented towards timber production and wood products, but also on ecological functions, forest biodiversity, landscape connectivity, and the capacity of forest-dependent social–ecological systems to adapt to disturbance (Melnykovych et al., 2018; Aszalós et al., 2022).

Recommended topics

- Natural disturbance dynamics, including alteration of disturbance regimes, vulnerabilities, and implications for habitat and ecosystem services
- Climate change effects, vulnerabilities, risks, and adaptation responses
- Spread of invasive species and their effects on forest ecosystems
- Reforestation and restoration of rare habitats, connectivity areas, and HCVFs
- Ecological silviculture, including but not limited to close(r)-to-nature forestry
- Distribution, status, and conservation opportunities for forest biodiversity, including rare, threat ened, and endangered species
- Forest carbon dynamics, carbon forestry alternatives, and implications for climate mitigation
- Role of protected areas as natural climate solutions
- Forest hydrology and relationships to flood regimes and risks
- Riparian ecology, forest-stream interactions, and flood-plain forests
- Improving the regional forest road networks, including state-of-the art layout, design and engineering standards
- Role of plant functional trait diversity in forest resilience
- Future-adapted tree species and genetic provenance selection for reforestation and restoration plantings
- Primary, "quasi-virgin," old-growth, and under-represented seral stages and communities
- Old-growth and high conservation value forests (HCVF) as regional climate and biodiversity assets
- Sustainable forest-based recreation and mitigating conflicting objectives
- Sustainable wood bioenergy and uncertainty regarding effects on carbon budgets
- Value-added wood products and non-timber forest products
- Close-to-nature and climate-smart forestry
- Forest restoration and reforestation
- Illegal timber harvesting and enforcement of country-specific forest laws

Recommended research questions

- What are the best options for enhancing resilience and adaptation to disturbance while reducing risks?
- What are the optimal criteria and methodologies for determining the most at-risk forest resources, functions, and biological diversity in the region?
- What are the main challenges of sustaining forest ecosystems into an uncertain future?
- Which forest attributes and forest management approaches best confer resilience or adaptability to climate change?
- How can the forest sector contribute to climate change mitigation through forestry practices, restoration, and conservation promoting Natural Climate Solutions?
- How can multifunctional forest management contribute to ecological connectivity and resilience to climate change?
- How can multifunctional forest management integrate a broad range of values and objectives, including non-timber ecosystem services?

References

Aszalós, R., Thom, D., Aakala, T., Angelstam, P., Brūmelis, G., Gálhidy, L., Gratzer, G., Hlásny, T., Katzensteiner, K., Kovács, B., Knoke, T., Larrieu, L., Motta, R., Müller, J., Ódor, P., Roženbergar, D., Paillet, Y., Pitar, D., Standovár, T., Svoboda, M., Szwagrzyk, J., Toscani, P., & Keeton, W. S. (2022). Natural disturbance regimes as a guide for sustainable forest management in Europe. Ecological Applications, 32, e259. https://doi.org/10.1002/eap.2596

Barredo, J. I., Brailescu, C., Teller, A., Sabatini, F. M., Mauri, A., & Janouskova, K. (2021). Mapping and assessment of primary and old-growth forests in Europe. Publications Office of the European Union, Luxembourg. ISBN 978-92-76-34230-4, doi:10.2760/797591, JRC124671

Brnkalakova, S., Melnykovych, M., Nijnik, M., Barlagne, C., Pavelka, M., Udovc, A., Marek, M., Kovac, U., & Kluvánková, T. (2022). Collective forestry regimes to enhance transition to climate smart forestry. Environmental Policy and Governance, 32(6), 492–503. https://doi.org/10.1002/eet.2021

Grabska-Szwagrzyk, E., Jakiel, M., Keeton, W. S., Kozak, J., Kuemmerle, T., Onoszko, K., Ostafin, K., Shahbandeh, M., Szubert, P., Szwagierczak, A., Szwagrzyk, J., Ziółkowska, E., & Kaim, D. (2024). Historical maps can substantially improve the identification of high-conservation-value forests. Conservation Letters, 17, e13043. https://doi.org/10.1111/conl.13043

Grabska, E. & Keeton, W. S. (2026). Mapping and characterizing riparian forests in headwater streams in the Carpathians Mountains of Europe. Ecological Indicators, 187, 114941. https://doi.org/10.1016/j.ecolind.2026.114941

Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P. & Woodbury, P. (2017). Natural climate solutions. Proceedings of the National Academy of Sciences, 114(44), 11645–11650. https://doi.org/10.1073/pnas.1710465114

Hajdukiewicz, H., Wyżga, B., & Zawiejska, J. (2019). Twentieth-century hydromorphological degradation of Polish Carpathian rivers. Quaternary International, 504, 181–194. https://doi.org/10.1016/j.quaint.2017.12.011

Keeton, W. S., McCallum, S., Kuraś, K., Fischer, E., & Egerer, H. (2025). Assessment of climate risks and adaptation options for Carpathian Forest ecosystems and their services. United Nations Environment Programme, Secretariat of the Carpathian Convention. Vienna, Austria.

Kowalski, K., Viana-Soto, A., Brandt, M., Ciais, P., De Keersmaecker, W., Fensholt, R., Pugh, T. A. M., Xu, Y., & Senf, C. (2026). Accelerating biomass loss from forest disturbances across Europe. Nature Geoscience, 19, 1132–1138. https://doi.org/10.1038/s41561-026-02032-y

Kozák, D., Svitok, M., Zemlerová, V., Mikoláš, M., Lachat, T., Larrieu, L., Paillet, Y., Buechling, A., Bače, R., Keeton, W. S., Vítková, L., Begovič, K., Čada, V., Dušátko, M., Ferenčík, M., Frankovič, M., Gloor, R., Hofmeister, J., Janda, P., … Svoboda, M. (2023). Importance of conserving large and old trees to continuity of tree-related microhabitats. Conservation Biology, 37, e14066. https://doi.org/10.1111/cobi.14066

Kruhlov, I., Thom, D., Chaskovskyy, O., Keeton, W. S., & Scheller, R. M. (2018). Future forest landscapes of the Carpathians: vegetation and carbon dynamics under climate change. Regional Environmental Change, 18,1555–1567. https://doi.org/10.1007/s10113-018-1296-8

Mancosu, E. (2023, June). Virgin Forest Inventory of the Carpathians [Map]. European Economic Area (EEA), European Topic Centre on Data Integration and Digitalisation (ETC DI). https://portal.discomap.eea.europa.eu/arcgis/home/item.html?id=66813f21202d4724a604a77a82a98ab0

Markuljaková, K., Mikoláš, M., Svitok, M., Meigs, G. W., Keeton, W. S., Kozák, D., Pavlin, J., Gloor, R., Kalaš, M., Ferenčík, M., Ralhan, D., Frankovič, M., Hofmeister, J., Dúhová, D., Mejstrík, M., Dušátko, M., Veber, A., Knír, T., & Svoboda, M. (2025). Rewilding beech-dominated temperate forest ecosystems: Effects on carbon stocks and biodiversity indicators. Biogeosciences and Forestry, 18, 1–9. https://doi.org/10.3832/ifor4600-017

Melnykovych, M., Nijnik, M., Soloviy, I., Nijnik, A., Sarkki, S., & Bihun, Y. (2018). Social-ecological innovation in remote mountain areas: Adaptive responses of forest-dependent communities to the challenges of a changing world. Science of the Total Environment, 613–614, 894–906. https://doi.org/10.1016/j.scitotenv.2017.07.065.

Melnykovych, M., Nijnik, M., Soshenskyi, O., Zibtsev, S., Lobchenko, G., Sarkki, S., Voloshyna, N., Soloviy, I., Kravets, P., Khan, Y., Yaroshchuk, R., Keeton, W. S., Rosset, C., Pauli, B., Garcia, C. A., & Waeber, P. O. (2026). Pathways for Ukraine's post-war recovery: Focus on forest socio-ecological systems. Ambio 55, 817–843. https://doi.org/10.1007/s13280-025-02263-0

Mikoláš, M., Svitok, M., Bače, R., Meigs, G.W., Keeton, W. S. Keith, H., Buechling, A., Trotsiuk, V., Kozák, D., Bollmann, K., Begovič, K., Čada, V., Chaskovskyy, O., Ralhan, D., Dušátko, M., Ferenčík, M., Frankovič, M., Gloor, R., Hofmeister, J., & Svoboda, M. (2021). Natural disturbance impacts on trade-offs and co-benefits of forest biodiversity and carbon. Proceedings of the Royal Society, B1 288(1961), 20211631. https://doi.org/10.1098/rspb.2021.1631

Sabatini, F. M., Burrascano, S., Keeton, W. S., Levers, C., Lindner, M., Pötzschner, F., Verkerk, P. J., Bauhus, J., Buchwald, E., Chaskovsky, O., Debaive, N., Horváth, F., Garbarino, M., Grigoriadis, N., Lombardi, F., Marques Duarte, I., Meyer, P., Midteng, R., Mikac, S., Mikoláš, Martin … & Kuemmerle, T. (2018). Where are Europe's last primary forests? Diversity and Distributions, 24(10),1426–1439. https://doi.org/10.1111/ddi.12778

Sabatini, F. M., Keeton, W. S., Lindner, M., Svoboda, M., Verkerk, P. J., Bauhus, J., Bruelheide, H., Burrascano, S., Debaive, N., Duarte, I., Garbarino, M., Grigoriadis, N., Lombardi, F., Mikoláš, M., Meyer, P., Motta, R., Mozgeris, G., Nunes, L., Ódor, P. … & Kuemmerle, T. (2020). Protection gaps and restoration opportunities for primary forests in Europe. Diversity and Distributions, 26(12), 1646–1662. DOI:10.1111/ddi.13158

Seidl, R., Thom, D., Kautz, M. Martin-Benito, D., Peltoniemi, M., Vacchiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M. J., Trotsiuk, V., Mairota, P., Svoboda, M., Fabrika, M., Nagel, T. A., & Reyer, C. P. O. (2017). Forest disturbances under climate change. Nature Climate Change, 7, 395–402. https://doi.org/10.1038/nclimate3303

Seidl, R., Schelhaas, M.-J., Rammer, W., & Verkerk, P. J. (2014). Increasing forest disturbances in Europe and their impact on carbon storage. Nature Climate Change, 4, 806–810.

Senf, C., & Seidl, R. (2021). Persistent impacts of the 2018 drought on forest disturbance regimes in Europe. Biogeosciences, 18, 5223–5230. https://doi.org/10.5194/bg-2021-.

Thom, D., Golivets, M., Edling, L., Meigs, G. W., Gourevitch, J. D., Sonter, L. J., Galford, G. L., & Keeton, W. S. (2019). Climate sensitivity of carbon, timber, and species richness in the boreal-temperate ecotone co-varies with forest development. Global Change Biology, 25, 2446–2458.

Zymaroieva, A., Sydorenko, S., Kunakh, O., Svenning, J. C., & Zhukov, O. (2026). War, climate change, and land use shape wildfire dynamics in Ukraine, 2001–2024. Fire Ecology, 22(82).

7 Conservation and sustainable use of biodiversity

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Healthy biodiversity underpins the resources and ecosystem services on which human survival, prosperity and wellbeing depend, yet continued population growth, expanding economic activity and unsustainable consumption patterns have led to a global decline in biodiversity at an unprecedented rate (Díaz et al., 2019; O'Brien et al., 2025). The Carpathian Mountains represent one of the major biodiversity hotspots of Europe, harbouring numerous relatively undisturbed ecosystems, including some of the continent's last large-scale unmanaged old-growth ("virgin") forests and the largest wolf and brown bear populations in Europe. A recent widespread Norway-spruce dieback in the Carpathians can be regarded as a serious threat to natural forests, while this may also represent an opportunity for restructuring commercial stands towards more diverse, climate-resilient species.



UNESCO World Heritage site: Uholka-Shyrokyi Luh, a primaeval beech forest in the Carpathian Biosphere Reserve (Polonyna Krasna Mountains, Ukraine). Credit: Dariia Kholiavchuk

The Carpathian region has undergone dynamic change since the political and economic transformation at the end of the twentieth century, accompanied by urbanisation and shifts in land use. The loss of natural habitats is driven mainly by forest exploitation, land-use conversion, nutrient enrichment and pollution, urban sprawl and transport infrastructure expansion, overtourism, and natural disturbances that are increasingly linked to climate change (Kholiavchuk et al., 2024).

Wetlands, among the most valuable habitats from a biodiversity perspective, are simultaneously the most threatened. Their decline results from a combination of historical and contemporary anthropogenic pressures linked to altered hydrological conditions – drainage, water abstraction, hydropower development, intensive agriculture and forestry, and the spread of non-native and invasive species. The management and restoration of wetlands and watercourses, including the re-establishment of river connectivity and the recovery of functional floodplains, rank among the priorities of national policies and strategies; nevertheless, their practical implementation at a broader scale remains limited (Černecký et al., 2025).



National Park of Veľká Fatra (Veľká Fatra Mountains, Slovakia).
Credit: Ondřej Cudlín

Ligularia sibirica wetland patches in the core zone of National Natural Park Cheremoskyi (Chornyi Dil, Ukraine).
Credit: Yana Popiuk



In addition, the Carpathians remain rich in near-natural, traditional landscapes (Björnsen-Gurung et al., 2009) that support a high level of biodiversity. Mountain meadows are of outstanding scientific and nature-conservation value and of considerable cultural and historical importance. Traditional pastoral systems are not only a feature of cultural heritage; but also contribute to the conservation of regional cultural identity when applied as effective management tools – which cannot be separated from the protection of nature itself (Kricsfalusy, 2013). The decline of near-natural habitats is largely caused by the cessation of traditional management, land abandonment, invasive species, or conversion to intensive, production-oriented practices including overgrazing and afforestation (Janišová et al., 2023).

The full effects of these multiple pressures on biodiversity remain insufficiently understood. There is therefore a clear need for evidence-based management strategies aimed at maintaining biodiversity and protecting the diversity of habitats and species. Recent European Union policies – notably the EU Biodiversity Strategy for

2030, the European Green Deal and the Nature Restoration Regulation (EU, 2024) – provide important new instruments and obligations in the field of ecosystem restoration.

Recommended topics

- Fostering research on endemic taxa
- Revealing the most threatened habitats and species and preparation of action plans for their protection
- Finalisation of the draft Red List of Species and Red List of Forest Habitats with involvement of relevant experts from all Carpathian countries
- Collection, harmonisation and interoperability of biodiversity data across Carpathian countries to support spatial planning and landscape conservation
- Designing monitoring systems for large carnivores
- Effects of linear infrastructure development on fragmentation of wild animal populations and animal–vehicle collisions; identification of measures to prevent or reduce these impacts
- Identification of conflicts between humans and wildlife (build on experience from other mountainous regions in resolving wolf-livestock conflicts) and of measures for resolution or reconciliation
- Restoration of wetlands, including the application of nature-based solutions as a tool for biodiversity conservation
- Identification of discrepancies between environmental policy and wetland protection in practice
- Mapping and conservation of old-growth forests
- Revitalisation of traditional forest and pasture economy, including pastoralism as a flexible strategy for sustainable use of marginal resources in remote areas
- Monitoring and mitigating the impact of land use change on the diversity and connectivity of natural and semi-natural habitats
- Addressing knowledge gaps in applying an ecosystem approach, and methods of mapping and assessment of ecosystem services provided by natural habitats

Recommended research questions

- What are the direct and indirect impacts of human activities and climate change on biodiversity, with a focus on old forest, wetlands, and near-natural meadows?
- What are effective long-term adaptive management frameworks for habitat protection and biodiversity maintenance?
- How do invasive species impact natural ecosystems and how can their spread be controlled?
- How does the restoration of floodplains and river branches impact the biodiversity of Carpathian wetlands?
- What barriers hinder effective wetland protection and restoration despite existing strategies?
- What type and level of management (including the restoration of traditional pastoral farming), is necessary to maintain a high diversity of mountain meadows while balancing nature conservation objectives?
- What are optimal sizes of large carnivore populations in the Carpathians?

- What are the effects of legal hunting on animal population structure and behaviour?
- What are the social, ecological and economic dimensions of human–carnivore coexistence in Carpathian landscapes, and what management interventions improve it?

References

Björnsen-Gurung, A., Bokwa, A., Chełmicki, W., Elbakidze, M., Hirschmugl, M., Hostert, P., Ibisch, P., Kozak, J., Kuemmerle, T., Matei, E., Ostapowicz, K., Pociask-Karteczka, J., Schmidt, L., van der Linden, S., & Zebisch, M. (2009). Global change research in the Carpathian Mountain Region. Mountain Research and Development, 29, 282–288. http://dx.doi.org/doi:10.1659/mrd.1105

Černecký, J., Špulerová, J., Ďuricová, V., & Kadlečík, J. (2025). Wetlands of Mountainous Regions of Slovakia. In Pullaiah, T. (Ed.). Wetlands of Mountainous Regions: Biodiversity, Livelihoods and Conservation. Wiley, 157–185. https://doi.org/10.1002/9781394235230.ch6

Díaz, S.M., Settele, J., Brondízio, E., Ngo, H., Guèze, M., Agard, J., …, Chan, K. (2019). The global assessment report on biodiversity and ecosystem services: Summary for policy makers – IPBES Secretariat, Bonn.

European Union. (2024, 29 July). Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869. Official Journal of the European Union. L, 2024/1991. http://data.europa.eu/eli/reg/2024/1991/oj

Janišová, M., Bojko, I., Ivașcu, C.M., Iuga, A., Biro, A.-S., & Magnes, M. (2023). Grazing hay meadows: History, distribution, and ecological context. Applied Vegetation Science 26: e12723. https://doi.org/10.1111/avsc.12723

Kholiavchuk, D., Gurgiser, W., & Mayr, S. (2024). Carpathian forests: Past and recent developments. Forests 15(1), 65. https://doi.org/10.3390/f15010065

Kricsfalusy, V. V. (2013). Mountain grasslands of high conservation value in the Eastern Carpathians: syntaxonomy, biodiversity, protection and management. Thaiszia – Journal of Botany, Košice, 23, 67–112.

O'Brien, K., Garibaldi, L. A., Agrawal, A., Bennett, E., Biggs, R., Calderón Contreras, R., Carr, E. R., Frantzeskaki, N., Gosnell, H., Gurung, J., Lambertucci, S. A., Leventon, J., Chuan, L., Reyes García, V., Shannon, L., Villasante, S., Wickson, F., Zinngrebe, Y., & Périanin, L. (2025). IPBES Transformative Change Assessment: Summary for Policymakers (10.2.0). Zenodo. https://doi.org/10.5281/zenodo.15645812

8 Ecosystem services and human wellbeing

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Ecosystem Services (ES) are central to the sustainability and wellbeing of the Carpathian mountain region. Forests, agricultural land, grasslands, freshwater ecosystems and semi-natural habitats jointly provide provisioning services (i.e., food, wood and non-wood forest products or NWFPs); regulating services (i.e., water regulation, erosion control, carbon sequestration, pollination and natural-hazard mitigation); and cultural services (i.e., recreation, tourism, heritage and landscape identity) (Nijnik et al., 2020; Melnykovych et al., 2026). Biodiversity and ecosystem integrity underpin the capacity of these systems to maintain ES provision over time, withstand disturbance and respond to environmental change. Research in the Carpathians has advanced ES mapping, assessment, and valuation. Landscape-scale economic assessment has been applied in Ukraine, including to the Ukrainian Carpathians (Prykhodko et al., 2023), while monetary and non-monetary valuation was applied in research on the Southern Carpathians (Chivulescu et al., 2024), and economic and stakeholder-based approaches to ES valuation were also applied in the Ukrainian Carpathians (Zahvoyska et al., 2017). Earlier research showed the importance of ES for mountain and forest-dependent communities (Melnykovych & Soloviy, 2014) and revealed commonalities and differences in stakeholder perceptions and preferences concerning forest ES (Zahvoyska & Bas, 2013; Grilli et al., 2016). The identification and understanding of public attitudes toward multifunctionality in ES provision in Carpathian forests have advanced (Nijnik & Melnykovych, 2016; Nijnik et al., 2017). Opportunities and challenges for adaptive management of forests for multiple ES have been explored (Zahvoyska et al., 2017). Carpathian research on ES has gone beyond forests to consider grasslands within the wider landscape. For example, the provision of ES in Carpathian grasslands is dependent on land use and land use changes (Špulerová et al., 2026). Provisioning of ES is shaped not only by ES abundance/availability and condition but also to a large extent by tenure rights, land management and use, and by land use changes, the legacy of resource use, institutions, markets, governance, local knowledge and socio-economic changes (Melnykovych et al., 2018; Nijnik et al., 2022). Consideration of what various stakeholders need and want is also crucial; future research, therefore, should move beyond ES mapping and valuation towards a broader social–ecological systems (SES) perspective. Recent work on multifunctional mountain forestry shows the value of mixed methods approaches that integrate ecological evidence with stakeholder perspectives and management objectives (Nijnik et al., 2026).

A key challenge is multi-functionality (Barraclough et al., 2026). Ecosystems provide multiple services simultaneously, and their combinations vary across land uses, ecological conditions and management regimes (Nijnik & Miller, 2013; Nijnik et al., 2026). Research should therefore focus increasingly on ecosystem-service bundles, synergies and trade-offs rather than individual services (Barraclough et al., 2026). Recent evidence shows that consistent ES bundles can emerge across mountain systems (Reader et al., 2024). Understanding how these bundles change under different management and environmental conditions (including those imposed by the changing climate) is essential for identifying both synergies and potential conflicts among production, regulation, and conservation and in meeting cultural aspirations and educational objectives.

Another major gap concerns the mismatch between supply and demand of ES. Potential ES supply is not equivalent to actual use or benefit. Future assessments should distinguish between ecosystem capacity, sup-



SBrasov County_ Bucegi Mountains. Credit: Dan Dinu

ply, actual flow and use of the benefits/services provided, and the demand for these and their beneficiaries (Edens et al., 2022). This is particularly important in mountain landscapes, where service-producing and service-benefiting areas are often spatially separated (Adler et al., 2020). Upstream ecosystems can provide water-regulation and erosion-control benefits downstream; recreation may benefit non-local visitors; and carbon sequestration generates benefits at regional and global scales (Adler et al., 2022). Research should therefore identify service-providing areas, flow pathways, beneficiaries and mismatches (if any) between ES supply and demand (as seen in Nijnik et al., 2017).

The plurality of values also requires greater attention. Economic valuation alone cannot capture the full range of instrumental, relational and intrinsic values associated with nature. Monetary valuation should therefore be complemented by non-monetary, deliberative, socio-cultural and participatory approaches (Njnik & Miller, 2017; Pascual et al., 2023; Himes et al., 2024). Methodological work also stresses that valuation approaches should be selected according to the decision context and type of value considered (Martino et al., 2024). Where relevant, the ES framework can be complemented by the Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) Nature's Contributions to People (NCP) perspective (Pascual et al., 2017, 2023; Díaz et al., 2018).

Climate change and land-use transitions should be treated as central drivers of future ES dynamics. Drought, altered precipitation, floods, wildfire, pests, land abandonment, agricultural intensification, forest expansion

and socio-economic change can interact and alter both ecosystem functioning and societal demand for services. Recent mountain research confirms that climate change is already affecting ES provision and human wellbeing (Melnykovych et al., 2026). Future research should, therefore, examine ES trajectories and resilience under alternative climate, land-use and socio-economic scenarios, rather than focusing only on present conditions (as seen in Ioan et al., 2025).

Institutions, ownership and access rights, markets, policy and power relations influence which services are prioritised, who benefits and who bears the costs of maintaining these (as seen in Langemeyer et al., 2024). Social and social–ecological innovation may support more sustainable and collaborative governance (Melnykovych et al., 2018; Nijnik et al., 2022; and see Chapter 16 on social innovations). Research should also address justice aspects: who receives benefits, who participates in decisions, and whose knowledge and values are recognised and considered so as to leave no one behind (Sarkki et al., 2022).

Recommended topics

- Analyse human–environment interactions shaping the ES demand and supply, use and the dependence on forest ES across the Carpathian social–ecological systems
- Investigate stakeholder perceptions, preferences and expectations regarding forest ES and integrate them into forest management and decision-making
- Assess and value ES using plural approaches to valuation/evaluation that combine biophysical, monetary and non-monetary methods to support better decision-making and sustainable governance of nature
- Adopt participatory approaches to capture instrumental, relational and intrinsic values associated with the Carpathian ecosystems and landscapes
- Analyse ES multi-functionality, bundles, synergies and trade-offs across different land uses and management systems
- Investigate ES supply, flows, demand and beneficiaries, including spatial mismatches between the areas where services are generated and where ES benefits are realised
- Develop trajectories and scenarios to assess the sustainability and resilience of the ES pro visioning under climate, land-use and socio-economic changes, and identify appropriate responses, including pertaining to social and social–ecological innovations
- Assess how power, institutions, ownership, access rights and economic (and other) interests shape the management, distribution and valuation of ES benefits, including opportunities for sustainable governance and the risks of inequity, commodification and conflicts

Recommended research questions

Central research questions around ES for human wellbeing could be formulated as follows: How and potentially under which circumstances/conditions, can the evolving Carpathian social–ecological systems generate, fairly distribute and sustain the ES services provisioning and their contributions to various end-users by meeting their demands and aspirations? Who would bear the associated costs? Under which management and governance arrangements (and other contexts and place specificity) can the resilience of the Carpathian ES and the ES provisioning and fair distribution be maintained under climate, land-use and socio-economic change?

- Which ES and their bundles contribute most to the wellbeing of the communities of places, practices and interests and various social groups in the Carpathian Mountains? How does the dependence on these services vary across the region?
- How do ES supply, demand, flows and beneficiaries vary across the Carpathian landscapes and land-use systems?
- Which combinations of methods and tools are most appropriate for assessing and valuing the plurality of and trade-offs between the multiple benefits and values associated with ES?
- What synergies and trade-offs emerge and how can they be addressed while using different management and land-use scenarios? Who benefits and who bears the associated costs? How can equity and fairness in distribution be improved?
- How will/could climate change, land-use transition and socio-economic changes affect ES provisioning and the resilience of the Carpathian socio-ecological systems over time?
- Which social and social–ecological and/or socio-political innovations (Sarkki et al., 2022) can support sustainable ES services provisioning, equitable governance and human well-being?

References

Adler, C., Balsiger, J., Grêt-Regamey, A., Heinimann, A., Huggel, C., Weingartner, R., Alcántara-Ayala, I., Gebrekirstos, A., Grau, R., Jimenez, E., Marchant, R. Mark, B., Marshall, S. Morin, S. Shahgedanova, M., Singh Shrestha, M. & Xu, J. (2020). Making connections for our changing mountains: Future directions for the Mountain Research Initiative (MRI). Mountain Research and Development, 40(3), 1–6. https://doi.org/10.1659/MRD-JOURNAL-D-20-00045.1

Adler, C., Wester, P., Bhatt, I., Huggel, C., Insarov, G. E., Morecroft, M.D., Muccione, V., & Prakash, A. (2022). Cross-Chapter Paper 5: Mountains. In H. O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, et al., (Eds.). Climate change 2022: Impacts, adaptation and vulnerability (pp. 2273–2318). Cambridge University Press. https://doi.org/10.1017/9781009325844.022

Barraclough, L., Ebner, M., & Tappeiner, U. (2026). Stakeholder expectations for future mountain forests: Synergies, trade-offs, limitations, and barriers in ecosystem service supply. Ecology and Society, 31(3). https://doi.org/10.5751/ES-17199-310303

Chivulescu, S., Hapa, M., Pitar, D., Lorenţ, A., Marmureanu, L., Leca, S., Radu, R., Cazacu, R., Dobre, A. C., Pascu, I. S., Marcu, C., Verghelet, M., Vezeanu, C., Racoviceanu, T., & Badea, O. (2024). Integrating monetary and non-monetary valuation for ecosystem services in Piatra Craiului National Park, Southern Carpathians: A comprehensive approach to sustainability and conservation. Frontiers in Forests and Global Change, 7,1280793. https://doi.org/10.3389/ffgc.2024.1280793

Díaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R.T., Molnár, Z., Hill, R., Chan, K. M. A., Baste, I. A., Brauman, K. A., Polasky, S. Church, A. Lonsdale, M. Larigauderie, A., Leadley, P. W., Van Oudenhoven, A. P. E., Van Der Plaat, F., Schröter, M. Lavorel, …. & Shirayama, Y. (2018). Assessing nature's contributions to people. Science, 359(6373), 270–272. https://doi.org/10.1126/science.aap8826

Edens, B., Maes, J., Hein, L., Obst, C., Siikamaki, J., Schenau, S., Javorsek, M., Chow, J., Chan, J., Steurer, A. & Alfieri, A. (2022). Establishing the SEEA Ecosystem Accounting as a global standard, Ecosystems Services, ISSN 2212-0416, 54, 101413, JRC126032.

Grilli, G., Jonkisz, J., Ciolli, M., & Lesinski, J. (2016). Mixed forests and ecosystem services: Investigating stakeholders' perceptions in a case study in the Polish Carpathians. Forest Policy and Economics, 66, 11–17. https://doi.org/10.1016/j.forpol.2016.02.003

Himes, A., Muraca, B., Anderson, C. B., Athayde, S., Beery, T., Cantú-Fernández, M., González-Jiménez, D., Gould, R. K., Hejnowicz, A. P., Kenter, J., Lenzi, D., Murali, R., Pascual, U., Raymond, C., Ring, A., Russo, K., Samakov, A., Stålhammar, A., Thorén, H., & Zent, E. (2024). Why nature matters: A systematic review of intrinsic, instrumental, and relational values. BioScience, 74(1), 25–43. https://doi.org/10.1093/biosci/biad109

Ioan, S., Roseo, F., & Brambilla, M. (2025). Mountain ecosystem services under a changing climate: A global perspective. Ecosystem Services, 73, 101732. https://doi.org/10.1016/j.ecoser.2025.101732

Langemeyer, J., Benra, F., Nahuelhual, L., & Zoderer, B. M. (2024). Ecosystem services justice: The emergence of a critical research field. Ecosystem Services, 69, 101655. https://doi.org/10.1016/j.ecoser.2024.101655

Martino, S., Martinat, S., Joyce, K., Poskitt, S., & Nijnik, M. (2024). A classification and interpretation of methodological approaches to pursue natural capital valuation in forest research. Forests, 15(10),1716. https://doi.org/10.3390/f15101716

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkaľáková, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvánková, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy, I., Waeber, P. O. & Zawiejska, J. (2026). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda. Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Melnykovych, M., Nijnik, M., Soloviy, I., Nijnik, A., Sarkki, S., & Bihun, Y. (2018). Social-ecological innovation in remote mountain areas: Adaptive responses of forest-dependent communities to the challenges of a changing world. Science of the Total Environment, 613–614, 894–906. https://doi.org/10.1016/j.scitotenv.2017.07.065

Melnykovych, M., & Soloviy, I. (2014). Contribution of forestry to the well-being of mountain forest-dependent communities in the Ukrainian Carpathians. Proceedings of the Forestry Academy of Sciences of Ukraine, 12, 233–241.

Nijnik, M., Kluvankova, T., & Melnykovych, M. (2022). The power of social innovation to steer sustainable governance of nature. Environ mental Policy and Governance, 32(6), 453–458. https://doi.org/10.1002/eet.2018

Nijnik, M., & Melnykovych, M. (2016). Exploring challenges to sustainability in the provision of ecosystem services by upland forests in Scotland and Ukraine. In W. Sekot, P. Toscani, & E. Ungerböck, (Eds.). IUFRO symposium proceedings: Advances and challenges in managerial economics and accounting (pp. 85–86).

Nijnik, M., Melnykovych, M., Martino, S., Sarkki, S., Nijnik, A., Kopiy, S., Kopiy, L., Joyce, K., Wang, C., Poskitt, S., & Miller, D. (2026). A mixed methods approach to better understand and steer multifunctional forestry in mountain regions of Europe. Forest Policy and Economics, 190, 103859. https://doi.org/10.1016/j.forpol.2026.103859

Nijnik, M., & Miller D. (2013). Targeting sustainable provision of forest ecosystem services with special focus on carbon sequestration. In R. Matyssek, N. Clarke, P. Cudlin, T. Mikkelsen, J.-P. Tuovinen, G. Wiesser, E. Paoletti (Eds.). Climate change, air pollution and global challenges: Understanding and perspectives from forest research (pp. 547–568). Elsevier. https://doi.org/10.1016/B978-0-08-098349-3.00025-6

Nijnik, M., & Miller, D. (2017). Valuation of ecosystem services: Paradox or Pandora's box for decision-makers? One Ecosystem, 2e14808. https://doi.org/10.3897/oneeco.2.e14808

Nijnik, M., Nijnik, A., Sarkki, S., Muñoz-Rojas, J., Miller, D., Kopiy, S., & Kopiy, L. (2017). Identifying and understanding attitudinal diversity on multi-functional changes in woodlands of the Ukrainian Carpathians. Climate Research, 73, 45–56. https://doi.org/10.3354/cr01448

Nijnik, M., Wiersum, F., Mutke, S., Kurttila, M., Sheppard, J., Wong, J., de Miguel, S., Nijnik, M., Spiecker, H., Miina, J., Melnykovych, M., Tsioras, P., Abraham, E., Enescu, M., & Kyriazopoulos, A. (2020). Considering NWFP in multi-purpose forest management. In H. Vacik, M. Hale, H. Spiecker, et al., (Eds.). Non-wood forest products in Europe: Ecology and management of mushrooms, tree products, understory plants and animal products (pp. 79–123). Norderstedt.

Pascual, U., Balvanera, P., Anderson, C. B., Chaplin-Kramer, R., Christie, M., González-Jiménez, D., Martin, A., Raymond, C. M., Termansen, M., Vatn, A., Athayde, S., Baptiste, B., Barton, D. N., Jacobs, S., Kelemen, E. Kumar, R., Lazos, E., Mwampamba, T. H. Nakangu, B. … & Zent, E. (2023). Diverse values of nature for sustainability. Nature, 620, 813–823. https://doi.org/10.1038/s41586-023-06406-9

Pascual, U., Balvanera, P., Díaz, S., Pataki, G., Roth, E., Stenseke, M., Watson, R. T., Dessane, E. B., Islar, M., Kelemen, E., Maris, V., Quaas, M., Subramanian, S. M., Wittmer, H., Adlan, A., Ahn, S., Al-Hafedh, Y. S. Amankwah, E., Asah, S. T. … & Figueroa, E. (2017).

Valuing nature's contributions to people: The IPBES approach. Current Opinion in Environmental Sustainability, 26–27, 7–16. https://doi.org/10.1016/j.cosust.2016.12.006

Prykhodko, M., Arkhypova, L., Fomenko, N., Syrovets, S., Varianichko, V., & Osypov, D. (2023). Economic value of ecosystem services in the landscapes of Ukraine. In 17th International Conference Monitoring of Geological Processes and Ecological Condition of the Environment (pp. 1–5). European Association of Geoscientists & Engineers. https://doi.org/10.3997/2214-4609.2023520221

Reader, M. O., Eppinga, M. B., de Boer, H. J., Petchey, O. L., & Santos, M. J. (2024). Consistent ecosystem service bundles emerge across global mountain, island and delta systems. Ecosystem Services, 66,101593. https://doi.org/10.1016/j.ecoser.2023.101593

Sarkki, S., Jokinen, M., Heikkinen, H. I., Nijnik, M., Melnykovych, M., & Kluvankova, T. (2022). "Going out to get in": Roles of forest conflicts in bottom-linked environmental governance progressing toward socio-political innovations. Environmental Policy and Governance 32(6), 478–491. https://doi.org/10.1002/eet.2020

Špulerová, J., Melicher, J., & David, S. (2026). Impact of land use changes on ecosystem services provision in grasslands: A case study from Slovakia. Scientific Reports, 16, 24823. https://doi.org/10.1038/s41598-026-55552-3

Zahvoyska, L., & Bas, T. (2013). Stakeholders' perceptions of mountain forest ecosystem services: The Ukrainian Carpathians case study. In J. Kozak, K. Ostapowicz, A. Bytnerowicz, B. Wyżga, (Eds). The Carpathians: Integrating nature and society towards sustainability (pp 353–367). Springer. https://doi.org/10.1007/978-3-642-12725-0_25

Zahvoyska, L., Pelyukh, O., & Maksymiv, L. (2017). Methodological considerations and their application for evaluation of benefits from the conversion of even-age secondary Norway spruce stands into mixed uneven-aged woodlands with a focus on the Ukrainian Carpathians. Austrian Journal of Forest Science, 134, 251–281. https://www.researchgate.net/publication/318505900



9 Urban and rural development

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Urban and rural development in the Carpathians is shaped by long-term interactions among topography, accessibility, natural-resource use, economic activities, population dynamics and governance (Melnykovych et al., 2026a). Many remote areas still experience depopulation, ageing, increasing unemployment, outmigration, land abandonment, weakening economic situations and limited institutional capacity (; Matei et al., 2016; Melnykovych et al., 2026a), while some urban, peri-urban and tourism-intensive areas are at the other extreme and face development pressures, housing constraints, and competition for land and resources (Săvulescu et al., 2019; Lozynskyy & Zubyk, 2022; Muntele et al., 2023). "Left-behindness" therefore cannot be reduced to remoteness or demographic decline (Sarkki et al., 2022; ESPON, 2025): interacting disadvantages may reinforce one another and create persistent "polytraps" (Sarkki et al., 2025; MARGISTAR, 2026; Zimmer et al., 2026). The Russian war against Ukraine has added a major territorial shock. Beyond destruction and displacement within Ukraine, it has generated refugee movements, altered labour and trade flows, increased pressures on housing and public services, changed transport and logistics, and heightened concerns over energy security, critical infrastructure and preparedness across neighbouring Carpathian countries (European Commission, 2025e, 2026; Melnykovych et al., 2026b).



Rural landscape in the Polonyna Borzhava Mountains, Ukraine. Credit: Nadin Nandin (@nadin_nandin)

Science should continue to generate evidence on unresolved challenges and dysfunctional processes, while providing a coherent framework to guide the future development, policies, and sustainability of settlements. Thus, research should examine the Carpathians as an interconnected settlement system rather than as separate urban and rural territories. Rural communities, small and medium-sized towns, peri-urban areas and larger centres are linked not only physically through transportation (for long- and short-term mobility such as migration or commuting), but, also, through employment, education, healthcare, markets, housing, tourism, infrastructure, ecosystem services, energy and digital connectivity (Kwiatek-Sołtys et al., 2014; Melnykovych et al., 2024; RURACTIVE, 2026). In mountain regions, topography and accessibility strongly shape such functional relations (Haller & Branca, 2023; Bertram et al., 2024). Research should therefore move beyond administrative urban–rural categories towards functional territories defined by labour markets, services, mobility and resource flows, while clearly distinguishing the formal Carpathian Convention area from broader analytical delimitations (European Commission, 2024; ESPON, 2025).

Research on small- and medium-sized towns should be focused on their critical intermediary roles as centres of employment, services, innovation and governance, connecting surrounding rural communities with wider economic and institutional networks (Kwiatek-Sołtys et al., 2014; European Commission, 2025a; OECD, 2026). Improved physical and digital accessibility, remote work, and circular- and bioeconomy activities may diversify local labour markets and strengthen regional value chains, but outcomes depend on infrastructure, skills, housing, ownership and the ability to retain value locally (Wiedermann, 2015, 2026).

Demographic decline in shrinking and marginalised rural areas should not be treated only as a deficit to be reversed, but as part of broader territorial restructuring requiring adaptation and place-based development (Kluvankova et al., 2021; ESPON, 2025). Consequences of demographic decline will depend on employment, accessibility, housing, healthcare and care provision, education, institutional capacity and environmental conditions. This is consistent with the Long-Term Vision for EU Rural Areas (European Commission, 2024) and the research agenda for mountain futures (Zimmer et al., 2026; Melnykovych et al., 2026a). Migration dynamics include youth and labour outmigration, return and amenity migration, cross-border commuting and, since 2022, large-scale forced displacement from Ukraine. Research should therefore examine whether people have a genuine possibility to stay, return or settle through access to jobs, housing, services, mobility and connectivity.

Special attention should be given to the following subjects:

Youth retention / attraction and generational renewal, which depend on access to skills, land, housing, finance, meaningful employment, entrepreneurship and participation in local decision-making. Gender inequalities can shape participation in employment, entrepreneurship and leadership, while unequal care responsibilities can constrain economic participation. In agriculture, women remain particularly underrepresented among younger farm managers (European Commission, 2025c). Research should also consider minorities, displaced people and other groups whose capacity to participate in and benefit from territorial transitions differs (Bizikova et al., 2012).

Place-based initiatives and capacity to act are important to ensure resilience. Agriculture, forestry, manufacturing, tourism, renewable energy, digital activities, creative industries and social and community

enterprises can support durable development where they strengthen local capabilities and retain value within communities. Research should address land access, farm succession, mountain food systems, local processing, post-industrial restructuring and brownfield reuse, alongside newer place-based solutions such as cooperatives, community enterprises, short value chains, energy communities, Living Labs and social innovation (see Chapter 16 on social innovation); the Rural Innovation Ecosystems approach developed through the RURACTIVE project provides such a model (Bertuca et al., 2024; RURACTIVE, 2026). Local capacity, multi-actor cooperation, knowledge exchange and enabling institutional conditions are very important (Mitrofanenko et al., 2025). Experience from Vlkolínec, Slovakia illustrates how networking and knowledge co-production can support farming, landscape management and social innovation (Melnykovych et al., 2019; Špaček et al., 2022), including carbon-related initiatives and collective forestry regimes (Brnkalakova et al., 2022). Entrepreneurial and project-development competences are increasingly important for participation in green and digital transitions (Melnykovych et al., 2024). Territorial capacity depends not only on leadership, skills and networks, but also on capacities of municipalities to act for change and access finance (Melnykovych et al., 2026a). Five Carpathian Convention Parties are EU Member States, while Serbia and Ukraine are EU candidate countries; EU cohesion, agricultural, and urban- and rural-development instruments therefore do not apply uniformly, yet accession and cross-border programmes nevertheless create opportunities for policy alignment and learning. In Ukraine, reconstruction and EU accession make municipal capacity, international partnerships and local participation particularly consequential (Mitrofanenko et al., 2025).

Circular economy, bioeconomy and renewable energy, which are extremely relevant topics in the Carpathians. The Carpathians' forest, agricultural and other biological resources create opportunities for sustainable forestry and wood processing, mountain food products, bio-based materials, reuse of agricultural and forestry residues, biogas and appropriately scaled bioenergy. The EU Bioeconomy Strategy links circular use of biological resources with rural jobs, SMEs, diversified incomes and resilience (European Commission, 2025b); yet resource abundance does not automatically create local prosperity or affordable energy. Evidence from the Ukrainian Carpathians shows that available forest resources can coexist with energy insecurity because access is mediated by infrastructure, markets, institutional arrangements and ownership (Soloviy et al., 2019). Research should therefore examine who owns resources, where processing occurs, who captures value, and how environmental costs and benefits are distributed. Bioenergy should be considered within a broader circular bioeconomy: biomass use should respect ecological limits and prioritise resource efficiency, cascading and higher-value uses. Russian attacks on Ukrainian energy infrastructure have further increased the importance of distributed renewable generation, energy-system resilience and cross-border energy integration (European Commission, 2025e; Melnykovych et al., 2026b; see also Chapter 10 on green energy). Circular approaches should also include repair, reuse, circular construction, secondary materials, and consideration of the reduction or reinforcement of territorial inequalities in transition (Drobniak et al., 2023).

Depopulation and demographic change still reshape Carpathian settlements, through housing abandonment, shrinking services, and outmigration. Depopulating areas may also experience vacancy and underuse, while peri-urban and tourism-intensive areas face second-home development, rising prices and affordability pressures. Displacement from Ukraine has added uneven housing, education, healthcare and social-service demand in receiving territories, while reconstruction creates different challenges within Ukraine. Adaptive reuse, energy renovation, affordable housing and circular construction should be explored while protecting cultural heritage and landscape character. The New European Bauhaus provides a relevant framework linking sustainability, inclusion and quality of place (European Commission, 2025d).

Rural–urban accessibility and connectivity are critical for linking dispersed Carpathian communities with jobs, services and markets. Research should assess transport travel time, affordability, frequency and reliability, while accounting for environmental impacts in sensitive mountain landscapes. Attention should be paid to sustainable public, demand-responsive and shared mobility; digital service provision; and functional links between rural areas and small- and medium-sized towns that are employment and service nodes (Guzik et al., 2022; European Commission, 2025f, 2026).

The operationalisation of **climate-resilient settlements** requires more research and policy attention, particularly to translate climate-resilient development principles into place-specific planning and implementation (Cheval et al., 2020; Muntele et al., 2021). Water scarcity, floods, landslides, wildfire risk and competing demands increasingly affect settlements and economic activities. Research should integrate future water availability, nature-based solutions, ecological connectivity and nature restoration into anticipatory and climate-resilient spatial planning (see Chapter 2 on water). Carbon-smart forestry may contribute where appropriately designed (Brnkalakova et al., 2022; see Chapter 6 on Forestry).

Tourism function and liveability, as it can sustain not only employment, services and local products but can also intensify seasonality, traffic, housing pressures, land price inflation, inhabitants' irritability and conflicts (Zawilińska et al., 2023), resource demand and landscape change (spatial structure, settlements' identity) (see Chapter 11 on tourism). War and security perceptions have further altered tourism flows unevenly across the region.

Research on urban and rural development in the Carpathians should move beyond sectoral analyses towards comparative, longitudinal and transboundary assessment of differentiated yet interconnected territorial development pathways.

Recommended topics

- Map and monitor depopulation, ageing, migration, displacement, settlement growth and shrinkage, peri-urbanisation, tourism" pro and cons", land-use change, post-industrial restructuring and cross-border relations;
- Consider youth retention / attraction, generational renewal, gender equality, housing, care, education, employment, mobility and digital connectivity;
- Assess the changing role of small and medium-sized towns in employment, services, innovation, markets and governance;
- Study local agency, leadership, skills, local municipalities' capacity, knowledge co-production and access to finance as factors that trigger rural and urban development projects;
- Assess forestry, agriculture, food systems, bioenergy, renewable energy, circular businesses, local processing and ownership, with attention to ecological limits and fair benefit sharing; and
- Examine how digital, energy, housing, tourism, climate, war and post-war reconstruction affect different territories and population groups in the Carpathians.

Recommended research questions

- How are urban and rural trajectories changing across the Carpathians, and how can these changes be consistently mapped and monitored?
- Which demographic, socioeconomic, accessibility, environmental, geopolitical and institutional factors drive marginalisation, adaptation or revitalisation?
- How do depopulation, ageing, migration and war-related displacement affect liveability and the "right to stay", especially for youth, women and other groups?
- What roles can small- and medium-sized towns play in connecting rural communities to jobs, services, innovation, markets and governance?
- How will tourism-driven development impact the liveability, spatial structure, and social-environmental sustainability of Carpathian settlements?
- Which combinations of governance capacity, finance, skills, networks and knowledge co-production enable effective place-based solutions?
- When can circular economy, bioeconomy, sustainable bioenergy and local value chains create jobs and retain value while ensuring affordability, fair benefit sharing and ecological sustainability?
- How could Carpathian settlements adapt their spatial development and connectivity to increasing climate change and natural–human hazard risks?
- How are the Russian military aggression in Ukraine, displacement, reconstruction and EU accession reshaping demographic, economic, infrastructure and cross-border development pathways in the entire region?
- How can green, digital, energy, housing, tourism and reconstruction-related transitions support inclusive and resilient development while preserving Carpathian ecosystems?
- How does war reshape regional relations and does development restore rather than degrade the ecosystems on which Carpathian livelihoods depend?

References

Bertram, D., Lambracht, M., & Chilla, T. (2024). Settlement systems in mountain regions: A research gap? Mountain Research and Development, 44(2), A1–A9. https://doi.org/10.1659/mrd.2023.00021

Bertuca, A., Cavalieri, B., De Luca, C., Selva, C., Domínguez, X., Fuentemilla, S., Pilla, F., & Valero, D. (2024). Activating RIEs for community-led development and empowerment. RURACTIVE Deliverable. Horizon Europe project RURACTIVE—Empowering Rural Communities to Act for Change (2023–2027), Grant Agreement No. 101084377.

Bizikova, L., Nijnik, M., & Kluvánková-Oravská, T. (2012). Sustaining multifunctional forestry through the developing of social capital and promoting participation: A case of multiethnic mountain communities. Small-scale Forestry, 11, 301–319. https://doi.org/10.1007/s11842-011-9185-8

Brnkalakova, S., Melnykovych, M., Nijnik, M., Barlagne, C., Pavelka, M., Udovc, A., Marek, M., Kovac, U., & Kluvankova, T. (2022). Collective forestry regimes to enhance transition to climate smart forestry. Environmental Policy and Governance. https://doi.org/10.1002/eet.2021

Cheval, S., Micu, D., Dumitrescu, A., Irimescu, A., Frighenciu, M., Iojă, C., Tudose, N. C., Davidescu, Ș. & Antonescu, B. (2020). Meteorological and ancillary data resources for climate research in urban areas. Climate, 8(3), p.37. https://doi.org/10.3390/cli8030037

Drobniak, A., Ochojski, A., Churski, P., Muster, R., Zakrzewska-Półtorak, A., Baron, M., Rzeńca, A. E., Trembaczowski, Ł., Korenik, S., Rynio,

D., Hajduga, P., Kozak, A., Janicki, W., Iwanicki, G., Jakubowski, A., Cyran, R., Rykała, P., Czornik, M., Magdoń, M., Kuźnik, F., Nowakowska, A., Gwosdz, K., Sitek, S., Wiedermann, K., Perdał, R., Burchardt, M., Badura, P., & Miracki, J. (2023). Strategic recommendations for just transition in Poland. Scientific Publications of the University of Economics in Katowice, 123–206.

ESPON. (2025). KARPAT—Determinants and opportunities for the socio-economic and spatial development of the Carpathian region: Final report. ESPON EGTC.

European Commission. (2024). The long-term vision for the EU's rural areas: Key achievements and ways forward, {COM(2024) 450 final}. European Commission.

European Commission. (2025a). An EU Agenda for Cities: Driving Growth and Prosperity. {COM (2025) 739 final}. European Commission.

European Commission. (2025b). A strategic framework for a competitive and sustainable EU bioeconomy. {COM (2025) 960 final}. European Commission.

European Commission. (2025c). Strategy for generational renewal in agriculture. {COM (2025) 872 final}. European Commission.

European Commission. (2025d). Horizon Europe Work Programme 2025. Part 13: New European Bauhaus Facility. European Commission.

European Commission. (2025e). Commission steps up support for Ukraine's energy security and paves the way for full market integration. Directorate-General for Enlargement and Eastern Neighbourhood, 24 February 2025.

European Commission (2025f). High Representative of the Union for Foreign Affairs and Security Policy. Joint Communication on the European Preparedness Union Strategy (JOIN (2025) 130). European Commission.

European Commission. (2026). Communication on the EU's eastern regions bordering Russia, Belarus and Ukraine: Strong regions for a safe Europe {COM (2026) 82 final}. European Commission.

Guzik, R., Kłoś, A., Kołoś, A., Solecki, M., & Wiedermann, K. (2022). Dostępność komunikacyjna i relacje przestrzenne w województwie małopolskim (Transportation accessibility and spatial relationships in the Małopolska Voivodeship). Instytut Geografii i Gospodarki Przestrzennej Uniwersytetu Jagiellońskiego (Institute of Geography and Spatial Planning at Jagiellonian University).

Haller, A., & Branca, D. (2023). Urbanization and the verticality of rural–urban linkages in mountains. In Montology Palimpsest (pp. 133–148). Springer. https://doi.org/10.1007/978-3-031-13298-8_8

Kluvankova, T., Nijnik, M., Spacek, M., Sarkki, S., Perlik, M., Lukesch, R., Melnykovych, M., Valero, D., & Brnkalakova, S. (2021). Social innovation for sustainability transformation and its diverging development paths in marginalised rural areas. Sociologia Ruralis, 61(2), 344–371. https://doi.org/10.1111/soru.12337

Kwiatek-Sołtys, A., Mainet, H., Wiedermann, K., & Édouard, J.-C. (Eds.). (2014). Small and medium towns' attractiveness at the beginning of the 21st century. Presses Universitaires Blaise Pascal. (Collection CERAMAC, 33).

Lozynskyy, R., & Zubyk, A. (2022). Transformation of the rural settlement network in the Carpathian region of Ukraine (1989–2020). European Countryside, 14, 281–301. https://doi.org/10.2478/euco-2022-0014

MARGISTAR. (2026). A European Forum for Revitalisation of Marginalised Mountain Areas. COST Action CA21125, European Cooperation in Science and Technology (COST), 2022–2026. https://margistar.eu/

Matei, E., Vasilcu, D., Manea, G., Cocoş, O., Cuculici, R., Vijulie, I., & Matei, D. (2016). Semi-subsistence farming development in a Carpathian declining mining area. A microscale study of landowners' perception: Stulpicani commune, Romania, Procedia Environmental Sciences, 32, 352-363, Elsevier. Doi: 10.1016/j.proenv.2016.03.041

Melnykovych, M., Böttinger, E., Waeber, P., Bertuca, A., De Luca, C., Domínguez, X., Fuentemilla, S., Hernández, S., Heikkinen, H., Kottawa Hewamanage, L., Nijnik, M., Pilla, F., Sarkki, S., Selva, C., Wilson, R., Valero, D., & Miller, D. (2024). Learning needs and gaps of rural

communities. Deliverable D3.1. Horizon Europe project RURACTIVE—Empowering Rural Communities to Act for Change, Grant Agreement No. 101084377.

Melnykovych, M., Kozová, M., Špaček, M., & Kluvánková, T. (2019). Revitalising plans for Vlkolínec—Slovakia. Report 5.4k, Analytical Case Study. Social Innovation in Marginalised Rural Areas (SIMRA).

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkalakova, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvankova, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy, I., Waeber, P. O., & Zawiejska, J. (2026a). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda. Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Melnykovych, M., Nijnik, M., Soshenskyi, O., Zibtsev, S., Lobchenko, G., Sarkki, S., Voloshyna, N., Soloviy, I., Kravets, P., Khan, Y., Yaroshchuk, R., Keeton, W. S., Rosset, C., Pauli, B., Garcia, C. A., & Waeber, P. O. (2026b). Pathways for Ukraine's post-war nature recovery: Focus on forest socio-ecological systems. Ambio, 55, 817–843. https://doi.org/10.1007/s13280-025-02263-0

Mitrofanenko, T., Škovira, R., Kholiavchuk, D., Csabay, J., Keeton, W., Zawiejska, J., Matei, E., & Melnykovych, M. (Eds.). (2025). Key messages and recommendations from Science for the Carpathians for the Carpathian Convention Implementation Committee. Science for the Carpathians.

Muntele, I., Istrate, M., Athes, H., & Bănică, A. (2023). An overview of population dynamics in Romanian Carpathians (1912–2021): Factors, spatial patterns and urban–rural disparities. Land, 12(9), 1756. https://doi.org/10.3390/land12091756

Organisation for Economic Co-operation and Development (OECD). (2026). Unlocking the potential of intermediary cities for regional development. OECD Regional Development Studies. OECD Publishing. https://doi.org/10.1787/55b14922-en

RURACTIVE. (2026). RURACTIVE—Empowering Rural Communities to Act for Change. Horizon Europe project, Grant Agreement No. 101084377. https://doi.org/10.3030/101084377

Sarkki, S., Ludvig, A., Nijnik, M., & Kopiy, S. (2022). Embracing policy paradoxes: EU's Just Transition Fund and the aim "to leave no one behind". International Environmental Agreements: Politics, Law and Economics, 22, 761–792. https://doi.org/10.1007/s10784-022-09584-5

Sarkki, S., Lynn, T., Hiedanpää, J., Vizzarri, M., Christoforidi, I., Brnkalakova, S., Crisan, V., Egli,A., Gültekinj, P., Gültekink, Y. S., Jokinen, M., Monteiro, A. T., Nastran, M., Özdemir, H. Y., Pelyukh, O., Sulc, I., Živojinović, I. & Ficko, A. (2025). Polytraps in European rural mountainous regions: An expert view. European Planning Studies, 33(5), 757–777. https://doi.org/10.1080/09654313.2025.2473380

Săvulescu, I., Mihai, B.-A., Vîrghileanu, M., Nistor, C., & Olariu, B. (2019). Mountain arable land abandonment (1968–2018) in the Romanian Carpathians: Environmental conflicts and sustainability issues. Sustainability, 11(23), 6679. https://doi.org/10.3390/su11236679

Soloviy, I., Melnykovych, M., Björnsen Gurung, A., Hewitt, R. J., Ustych, R., Maksymiv, L., Brang, P., Meessen, H., & Kaflyk, M. (2019). Innovation in the use of wood energy in the Ukrainian Carpathians: Opportunities and threats for rural communities. Forest Policy and Economics, 104, 160–169. https://doi.org/10.1016/j.forpol.2019.05.001

Špaček, M., Melnykovych, M., Kozová, M., Pauditšová, E., & Kluvánková, T. (2022). The role of knowledge in supporting the revitalisation of traditional landscape governance through social innovation in Slovakia. Environmental Policy and Governance, 32, 560–574. https://doi.org/10.1002/eet.2026

Wiedermann, K. (2015). The role of industry in the labor market of small towns. Annales Universitatis Paedagogicae Cracoviensis Studia Geographica, 8, 67–79.

Wiedermann, K. (2026). The processes of industrialization in local and regional development—Contemporary challenges for urban areas in the Silesian and Małopolska regions. Prace Geograficzne, 183, 45–70.

Zawilińska, B., Nestorová Dická, J., Matei, E., Švajda, J., Łapczyński, M., Majewski, K., Megyeri, B., Călin, C. A., & Gessert, A. (2023).

Applying Q-methodology to investigate the perception of the social and economic role of the national park by local stakeholders. Cases of national parks in the Carpathians. Journal for Nature Conservation, 75,126459. DOI:10.1016/j.jnc.2023.126459

Zimmer, A., Grêt-Regamey, A., Palomo, I., Adler, C., Aakairi, M., Anière, M., Anthelme, F., Baruffa, C., Bele, B., Clark, V. R., Cuni-Sanchez, A., Eiter, S., Field, R., Flores, W., Hanly, K., Hartmann, J., Maharjan, A., Manuelli, S., Martin, D. A., … & Marchant, R. (2026). A research agenda for mountain futures. Cell Reports Sustainability, 3, 100775. https://doi.org/10.1016/j.crsus.2026.100775



10 Green energy and resilience

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The Carpathian region has historically had a highly diverse energy mix. The Russian Federation military aggression against Ukraine reemphasised regional energy vulnerability and the need for locally embedded energy security and interconnected energy systems. A large disconnect exists between European Union (EU) and national policies and local needs, especially when it comes to the most vulnerable populations (Marinicova et al., 2023). Recent research from the Ukrainian Carpathians demonstrates that high local forest availability does not necessarily translate into affordable or sustainable household energy. Whether similar resource–access paradoxes occur elsewhere in the Carpathians – and through which institutional, infrastructural, market and socio-economic mechanisms – remains an important comparative research question (Soloviy et al., 2018). Local communities suffer from energy scarcity, energy insecurity and high energy costs, and thus experience a lack of energy efficiency. In an effort to understand how to make better use of bioenergy resources, address sustainability goals as well as the needs of local communities, there is a need to assess the significance and future potential of wood energy and other renewable energy sources (i.e., wind, solar) for regional economies and households from an environmental, economic and social perspective.

As such, energy effectiveness and the green energy transition must be understood and go hand-in-hand with alleviating energy poverty. One key measure to be considered is the ability to keep homes adequately warm. According to Eurostat 2024 data, Carpathian EU countries perform better than the EU average (9.2%), as most fall below it. Romania is the exception, with 10.8% of its population affected (Eurostat, 2026). Poland stands out with only 3.3%, making it one of the best-performing EU member states, further highlighting regional variation, even within the Carpathian countries. Interestingly, Carpathian countries show results similar to Alpine countries, though they are less favourable than Scandinavian countries, known for their strong social systems, with considerable wealth-redistribution measures. Besides the heating-related indicator, cooling-related vulnerability remains underexplored. Although no longer systematically collected, such data shows risks of indoor heat stress (Castaño-Rosa et al., 2021, p. 8). Monitoring this would require assessing both access and affordability of cooling (the ownership alone of air conditioning does not necessarily mean resources are available for its utilisation). Energy vulnerability is also linked to heating sources. Fuelwood – counted as renewable – often serves as a coping strategy against energy poverty. Consumption exceeds the EU average (17%) in Slovakia and Hungary (both 21%) (Stojilovska et al., 2023, p. 4–5). Importantly, beyond the technical and technological aspects of energy access, energy vulnerability and energy poverty are strongly connected with wider social, economic, and institutional systems in place (Figulova & Csabay, 2026). One such vulnerable group includes communities living in informal settlements who often lack access to basic utilities, notably marginalised Roma communities who are consequentlyoften excluded from energy poverty measurements. In the Ukrainian Carpathians, energy vulnerability has been intensified by the Russian military aggression in Ukraine. Although relatively distant from the frontline, the region remains exposed to nationwide electricity and heating disruptions caused by attacks on the Ukrainian energy system, while the region has also experienced substantial inflows of internally displaced people, increasing pressure on housing, municipal services

and local infrastructure (Romanko et al., 2025). These wartime pressures interact with pre-existing challenges of remote mountain settlements, low household incomes, inefficient buildings and heating systems, and dependence on fuelwood, making energy resilience, decentralised supply and affordable heating particularly important research priorities (Pelyukh et al., 2025). Importantly, the localised approach needs not to be limited to the context of the Carpathian communities but instead should be connected with wider energy systems and infrastructure in the region across the borders with the neighbouring Carpathian countries and regions as well as with other regions of Ukraine that are most affected by the war.

For these purposes, transdisciplinary methodologies combining technical measurements, such as auditing, with socio-economic indicators and qualitative methods, such as ethnography or action research, are essential to not only grasp the reality on the ground but also the research impact (Csabay and Teru, 2023). As already shown by Bouzarovski and Tirado Herrero (2017) in the EU (thus as well the Carpathian region) energy efficiency measures remain constrained by high upfront capital costs, structural regional inequalities, and limited access to tailored financial instruments. Consequently, integrated energy strategies aiming to foster community resilience should then combine technical audits and smart energy management with local socio-economic support within the locally operating institutional systems, ensuring that vulnerable households are not excluded from green energy transition programmes (Figulova and Csabay, 2026).

Understanding the underlying institutional and systemic conditions of successful application of innovative socio-ecological governance approaches, such as energy communities, energy sharing, and citizen energy models (Soloviy et al., 2019; Ryszawska et al., 2021; Geissler & Lleshi, 2025), should be explored to revitalise both rural and urban Carpathian areas, including the segregated localities for whom it might serve as an energy access model (Csabay & Teru, 2022). Besides the fulfilment of objectives in creating renewable-energy systems, the societal and political aspects of energy transition should be considered for the sake of policy consensus (Cantarero, 2020) in addition to the economic and environmental priorities; doing so could address the considerable gap between general and local support for renewable-energy sources (Frantál & Kučera, 2009). Energy projects in the Carpathian region must be planned and assessed not only according to their contribution to renewable-energy generation, decarbonisation and energy security, but also in relation to their environmental, social and territorial impacts. Recent "conflicts" around wind-energy and hydropower development in the Ukrainian Carpathians, including controversies concerning sensitive mountain landscapes, river ecosystems, associated infrastructure, environmental assessment and public participation, demonstrate that projects labelled as "green" can generate significant ecological and social trade-offs when poorly located or governed (Melnykovych et al., 2026). In this regard, one of the highly contested examples is the wind energy project at Polonyna Mount Runa in the Ukrainian Carpathians (Csabay 2026). These experiences are highly relevant for the wider Carpathian region, where renewable-energy expansion increasingly intersects with areas of high biodiversity, ecological connectivity, valuable forests and river systems, traditional landscapes and rural communities. Research should therefore address the spatial suitability and ecological limits of energy infrastructure; cumulative impacts of energy infrastructure and impacts of associated roads, transmission lines and construction infrastructure; meaningful early participation of local communities, scientists and civil society; transparent environmental assessment and consideration of technological and locational alternatives; and the distribution of costs, benefits and decision-making power among local and external actors (see Chapter 20 on legal governance). Particular attention should be paid to ensuring local participation and the quality and binding nature of environmental impact assessments (EIA) as mechanisms for preventing and managing energy-development

conflicts and to identifying conditions under which renewable-energy projects can strengthen local resilience and economic development while avoiding unacceptable impacts on biodiversity, ecosystem services and local communities.

Municipalities and other local actors play a role in the acceptance of renewable energy projects by addressing the gap between centralised planning and local responses. Nevertheless, the development of a funded participatory framework with diverse means of inclusion does not guarantee its utilisation for controversial projects (Škovira, 2026). Therefore, in addition to addressing the means of including public positions (input), evaluating the positions and mechanisms in place (throughput), and scrutinising the impact of such participation (output), research also needs to cover the type of projects utilising such participation and the criteria applied in making such decisions. Potential motivations (e.g., an opposition of political actors towards the project) should be considered in project selection vis-à-vis a participatory process. Energy resilience depends not only on access to renewable-energy technologies, but also on local capacities, institutional partnerships, international knowledge exchange, and the ability of municipalities to translate knowledge into implementable projects.

Recommended topics

- Social and technological innovations for transition to green renewable energy (RE)
- Mapping and measuring energy poverty amongst different segments of the population and vulnerable groups, including those living in informal settlements as a part of quality-of-life measurements
- Knowledge and technology transfer to local communities to support energy efficiency along with climate-mitigation efforts (different forms of energy communities and citizen energy initiatives)
- Community-driven bioenergy initiatives (e.g., local cooperatives)
- Best practices of energy strategies embedding in local economic-development strategies so that they reflect local potential and needs
- Integration of renewable energies within larger supply chains in rural economies, such as agriculture, forestry, traditional manufacturing and green tourism
- Use of renewable energy resources appropriate for specific areas and focussed on relatively mature technologies such as heat from biomass
- Establishment of integrated energy systems based on small grids able to support manufacturing activities
- Social acceptance of green energy projects through the engagement of local communities in the process
- Balance between infrastructure, biodiversity and benefit-sharing
- Financial and institutional mechanisms for supporting low–income households in energy efficiency upgrades

Recommended research questions

- What innovative renewable energy initiatives are currently implemented in the regions and how do they contribute to sustainability and building resilience to future energy challenges?

- What are the underlying conditions needed for emergence, replicability and scalling of social and technological innovations in the field of renewable energy and energy efficiency, and how can these promote local sustainable development in the region?
- What are the co-creation pathways for energy transition with multiple stakeholders?
- How can energy security and effectiveness challenges inform more locally embedded EU energy policies?
- How can EU and Carpathian states support environmentally aware energy security and green recovery in Ukraine?
- What are the guiding principles for determining and balancing social-environmental indicators in renewable energy projects?
- What are the national policy-related challenges across the Carpathian countries vis-à-vis the expansion of energy communities?
- What are the primary socio-technical and financial barriers preventing low-income Carpathian households from adopting energy efficiency solutions?
- How are the different means of public and stakeholder participation utilised in the region? How do the public and stakeholder means of participation affect acceptance of RES in the region?

References

Bouzarovski, S., & Tirado Herrero, S. (2017). The energy divide: Integrating energy transitions, regional inequalities and poverty trends in the European Union. European Urban and Regional Studies, 24(1), 69–86. https://doi.org/10.1177/09697764155964

Cantarero, M. M. V. (2020). Of renewable energy, energy democracy, and sustainable development: A roadmap to accelerate the energy transition in developing countries. Energy Research & Social Science, 70, 101716.

Csabay, J. & Teru, V. (2023). Methodology for energy poverty chapter in decarbonisation strategies: Context of marginalised Roma communities, Slovak Innovation and Energy Agency [in Slovak, restricted].

Csabay, J. & Teru, V. (2022). Analysis of pilot interventions for addressing energy poverty of Roma communities at Lunik IX, Kosice, based on an Energy Audit of the 1-3 Hrebendova block of flats, Friends of the Earth-CEPA & RESDI [in Slovak].

Csabay, J. (2026) "Dilemmas" of Renewable Energy Projects in Biodiversity Hotspots in High-Risk Institutional Environments: The Case of Wind Energy Project at Mount Runa in Western Ukraine. Presentation at the Cambridge International Symposium on Economic Crime, Alternative Programme: Terracide, 25th August 2026.

Eurostat. (2026, February 2). 9.2% of EU population struggled to keep their home warm. European Commission. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20260202-2

Figulova, A. & Csabay, J. (2026). Energy Security. In Z. Fialova, (Ed.). Minimum environmental standards of living. Climate Coalition Slovakia. https://klimatickakoalicia.sk/enviromentalne-zivotne-minimum/#.

Frantál, B., & Kučera, P. (2009). Impacts of the operation of wind turbines as perceived by residents in concerned areas. Moravian Geographical Reports, 17(2), 35-45.

Geissler, G., & Lleshi, R. (2025). Advancing Just Energy Transition: Community Energy Projects in Central and Eastern Europe. Global Solutions Journal, 10, 80-87. https://www.global-solutions-initiative.org/wp-content/uploads/2025/03/GS_journal_10_Geisler_Lleshi.pdf

Marinicova, E., Pastorelli, E., Apine, L., Mrozek, K., Csabay, J., & Melichar, J. (2023). Tackling Energy Poverty in EU Member States, CEE Bankwatch Network.

Pelyukh, O., Seidl, I., & Björnsen, A. (2025). Transition to energy autonomy of schools in the Carpathian region: An analysis of stakeholder perspectives. Proceedings of the Forestry Academy of Sciences of Ukraine, 28, 215–228. https://doi.org/10.15421/412516.

Romanko, R., Kurtova, S., Baldi, O., Neliubina, I., Yefimov, V., Serdiuk, A., Bostan, S., & Melnykovych, M. (2025, September 9–11). Empowering Ukrainian communities through education in energy solutions: A case from the CAS Rebuild Ukraine Program in Switzerland [Conference presentation]. 8th Forum Carpaticum 2025: Taking Stock and Building Partnership for Sustainable Development of the Mountain and Rural Areas, Bratislava, Slovakia.

Ryszawska, B., Rozwadowska, M., Ulatowska, R., Pierzchała, M., & Szymanski, P. (2021). The Power of Co-Creation in the Energy Transition—DART Model in Citizen Energy Communities Projects. Energies, 14, 5266. https://doi.org/10.3390/en14175266

Soloviy, I., Melnykovych, M., Björnsen Gurung, A., Hewitt, R. J., Ustych, R., Maksymiv, L., Brang, P., Meessen, H., & Kaflyk, M. (2019). Innovation in the use of wood energy in the Ukrainian Carpathians: Opportunities and threats for rural communities. Forest Policy and Economics, 104, 160–169. DOI: https://doi.org/10.1016/j.forpol.2019.05.001

Stojilovska, A., Dokupilová, D., Gouveia, J. P., Bajomi, A. Z., Tirado-Herrero, S., Feldmár, N., Kyprianou, I., & Feenstra, M. (2023). As essential as bread: Fuelwood use as a cultural practice to cope with energy poverty in Europe. Energy Research & Social Science, 97, 102987. https://doi.org/10.1016/j.erss.2023.102987

Škovira, R. (2026). German participatory experiences in wind energy planning – Lessons learnt for the Czech and Slovak multilevel energy transitions. Deutsche Bundesstiftung Umwelt. https://www.dbu.de/moe-fellowship/30025-075/





11 Tourism development and human–nature Interactions

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Tourism development in rural areas is closely connected to land-use patterns, environmental stewardship and local cultural practices. Furthermore, tourism governance in mountain environments requires balancing economic benefits with ecological and social capacities across highly heterogeneous contexts. Remote rural areas grapple with demographic and land-use changes while popular destinations are exposed to overtourism, struggling to address carrying-capacity constraints. In many peripheral regions, tourism, considered an important rural innovation catalyst, plays an increasingly important role in income generation and local economic diversification. Tourism development must also respond to emerging visitor demands and innovative practices while remaining conscious of the environmental and social carrying capacity of local areas, balancing profitability with inclusiveness and long-term sustainability. This is especially true in relatively isolated and challenging ecosystems that abound in mountainous regions such as the Carpathians (Moga, 2016; Angelstam, 2017). Knowledge embedded in local practices, land use and environmental stewardship shapes destination identity, visitor experience and long-term sustainability within tourism development (Font et al., 2019). Knowledge-based practices rooted in local environmental experience can also function as enabling mechanisms for tourism governance, product design and participatory conservation in the framework of sustainable tourism destination development, where an equilibrium among environment quality, local community benefits, tourist satisfaction and the economics of investor welfare is required (Gato et al., 2022). Such forms of knowledge, including traditional ecological knowledge (TEK), increasingly understood as a key component of human engagement with ecosystems historically and moving forward, are often embedded within broader local traditions and cultural landscapes that become integral elements of tourism destinations.

More attention should thus be paid to research on tourist satisfaction with the originality of eco-tourist products (Matei et al., 2014); functioning of environmental conservation areas (Widawski et al., 2018); or sustainability of economic tourism business (Filimonau et al., 2020). However, the concept of "local communities" needs to be clarified and included as part of research findings. In areas with strong tourism impacts, interactions between local communities who retain TEK, more recent migrants to any given area, and tourists ought to be considered (as seen in Cooley, 2005, pp. 58–82; Dabrowski, 2021, in the Polish Tatra Mountain region). This perspective shifts the focus from knowledge as heritage alone towards tourism as a dynamic arena of negotiation, adaptation and innovation.

Moreover, contemporary tourism is increasingly shaped by rapid advances in digitalisation, both within tourism services and across society more broadly. Digital technologies are transforming how tourism is planned, experienced, managed, and marketed, while simultaneously creating new opportunities for innovation, connectivity, and more efficient resource use. At the same time, the tourism sector is embedded within the broader twin transition, which combines the green and digital transitions. This requires tourism destinations and businesses to pursue digital innovation while addressing environmental challenges, improving resource efficiency, and strengthening the long-term sustainability and resilience of tourism development.

This research agenda aims to generate new knowledge about the ties and tensions between tourism as an economic driver and the pressure this puts on ecosystems and the local communities with long traditions of living symbiotically with delicate mountain environments. It also aligns with emerging approaches in the Carpathian region (and beyond) that frame tourism as a platform for human–nature interactions and participatory conservation, including developments of the Carpathian Convention Working Group on Sustainable Tourism, Protocol on Sustainable Tourism (Carpathian Convention, 2011) and Carpathian Sustainable Tourism Platform (CSTP, 2025). This intersectoral and multi-actor understanding of tourism development is also compatible with the current European Union policy reflected in strategic documents such as the "Transition Pathway for Tourism" (European Commission, 2022, 2024) or the upcoming European Strategy for Sustainable Tourism 2050. The topics proposed suggest the value of research teams that include specialists in the arts and humanities working collaboratively with environmental scientists, geographers, and others to develop new models for sustainable tourism. Such models should integrate destination governance, monitoring of impacts and regional planning instruments (CSTP, 2025). We ask if there are links between displacing local communities or replacing their land-use practices and damaging local ecosystems. More positively, we ask if supporting or renewing traditional ecological knowledge and practices may help us restore damaged ecosystems, encourage resilience and enhance tourism values. As researchers, how can we better understand the impact of human cultural practices on ecosystems? Since environmental restoration efforts often rely on the active engagement of local stakeholders, tourism can act as a coordination space where knowledge, policy and practice intersect, improving the success of S4C policy recommendations, including regional and global efforts such as the Kunming-Montreal Global Biodiversity and the Conference of the Parties of the Carpathian convention.



Nature-based tourism is important in the Carpathians. Credit: FORZA.

Recommended topics

- Strengthening resilience, adaptation capacity and innovations for sustainable Carpathian tourist destinations
- Balancing climate change mitigation and tourism development, quantifying the tensions need for slowing climate change to sustain regional ecosystems and tourism development to support economic development, necessity of designating sites for climate change (or low-carbon) and cultural sensitivity (Melbourne-Thomas et al., 2024).
- Human–wildlife interactions in tourism-related research: conflicts, their strategic management framed both by conservation and responsible visitor behaviour
- Re-evaluating alternatives to existing understandings of ecotourism that will be better suited to ecological and social conditions by integrating local knowledge, traditions, and landscape stewardship
- Traditional ecological knowledge and mountain

ecosystem resilience: investigating past, current, and future roles of traditional ecological knowledge in sustaining resilient mountain ecosystems

- Integrated mapping and knowledge infrastructure: mapping of the entire region in a standardised way and the development of a living atlas of the Carpathian Region that focuses on traditional practices (i.e., pastoralism, forest and meadow management) that contribute to biodiversity conservation and strengthen tourism values.
- Interdisciplinary research and collaboration: the potential value of research teams that include specialists in the arts and humanities working collaboratively with environmental scientists, geographers, and others to develop suitable models for sustainable tourism; scientists and humanists working together with practitioners to propose new (and revive old) approaches to ecology in the Carpathians
- Quantifying the tensions between slowing climate change to support regional ecosystems and tourism development to support economic development
- Branding, communication and identity building (e.g., "Carpathia brand" or an interpretive strategy of the Carpathians) as tools for destination development
- Integration of ecotourism destinations, long-distance trails and local gastronomic networks as knowledge-based tourism products
- Cross-border cooperation mechanisms for sustainable tourism governance
- Governance, policy, and stakeholder inclusion: incorporation into policy recommendations requires that traditional ecological knowledge be respected by inclusive governance frameworks where traditional local stakeholders and local communities participate in land-use and tourism decisions
- Visitor monitoring and visitor management within ecological and social capacities
- Twin transitions (green and digital transition) in mountain tourism
- Digitalisation and innovation in mountain tourism governance

Recommended research questions

- How can we clarify the conception of "local communities" and their relationships to traditional ecological knowledge?
- Is it desirable and possible to (a) openly recognise distinctions between populations who may be considered "traditional" to a region, and (b) prioritise traditional residents in particular regions as integral to our understanding of those regions' ecologies? How might this impact tourism to these same regions?
- Where is it possible and helpful to defer to traditional ecological knowledge as interpreted by traditional residents of regions-of-interest as the starting point for any land use, including tourism?
- How can the causes of depopulation and population ageing become a priority research question that precedes policy recommendations of tourism development?
- How can we best change or pair the concept of "sustainability" with "resilience", since "to sustain" too often implies keeping things as they are rather than adapting to changing circumstances (see Allen, 2019)?
- How can we strengthen the link between the protection and valorisation of cultural heritage

and climate mitigation?

- How might traditional ecological knowledge be encouraged and in some cases adapted for present changing environmental conditions?
- How should we measure tourism impacts, design participatory monitoring, and embed tourism into regional planning?
- How can tourism governance platforms operationalise place-based knowledge in destination planning?
- How can participatory monitoring frameworks measure tourism impacts on ecosystems and communities?
- What role can cross-border platforms (e.g., CSTP) play in scaling sustainable tourism innovations?
- How can sustainability standards be embedded into destination development rather than applied post-hoc?
- How can overtourism in popular mountain destinations be effectively managed?
- How can visitor flows and allocation of services be effectively managed?
- How can the tourism sector act as an agent of social-ecological transformation towards sustainability and rural innovation?
- What is the role of nature-based mountain tourism in fostering human–nature connectedness and pro-environmental behaviour?
- What are the health and wellbeing benefits of nature-based tourism and recreation in mountain settings?



On the way to Turbacz. A view from a former shepherd's hut on Bukowina Waksmundzka (Tatra Mountains, Poland). Credit: Kinga Bargiel

References

Allen, A. S. (2019). Sounding Sustainable: or the challenge of sustainability. In Cultural Sustainabilities: Music, Media, Language, Advocacy. T. Cooley (Ed.). (2019). University of Illinois Press.

Angelstam, P., Khaulyak, O., Yamelynets, T., Mozgeris, G., Naumov, V., Chmielewski, T. J., Elbakidze, M., Manton, M., Prots, B., & Valasiuk, S. (2017). Green infrastructure development at European Union's eastern border: Effects of road infrastructure and forest habitat loss. Journal of Environmental Management 193(2017) 300–311. 10.1016/j.jenvman.2017.02.017

Cooley, T. (2005). Making music in the Polish Tatras: Tourists, ethnographers, and mountain musicians. Indiana University Press.

Carpathian Convention. (2011). Protocol on Sustainable Tourism to the Framework Convention on the Protection and Sustainable Development of the Carpathians. http://www.carpathianconvention.org/convention/protocols/protocol-on-sustainable-tourism/

Carpathian Sustainable Tourism Platform (CSTP). (2025). CSTP Work Plan. Designing and testing a new Carpathian Sustainable Tourism Platform Cooperation System. https://www.interreg-central.eu/wp-content/uploads/2025/10/Carpathian-Sustainable-Tourism-Platform-pilot-action.pdf

Dabrowski, P. M. (2021). The Carpathians: Discovering the highlands of Poland and Ukraine. Northern Illinois University Press.

European Commission. (2022; 2024). Transition pathway for tourism. European Commission. https://transition-pathways.europa.eu/system/files/2024-09/Transition_Pathway_For_TourismFEB2022_correctedlink.pdf

Filimonau, V., Matute, J., Kubal-Czerwińska, M., Krzesiwo, K., & Mika, M. (2020). The determinants of consumer engagement in restaurant food waste mitigation in Poland: An exploratory study. Journal of Cleaner Production, 247, 119105.

Font, X., Higham, J., Miller, G., & Pourfakhimi, S. (2019). Research engagement, impact and sustainable tourism. Journal of Sustainable Tourism, 27(1), 1–11. https://doi.org/10.1080/09669582.2019.1560673

Gato, M., Dias, Á., Pereira, L., da Costa, R. L., & Gonçalves R. (2022). Marketing communication and creative tourism: An analysis of the local destination management organization. Journal of Open Innovation: Technology, Market, and Complexity, 8(40). https://doi.org/10.3390/joitmc8010040

Matei, E., Vijulie, I., Manea, G., Tîrlă, L., & Stefan, D. (2014). Changes in Romanian Carpathian tourism after the communism collapse and the domestic tourists' satisfaction. Acta geographica Slovenica, 54(2), 335–344. https://doi.org/10.3986/AGS54207

Melbourne-Thomas, J., Lin, B., Hopkins, M., Hill, R., Dunlop, M., Macgregor, N., Merson, S., Vertigan, C., Donegan, L., Sheppard, M., Meyers, J., Thomas, L., Visschers, L., McNeair, B., Syme, L., Grant, C., Pedrocchi, N., Oakley, P., Stevens, A., & Ireland, T. (2024). Building capacity for climate adaptation planning in protected area management: Options and challenges for World Heritage. Biological Conservation, 290, 110459. https://10.1016/j.biocon.2024.110459

Moga, C.I., Samoilă, C., Öllerer, K. et al., (2016, May). Environmental determinants of the old oaks in wood-pastures from a changing traditional social-ecological system of Romania, Ambio, 45, 480–489. https://doi.org/10.1007/s13280-015-0758-1

Widawski, K., Jary, Z., Oleśniewicz, P., Owczarek, P., Markiewicz-Patkowska, J. & Zaręba, A. (2018). Attractiveness of protected areas for geotourism purposes from the perspective of visitors: The example of Babiogórski National Park (Poland). Open Geosciences, 10(1), 2018, 358–366. https://doi.org/10.1515/geo-2018-0028



12 Cultural heritage

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Local cultures and their diversity, the result of long-term adaptation of local communities and their connection to the environment, are part of the essential values of the Carpathian region. However, throughout the region, this heritage is threatened by declining knowledge of traditional land-use management and governance, diminished intergenerational transfer as well as climate change impacts, and expanding unsustainable tourism (Spacek et al., 2022).

Cultural heritage can be understood as a group of resources inherited from the past which people identify, independently of ownership, as a reflection and expression of their constantly evolving values, beliefs, knowledge and traditions. In this sense, heritage encompasses not only material remains, but also the relationships between people, places and the environment that have developed over time and the meanings that communities attribute to them (Graham et al., 2000; Howard, 2003; Council of Europe, 2005; Ashworth et al., 2007). It is therefore not a fixed or closed set of objects, but a socially and culturally constructed resource that is continually reinterpreted and reproduced by communities and groups in response to their environment, their interaction with nature and their history, contributing to a sense of identity and continuity (Harrison, 2010; Ciobanu, 2016). What is recognised as heritage may consequently differ between communities and generations, reflecting different personal, regional and national identities and changing perceptions of value (Throsby, 2001; Towse, 2022). Heritage is passed on by those who hold it and inherited by subsequent generations, while its continuity may depend on both the preservation of material resources and the transmission of associated knowledge, practices and meanings. Intangible cultural heritage, as defined by the UNESCO Convention for the Safeguarding of the Intangible Cultural Heritage (2003), refers to practices, representations, expressions, knowledge and skills, together with the associated instruments, objects, artefacts and cultural spaces, that communities, groups and, in some cases, individuals recognise as part of their cultural heritage (UNESCO, 2003). These dimensions are closely interrelated: buildings, landscapes, objects and other material resources may carry and sustain knowledge, practices and traditions, while intangible heritage can give meaning and value to places and material culture. Within international and national heritage frameworks, these interconnections are reflected in a range of categories, including tangible, movable, immovable, underwater and intangible cultural heritage, as well as natural heritage with a cultural dimension (Karadeniz, 2020, p. 42).

According to the constructivist paradigm, the catalogue of heritage can be considered open and can include a variety of natural elements as well as the intellectual and cultural achievements of mankind. Its openness stems from its social nature: heritage is constantly reproduced by communities and groups in response to their environment, their interaction with nature and their history, ensuring their sense of identity and continuity, thus promoting respect for cultural diversity and human creativity (UNESCO, 2003; Ciobanu 2016, p.104). Therefore, what can be considered as a heritage resource are those instruments, objects, artefacts and cultur-

al spaces that communities, groups and even individuals consider to be significant carriers of a community's identity and memory (Throsby, 2001; Towse, 2022).



Vernacular wooden architecture, Campulung Moldovenesc, Suceava County, (Bucovina Carpathians, Romania). Credit: Ioana Baskerville

The assessment of their validity is strongly evaluative, subjective and dependent on the perspective taken. What some people consider heritage may not be such for others, depending on their individual evaluative judgements based on personal, regional and national identities (Harrison, 2010). Moreover, the recognition of a given resource as heritage is a dynamic process. A resource considered worthless at one moment may be recognised as valuable in another (Throsby, 2001). Generational differences are crucial to this assessment and its changes since the key role in the preservation and development of the tangible and intangible heritage of the Carpathians is played by the inhabitants' knowledge about it and the perception of the value of its individual elements, which is subject to evolve over time.

The cultural heritage of the Carpathian region is dynamic, in particular intangible manifestations, but it is increasingly threatened, by social transformations, changing economic conditions, the ongoing depopulation of rural areas (particularly in marginalised mountain areas), and by globalisation of culture, which can lead to its deterioration, abandonment and disappearance (Iuga et al., 2024).

Article 11 of the Carpathian Convention requires parties to pursue policies to preserve and protect cultural heritage and traditional knowledge, which includes cultural heritage, traditional knowledge, architecture, land use, animal husbandry, horticulture and botany (Carpathian Convention, 2003).
Based on the Carpathian Convention documents pertaining to cultural heritage and traditional knowledge,

such as the Background document for the Protocol on cultural heritage and traditional knowledge Carpathian Convention (2018), discussed at the Fifth Meeting of the Working Group Cultural Heritage and Traditional Knowledge in Szentendre, Hungary, the following research topics and questions could be formulated as an aim for the near future:



Traditional costumes of the pastoral community of Corbi Village, Argeș County (foothills of Făgăraș Mountains, Romania). Credit: Ioana Baskerville

Recommended topics

- Identification and mapping of the cultural heritage and traditional knowledge of the Carpathians, within both tangible and intangible heritage domains, building on existing research carried out by Carpathian countries under the UNESCO 1972 World Heritage Convention (cultural land scapes in particular) and the UNESCO 2003 Convention (Babai & Molnár, 2014);
    - Inventory of the local material culture still in use today, present in the rural areas of the Carpathian region that uses natural components or local natural resources (i.e., clay, wood, wool, hemp, linen, and so on), as part of the local tangible heritage, adapt ed to the local traditional occupations, and the artisans who produce, use or maintain it;
    - Inventory of local products across the Carpathian region and their promotion at a regional/national level (i.e., raising awareness among local communities regarding their importance, local resources and production systems, and the tools, foods and broader ecosystems surrounding these products);
    - Inventory of local foods and beverages (i.e., alcoholic drinks, fermented drinks, teas)

across the Carpathian region and their connection with community organisation and empowerment, local cultural practices, local land use, local livestock and the local environment as an important phase in the development of "slow tourism" (local gastronomic experiences connected to cultural tourism or nature tourism);
    - Inventory of the cultural heritage and traditional ecological knowledge of the Carpathians as part of the implementation of the UNESCO 2003 Convention, particularly under the domain "knowledge and practices concerning nature and the universe" and connecting the existing intangible cultural heritage data in the Carpathian countries' cultural national management systems; and
    - Mapping new intangible heritage (i.e., adapted traditional ecological knowledge) connected to shepherding and grazing management in time of crisis (i.e., climate change).

- Advancing the digital update and preservation of traditional Carpathian architecture archives, based on efforts initiated in the 1960s by Czech experts such as Frolec and Langer (Langer & Bočková, 2014), by aligning current research with contemporary inventorying of local wood carving techniques, geological features, natural resource utilisation, and climate-adaptive mountain building practices;
- Development of shared inventorying methodologies through multi-, inter- and transdisciplinary and transnational collaboration for documenting Carpathian cultural landscapes, considering the varying capacities and existing strategies in administration and development of States, in cluding traditional land-use patterns, vernacular architecture, agricultural practices, cultural expressions, local breeds of domestic animals, cultivated plant varieties, and the sustainable use of wild resources (Hartel et al., 2017);
- Mapping cultural ecosystem services;
- Assessing the socio-economic value of traditional arts and handicrafts in local communities
- identifying and operationalizing cultural heritage elements for educational, research, and social innovation frameworks;
- Exploring the role of oral traditions, folklore, legends and fairy tales in the transmission of Carpathian cultural heritage and identity across generations (i.e., Carpathian Convention, 2011; Zalka, 2018), including their potential contribution to education, community resilience and the revitalisation of cultural heritage and traditional ecological knowledge;
- Bridging cultural heritage and traditional ecological knowledge in the Carpathians through educational strategies and materials for diverse age groups;
- Perception of cultural heritage elements of the Carpathians by the younger generation; and
- Assessment of the impact of cultural identity and sense of belonging on local cultural and natural resource management and recreation.



Timber rafting on the river Bistrita, Ciocanesti village, Suceava County (Bucovina Carpathians, Romania). Credit: Ioana Baskerville

Recommended research questions

- How can cultural heritage and traditional knowledge of the Carpathian region enrich the European and global understanding and frameworks for heritage safeguarding?
- What region-specific best practices and strategies can advance cultural heritage research, safeguarding and education in the Carpathian region?
- How can best global practices of tangible cultural heritage preservation be adopted to the Carpathian region?
- What is the role of tangible heritage in safeguarding intangible heritage in the Carpathian region?
- How could soft tourism, the production of local 'labelled' products and the maintenance of local livestock breeds, and local crop varieties help maintain local cultural heritage? What practices are harmful to the development and adaptation of local cultural heritage (Niewiadomski, 2017)?
- Which elements of the Carpathian cultural heritage are perceived by residents as worth preserving and /or relevant for sustainable development?
- What are the perceptions of Carpathian cultural heritage among the young generations living in the Carpathian region? How do these perceptions differ across individual countries?
- What species and ecosystem types are most prominently recognised and used within the traditional ecological knowledge systems (Babai & Molnár, 2014; Roué. & Molnár, 2017)?
- What ideas and understandings do traditional ecological knowledge holders have of the causes of ecological change, including undesirable changes linked to their own cultural practices, as

well as drivers of change beyond their control, such as climate change or policies made by remote governments (Hill et al., 2020)?

- How can traditional ecological knowledge and modern resource management develop in parallel in an adaptive, dynamic way, and what is the role of regulations and subsidies (Babai et al., 2015)?
- How can traditional ecological knowledge from the Carpathian region contribute to international knowledge and policy frameworks on biodiversity and sustainable resource management (McEl wee et al., 2020)?

References

Ashworth, G.J., Graham, B. & Tunbridge, J.E. (2007). Pluralising pasts: Heritage, identity and place in multicultural societies. Pluto Press.
Babai, D. & Molnár, Zs. (2014). Small-scale traditional management of highly species-rich grasslands in the Carpathians. Agriculture, Ecosystems and Environment, 182, 123–130. 10.1016/j.agee.2013.08.018

Babai, D., Tóth, A., Szentirmai, I., Biró, M., Máté, A., Demeter, L., Szépligeti, M., Varga, A., Molnár, A., Kun, R. & Molnár, Zs. (2015). Do conservation and agri-environmental regulations support effectively traditional small-scale farming in East-Central European cultural landscapes? Biodiversity and Conservation, 24, 3305–3327. https://doi.org/10.1007/s10531-015-0971-z

Carpathian Convention. (2011). Carpathian legends and fairy tales. Vydavatel'stvo Matice slovenskej. Martin, Slovakia.

Carpathian Convention. (2003). Framework Convention on the Protection and Sustainable Development of the Carpathians. http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/01%20The%20Convention/1.1.1.1_CarpathianConvention.pdf

Carpathian Convention. (2018, April 4–5). Fifth meeting of the Working Group on Cultural Heritage and Traditional Knowledge, Szentendre (Skanzen) and Budapest, Hungary. https://www.carpathianconvention.org/2018/04/04/fifth-meeting-of-the-wg-cultural-heritage-and-traditional-knowledge-04-04-2018-05-04-2018-szentendre-skanzen-and-budapest-hungary/

Ciobanu, C. (2016). Space and time Perception and the Geopark's communities: From mythical geography to heritage interpretation, International Review of Social Research, 6(2), 98–106. https://doi.org/10.1515/irsr-2016-0013

Council of Europe. (2005). Council of Europe Framework Convention on the Value of Cultural Heritage for Society (CETS No. 199). https://www.coe.int/en/web/conventions/full-list2?module=treaty-detail&treatynum=199
Graham, B., Ashworth, G.J. & Tunbridge, J.E. (2000). A Geography of Heritage. Routledge.
Harrison, R. (2010). What is heritage? In R. Harrison. (Ed.). Understanding the politics of heritage (pp. 5–42). Manchester University Press,
Hartel, T. Kinga-Olga, R., & Craioveanu, C. (2017). Valuing scattered trees from wood-pastures by farmers in a traditional rural region of Eastern Europe. Agriculture, Ecosystems & Environment, 236, 304–311. 10.1016/j.agee.2016.11.019

Hill, R., Adem C., Alangui, W., Molnár, Z., Aumeeruddy-Thomas, Y., Bridgewater, P., Tengö, M., Thaman, R., Adou Yao, C., Berkes, F., Carino, J., Carneiro da Cunha, M., Diaw, M., Díaz, S., Figueroa, V., Fisher, J., Hardison, P., Ichikawa, K., Kariuki, P., Karki, M., Lyver, P., Malmer, P., Masardule, O., Oteng, A., Pacheco, D., Pataridze, T., Perez, E., Roué, M., Roba, H., Rubis, J., Saito, O., & Xue D. (2020). Working with Indigenous, local and scientific knowledge in assessments of nature and nature's linkages with people. Current Opinion Environmental Sustainability 43, 8–20. DOI: 10.1016/S1877-3435(20)30044-0
Howard, P. (2003). Heritage: Management, Interpretation, Identity. Methuen.

Iuga, A., Mihalache, C., & Andreescum, M. (Eds). (2024). MARTOR. Dynamics of Intangible Heritage. Shepherding, 29. www.doi.org/10.57225/martor.2024.29

Karadeniz, C.B. (2020). Assessment for Awareness and Perception of the Cultural Heritage of Geography Students, Review of International Geographical Education Online (RIGEO), 10(1), 40–64. https://doi.org/10.33403/rigeo.640722

Langer, J. & Bočková, H. (2014). House in Carpathians, Ethnologia Polona, 35, 25–77. https://journals.iaepan.pl/ethp/article/view/583

The United Nations Educational, Scientific and Cultural Organization (UNESCO). (2003). Convention for the Safeguarding of the Intangible Cultural Heritage.

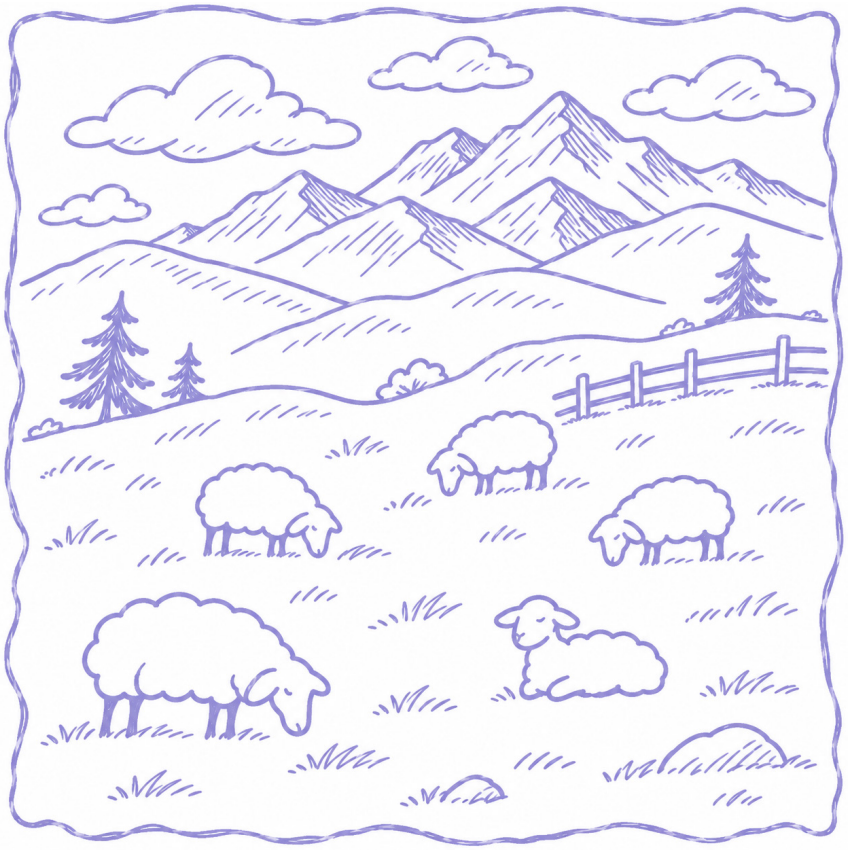
McElwee, P, Fernández-Llamazares, Á, Aumeeruddy-Thomas, Y, Babai, D., Bates, P., Galvin, K., Guèze, M., Liu, J., Molnár, Zs., Ngo, H.T., Reyes-García, V., Roy Chowdhury, R., Samakov, A., Shrestha, U. B., Díaz, S., & Brondízio, E. S. (2020). Working with Indigenous and local knowledge (ILK) in large-scale ecological assessments: Reviewing the experience of the IPBES Global Assessment. Journal of Applied Ecology, 2020, 57, 1666–1676. DOI: 10.1111/1365-2664.13705

Niewiadomski, Z. (2017). World Heritage and sustainable tourism in the Carpathians [Background paper]. United Nations Environment Programme, Vienna Programme Office, Secretariat of the Carpathian Convention. https://www.carpathianconvention.org/wp-content/uploads/2024/04/World-Heritage_Sustainable-Tourism_Carpathians_Background-paper_online-size.pdf

Roué, M. & Molnár, Zs. (Eds.). (2017). Knowing our lands and resources: Indigenous and local knowledge of biodiversity and ecosystem services in Europe and Central Asia, Knowledge of Nature, 9(8), UNESCO Publishing. https://unesdoc.unesco.org/ark:/48223/pf0000247462

Spacek, M., Melnykovych, M., Kozová, M., Pauditsova, E. & Kluvánková, T. (2022). The role of knowledge in supporting the revitalisation of traditional landscape governance through social innovation in Slovakia. Environmental Policy and Governance, 32, 560-574. 10.1002/eet.2026.
Throsby, D. (2001). Economics and Culture. Cambridge University Press.
Towse, R. (2022). The cultural economy of heritage, In R. I. Rizzo (Ed.). The economics of heritage: A study in the political economy of culture in Sicily (pp. 3–19). Edward Elgar.
Zalka, C.V. (2018). Dancing on Blades: Rare and Exquisite Folktales from the Carpathian Mountains. Parkhurst Brothers. eISBN: 978-1-62491-104-0.





13 Carpathian Pastoralism

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Pastoralism constitutes an ecological and cultural knowledge-based system that actively shapes landscapes while sustaining biodiversity, rural economies, and intergenerational cultural heritage (Bindi, 2022). Pastoralism relies on the use of mobile livestock production through flexible and adaptive grazing practices (Seid et al., 2016). Mobility is central to this system and can range from short-distance movements within local territories (micro-mobility of sedentary herders)[3] to vertical seasonal shifts and long-distance migration across regions. Within this spectrum, transhumance represents a structured and cyclical form of mobility – the seasonal relocation of herds between lowland winter grazing areas or autumn and winter grazing in the community of origin and higher-altitude summer pastures along established routes (Bowden & Herring, 2021; El-Hage Scialabba, 2022). Mobility allows sustained pasture productivity under changing conditions, thereby reinforcing broader social-ecological resilience (González Díaz et al., 2022; Ivașcu & Iuga, 2022).

Mobile grazing systems contribute significantly to ecosystem functioning and biodiversity conservation. Managed grazing has been shown to enhance species richness, primary productivity, (Ingty, 2021) and habitat diversity (Seid et al., 2016). In several European mountain systems, the reduction or abandonment of mobile pastoralism has been associated with the loss of culturally shaped open landscapes (Garzón-Heydt, 2004; González Díaz et al., 2022). At the same time, pastoralism embodies accumulated traditional ecological knowledge that links environmental management with cultural practice, closely resonating with current sustainability science approaches (Molnár & Babai, 2021; Sharifian et al., 2022; Easdale et al., 2023; Molnár et al., 2024). Changing grazing practices determined by social, cultural and political changes have a direct impact not only on the local culture, but also on the social structure of the communities, as well as the landscape (Baskerville, 2022; Ivașcu & Iuga, 2022; Iuga et al., 2024).

In the Carpathian region, pastoralism has shaped mountain landscapes, biodiversity, and rural livelihoods for centuries. Seasonal herding connects lowland and highland ecosystems, supporting a mosaic of habitats that contribute to high levels of biodiversity and cultural landscape value (Angelstam et al, 2013; Juler, 2014; Janišová et al., 2023). Beyond its ecological role, Carpathian pastoralism, rooted in the Wallachian transhumant tradition, shaped language and culture, as well as cultural heritage. Pastoralism sustains traditional knowledge systems, local breeds, and rural economies that remain essential for regional resilience (Dobrovolski 1930; Chaloupecký, 1947; Migdał et al., 2021; Cosma, 2023; Dragnea et al., 2025). However, this heritage is increasingly threatened by rural depopulation, land fragmentation, economic interests, changing land-use patterns, and regulatory constraints on mobility enforced by different local or national authorities and other entities. These pressures echo concerns raised by pastoralists internationally through efforts of the Interna-

[3] Local pastoralism, although it encompasses limited territorial mobility (within the administrative territories of the native villages) is also extremely complex and makes use of different types of semi-natural, natural ecosystems (including forests), ecotones (transition zones between ecosystems/biological communities) and stubbles (managed, man-made agricultural landscapes) (Vuia, 1964).

tional Year of Rangelands and Pastoralists (IYRP, 2026) including restricted mobility, exclusion of pastoralists from decision-making, and the undervaluation of pastoral practical knowledge. Traditional herders also experience various forms of social injustice in Europe (Molnár et al., 2023). Safeguarding Carpathian pastoralism requires protecting communal grazing systems by mapping and protecting traditional migration routes, recognising their role in ecosystem services and the continuity of local culture, and ensuring that pastoralist voices are included in governance and land-use planning.





Traditional sheep grazing in Grădiștea Muncelului-Cioclovina Natural Park, Hunedoara County, (Șureanu Mountains, Romania). Credit: Ioana Baskerville

Traditional sheep grazing in Grădiștea Muncelului-Cioclovina Natural Park, Hunedoara County, (Șureanu Mountains, Romania). Credit: Ioana Baskerville

The Carpathian Convention has encouraged coordinated action to safeguard pastoralism practices in the region. A key contribution has been facilitating Parties' participation in the transnational inscription of "Transhumance – the seasonal droving of livestock" on the UNESCO Intangible Cultural Heritage List. This initiative strengthens recognition of transhumance as a living heritage practice, while also reinforcing policy alignment across Carpathian countries. Such efforts align with broader international calls to recognise pastoral mobility as a cultural right, protect commons-based land systems, and ensure that pastoralist communities – especially youth – are included in decision-making processes shaping their futures (IYRP, 2026).

Recommended topics

- Evolution of mobility routes and seasonal mobility patterns in the Carpathian Mountains
- Socio-ecological impacts of land fragmentation on pastoral systems in Central and Eastern Europe
- Ecosystem services, biodiversity conservation, and climate resilience related to pastoral systems
- Climate change impacts on mountain rangelands and adaptive pastoral strategies

- Integration of traditional ecological knowledge into modern land-use planning, biodiversity conservation, and climate change mitigation
- Interactions between customary land tenure, conservation policies, and infrastructure development in the Carpathian region
- Impact of culturally and/or ecologically inappropriate European and national agricultural and other laws and regulations on Carpathian pastoralism, pastoralists, and pastures
- Role of pastoral activities in the conservation of species-rich semi-natural ecosystems with a special focus on semi-natural grasslands
- Importance of pastoral practices in the management of protected areas of the Carpathians
- Pastoral routes as ecological corridors for wildlife and landscape connectivity
- Effectiveness of UNESCO Intangible Cultural Heritage recognition in safeguarding living pastoral traditions
- Opportunities and threats related to interactions between safeguarding pastoralism and sustainable tourism development
- Study of current pastoral activities in the Carpathians and their relevance for local food security
- Sustainable pastoral value chains, entrepreneurship, and digital innovation in mountain economies
- Youth participation and intergenerational dialogue in Carpathian pastoral communities
- Culturally adapted education systems, intergenerational mentorship, and "reverse extension" approaches fostering two-way knowledge exchange between pastoralists and decision makers, including learning from local pastoral knowledge and experience.
- Gender-balanced representation and the role of women and youth in pastoral systems in the Carpathian region
- Links between pastoral systems and health and wellbeing



High-altitude grazing (Marmaros Mountains, Ukraine).
Credit: Dariia Kholiavchuk

Recommended research questions

- How have transhumance routes and seasonal mobility patterns in the Carpathians changed over the past century, and what are the main social, economic, environmental, and policy drivers of these changes?
- How can legal and policy frameworks, including the Carpathian Convention, better protect transhumance corridors, communal grazing systems, and cross-border pastoral mobility?
- How does land fragmentation, land abandonment, and changing land use patterns affect pastoral mobility, access to communal grazing areas, the ecological sustainability, and economic viability of pastoral systems in the Carpathians?
- How do traditional and extensive grazing systems contribute to biodiversity conservation, ecosystem services, and climate resilience in the Carpathian region?
- How is climate change affecting mountain rangelands and pastoral livelihoods in the Carpathians, and what are the traditional and current adaptive strategies that pastoralists use to mitigate these impacts?
- How can traditional ecological knowledge be recognised and integrated into land use planning, biodiversity conservation, and climate change mitigation strategies in the Carpathians, while ensuring the recognition and participation of pastoralists as knowledge holders?
- How do EU and national laws and regulations positively or negatively influence pastoral life styles, herders, and pastures?
- How do customary rights and cultural rights of pastoralists over traditional grazing lands in teract with conservation policies, infrastructure development, and changing land-use regimes in the Carpathians, and how can these rights be recognised and protected in land-use planning and governance?
- How do European and national agricultural, environmental, veterinary, and other regulatory frameworks affect pastoral practices, pastoral mobility, pastoralists' livelihoods, and the ecological management of pastures in the Carpathians?
- How do different forms of pastoral activity contribute to the maintenance and conservation of species-rich semi-natural ecosystems, particularly semi-natural grasslands, in the Carpathians? What management and policy approaches can strengthen these contributions?
- How can traditional pastoral practices be included in cultural landscape stewardship and the management of protected areas in the Carpathians?
- How do traditional pastoral routes and transhumance corridors contribute to ecological connectivity and wildlife movement across the Carpathian landscape? How can their role as ecological corridors be maintained or strengthened through conservation and land-use planning?
- To what extent does the UNESCO recognition of "Transhumance – the seasonal droving of livestock" contribute to the safeguarding of pastoralism in the Carpathian countries?
- How can UNESCO recognition and other heritage frameworks contribute to safeguarding the interconnected tangible, intangible, and natural heritage of Carpathian pastoralism? How can transnational research and cooperation among Carpathian and other pastoral regions strengthen comparative knowledge, heritage safeguarding, and sustainable pastoral practices?
- How can culturally sensitive and equitable tourism models in the Carpathians support the safe guarding of pastoralism, while ensuring meaningful participation and benefits for pastoral com

munities and promoting understanding of pastoral cultures and landscapes?

- What forms of pastoral activity in the Carpathians can contribute to local food security, sustain able food systems, and the resilience of rural communities?
- How can the cultural value of pastoral products be recognised, strengthened, and communicat ed through sustainable value chains, entrepreneurship, and digital innovation while ensuring fair returns for pastoral communities and contributing to the long-term viability of pastoral livelihoods?
- How is traditional knowledge transmitted between generations within contemporary pastoral communities?
- What economic and policy mechanisms can strengthen the long-term viability of pastoral livelihoods for younger generations?
- How can pastoralist knowledge systems be integrated into formal and non-formal education, biodiversity protection, and climate adaptation strategies in the region?
- How can pastoralists be supported when facing climate change for them not to abandon their occupation?
- What barriers do young pastoralists and women pastoralists face in accessing land, resources, and decision-making in Carpathian pastoral systems?
- How can governance systems in the Carpathian region ensure meaningful and gender-balanced participation of young pastoralists in decision-making processes from the local to regional levels?
- How do pastoral systems contribute to the health and well-being of pastoralists and their communities? How do social, economic, environmental, and cultural changes affect their livelihoods, social services, and overall quality of life?

References

Angelstam, P., Elbakidze, M., Axelsson, R., Čupa, P., Halada, Ľ., Molnar, Zs., Pătru-Stupariu, I., Perzanowski, K., Rozulowicz, L., Standovár, T., Svoboda, M., & Törnblom, J. (2013). Maintaining cultural and natural biodiversity in the Carpathian Mountain ecoregion: Need for an integrated landscape approach. In The Carpathians: Integrating nature and society towards sustainability, 393–424. Springer. https://doi.org/10.1007/978-3-642-12725-0_28

Bindi, L., (Ed.). (2022). Grazing communities: Pastoralism on the move and biocultural heritage frictions. Berghahn Books. doi:10.3167/9781800734753

Bowden, M., & P. Herring, (Eds.). (2021). Transhumance: Papers from the International Association of Landscape Archaeology Conference, Newcastle upon Tyne, 2018. Archaeopress.

Baskerville, I. (2022). Romanian transhumance: From enduring folk mythology to contemporary cultural and biological heritage. In L. Bindi (Ed.). Perspectives on rural development. Bio-cultural heritage and communities of practice. participatory processes in territorial development as a multidisciplinary fieldwork (pp. 209–229). University of Salento. doi:10.1285/i26113775n6.

Chaloupecký, V. (1947). Valasi na Slovensku [The Wallachians in Slovakia]. Prague.

Cosma, E. (2023). A Historiographical Survey of Ius Valachicum Among Romanians and Vlachs. Balcanica Posnaniensia. Acta et Studia, 30, 271–313. doi:0.14746/bp.2023.30.16.

Dobrovolski, K. (1930). Migracje wołoskie na ziemach polskich. [The Wallachian Migration in the Polish Lands]. In V. Pamiętnik (Ed.). Zjazdu Historyków Polskich [Congress of Polish Historians]. Lviv.

Dragnea, M., Marek, M., Jawor, G., & Polemikos, J. (Eds.). (2025). Wallachian mobility and settlement along the Carpathian arc. Routledge. doi:10.4324/9781003502135.

Easdale, M. H., Michel, C. L., & Perri, D. (2023). Biocultural heritage of transhumant territories. Agriculture and Human Values 40(1), 53–64. doi:10.1007/s10460-022-10361-y

El-Hage Scialabba, N. (2022). Introduction to livestock systems. In N. El-Hage Scialabba, Managing healthy livestock production and consumption. Academic Press. doi:10.1016/B978-0-12-823019-0.00010-6.

Garzón-Heydt, J. (2004). Recovering transhumance in Spain for long-term nature conservation. In R. G. H. Bunce, M. Pérez-Soba, R. H. G. Jongman, A. Gómez Sal, F. Herzog, & I. Austrad, (Eds.). Transhumance and biodiversity in European mountains (pp. 259–269). Alterra.

González Díaz, J. A., González Díaz, B., & Rosa-García, R. (2022). Role of Socioeconomy and land management in the evolution of agrosilvopastoral landscapes in northern Spain: Redes Biosphere Reserve. Frontiers in Ecology and Evolution, 10, 949093. doi:10.3389/fevo.2022.949093

Ingty, T. (2021). Pastoralism in the highest peaks: Traditional grazing systems and alpine biodiversity. PLOS ONE 16(1): e0245221. https://doi.org/10.1371/journal.pone.0245221

International Year of Rangelands and Pastoralists [IYRP]. (2026). Global declaration of young pastoralists: Madrid call to action. https://iyrp.info/sites/default/files/documents/Global-Declaration-Young-Pastoralists-short-version-Eng-Fr-Esp.pdf

Ivașcu, C. M. & Iuga, A. (2022). Contemporary transformation of the pastoral system in the Romanian Carpathian: A case study from Maramureș Region. In L. Bindi (Ed.). Grazing communities: Pastoralism on the move and biocultural heritage frictions (pp. 205–223). Berghahn. https://doi.org/10.3167/9781800734753

Iuga, A., Mihalache, C. & Andreescu, M. (Eds.). (2024). MARTOR. Dynamics of intangible heritage. Shepherding, 29. www.doi.org/10.57225/martor.2024.29

Janišová, M., Bojko, I., Ivașcu, C. M., Iuga, A., Biro, A. S., & Magnes, M. (2023). Grazing hay meadows: history, distribution, and ecological context. Applied Vegetation Science, e12723. https://doi.org/10.1111/avsc.12723

Juler, C. (2014). După Coada Oilor: Long-Distance Transhumance and its Survival in Romania. Pastoralism: Research, Policy and Practice, 4(4): 1–17. https://doi.org/10.1186/2041-7136-4-4

Migdał, W., M. Walczycka, Ł. Migdał, & Tabor, S. (2021). Farm Animals and Traditional Products of the Carpathian Mountains. In J. Hernik, M. Walczycka, E. Sankowski, & B. J. Harris, (Eds.). Cultural Heritage – Possibilities for Land-centered Societal Development (209–228). Environmental History, vol 13. Springer. https://doi.org/10.1007/978-3-030-58092-6_13

Molnár, Zs., Aumeeruddy-Thomas, Y., Babai, D., Díaz, S., Garnett, S. T., Hill, R., Bates, P., Brondízio, E., Carino, J., Demeter, L., Fernández-Llamazares, Á., Guèze, M., McElwee, P., Öllerer, K., Purvis, A., Reyes-García, V., Samakov, A., & Singh, R. (2024). Towards richer knowledge partnerships between ecology and ethnoecology. Trends in Ecology and Evolution, 39(2), 109–115. https://doi.org/10.1016/j.tree.2023.10.010
Molnár, Zs., & Babai, D. (2021). Inviting ecologists to delve deeper into traditional knowledge. Trends in Ecology and Evolution, 36, 679-690.

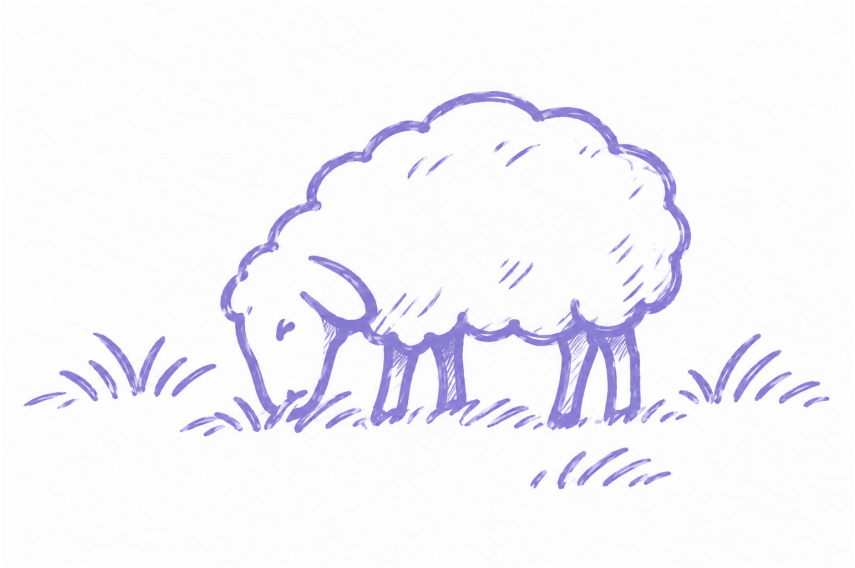
Molnár, Zs., Fernandez-Llamazares, Á., Schunko, C., Teixidor-Toneu, I., Jaric, I., Díaz-Reviriego, I., Ivascu, C., Babai, D., Sáfián, L., Karlsen, P., Dai, H., & Hill, R. (2023). Social justice for traditional knowledge holders will help conserve Europe's nature. Biological Conservation, 285, 110190. https://doi.org/10.1016/j.biocon.2023.110190

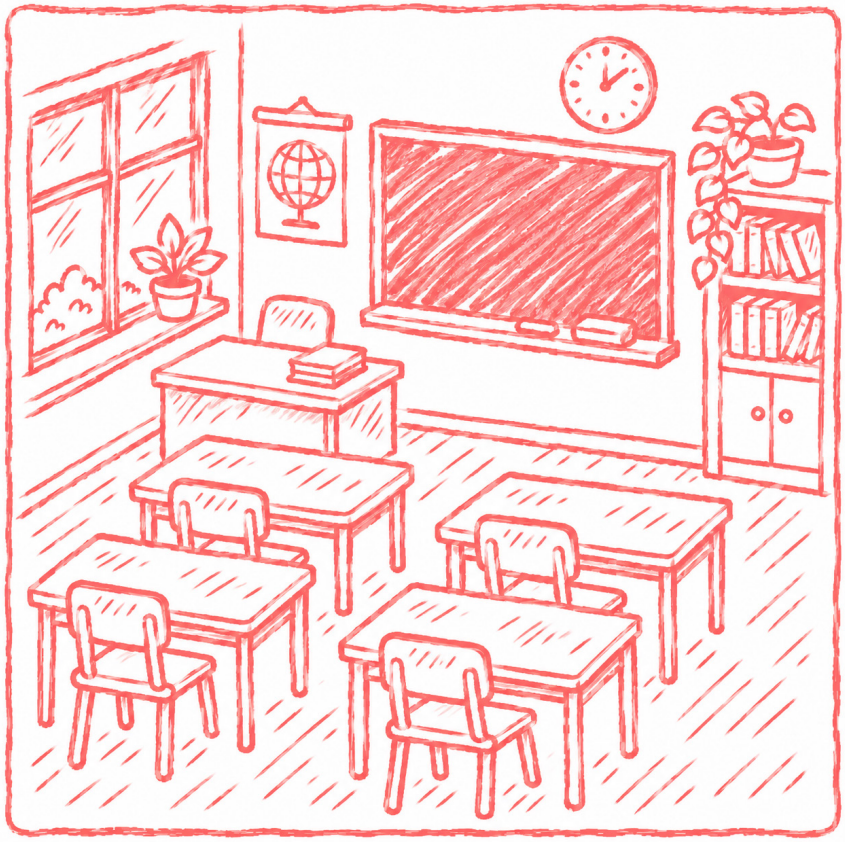
Seid, M. A., Kuhn, N. J. & Fikre, T. Z. (2016). The role of pastoralism in regulating ecosystem services. Revue Scientifique et Technique de

l'OIE [Scientific and Technical Review of the International Office of Epizootics], 35(2), 435–444. 10.20506/rst.35.2.2534

Sharifian, A., Fernández-Llamazares, Á., Wario, H. T., Molnár, Z. & Cabeza, M. (2022). Dynamics of pastoral traditional ecological knowledge: A global review. Ecology and Society, 27(1): 14. DOI:10.20506/rst.35.2.2534

Vuia, R. (1964). Tipuri de păstorit la romîni: (sec. XIX– începutul sec. XX). [Types of Shepherding among the Romanians: (19th century–early 20th century).] Bucharest: Publishing House of the Academy of the Romanian People's Republic.





14 Education for Sustainable Development

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Education for Sustainable Development (ESD) has become a cornerstone of global and regional strategies for achieving the Sustainable Development Goals (SDGs) (UN 2015). Education serves as both an enabler and an instrument for broader policy agendas, notably under frameworks such as the United Nations Framework Convention on Climate Change (UNFCCC1992) and the Convention on Biological Diversity (CBD 1992). Global and regional efforts, such as the UNESCO Education for Sustainable Development for 2030 Framework (focusing on greening schools, curricula, communities, and teacher training) and the UNECE Strategy for ESD and its Nicosia 2030 Implementation Framework (emphasizing standards, whole-institution approaches, new technologies, entrepreneurship, and employment), are dedicated to advancing the field (UNESCO 2014; Barth 2016; Garcia et al 2017; UNESCO 2019, UNECE 2022). Furthermore, European and regional strategic documents provide guidance related to education (e.g. Bianchi et. al. 2022; OECD 2025). Despite its strategic integration, however, access to ESD remains uneven. It is often perceived as a privilege, with marginalized communities (including people with disabilities), rural areas, and mountain regions facing barriers to meaningful engagement.

In the Carpathian region, these international frameworks intersect with local and regional initiatives. The Carpathian Convention, in Article 13, mandates awareness-raising, education, and public participation (Borsa et al., 2008). The Science for the Carpathians network, in collaboration with the Carpathian Convention Secretariat, is facilitating stronger integration of ESD into the Convention Programme of Work.

The Carpathian ESD Expert Network, established in collaboration with the Convention Secretariat, is developing a mission to "promote ESD-focused networking and collaborations that aim to improve quality of life, strengthen local economies and communities, and protect natural and cultural heritage in the Carpathians" (Mitrofanenko et al., 2020). A Carpathian ESD Roadmap is being developed in 2026 to operationalise these efforts and to guide the network in the coming years. The network recognises ESD as a participatory, place-based, and transdisciplinary process, deeply connected to community engagement and knowledge co-production. Strengthening connections between formal, non-formal and informal education, including citizen science science and community-based learning, can enhance the relevance, legitimacy and long-term impact of ESD in

[4] https://www.fenntarthatosagikutatas.hu/en/?l; The annual Teachers' and Students' Attitudes toward Sustainability research, conducted in connection with Hungary's Sustainability Thematic Week, provides a large-scale and longitudinal dataset on environmental attitudes, sustainability-related knowledge, and learning experiences among both upper-primary and secondary students, as well as participating teachers since 2020. This dataset offers valuable insight into how ESD is being implemented at classroom and whole school levels across the country. The research series has also included Hungarian language schools across the Carpathian Basin, enabling the participation of institutions in Slovakia, Romania, Serbia, and Ukraine. A representative study linked to the research series was conducted in 2022 with 17 year old students from the Czech Republic, Slovakia, and Hungary (Szabó et al., 2023, Sziva et al., 2026)

the region. However, the implementation of ESD in the Carpathians is not uniform. At the national level, environmental education (EE) often takes precedence over ESD, or the two approaches are used interchangeably. There is no comprehensive understanding yet of what a Carpathian approach to ESD might entail.

Nevertheless, there is much to be learned from existing ESD research, which could be scaled and replicated across the Carpathians to build a regional knowledge base. Existing studies, such as the annual Hungarian Teachers' and Students' Attitudes towards Sustainability research,[4] provide a strong foundation.

Understanding the current state of ESD, while crucial, is only part of the equation. The research agenda offers a unique opportunity to reimagine the future of ESD, particularly as the world moves beyond the SDGs. While ESD has often been framed as a tool for achieving predefined sustainability goals, critical perspectives highlight its potential to address deeper systemic challenges. This agenda should therefore not only build on existing knowledge but also allow for engagement with critical approaches to ESD, exploring how the field can evolve to foster justice, inclusivity, and adaptive responses to a changing world.





Nature-based workshop for highschool students "Tree doctors"
using dendrochronology in the beech forests (Bukovyna Mountains foreland, Ukraine)

International student summer school "Capacity building workshop
for natural forests in the Eastern Carpathians". (Marmaros Mountains, Ukraine).
Credit: Dariia Kholiavchuk

Recommended topics

- Integration of real-world labs and other transdisciplinary teaching and learning approaches into university education
- Lifelong teacher education
- Integrating research findings and applied knowledge into school and university curricula, and informal and non-formal education practice
- Comparison of EE and ESD systems in different (Carpathian) countries to provide recommendations of which policies and implementation systems are more effective in given contexts and reconciliation of national differences and recognition of similarities in approaches to ESD
- Assessment of how socio-economic-ecological challenges of the Carpathian region are addressed in teaching materials and teacher training courses and materials (for teachers and future teachers)
- Assessment of teacher competences, perception and teacher training needs
- Creation of a single, shared educational programme for/about the Carpathian area
- Integration of participatory and place-based learning approaches (e.g., citizen science, living labs, community-based education) into ESD practices in the Carpathians
- Carpathian identity in environmental education and education for sustainable development.
- Strengthening links between education, traditional ecological knowledge (TEK) and Carpathian identity to support locally grounded sustainability transitions
- Development of a comprehensive methodology that can be applied across Carpathian Countries
- Assessment of informal and non-formal education initiatives in the Carpathian region; overview of relevant actors and initiatives at the national level; assessment of legal frameworks and support systems of informal ESD in Carpathian countries
- Assessment of ESD-related needs of adult populations in mountainous areas
- Assessment of formal education related to the Carpathians: identification and analysis of curriculum content related to the Carpathians included in the national core curricula of the Carpathian countries; analysis of how educational content related to the Carpathians is presented in school textbooks; assessment of the effectiveness of the transfer of scientific knowledge to schools (comparing teachers' knowledge and perception of selected issues related to the Carpathian region with current scientific knowledge on these topics)
- Development of recommendations for curricula and educational materials, including textbooks, based on the results of the conducted research

Recommended research questions

- How can teacher education and lifelong professional development better prepare teachers to address complex socio-ecological challenges and integrate local and regional knowledge into ESD?
- How can hands-on and place-based learning (e.g. learning from local environments and communities) help students better understand sustainability and become more engaged?
- How does education for sustainable development influence people's behaviour, care for the environment and sense of belonging to the Carpathian region?

- To what extent does participation in experiential or outdoor education influence stakeholders' knowledge, attitudes, and behaviours regarding nature's contribution to people and the under standing of human-nature relations?
- How could ESD offer skills useful for protecting the environment and provide economic income at the same time?
- How could digital learning environments (e.g., VR field trips, AI supported tools) influence students' understanding of Carpathian socio ecological systems and their motivation to engage in sustainability actions?
- How does exposure to local environmental controversies (e.g., logging conflicts, tourism pressures, wildlife management debates) shape young people's civic engagement and critical think ing skills within ESD programs?
- How can Carpathian identity, Traditional Ecological Knowledge and place-based knowledge be integrated in ESD in ways that support locally grounded sustainability transitions?
- To what extent can youth-led community projects (e.g., local climate action, biodiversity monitoring, cultural heritage revitalization) strengthen place attachment and foster long-term environmental stewardship in mountain communities?
- How do teachers across different Carpathian countries perceive the balance between global sustainability narratives and local cultural–ecological knowledge, and how do they navigate tensions between them in classroom practice?

Research questions supporting the development of the ESD Roadmap:

- How are international ESD frameworks (UNESCO, UNECE, EU) contextualised and operation alised in the Carpathian context?
- How can national differences and common regional characteristics be reconciled in the development of shared and / or coordinated approaches to ESD in the Carpathian region?
- How can the Carpathian ESD Expert Network develop a common language and shared strategic understanding of ESD that resonates across the region?
- What are the core values, themes, and sustainability goals that are specific to the Carpathian region? To what extent are these reflected in formal education systems?
- To what extent do formal education systems address Carpathian themes and ESD?
- What role does non-formal education play in advancing ESD in the Carpathians?
- How can youth-led projects be scaled to foster long-term youth engagement and stewardship?
- What are the key needs and challenges of young people in the Carpathians? Can these be addressed via ESD?
- What vocational and lifelong learning currently exist in the Carpathians, and how can they be strengthened to support ESD?
- How can ESD be made more inclusive, accessible, and relevant for marginalized groups?
- What are the best practices and success stories in Carpathian ESD?
- What are the common challenges or failures in implementing ESD in the Carpathians, and what lessons can be learned from them?

References

Barth, M. (2016). Teaching and learning in sustainability science. In H. Heinrichs, P. Martens, G. Michelsen, & A. Wiek, (Eds.), Sustainability science: An introduction (pp 325–333). Springer.

European Commission: Joint Research Centre. (2022). GreenComp: The European sustainability competence framework. Publications Office of the European Union, Luxembourg. https://data.europa.eu/doi/10.2760/13286

Borsa, M., Chifelea, C., Egerer, H., Gal, Z., Glowacki, W., Halas, M., Hopfgartner, V., Illes, I., Niewiadomski, Z., Ptacek, P. & Wiederwald, D. (2008). Visions and strategies in the Carpathian Area (VASICA): Protection and sustainable spatial development of the Carpathians in a transnational framework. Vienna, Austria: Carpathian Project. http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/04%20Publications%20-%20Press%20-%20Gallery/Documents%20and%20Publications/4.1.2.3%20VASICA.pdf.

Conference of the Parties to the Convention on Biological Diversity. (2022). Kunming-Montreal Global Biodiversity Framework. https://www.cbd.int/doc/decisions/cop-15/cop-15-dec-04-en.pdf

Garcia, J., Aguiar da Silva, S., Simas Carvalho, A., & Salgueirinho Osório de Andrade Guerra, J. B. (2017). Education for sustainable development and its role in the promotion of the sustainable development goals. In J. P. Davim (Ed.). Curricula for sustainability in higher education, management and industrial engineering (pp 1–18). Springer.

Mitrofanenko, T., Varga, A., & Zawiejska, J. (2020). Towards stronger integration of ESD into the Carpathian Convention activities: A reflection on the process to-date and on the outlook. Mountain Research and Development 40(4), A1-A14. https://www.jstor.org/stable/27029083

Organisation for Economic Co-operation and Development (OECD). (2025). PISA 2029 Climate Literacy Framework Preliminary Draft. https://www.oecd.org/en/about/projects/PISA-2029-Climate-Literacy.html
Secretariat of the Convention on Biological Diversity. (1992). Montreal Convention on Biological Diversity. https://www.cbd.int/doc/legal/cbd-en.pdf

Szabó, A. Z, Berze, Zs., I. Ágoston, C., Varga, A., Činčera, J., Hengerics Szabo A., Sziva, D., Rosta, G., & Dúll, A. (2023). International student research on sustainability: Research report on the factor structures and psychometric characteristics of the applied scales. ELTE Eötvös Loránd University Institute of People–Environment Transaction (EKTI–IPET). https://www.fenntarthatosagikutatas.hu/letoltes/v3_report_final_for_publication.pdf

Sziva, D., Berze, I. Z., Cincera, J., Hengerics-Szabó, A., Mónus, F., Rosta, G., ... & Varga, A. (2026). Pathways from education for sustainable development to pro-environmental behaviour: The mediating role of action competence. Environmental Education Research, 1-36. https://doi.org/10.1080/13504622.2026.2671433

United Nations. (1992). United Nations Conference on Environment and Development, Rio de Janerio, Brazil, 3 to 14 June 1992. Agenda 21. United Nations. https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.
United Nations. (2015). Resolution adopted by the General Assembly on 25 September 2015. Transforming our world: The 2030 Agenda for Sustainable Development. General Assembly Report No. A/RES/70/1. United Nations. http://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E

United Nations Economic Commission for Europe (UNECE). (2022). Framework for the implementation of the United Nations Economic Commission for Europe Strategy for Education for Sustainable Development from 2021 to 2030.Ninth Environment for Europe Ministerial Conference, Nicosia, Cyprus, 5–7 October 2022. https://unece.org/sites/default/files/2022-08/ECE_NICOSIA.CONF_2022_10_E_0.pdf

United Nations Educational, Scientific and Cultural Organization (UNESCO). (2014). UNESCO Roadmap for Implementing the Global Action Programme on Education for Sustainable Development. UNESCO. http://unesdoc.unesco.org/ images/0023/002305/230514e.pdf.

UNESCO. (2018). Students take the Lead to Spread an Eco-Schools Initiative in Hungary. Building Peace in the Minds of Men and Women. https://en.unesco.org/news/students-take-lead-spread-eco-schools-initiative-hungary.

UNESCO. (2019). Framework for the Implementation of Education for Sustainable Development (ESD) Beyond 2019. https://unesdoc.unesco.org/ark:/48223/pf0000370215.

United Nations Framework Convention on Climate Change (UNFCCC). (1992). FCCC/INFORMAL/84GE.05-62220 (E) 200705 https://unfccc.int/resource/docs/convkp/conveng.pdf



15 Participatory research, multi-actor dialogues and knowledge co-production

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Tourism development in rural areas is closely connected to land-use patterns, environmental stewardship and local cultural practices. Furthermore, tourism governance in mountain environments requires balancing economic benefits with ecological and social capacities across highly heterogeneous contexts. Remote rural areas grapple with demographic and land-use changes while popular destinations are exposed to overtourism, struggling to address carrying-capacity constraints. In many peripheral regions, tourism, considered an important rural innovation catalyst, plays an increasingly important role in income generation and local economic diversification. Tourism development must also respond to emerging visitor demands and innovative practices while Addressing the complex challenges of sustainable development requires integrating knowledge that reaches beyond single disciplines and academic fields. Participatory action research involves bringing together different academic and non-academic actors, including those who can contribute relevant knowledge to the research process and/or those who are affected by the issues addressed by the research (Enengel et al., 2012). Research is thus framed as a process of collective learning and co-production of actionable knowledge conducted with actors and stakeholders rather than for or about them; non-academic actors therefore become co-producers of knowledge and help shape the research (Chevalier & Buckles, 2019). Transdisciplinary research constitutes an approach towards this end: shaping research questions based on societal problems and integrating different types of knowledge to generate action-oriented insights that are credible and legitimate for involved and affected actors (Pohl & Hirsch Hadorn, 2007; Moulaert, 2013; Vañó-Agulló et al., 2026). Embedding participatory and transdisciplinary approaches in the teaching and research of higher education institutions can help institutionalise them more broadly, while producing more robust learning outcomes and raising awareness among the actors involved – a self-reinforcing cycle that advances sustainable development (Peer & Stoeglehner, 2013; Mitrofanenko et al., 2020). es to pursue digital innovation while addressing environmental challenges, improving resource efficiency, and strengthening the long-term sustainability and resilience of tourism development.

Applying these paradigms to shape multi-stakeholder cooperation with science can help provide a comprehensive and systematic participatory approach to addressing socio-economic-ecological challenges in the Carpathian region via formulation and implementation of sustainable development policies (Melnykovych et al., 2018; Mitrofanenko et al., 2024).

Genuine collaboration among scientists, practitioners, holders of traditional and place-based knowledge, and policymakers is often demanding in practice: it requires forming collaborative teams, sharing decision-making, and remaining mindful of the tensions, power asymmetries and diverging values that can emerge among the actors involved (Harris et al., 2024; Melnykovych et al., 2024). However, through efforts of committed research and practice communities, such as Integration and Implementation Sciences (i2S), or the Network for Transdisciplinary Research (TD-Net), successful examples and learning outcomes for such collaborations emerge

(i.e., Mitrofanenko et al., 2020; Leitheiser et al., 2026). Applying such approaches consistently in the Carpathian region requires structured platforms that connect the Science for the Carpathians and other research networks, policymakers, national and local administrations, protected areas and civil-society actors (Melnykovych et al., 2026).

Citizen science is an example of another participatory research approach that can be used to increase awareness on resource protection in the Carpathian region and, at the same time, promote engagement in participatory actions; awareness and engagement are critically low in some parts of the region (Stefanescu et al., 2025). Moreover, citizen science could significantly enhance biodiversity monitoring, particularly in the Eastern Carpathians – where participation in volunteering is low and thus requires targeted capacity-building, education, and stronger institutional support to sustain be sustained (Loos et al., 2015). Yet local and traditional knowledge in regions such as the Carpathians is a vital data source – both because it can provide important insights for addressing local challenges, and because it links participation to places, practices, and meanings that people already recognise as their own (Greving et al., 2023).

Participatory approaches and methodologies are equally essential for working with local vulnerable communities and triggering multi-stakeholder collaborations for local sustainable development and a social and solidarity economy, involving all the relevant actors of local development, notably municipalities, private enterprises, local institutions and organisations such as schools, NGOs, community centres, and, importantly, local communities. Methodologies of co-design and co-creation, which involve the target groups as active participants from the very beginning of the research process, are particularly useful for bringing different benefits to the partners and impacting the local level. However, strict ethical considerations are needed for such research that must not be experimenting with local relations and the lives of communities, especially when it comes to vulnerable groups (Bock et al., 2024; Pandey et al., 2024).

The above insights have shaped efforts of the Science for the Carpathians (S4C) to address socio-economic-ecological challenges in the Carpathian region, including via supporting the implementation of the Carpathian Convention (Björnsen Gurung, 2013; Cudlín et al., 2022; Mitrofanenko et al., 2024, 2025). While continuously drawing insights from the Forum Carpaticum conferences and collaboration with other scientific and transdisciplinary networks, our recent joint reflection in Melnykovych et al. (2026) calls for strengthening structured platforms for dialogue and co-creation of joint solutions, linking the Carpathian Convention, S4C, national agencies, municipalities, protected areas and civil-society actors; and for the systematic, meaningful and reflective inclusion of local, traditional and practice-based knowledge in vulnerability assessments, scenario processes and monitoring.

Recommended topics

- Modes of meaningful local communities' participation in research (e.g., through citizen science, living labs, participatory action research)
- Integrating inter- and transdisciplinary approaches and participatory methods connecting academia, local action groups and policymakers
- Participatory social innovation practices that trigger transformations towards sustainability in the Carpathians

- Best practices and social innovation initiatives of local communities for tackling challenges that are not addressed by existing institutions (e.g., sustainable governance of landscapes along with promoting local culture, food, creating value-added local products)
- Documenting and strengthening mechanisms that translate transdisciplinary research into actionable recommendations for regional policy processes
- Multilevel governance (MLG) assessment of processes and dynamics fuelling socio-economic--ecological transitions (Allain-Dupré, 2020)
- Public participation and public engagement in planning processes (e.g., wind-energy planning, particularly in concrete, local-based settings and at municipal level) (Kastelein, 2024)
- Carpathian identity and sense of belonging:
    - Perception of "Carpathian identity" by the population living in the Carpathian region
    - Cultural, historical, and social factors shaping this identity and the extent to which it influences cooperation, community cohesion, and sustainable regional development
- Multi-stakeholder dialogues and partnerships for local sustainable development, through and beyond social and solidarity economy
- Aarhus Convention mechanisms as tools for facilitating participation of vulnerable groups in the green transition, and environmental policies more broadly

Recommended research questions

- What is the state of participatory, inter- and transdisciplinary research in the Carpathian region?
- What good examples exist of collaboration and co-creation of knowledge with local communities in research in the Carpathian region?
- How do trust, shared decision-making, and local ownership in participatory research partnerships shape behavioural outcomes in the Carpathian region?
- What are barriers to integrating participatory action and inter- and transdisciplinary research as a common practice among scientists working in the Carpathian region?
- How heritage narratives, awareness campaigns, and participatory approaches enhance acceptance and responsibility
- What are the underlying conditions required for facilitating an effective multi-stakeholder local dialogue involving municipal actors, the private sector, and local communities?
- How can participatory approaches and environmental, social, and governance (ESG) frameworks be used to actively engage the private sector?
- What is the potential and what are the barriers to the effective use of Aarhus Convention mechanisms as tools for participation of vulnerable groups in the green transition and the Carpathian environmental policies?
- How can structured science-policy platforms (i.e., S4C and the Carpathian Convention) be further strengthened to ensure that co-produced knowledge – including local and traditional knowledge – is systematically integrated into regional policy processes?

References

Allain-Dupré, D. (2020). The multi-level governance imperative. The British Journal of Politics and International Relations, 22(4), 800-808. https://doi.org/10.1177/1369148120937984

Björnsen Gurung, A. (2013). Science for the Carpathians: Using regional capacity to cope with global change. In J. Kozak, K. Ostapowicz, A. Bytnerowicz, & B. Wyżga (Eds.). The Carpathians: Integrating nature and society towards sustainability (pp. 13-21). Springer.

Bock, B., Hofer, K., Klok, J., Somaye, L., & Wiesinger, G. (2024). SERIGO D1.1. Initial Integrated Conceptual Framework. https://www.serigo-project.eu/wp-content/uploads/2025/02/D1.1_IICF-with-template_2.10.2025.pdf

Chevalier, J. & Buckles, D. (2019). Participatory action research: Theory and methods for engaged inquiry. Routledge. DOI: 10.4324/9781351033268.

Cudlín P, Zawiejska J, Mitrofanenko T, Mazsa K, & Melnykovych M. (Eds.). (2022). S4C Research Agenda 2022–2030. Science for the Carpathians (S4C) and Global Change Research Global Change Research Institute of the Czech Academy of Sciences (CAS), Brno, Czechia and Krakow, Poland.

Enengel, B., Muhar, A., Penker, M., Freyer, B., Drlik, S., & Ritter, F. (2012). Co-production of knowledge in transdisciplinary doctoral theses on landscape development: An analysis of actor roles and knowledge types in different research phases. Landscape and Urban Planning, 105(1–2), 106–117. https://doi.org/10.1016/j.landurbplan.2011.12.004

Greving, H., Bruckermann, T., Schumann, A., Stillfried, M., Börner, K., Hagen, R., Kimmig, S. E., Brandt, M. & Kimmerle, J. (2023). Attitudes toward engagement in citizen science increase self-related, ecology-related, and motivation-related outcomes in an urban wildlife project. BioScience, 73(3), 206–219.

Harris, F., Lyon, F., Sioen, G. B., & Ebi, K.L. (2024). Working with the tensions of transdisciplinary research: A review and agenda for the future of knowledge co-production in the Anthropocene. Global Sustainability, 7, e13. https://doi.org/10.1017/sus.2024.11

Kastelein, R. (2024). Role of local governments in EU member states' climate policy and legislation. npj Climate Action, 3(1), 92. https://doi.org/10.1038/s44168-024-00177-3

Leitheiser, S., van Dam, D., Egmose, J., Zagaria, C., Hauggaard-Nielsen, H., Kazakova, Y., Luján Soto, R., Dumont, B., Barlagne, C., Schaan, L. N., Duval, J., & Rossing, W. A. H. (2026). Actionable knowledge for agroecological transformation: a critical realist analysis of co-innovation in a transdisciplinary project. Sustainability Science. https://doi.org/10.1007/s11625-026-01867-z

Loos, J., Horcea-Milcu, A. I., Kirkland, P., Hartel, T., Osváth-Ferencz, M., & Fischer, J. (2015). Challenges for biodiversity monitoring using citizen science in transitioning social-ecological systems. Journal for Nature Conservation, 26 (July), 45–48. https://doi.org/10.1016/j.jnc.2015.05.001

Melnykovych, M., Böttinger, E., Waeber, P. O., Bertuca, A., De Luca, C., Domínguez, X., Fuentemilla, S., Hernández, S., Heikkinen, H.I., Kottawa Hewamanage, L., Nijnik, M., Pilla, F., Sarkki, S., Selva, C., Wilson, R., Valero, D., & Miller, D. (2024). Learning needs and gaps of rural communities. Report D. 3.1. Horizon Europe Project RURACTIVE: Empowering rural communities to act for change (2023–2027). GA no. 101084377. University of Bologna.

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkaľáková, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvánková, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy, I., Waeber, P. O. & Zawiejska, J. (2026). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda, Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Mitrofanenko, T., Melnykovych, M., Kubal-Czerwińska, M., Kuras, K., Vetier, M., Halada, L., Zawiejska, J., & Nijnik, M. (2024). Science–policy–practice collaborations towards sustainable development in the Carpathian Region. In S. Schneiderbauer, J. Szarzynski, J. Shroder, P. Fontanella Pisa (Eds.). Safeguarding mountain social-ecological systems: A global challenge, Vol. 2, Elsevier's Hazards and Disasters Series, Elsevier.

Mitrofanenko, T., Škovira, R., Kholiavchuk, D., Csabay, J., Keeton, W. S., Zawiejska, J., Matei, E., & Melnykovych, M., (Eds.). (2025). Key Messages and Recommendations from Science for the Carpathians for the Carpathian Convention Implementation Committee: Based on Forum Carpaticum 2025: Taking stock and building partnership for sustainable development of the mountain and rural areas, Bratislava, Slovakia, 9–11 September 2025. Science for the Carpathians (S4C). http://www.carpathianconvention.org/wp-content/uploads/2025/11/S4C-Recommendations-2025-to-CCIC_by-COP7-Decisions.pdf

Mitrofanenko, T., Zitnanova, A., Keryan, T., Khartishvili, L., Salukvadze, G., Gugushvili, T., Kekenadze, N., Katalieva, M., Khokhobaia, M., Matosyan, M., & Khoetsyan, A. (2020). Developing and Implementing a Transdisciplinary Case Study Course, Manual for University Lecturers: Prepared in the framework of the project Transdisciplinarity for Sustainable Tourism Development in the Caucasus Region (CaucaSusT), 130; Eigenverlag, BOKU, ILEN, Vienna. https://caucasust.boku.ac.at/wp-content/uploads/2020/12/CaucaSusT-Manual-for-Lecturers_Implementing-a-TD-Case-Study-Course_final_web.pdf

Moulaert, F. (2013). The international handbook on social innovation: Collective action, social learning and transdisciplinary research. Edward Elgar Publishing.

Pandey, P., Csabay, J., Rankovová, K., Gyarfášová, O., Bona, M., Motteran, I., Dalla Torre, C. & Chizzali, C. (2024). SERIGO D3.1. Guidelines for field research and case study analysis. https://www.serigo-project.eu/wp-content/uploads/2025/06/D3.1_CS-Methodology_2.10.2025.pdf

Peer, V. & Stoeglehner, G. (2013). Universities as change agents for sustainability: Framing the role of knowledge transfer and generation in regional development processes. Journal of Cleaner Production 44, 85–95.

Pohl, C., & Hirsch Hadorn, G. (2007). Principles for Designing Transdisciplinary Research. Oekom Verlag.

Stefanescu, L., Alexandrescu, F., & Meltzer, M. (2025). Embedded environmental activism in the Apuseni Mountains of Romania: The case of deficient local waste management. Eurasian Geography and Economics, 67(6), 706–732. https://doi.org/10.1080/15387216.2025.2480281

Vañó-Agulló, C., Prades, A., Espluga, J., & Lehtonen, M. (2026). Transdisciplinarity from principles to practice: Insights from EU Horizon research projects on sustainability. Sustainable Development 34(2), 2762–2779. https://doi.org/10.1002/sd.70411



16 Social innovations for sustainable development

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Social innovation (SI) has gained attention as a means of addressing sustainability challenges in mountain regions where demographic decline, limited accessibility, weak markets, constrained public services and environmental pressures interact. Rather than referring exclusively to new products or technologies, SI concerns changes in social practices, relationships, governance arrangements and forms of collective action that respond to societal challenges and seeks to improve societal wellbeing (Kluvánková et al., 2018; Melnykovych et al., 2018; Nijnik et al., 2019, 2022).

Research undertaken within the EU Horizon 2020 project, Social Innovation in Marginalised Rural Areas (SIMRA, 2020), has advanced the understanding of SI in rural settings (Nijnik et al., 2021; Marini Govigli et al., 2022). SIMRA demonstrated that the emergence and development of SI depend on the context, including on local agency, leadership, human and social capital (e.g., trust), and on institutional arrangements, intermediary actors and access to knowledge and resources (Slee & Mosdale, 2020). Evidence from 238 validated SI examples (Nijnik et al., 2022) from European and circum-Mediterranean rural areas and in-depth SIMRA case studies have shown that SI can mobilise territorial assets and contribute to new forms of governance to promote sustainable development (SD). However, outcomes are place-, case-, and context-specific.

Remote communities in the Carpathians have access (subject to the law) to valuable social, cultural and ecological assets, but they commonly face structural disadvantages (Melnykovych et al., 2026a). Research shows that SI can strengthen the communities' capacity to respond to socio-economic and environmental challenges, however, Nijnik et al. (2019) emphasised the need to examine outcomes of SI rather than to assume that SI is inherently beneficial to all. Success would depend on various factors, including on interactions between the institutional (e.g., governance) and natural capital conditions.

Adaptive responses are shaped by local livelihoods (Melnykovych et al., 2026b); they are underpinned by human and social capital (e.g., community networks), as well as by availability and sustainability in using the valuable natural assets. However, governance arrangements do not always reflect social-ecological realities (Melnykovych et al., 2018). Therefore, to enhance sustainable regional development, SI should be understood and applied broadly (SIMRA, 2020) to encompass socio–ecological innovation (Melnykovych et al., 2018; Sarkki et al., 2019b), socio-political innovation and/or institutional innovation (Sarkki et al., 2022).

The research has been advanced by the SIMRA H2020 and the Horizon Europe RURACTIVE projects towards furthering the understanding of how SI emerges and develops (Kluvánková et al., 2021), what effects it generates, whether (and under which conditions) positive effects can persist, and how the spreading of SI (e.g., scaling up or scaling out) can be enhanced (Melnykovych et al., 2024). The role of human values (over purely material gains) to guide human behaviours and shape social structures by prioritising ethics, empathy, responsible stewardship of the environment and social justice is imperative for promotion of sustainable development through SI (Sarkki et al., 2019a). These questions are central to reduce inequalities (SDG 10), support sustainable and resilient communities (SDG 11), strengthen inclusive and participatory institutions (SDG 16), and advance the sustainable management of ecosystems (SDG 15).

Comparative research in European forest-dependent mountain communities has shown that values can act both as SI catalysts and consequences (Nijnik et al., 2022). Relational values, including stewardship, trust, responsibility, belonging and relationships with place and nature, may encourage collective action and can be transformed through SI (Sarkki et al., 2019). This provides an important connection between SI, ecosystem-service valuation and emerging approaches to plural values (see Chapter 8 on ecosystem services; Nijnik et al., 2026a). In this regard, SERIGO project findings show that while it is not a straightforward process, social and solidarity economic practices can redefine not only institutional systems but also socio-ecological and economic value systems at the local level (Dalla Torre et al., 2026). Indeed, SI promotes sustainable development and, therefore, increasingly needs to move beyond an instrumental understanding of nature (Nijnik et al., 2022). Mountain landscapes are valued not only for material benefits but also for cultural identity, attachment to place, stewardship and intergenerational continuity (Melnykovych et al., 2026a; Nijnik et al., 2026b). Integrating plural values into SI research can help explain why actors mobilise, why conflicts arise and why apparently similar policy interventions generate different responses in different communities.

Another important research frontier concerns scaling and institutionalisation. Innovations may spread horizontally between communities (or scale up vertically, which is more difficult). They could influence policies and institutions or produce deeper changes in values and relationships. However, evidence from marginalised rural areas indicates that SI is strongly place-dependent. Successful practices cannot necessarily be transferred intact between communities; rather, principles, organisational arrangements and learning processes may need to be adapted to local institutional and cultural conditions. This is particularly important for vulnerable groups (e.g., marginalised Roma communities as discussed by Bizikova et al., 2012; Csabay & Teru, 2022) whose living conditions such as those related to energy poverty, for example, vary significantly, even between neighbouring settlements (Csabay & Teru, 2023). This naturally carries implications for possible SI pathways (Kluvankova et al., 2021) to address the challenges that the Carpathian region faces (see Špaček et al., 2022 on revitalisation of traditional landscape governance through SI in Slovakia). This is also highlighted by SIMRA (2020) and is evident from numerous case studies and innovation actions (Górriz-Mifsud et al., 2019).

For the Carpathians, all these issues are crucial because the region combines ecological significance with strong territorial diversity and cross-border interdependence. Rural depopulation, ageing, migration, changing land use, tourism pressures, climate change and uneven access to public services interact differently across the seven Carpathian countries. The Ukrainian Carpathians additionally face the consequences of war, displacement and future reconstruction, creating additional challenges for community resilience, natural-resource governance and sustainable development (Melnykovych et al., 2026a).

The principal research gap is therefore no longer whether SI can contribute to sustainable development, but under which conditions, through which mechanisms and how and for whom SI can contribute to attaining just and sustainable transformation of the Carpathian region. Analysing, designing and ensuring ways that public and private sectors, various partnerships and collaborations can enhance, scale up and scale out SI in mountain areas is crucial (Nijnik et al., 2020), as well as involving local communities and vulnerable groups as active agents of change from the very beginning and throughout. Attention is to be paid to advancing the understanding of enablers and barriers and how SI can deliver transformative opportunities to people and socio-ecological systems to promote sustainable development at the local level (RURACTIVE, 2026).



Co-designing social innovation in Ukrainian Carpathians communities.
Credit: FORZA

Recommended research topics

- Emergence and drivers of SI in the Carpathians (e.g., the challenges faced and unmet needs, institutional gaps, social and human capital, local leadership, collective agency)
- Actors who initiate and drive SI, decide how different actors mobilise resources and knowledge, and how agency's leadership supports innovations
- Processes and trajectories over time, from problem recognition and mobilisation to experimentation, consolidation, adaptation, institutionalisation and diffusion
- The spreading of SI across the Carpathians, and how it influences policies and institutions, and generates broader changes in social practices and relationships
- Social and solidarity economy as a mechanism for systems change and empowerment in the Carpathians, particularly its potential to enable vulnerable groups to participate in sustainable development, socio-ecological resilience and the green transition
- Enabling and constraining conditions for SI across different Carpathian settings, including trust, reciprocity, organisational capacity, access to finance, institutional flexibility, local networks, social capital and supportive or constraining governance
- SI ecosystems and intermediary support beyond individual initiatives, including the roles and interactions of municipalities, civil-society organisations, universities, businesses, development agencies and intermediary actors
- Living Labs as science-based, user-led and open innovation ecosystems in which researchers, policymakers, communities, forest managers and other end-users co-design and test socially in-

novative solutions to sustainability and climate-adaptation challenges in real-world Carpathian contexts
- Social, economic, institutional and territorial outcomes and impacts of SI, including who benefits, how benefits/disbenefits are distributed, and whether SI generates unintended, uneven or exclusionary outcomes
- Durability and institutionalisation of SI, including the conditions enabling initiatives to persist beyond short-term projects, individual leaders or external funding through organisational continuity, sustainable financing, succession and community ownership
- Social learning and adaptation, including how innovators learn through experimentation, peer exchange and successful/unsuccessful, contested or discontinued initiatives
- Transboundary SI, including how cross-border learning, communities of practice and transnational networks can support SI, and the roles of the Carpathian Convention and Science for the Carpathians in facilitating comparative research and knowledge exchange

Recommended research questions

- What combinations of local agency, social capital, institutions, governance and resources enable SI to emerge and persist in the Carpathian mountain communities?
- How and under what conditions does SI improve community wellbeing, economic resilience and the sustainable governance of Carpathian social–ecological systems?
- Who benefits from SI? Who participates in decision-making and which groups or values risk being excluded?
- How do local, traditional and scientific knowledge and plural environmental values shape SI and collective action?
- How can SI support resilient and diversified mountain economies while maintaining ecosystem services, biodiversity and locally embedded livelihoods?
- To what extent can social and solidarity economy and SI empower vulnerable groups to become active agents in the green transition of the region?
- To what extent can critical systems thinking enable improved understanding of interrelation ships between SI within local and wider institutional systems and hierarchies?
- Which elements of successful SI are transferable across the territories, and which strongly depend on specific social, economic, ecological and/or institutional contexts?
- How can SI scale from local initiatives towards wider institutional and policy change without losing local ownership and legitimacy?
- What forms of transboundary cooperation and science–policy–practice interaction can strengthen SI and sustainability transformations across the Carpathian region?

References

Bizikova, L., Nijnik. M., & Kluvánková-Oravská, T. (2012). Sustaining multifunctional forestry through the developing of social capital and promoting participation: A case of multiethnic mountain communities. Small-scale Forestry 11(3), 301–319. https://doi.org/10.1007/s11842-011-9185-8

Csabay, J., & Teru, V. (2022). Analysis of pilot interventions for addressing energy poverty of Roma communities at Luník IX, Košice, based on an energy audit of the 1–3 Hrebendova block of flats. Friends of the Earth-CEPA and RESDI.

Csabay, J., & Teru, V. (2023). Methodology for energy poverty chapter in decarbonisation strategies: Context of marginalised Roma communities. Slovak Innovation and Energy Agency.

Dalla Torre, C., Bona, M., Pandey, P., Valovic, R., Figulova, A., & Csabay, J. (2026). Analytical case study reports. SERIGO Project Working Document 3.2.

Górriz-Mifsud, E., Melnykovych, M., Marini Govigli, V., Alkhaled, S., Arnesen, T., Barlagne, C., Bjerk, M., Burlando, C., Jack, S., Rodríguez Fernández-Blanco, C., Prokofieva, I., Sfeir, P., Slee, B., & Miller, D. (2019). Report on lessons learned from social innovation actions in marginalised rural areas (Deliverable 7.3, Social Innovation in Marginalised Rural Areas [SIMRA], Horizon 2020). https://doi.org/10.13140/RG.2.2.33308.23680

Kluvánková, T., Brnkaľáková, S., Špaček, M., Slee, B., Nijnik, M., Valero, D., Miller, D., Bryce, R., Kozová, M., Polman, N., Szabo, T., & Gežík, V. (2018). Understanding social innovation for the well-being of forest-dependent communities: A preliminary theoretical framework. Forest Policy and Economics, 97, 163–174. https://doi.org/10.1016/j.forpol.2018.09.016

Kluvánková, T., Nijnik, M., Špaček, M., Sarkki, S., Perlik, M., Lukesch, R., Melnykovych, M., Valero, D., & Brnkaľáková, S. (2021). Social innovation for sustainability transformation and its diverging development paths in marginalised rural areas. Sociologia Ruralis, 61(2), 344–371. https://doi.org/10.1111/soru.12337

Marini Govigli, V. M., Rois-Díaz, M., den Herder, M., Bryce, R., Tuomasjukka, D., & Górriz-Mifsud, E. (2022). The green side of social innovation: Using sustainable development goals to classify environmental impacts of rural grassroots initiatives. Environmental Policy and Governance, 32(6), 459–477. https://doi.org/10.1002/eet.2019

Melnykovych, M., Böttinger, E., Waeber, P. O., Bertuca, A., De Luca, C., Domínguez, X., Fuentemilla, S., Hernández, S., Heikkinen, H. I., Kottawa Hewamanage, L., Nijnik, M., Pilla, F., Sarkki, S., Selva, C., Wilson, R., Valero, D. & Miller, D. (2024). Learning needs and gaps of rural communities. Report D3.1. RURACTIVE—Empowering Rural Communities to Act for Change, Horizon Europe Grant Agreement No. 101084377.122.

Melnykovych, M., Nijnik, M., Soloviy, I., Nijnik, A., Sarkki, S., & Bihun, Y. (2018). Social-ecological innovation in remote mountain areas: Adaptive responses of forest-dependent communities to the challenges of a changing world. Science of the Total Environment, 613–614, 894–906. https://doi.org/10.1016/j.scitotenv.2017.07.065

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkaľáková, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvánková, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy, I., Waeber, P. O. & Zawiejska, J. (2026a). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda, Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Melnykovych, M., Nijnik, M., Soshenskyi, O., Zibtsev, S., Lobchenko, G., Sarkki, S., Voloshyna, N., Soloviy, I., Kravets, P., Khan, Y., Yaroshchuk, R., Keeton, W. S., Rosset, C., Pauli, B., Garcia, C. A. & Waeber, P. O. (2026b). Pathways for Ukraine's post-war nature recovery: Focus on forest socio-ecological systems, Ambio, 55, 817–843. doi: 10.1007/s13280-025-02263-0

Nijnik, M., Kluvánková, T., Nijnik, A., Kopiy, S., Melnykovych, M., Sarkki, S., Barlagne, C., Brnkaľáková, S., Kopiy, L., Fizyk, I. & Miller, D. (2020). Is there a scope for social innovation in Ukrainian forestry? Sustainability, 12(22), 9674. https://doi.org/10.3390/su12229674

Nijnik, M., Kluvánková, T., Melnykovych, M., Nijnik, A., Kopiy, S., Brnkaľáková, S., Sarkki, S., Kopiy, L., Fizyk, I., Barlagne, C. & Miller, D.

(2021). An institutional analysis and reconfiguration framework for sustainability research on post-transition forestry: A focus on Ukraine. Sustainability 13(8), 4360. https://doi.org/10.3390/su13084360

Nijnik, M., Kluvánková, T., & Melnykovych, M. (2022). The power of social innovation to steer sustainable governance of nature. Environmental Policy and Governance 32(6), 453–458. https://doi.org/10.1002/eet.2018

Nijnik, M., Martino, M., Miller, D., Waeber, P., Melnykovych, M., & Rosset, C. (2026a). How can institutional support, incentives, and science-driven knowledge sharing enable multifunctional forest management and use? In Productive and biodiverse: managing Europe's forests for economic and ecological outcomes. Vienna, Austria: IUFRO Science-Policy Programme and Teaming Up 4 Forests. Forthcoming.

Nijnik, M., Melnykovych, M., Martino, S., Sarkki, S., Nijnik, A., Kopiy, S., Kopiy, L., Joyce, K., Wang, C., Poskitt, S., & Miller, D. (2026b). A mixed-methods approach to better understand and steer multifunctional forestry in mountain regions of Europe. Forest Policy and Economics, 190, 103859. https://doi.org/10.1016/j.forpol.2026.103859

Nijnik, M., Secco, L., Miller, D., & Melnykovych, M. (2019). Can social innovation make a difference to forest-dependent communities? Forest Policy and Economics, 100, 207–213. https://doi.org/10.1016/j.forpol.2019.01.001

Sarkki, S., Ficko, A., Miller, D., Barlagne, C., Melnykovych, M., Jokinen, M., Soloviy, I., & Nijnik, M. (2019a). Human values as catalysts and consequences of social innovations. Forest Policy and Economics 104, 33–44. https://doi.org/10.1016/j.forpol.2019.03.006

Sarkki, S., Parpan, T., Zahvoyska, L., Voloshyna, N., Derbal, J., Melnykovych, M., & Nijnik, M. (2019b). Beyond participation! Social-ecological innovations facilitating movement from technocratic state to collaborative landscape governance in Ukraine. Landscape Ecology, 34, 1601–1618, 10.1007/s10980-019-00787-x

Sarkki, S., Jokinen, M., Heikkinen, H., Nijnik, M., Melnykovych, M., & Kluvankova, T. (2022). "Going out to get in": Roles of forest conflicts in bottom-linked environmental governance progressing toward socio-political innovations. Environmental Policy and Governance, 32(6) https://doi.org/10.1002/eet.2020

Slee, B., & Mosdale, L. (2020). How policy can help bring about social innovation in rural areas. SIMRA Policy Brief. Social Innovation in Marginalised Rural Areas Project. 16 pp.

Špaček, M., Melnykovych, M., Kozová, M., Pauditšová, E., & Kluvánková, T. (2022). The role of knowledge in supporting the revitalisation of traditional landscape governance through social innovation in Slovakia. Environmental Policy and Governance 32(6), 560–574. https://doi.org/10.1002/eet.2026

SIMRA [Social Innovation in Marginalised Rural Areas]. (2020). Social Innovation in Marginalised Rural Areas. Horizon 2020 Project, Grant Agreement 677622.

RURACTIVE. (2026). Empowering Rural Communities to Act for Change. RURACTIVE project website. https://www.ruractive.eu/

17 Addressing vulnerability

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Vulnerability, due to its debated conceptual underpinnings (Füssel, 2007), has diverse indicators for climate contexts. European Union (EU) policy frameworks, particularly the Social Climate Fund (over €86 billion) and the ETS2 Directive, aim to address these issues by targeting vulnerable households, micro-enterprises, and transport users with gender-based vulnerability underlining the efforts. However, the identification of specific vulnerable groups is largely left to member states, emphasising bottom-up planning and public consultation (Art. 2, Art. 5), which is often done pro forma rather than in practice as public consultations for the Social-Climate Plans across the Carpathians have shown. Socio-economic indicators further illustrate disparities. Carpathian countries fall below the EU median income (18,700 PPS), ranging from ~9,800 to 14,000 PPS. Poverty and exclusion risks vary: Poland is below the EU average (16% vs. 21%), while Romania exceeds it at 27%, partly linked to its Roma population. Income inequality is generally lower than the EU average, though differences between countries (e.g., Slovakia vs. Romania) further underline regional complexity.

Overall, vulnerability in the Carpathian region is shaped by interconnected climate, energy, and socio-economic factors that require context-specific and multilevel responses (Füssel, 2007). While some indicators – such as the ability to heat households (as argued in Chapter 10 on green energy and energy efficiency) suggest relatively favourable conditions compared to the EU average, these coexist with structural challenges like lower incomes, energy poverty coping strategies, and uneven social outcomes.

Although Carpathian countries rank high in the Human Development Index, their scores decline when adjusted for planetary pressures (PHDI). Combined with existing socio-economic hardships, this creates a complex landscape where relatively strong performance in some indicators does not eliminate broader, complex accounts of vulnerability under ongoing climate change (Csabay, 2025).

These macro indexes, however, do not do justice to the plethora of vulnerabilities present across the region. Current policy and academic scholarship (Sovacool, 2021; Prainsack, 2026) frequently criticise a macro-perspective that omits contextual nuances and the specific barriers – such as a lack of trust or local knowledge or meaningful engagement – facing vulnerable groups (see CEESEN BENDER, n.d.; CEE Bankwatch Network, n.d.). Moreover, data collection is often restricted to a specific silo such as "energy" or "labour", without connecting these findings to broader policy areas (see Villani et al., 2025; Kappe et al., 2025). A critical gap exists in data collection; while national-level indexes like the mentioned EU-SILC or national censuses are available, they remain insufficient for designing tailored and micro-regional interventions. Furthermore, these indicators often use the "one-size-fits-all" label, effectively ignoring how overlapping identities including gender, age, disability, migration or social status intersect to create unique forms of vulnerability. Therefore, a move towards decentralised participation is needed to involve communities in core decision-making. In addition to the marginalised Roma communities, war-affected vulnerable groups from Ukraine, particularly internally displaced persons and those living in the most war-affected areas, as well as communities living in formerly industrial, declining regions deserve special attention in this regard.

Towards more inclusive conceptual and methodological framework for involving vulnerable groups in the research process

Vulnerability cannot be understood as a stand-alone phenomenon, neither can any single disciplinary focus encompass its necessary complexity. For example, the connection between health effects and air quality in the context of environmental governance cannot be understood alone; neither by the technical tool of measuring air quality and health impact nor through qualitative tools to understand the underlying causes and the social and political realities on the ground. They are all complementary to each other, calling for more transdisciplinary engagement in the study of vulnerability in the context of the Carpathian region and beyond.

Given the limitations and gaps identified above, we propose moving beyond the traditional disciplinary, methodological, and conceptual framings. First, vulnerable groups hardly face a singular challenge that can be addressed through a single-bullet solution. Challenges are often interconnected; hence our definition and conceptualisation of vulnerability need to emerge bottom-up and should correspond to a non-uniform and flexible understanding of vulnerability based on intersectionality (Bock et al., 2024). For instance, the underlying causes and possible solutions to transport or energy poverty or environmental injustice would vary significantly for a male pastoralist living in the mountains or a female Romani living in an informal settlement, both representing vulnerable groups of the Carpathian region. Patterns alter based on the different contexts of individuals, households or communities (single-parent or large families, formal vs. informal housing, infrastructure quality, educational levels, air quality, or access to employment). Such an intersectional framing will allow us to not only understand the interconnections between different vulnerabilities but also propose more tailored solutions at different levels of governance. In this regard, vulnerability needs to be understood as an issue operating within a complex and evolving institutional system of policy mechanisms and actors, including the vulnerable groups themselves, within the currently diverging and at times competing yet highly overlapping and complementary policy framings of environmental, biodiversity, sustainable and climate policies. To encompass this, hands-on analytical frameworks such as critical systems thinking (CST) need to be considered to capture these nuances, including complex feedback loops (Pandey et al., 2024).

Finally, the role of vulnerable groups in research and implementation needs to be redefined at the level of both policy and scholarship from passive victims or subjects of study to active agents. For this purpose, participatory methodologies offer tools for actively engaging vulnerable groups in a way that allows their voices and perspectives to count and actively shape the research and policy process rather than trying to fit into predefined theoretical categories (Pandey et al., 2024). These can range from more participatory methods of data collection (e.g., photo-voicing, walking interviews) and analysis to more complex methodologies, such as living labs, co-design and co-creation, that allow for development of specific concrete solutions in which the target groups are actively involved in the whole process. In such instances, however, ethical considerations and the wellbeing of the vulnerable groups rather than research outputs need to be of prime consideration.

Recommended topics

- Mapping of intersectional vulnerability across the Carpathian region
- Vulnerable regions across the Carpathian region in a comparative assessment in the context of the European Union

- Climate vulnerability among Roma communities and other vulnerable groups: intersections of social and economic poverty (access to employment, healthcare and education), housing insecurity, and environmental injustice
- Using critical systems thinking to understand interconnected vulnerabilities
- Designing locally tailored adaptation policies through participatory approaches to address vulnerable populations in the Carpathian region

Recommended research questions

- What are the systemic causes and interconnections between different vulnerabilities in the Car pathian region?
- What are the institutional barriers specific to the Carpathian region and context that prevent vulnerable people from actively participating in the EU Green Deal and environmental governance more broadly?
- What are the possible pathways at different systemic levels (EU, the Carpathians, national, municipal, community) for inclusion and participation of vulnerable groups as active agents of change?
- How can regional and municipal policies engage vulnerable populations to mitigate climate-related vulnerabilities while avoiding "policy resentment"?

References

Bock, B., Hofer, K., Klok, J., Somaye, L., & Wiesinger, G. (2024). SERIGO D1.1. Initial Integrated Conceptual Framework. Available at: https://www.serigo-project.eu/wp-content/uploads/2025/02/D1.1_IICF-with-template_2.10.2025.pdf

CEE Bankwatch Network. (n.d.). Just transition. https://bankwatch.org/project/just-transition#project-publications

Central and Eastern European Sustainable Energy Network (CEESEN). (n.d.). BENDER expert article projects. https://ceesen.org/projects/ - https://ceesen.org/wp-content/uploads/2025/11/BENDER_expert-article_eng_aftercom.pdf

Csabay, J. (2025). Critical perspectives to growth-based approach as a policy goal and dominant measure of policy performance in Slovakia. In B.S. Sergi. (Ed.). Modelling economic growth in Slovakia (pp. 71–83). Emerald Publishing.

Füssel, H. M. (2007). Vulnerability: A generally applicable conceptual framework for climate change research. Global environmental change, 17(2), 155-167. https://doi.org/10.1016/j.gloenvcha.2006.05.002

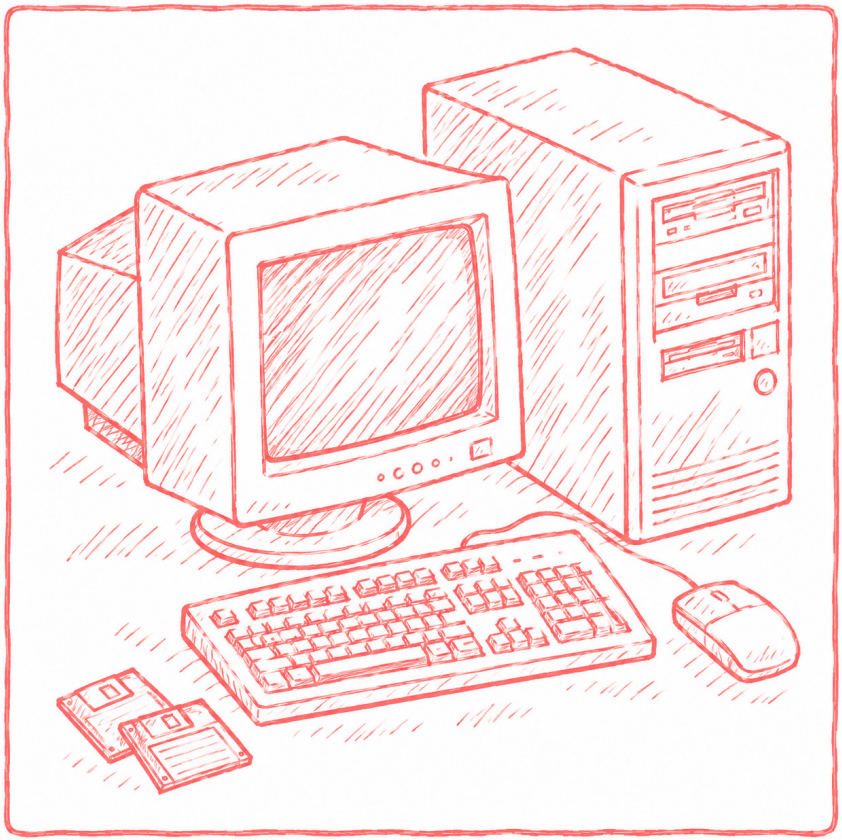
Kappe, K., Mikaelsson, M.A., & Krustok, I. (2025). The EU Green Deal in turbulent times: Insights from the EU Green Policy Tracker from Sweden and Estonia. SEI Discussion Brief. Stockholm Environment Institute. https://doi.org/10.51414/sei2025.017

Pandey, P., Csabay, J., Rankovová, K., Gyarfášová, O., Bona, M., Motteran, I., Dalla Torre, C. & Chizzali, C. (2024). SERIGO D3.1. Guidelines for field research and case study analysis. https://www.serigo-project.eu/wp-content/uploads/2025/06/D3.1_CS-Methodology_2.10.2025.pdf

Prainsack, B., do Céu Patrão Neves, M., Sahlin, N. E., Biller-Andorno, N., van den Hoven, J., Laukyte, M., Łuków, P., Molnár-Gábor, F., Murphy, T., Sharon, T., Vidalis, T., & Kritikos, M. (2026). The green transition will be just – or it won't succeed. Environmental Science & Policy, 179, 104372. https://doi.org/10.1016/j.envsci.2026.104372

Sovacool, B. (2021). Who are the victims of low-carbon transitions? Towards a political ecology of climate change mitigation. Energy Research & Social Science, 73, 101916. https://doi.org/10.1016/j.erss.2021.101916

Villiani, D., Gonzales Vazquez, I. & Fernandez Macias, E. (2025). Green Jobs: A critique of the occupational approach to measure the employment implications of the green transition. European Commission. JRC140967.



18 Data management

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The availability, proper management and use of high-quality data are prerequisites for scientific inquiry, understanding socio-ecological processes and addressing socio-ecological challenges. Historical data in digital form is increasingly available in the Carpathian region; thus long-term processes and phenomena will be easily detectable in many research areas in the Carpathians. The existing information infrastructures, in particular the Carpathian Countries' Integrated Biodiversity Information System (CCIBIS), the main information and geoportal platform supporting the implementation of the Carpathian Convention, could be advanced. CCIBIS was developed to facilitate the exchange, management and dissemination of biodiversity and environmental information across the Carpathian region and already hosts results from major European Union-funded regional projects, including TRANSGREEN, ConnectGREEN, SaveGREEN, BioREGIO Carpathians and ForestConnect.

Rather than creating a completely new data infrastructure, further development and integration of CCIBIS could provide a basis for the progressive establishment of a unified regional data environment, including all available historical aerial and remote-sensing imagery at higher resolutions for the entire Carpathian region – for example, DECLASS 1 and 2 imagery from USGS are available for Eastern European countries and can be processed as historical orthoimages to be integrated in landscape change mapping and analysis (Mihai et al., 2016, Nistor et al., 2017; Niță et al., 2018; Mihai et al., 2019; Jabs-Sobocińska et al., 2021, Olariu et al., 2022). LiDAR landscape visualisations could be used for mapping and identifying current and historical anthropogenic landscape features (Kolecka & Kozak, 2019; Affek et al., 2021; Hrdy et al., 2025). However, LiDAR can also be used for mapping soil degradation and geomorphic processes (Březný & Pánek, 2017; Kłapyta, 2020; Placzkovska et al., 2021; Toločka, 2025). As LiDAR data are becoming available in Carpathian countries, collecting available LiDAR data into a coordinated regional dataset could further strengthen the information base for the Carpathians (Kolecka et al., 2016). Systematic integration of the available ESA Copernicus complementary satellite data could help generate maps based on derived models covering the Carpathian mountains and neighbouring regions (Vîrghileanu et al., 2026).

Ongoing cooperation between the Carpathian Convention and the European Environment Agency (EEA) to align CCIBIS with relevant EEA standards and information systems provides an additional opportunity to ensure interoperability and compatibility with wider European data infrastructures. This could facilitate the integration of Carpathian data with existing European platforms and services, while avoiding duplication and the development of parallel systems. Further development of CCIBIS as an interoperable regional gateway for historical and current biodiversity, environmental and spatial data could therefore provide a cost-effective basis for improving data availability, accessibility and long-term use across the Carpathian region.

The Carpathian Environmental Outlook (2007), reviewed by Price (2008), has remained the basis of different approaches for two decades. Data management for the Carpathian Region was an objective of the EEA, with the data catalogue updated for larger coverage in 2016 (EEA, 2016), while some specialised documentation provided relevant synthesis on current topics like biodiversity and climate change (Alberton et al., 2017). The

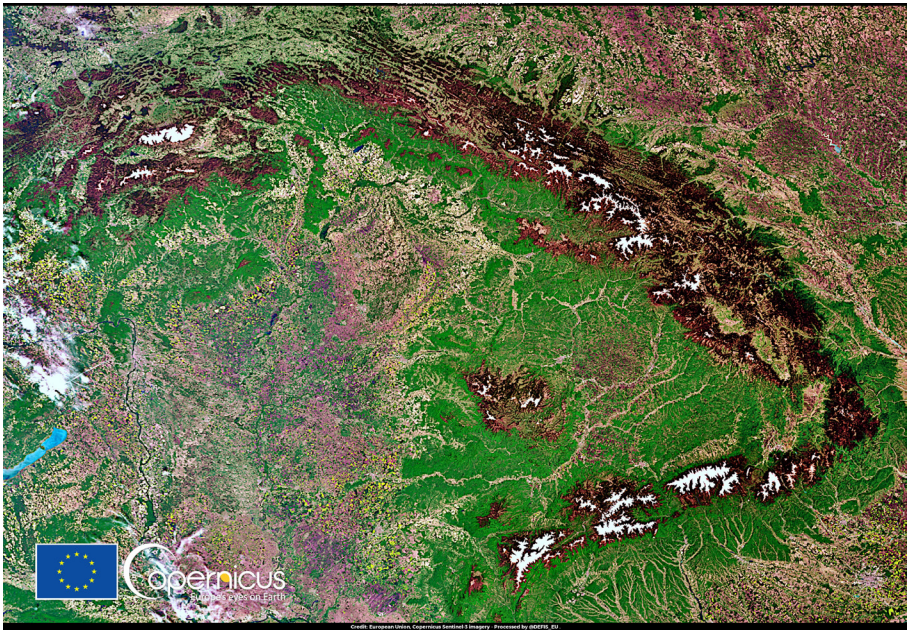
current and emerging need is to step forward a new edition of the Carpathian Environmental Outlook after two decades of enrichment of data archives, improved big-data processing instruments and increased algorithm performance.

Recommended topics

- Applications of historical data in geography, land use, ecology and conservation
- Advances in Earth observations for sustainable development in mountainous regions including:
    - Systematic integration of the available ESA Copernicus complementary satellite data (free access starts from 2014) in regional scale analysis for Carpathian environmental mapping in a unified formula for the entire region.
    - Development of unified semi-automatic/automatic approaches for land-cover change mapping in the Carpathian Region by integrating panchromatic aerial and satellite analogical imagery with recent multispectral digital imagery to generate synthetic maps for the entire region.
    - Improvement of accessibility and interoperability of hydrological information. More insight is needed on mechanisms that facilitate scientific access to hydrological, hydraulic, sedimentological, and ecological datasets collected by water administrations and monitoring networks from the Carpathian countries. Improving data accessibility, while respecting national regulations, would strengthen collaborative research, enable transboundary analyses, and support evidence-based river basin management.

Recommended research questions

- How is it possible to validate, through fieldwork, mountain landscape changes in the last decades in reforested areas after the remote-sensing integrated approach?
- How can historical data and remote sensing, including LiDAR, be integrated to reconstruct traditional farming landscapes in mountain areas?
- Which are the most objective radiometric indices derived from Sentinels data to be adapted for the mapping of the entire Carpathian Region? Is it possible to propose a broad validation of them with field data and other independent data (i.e., wildfire event inventoried data) (see Mihai et al., 2019).
- Which cultural landscape features could be reconstructed using LiDAR visualisations?
- Which geomorphological processes and landforms can be mapped and monitored through LiDAR data?



Cloud-free Sentinel 3 view of the Carpathian Mountains, May 10 2021, spatial resolution 300 m. The image shows the high diversity of landscapes dominated by forests – deciduous and coniferous, by alpine pastures, with snow cover on the highest ridges at 1800–2600 mm (High and Low Tatras, Ciornohora-Maramureș Rodna, Călimani, Făgăraș, Bucegi, Parâng, Retezat-Godeanu-Țarcu massifs).

Credit: European Space Agency, Copernicus, European Union:
https://www.copernicus.eu/en/media/image-day-gallery/cloud-free-sentinel-view-carpathian-mountains.

References

Affek, A. N., Wolski, J., Latocha, A., Zachwatowicz, M., & Wieczorek, M. (2022). The use of LiDAR in reconstructing the pre-World War II landscapes of abandoned mountain villages in southern Poland. Archaeological Prospection, 29(1), 157–173. https://doi.org/10.1002/arp.1846

Alberton, M., Andresen, M., Cittadino, F., Egerer, H., Fritsch, U., Götsch, H., Hoffmann, C., Klemm, J., Mitrofanenko, A., Musco, E., Noellenburg, N., Pettita, M., Renner, K., & Zebisch, M. (2017). Mountain adaptation outlook series: Outlook on climate change adaptation in the Carpathian Mountains. United Nations Environment Programme, GRID-Arendal.

Březný, M. & Pánek, T. (2017). Deep-seated landslides affecting monoclinal flysch morphostructure: Evaluation of LiDAR-derived topography of the highest range of the Czech Carpathians, Geomorphology, 285, 44–57. https://doi.org/10.1016/j.geomorph.2017.02.007

European Environment Agency (EEA). (2016, April). Carpathian environment outlook (KEO) boundary extended with a 50 km buffer zone. https://sdi.eea.europa.eu/catalogue/biodiversity/api/records/3eb6231c-6cc3-4162-9b6f-3d3607480436

Hrdý, T., & Hronček, P. (2025). Digital reconstruction of mid-16th century forests in the Western Carpathians using archival written documents. The Holocene, 35(11), 1118–1132. https://doi.org/10.1177/09596836251358697

Jabs-Sobocińska, Z., Affek, A. N., Ewiak, I., & Nita, M. D. (2021). Mapping Mature Post-Agricultural Forests in the Polish Eastern Carpathians with Archival Remote Sensing Data. Remote Sensing, 13(10). doi:10.3390/rs13102018

Kłapyta, P. (2020). Geomorphology of the high-elevated flysch range: Mt. Babia Góra Massif (Western Carpathians). Journal of Maps, 16(2), 689–701. https://doi.org/10.1080/17445647.2020.1800530

Kolecka, N., & Kozak, J. (2019). Wall-to-wall parcel-level mapping of agricultural land abandonment in the Polish Carpathians. Land, 8(9), 129. https://doi.org/10.3390/land8090129

Kolecka, N., Kozak, J., Kaim, D., Dobosz, M., Ginzler, C., & Psomas, A. (2015). Mapping secondary forest succession on abandoned agricultural land with LiDAR point clouds and terrestrial photography. Remote Sensing, 7(7), 8300-8322. https://doi.org/10.3390/rs70708300

Mihai, B., Nistor, C., Toma, L., & Săvulescu, I. (2016). High resolution landscape change analysis with CORONA KH-4B imagery. A case study from Iron Gates Reservoir area. Procedia Environmental Sciences, 32, 200–210. doi: https://doi.org/10.1016/j. proenv.2016.03.025

Mihai, A. B., Savulescu, I., Vîrghileanu, M., & Olariu, B. (2019). Evaluation of Sentinel-2 MSI and Pleiades 1B Imagery in forest fire susceptibility assessment in temperate regions of Central and Eastern Europe: A case study of Romania. In H. Pourghasemi & M. Rossi (Eds.). Natural hazards GIS-based spatial modeling using data mining techniques. Advances in Natural and Technological Hazards Research (pp. 253–269). Vol. 48. Springer.

Nistor, C., Mihai, B.-A., Toma, L., Olariu, B., & Rujoiu-Mare, M.-R. (2017). Urban landscape change in Carpathian Mountain Resorts. Journal of Maps, 13(1), 101–106. doi:10.1080/17 445647.2017.1395771

Nita, M. D., Munteanu, C., Gutman, G., Abrudan, I. V., & Radeloff, V. C. (2018). Widespread forest cutting in the aftermath of World War II captured by broad-scale historical Corona spy satellite photography. Remote Sensing of Environment, 204, 322–332. https://doi.org/10.1016/j.rse.2017.10.021

Olariu, B., Vîrghileanu, M., Mihai, B.-A., Săvulescu, I., Toma, L., & Săvulescu, M.-G. (2022). Forest habitat fragmentation in mountain protected areas using historical corona KH-9 and Sentinel-2 Satellite Imagery. Remote Sensing, 14(11), 2593. https://doi.org/10.3390/rs14112593

Płaczkowska, E., Cebulski, J., Bryndza, M., Mostowik, K., Murawska, M., Rzonca, B., & Siwek, J. (2021). Morphometric analysis of the channel heads based on different LiDAR resolutions, Geomorphology, 375 (107546). https://doi.org/10.1016/j.geomorph.2020.107546.

Price, M. F. (2008), Carpathians environmental outlook 2007 [Review]. Mountain Research and Development, 28(2), 182–183. https://doi.org/10.1659/mrd.mm035

Toločka, A. (2025). Understanding the geomorphology of deep-seated landslides: Insights from the Váh River Valley, Western Carpathians, Slovakia. Austrian Journal of Earth Sciences, 118(1), 265-280. https://doi.org/10.17738/ajes.2025.0015

Vîrghileanu, M., Șandric, I., Mihai, B.-A., Săvulescu, I., & Bizdadea, C.-G. (2026). Comparative assessment of vegetation cover and management factor in soil loss modelling using Sentinel-2 MSI time-series imagery: A case study from the Romanian Carpathian-Subcarpathian region, Remote Sensing Applications: Society and Environment,42. https://doi.org/10.1016/j.rsase.2026.102013

19 Mapping the Carpathians

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The Carpathian Mountains, one of the three largest mountain regions in Europe, are approximately 1,500 km long and 500 km wide, covering about 190,000 km2. They extend across seven countries with different languages, geographical names, and levels of territorial knowledge. One of the main challenges for the S4C is to unify scientific networks and efforts across this mountain region, three decades after the fall of the Iron Curtain and two decades after the European Union integration of the first four Carpathian countries. Although a large amount of spatial data is currently available, including open-access resources (Olariu et al., 2022), converting this data into regional maps, which could be used for analysis, visualisation of geographic, socio-ecological and economic information or education and awareness raising about the region, requires dedicated efforts. Furthermore, an overview of data availability and consistency across the region is needed.

The available national atlases include academic, research-based works produced in different periods, dating from the 1970s in Romania, the 1990s in Poland, the 2000s in the Czech Republic, Slovakia and Ukraine, and in Hungary in more recent years (2018–2024). These atlases provide complementary systematic map collections in terms of scale, content, cartographic methodology, geographical names, and representation of basic field features, and some also include general maps. Previously published atlas maps also have historical significance, such as those included in the Atlas of Danubian Countries (Österreichisches Ost-und Südosteuropa-Institut, 1970–1989), where general and thematic maps form part of a broader geographical context at a scale of 1:2 million. The continuity of this cartographic work was the Atlas of Eastern and Southeasern Europe (1989-2014), a collection of ensemble and even diachronic thematic maps covering the Carpathian macroregion in a larger geographical and geopolitical context (map scales from 1:1.5 million to 1:20 million). These covered six thematic areas covering social and economic topics like ecology, population, economy, traffic, tourism, territorial planning and political geography.

The Atlas of the Carpathian Macroregion (Ptaček & Ruffini, 2009), provides a synthesis of maps at a limited scale of 1:3 million and is not always coherent in terms of detail, standardisation of spatial data, and related knowledge. The Atlas, based on a collaborative work between EURAC researchers in Bolzano, Italy and Palacký University of Olomouc, Czech Republic, within the framework of the INTERREG III B CADSES Carpathian Project, includes 40 maps and figures intended to support the Carpathian Convention. The Digital Climate Atlas of the Carpathian Region, prepared by Serbian climatologists (Antolović et al., 2013) constitutes an example of a thematic atlas covering the entire Carpathian Macroregion, although with limited access.

Two additional spatial resources, supported by the European Environment Agency (EEA) are particularly relevant for defining and operationalising the Carpathian Macroregion. The Carpathian Environment Outlook (KEO) boundary represents the area of interest for activities and research promoted by the Carpathian Convention Parties (UNEP, 2007); it identifies the area described in the Carpathian Environment Outlook and in the EEA publication "Europe's ecological backbone: Recognising the true value of our mountains" (EEA, 2010), covering parts of Czechia, Hungary, Poland, Romania, Slovakia, Serbia and Ukraine. A complementary resource is the interactive map of Carpathian administrative units produced by the EEA and the European Topic Centre on

Urban, Land and Soil Systems based on information submitted by the Carpathian Convention Parties following Decisions adopted by the 4th Meeting of the Carpathian Convention Conference of the Parties (Carpathian Convention, 2014; COP4/2). This map identifies the administrative units within which the Carpathian Convention and its Protocols are implemented, or planned to be implemented, using different territorial levels such as NUTS2, NUTS3, LAU1 and LAU2, from the Eurogeographic product EuroBoundaryMaps v.10. A more recent contribution is the Atlas of the determinants and opportunities for the socio-economic and spatial development of the Carpathian region, developed by Polish researchers and available only in a digital format (Smętkowski et al., 2025). The atlas provides a collection of general thematic scale maps covering all the Carpathian countries and serves as an informative tool for regional planners and governments.

Thematic maps of the Carpathian macroregion are increasingly appearing in papers on climate (Spinoni et al., 2015), forest cover (Griffiths et al., 2014; Kholiavchuk et al., 2024), and land use and land cover (Griffiths et al., 2013; Lieskovsky et al., 2017; Munteanu et al., 2017). However, there are few methodologically oriented approaches seeking the most adequate representation of Carpathian regional features in a more synthetic and nearly comprehensive form (Buterez et al., 2016). Mapping specific thematic issues across the Carpathians, such as transhumance routes, requires the integration of scientific knowledge with local and traditional knowledge. Such integrated mapping can provide an important evidence base for informing policy and supporting the development of more coherent landscape and regional governance strategies across the Carpathian macroregion. An effort by the cartography and geomatics specialists of the S4C group is therefore needed to coordinate exchange and collaboration on mapping the Carpathian region.



Section of the General Map of Prahova County (Bucegi Mountains, Romania).
Credit: Bogdan Mihai et al.2016.

Recommended topics

- Assessment of the availability, comparability, and consistency of thematic spatial and statistical data across the Carpathian countries
- Mapping, overviewing, and collecting existing general, thematic, and interdisciplinary knowledge and information on Carpathian territorial systems and landscapes, to build a structured knowledge base supporting future research and development projects across scales (regional to local)
- Producing thematic regional maps that integrate different knowledge types (scientific, statistical, and local/traditional (e.g., a map of transhumance routes), including developing and validating the methodology for combining these sources and assessing the quality of results
- Mapping the activities of the Science for the Carpathians (S4C) network to strengthen coordination, interdisciplinary/transdisciplinary collaboration, and visibility of the scientific community

Recommended research questions

- Is the Carpathian macroregion accurately defined in terms of limits for cartographic works development?
- What common data standards, classifications, and harmonisation approaches, building on existing frameworks (e.g., INSPIRE and the EEA/Carpathian Convention datasets) are needed to make thematic spatial and statistical data comparable across all seven Carpathian countries?
- What methodological approach can be used to integrate scientific, statistical, and local/traditional knowledge into thematic maps of the Carpathian region (e.g., mapping transhumance routes or other cultural-landscape features), and how can the quality, consistency, and validity of the resulting maps be assessed?
- Is it possible to collect, map, and explain typical geographical names encountered across the mapped regions? How important is this for defining present-day landscapes?
- How might it be possible to fill the spatial data gaps for Carpathian countries and regions outside the EU (Serbia and Ukraine) in an accurate way using existing free data sources?

References

Antolović, I., Mihajlović, V., Rančić, D., Mihić, D., & Djurdjević, V. (2013). Digital climate atlas of the Carpathian Region, Advances in Science and Research, 10, 107–111. https://doi.org/10.5194/asr-10-107-2013

Austrian Academy of Sciences (ÖAW). (1989–2014). Atlas of Eastern and Southeastern Europe (AOS) (Instalments 1–30). Schweizerbart Science Publishers.

Buterez, C., Olariu, B., Mihai, B., Rujoiu-Mare, M., & Cruceru, I. (2016). General topography of Prahova County, Romania. Journal of Maps, 12(sup1), 541–545. https://doi.org/10.1080/17445647.2016.1197162

Carpathian Convention. (2014). Decisions of the Fourth Meeting of the Conference of the Parties to the Framework Convention on the Protection and Sustainable Development of the Carpathians (COP4). UNEP/CC/COP4/DOC10/REV1. Mikulov, Czech Republic, 23–26 September 2014. http://www.carpathianconvention.org/tl_files/carpathiancon/Downloads/03%20Meetings%20and%20Events/COP/2014_

COP4_Mikulov/Follow%20Up/COP4%20DECISIONS_FINAL_26September.pdf

European Environment Agency (EEA). (2010). Europe's ecological backbone: Recognising the true value of our mountains. EEA Report No. 6/2010. European Environment Agency. https://www.eea.europa.eu/publications/europes-ecological-backbone

Griffiths, P., Kuemmerle, T., Baumann, M., Radeloff, V.C., Abrudan, I.V., Lieskovský, J., Munteanu, C., Ostapowicz, K., & Hostert, P. (2014). Forest disturbances, forest recovery, and changes in forest types across the Carpathian ecoregion from 1985 to 2010 based on Landsat image composites. Remote Sensing of Environment, 151, 72–88. http://dx.doi.org/10.1016/j.rse.2013.04.022

Griffiths, P., Müller, D., Kuemmerle, T., & Hostert, P. (2013). Agricultural land change in the Carpathian ecoregion after the breakdown of socialism and expansion of the European Union. Environmental Research Letters, 8, 045024. doi:10.1088/1748-9326/8/4/045024

Kholiavchuk, D., Gurgiser, W., & Mayr, S. (2024). Carpathian Forests: Past and recent developments. Forests, 15(1), 65. https://doi.org/10.3390/f15010065

Lieskovský, J., Kaim, D., Balázs, P., Boltižiar, M., Chmiel, M., Grabska, E., … & Radeloff, V. C. (2018). Historical land use dataset of the Carpathian region (1819–1980). Journal of Maps, 14(2), 644–651. https://doi.org/10.1080/17445647.2018.1502099

Mihai, B. A., Nedelcu, A., Buterez, C. (Eds.). (2016). Județul Prahova. Spațiu, societate, economie, mediu (Prahova County. Space, society, economy, environment). Editura Academiei Romane (The Romanian Academy Publishing House). Bucharest, Romania. ISBN 978-973-27-2542-9

Munteanu, C., Kuemmerle, T., Boltiziar, M. Lieskovský, J., Mojses, M., Kaim, D., Konkoly-Gyuró, É., Mackovčin, P., Műller, D., Ostapowicz, K. & Radeloff, V.C. (2017). Nineteenth-century land-use legacies affect contemporary land abandonment in the Carpathians. Regional Environmental Change, 17, 2209–2222 https://doi.org/10.1007/s10113-016-1097-x

Olariu, B., Vîrghileanu, M., Mihai, B.-A., Săvulescu, I., Toma, L., & Săvulescu, M.-G. (2022). Forest habitat fragmentation in mountain protected areas using historical Corona KH-9 and Sentinel-2 satellite imagery. Remote Sensing, 14(11), 2593. https://doi.org/10.3390/rs14112593

Österreichisches Ost-und Südosteuropa-Institut (Hrsg.) [Austrian Eastern and Southeastern European Institute]. (1970–1989). Atlas der Donauländer [Atlas of Danube countries]. Deuticke. Vienna.

Price, M. F. (2008), Carpathians Environmental Outlook 2007 [Review]. Mountain Research and Development, 28(2), 182–183. https://doi.org/10.1659/mrd.mm035

Ptáček, P., & Ruffini, F.V. (Eds.) (2009). Atlas of the Carpathian Macroregion. Palacký University Olomouc, Viktor Hořín – EPAVA, Olomouc.

Secretariat of the Carpathian Convention (n.d.). Carpathian administrative units [Map]. Vienna: Secretariat of the Carpathian Convention, in collaboration with the European Environment Agency and the European Topic Centre on Urban, Land and Soil Systems. http://www.carpathianconvention.org/convention/carpathian-administrative-units/

Smętkowski, M., Wojnar, K., Czepkiewicz, M., Olechnicka, A., Romańczyk, K., Kupiec, T., Przekop-Wiszniewska, E., Orchowska, J., Rok, J., Herbst, M., Płoszaj, A., Miszczuk, P., Zegler-Poleska, E., Szul, R., Majewski, J. & Chumachenko, A. (2025). KARPAT – Determinants and opportunities for the socio-economic and spatial development of the Carpathian region: Atlas. ESPON EGTC. https://www.espon.eu/sites/default/files/2025-07/karpat_atlas.pdf (Accessed: 27 August 2026).

Spinoni, J., Szalai, S., Szentimrey, T., Lakatos, M., Bihari, Z., Nagy, A., Németh, Á., Kovács, T., Mihic, D., Dacic, M., Petrovic, P., Kržič, A., Hiebl, J., Auer, I., Milkovic, J., Štepánek, P., Zahradnícek, P., Kilar, P., Limanowka, D., Pyrc, R., Cheval, S., Birsan, M.-V., Dumitrescu, A., Deak, G., Matei, M., Antolovic, I., Nejedlík, P., Štastný, P., Kajaba, P., Bochnícek, O., Galo, D., Mikulová, K., Nabyvanets, Y., Skrynyk, O., Krakovska, S., Gnatiuk, N., Tolasz, R., Antofie, T. & Vogt, J. (2015), Climate of the Carpathian Region in the period 1961–2010: Climatologies and trends of 10 variables. International Journal of Climatology, 35, 1322–1341. https://doi.org/10.1002/joc.4059

United Nations Environment Programme (UNEP). (2007). Carpathians Environment Outlook (KEO) 2007. United Nations Environment Programme. https://digitallibrary.un.org/record/641453/files/Carpathians_Environment_Outlook_2007.pdf

20 Legal dimensions of governance in the Carpathians

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Achieving the objectives of the Carpathian Convention requires coherent governance frameworks capable of translating shared commitments into effective action across the region. While the Convention and its protocols establish a common framework for cooperation, their implementation occurs within diverse national and sub-national policy and legal frameworks, institutional arrangements and administrative processes. Differences in policy priorities, legislation, institutional mandates and capacities, decision-making procedures, funding, enforcement practices and coordination mechanisms may therefore influence the effectiveness and consistency of implementation, particularly for challenges that cut across sectors, administrative levels and national borders.

Stronger research on governance could support more systematic cooperation between the Carpathian Convention and relevant institutions at national and sub-national levels (De Bortoli & Menzardi, 2024). Following the sequence from policy frameworks to legal measures and then to administrative processes, attention could be given to how scientific knowledge and recommendations inform policy choices, are translated into legal instruments and are put into practice through administrative action; how implementation and impacts can be monitored; and how accountability, oversight and stakeholder participation can be strengthened. Research could also help clarify how existing platforms for coordination, technical exchange and follow-up can be better used to connect evidence with policy processes (Haberfellner & Duske, 2025). Rather than adding new frameworks, research should also explore how existing policy and legal mechanisms can be better connected, operationalised and supported by appropriate institutional capacities and resources (Central Mountains, 2026).

In this context, closer cooperation between S4C and the Carpathian Convention could provide an important interface between research, policy and implementation. Potential areas for development include mechanisms for monitoring the uptake and implementation of science-based recommendations and approaches for rapidly mobilising interdisciplinary expertise when emerging socio-ecological challenges require timely scientific, legal or administrative inputs (Ćwik & Hrehorowicz-Gaber, 2021). Such mechanisms could strengthen the capacity of the Convention and its Parties to draw systematically on research evidence while responding to both longer-term multi-level governance challenges and emerging risks across the Carpathian region.

Recommended topics

- Comparative analysis of governance and institutional frameworks underpinning the implementation of the Carpathian Convention, based on a structured mapping of relevant legislation, policy instruments, institutional mandates and implementation procedures across the Carpathian countries. The analysis could examine the allocation of competences across national, regional and local authorities; decision-making, accountability and oversight mechanisms; transparency and stakeholder participation; governance financing; intersectoral coordination; and institutional capacities for effective policy delivery, monitoring and enforcement.

- Assessment of legal mechanisms and administrative procedures for ensuring compliance with environmental regulations, including investigation, enforcement, sanctioning, access to justice and follow-up in cases such as illegal logging, waste dumping and poaching.

- Analysis of how Carpathian Convention-related priorities, recommendations and work programmes are translated into national and sub-national implementation processes, with attention to policy uptake, intersectoral coordination, stakeholder participation, institutional learning and feedback loops between scientific evidence, policy deliberation and implementation practice.

Longer-term topic

- Legal and policy frameworks addressing the principle of territorial equity, ensuring that mountain communities enjoy rights and access to public services (i.e., healthcare, education, social infrastructure) at a comparable level to other regions.

Recommended research questions

- What are the key similarities, differences and gaps in Carpathian countries' legislation on common issues such as sustainable tourism, forest management, and spatial planning?
- How do variations in institutional mandates, administrative procedures, capacities and coordination mechanisms of national and regional authorities responsible for the Carpathian Convention's implementation affect policy delivery, monitoring, enforcement and transboundary cooperation?
- What procedural bottlenecks, institutional barriers and enforcement gaps limit the effective implementation of environmental regulations in the Carpathians, and what good practices can be identified through comparative country analysis and case studies?
- How can access to information, public participation in decision-making and access to justice, in accordance with the Aarhus Convention, be strengthened to enable local communities and civil society to contribute more effectively to environmental governance and oversight?

Longer-term research questions

- How do taxation and fee systems for natural resource use affect local development, conservation incentives and equity among regions and stakeholders, once the relevant institutional and regulatory frameworks have been mapped?
- What are the legal mechanisms for controlling and auditing the sustainable use of common-pool resources across different jurisdictions?
- What legal instruments and administrative procedures are needed to ensure effective cross-border cooperation between Carpathian countries in emergency response and spatial planning?
- How can legal frameworks better integrate sectoral policies (e.g., agriculture, energy, transport)

to minimise negative impacts on Carpathian ecosystems and promote policy coherence for sustainable development?

- To what extent do national legal frameworks recognise the specific challenges of mountain regions and provide for differentiated or compensatory measures to ensure equal access to public services?
- How do administrative boundaries and decentralisation reforms affect the capacity of local governments in the Carpathians to deliver essential services and manage local development?

References

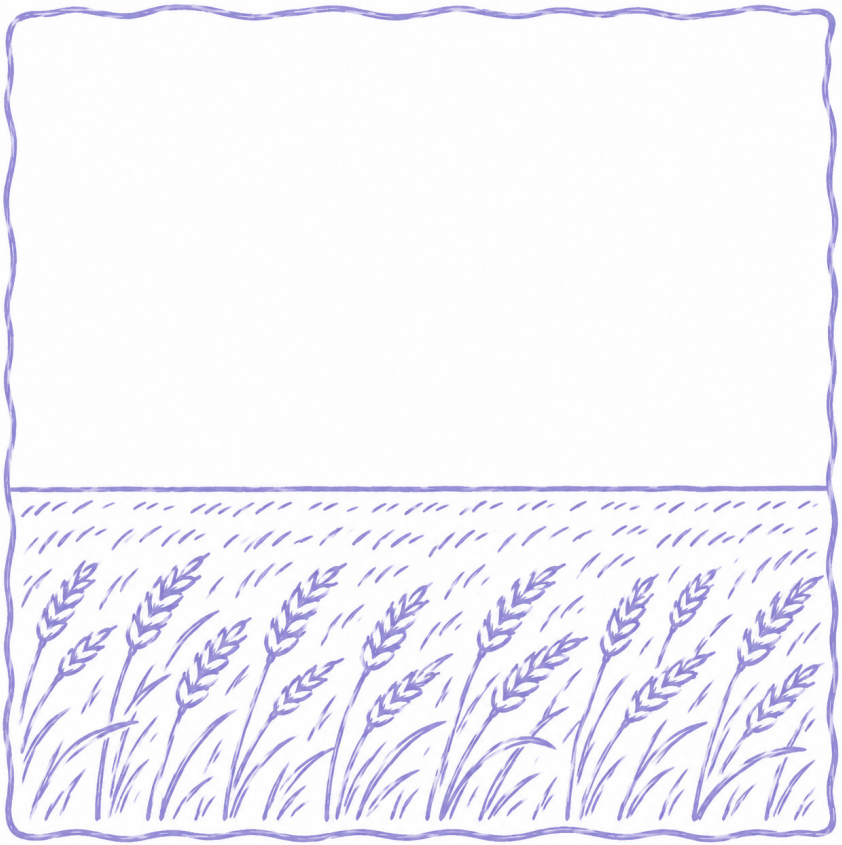
Central Mountains. (2026). Improved structure for cooperation of civil society organizations (CSOs) from the Carpathian region. Interreg CENTRAL EUROPE. https://www.interreg-central.eu/wp-content/uploads/2026/03/Cooperation-Of-The-Civil-Society-Organizations-In-The-Carpathians.pdf

Ćwik, A., & Hrehorowicz-Gaber, H. (2021). Causes and effects of spatial chaos in the Polish Carpathians—A difficult way to sustainable development. European Countryside, 13(1), 153–174. https://doi.org/10.2478/euco-2021-0009

De Bortoli, I., Menzardi, P., Laterza, R., Duske, P., & Dietachmair, J. (2024). Joint strategy for community-led sustainable development of mountain areas in Central Europe with a special focus on participatory governance. Interreg CENTRAL EUROPE. https://www.interreg-central.eu/wp-content/uploads/2024/03/Central-Mountains_Joint-strategy-report.pdf

Haberfellner, L., & Duske, P. (2025). Alpine-Carpathian toolbox for participation in Central European mountain areas. Interreg CENTRAL EUROPE. https://www.interreg-central.eu/wp-content/uploads/2025/11/Alpine-Carpathian-Toolbox-for-Participation.pdf

Kasiyanchuk, D. (2025). Tourism pressure and vegetation dynamics in the Carpathian Mountains. Eco-Tourism and Sustainable Development, 1(2), 39–51. https://doi.org/10.63385/etsd.v1i2.265



21 Carpathian resilience with a green recovery of Ukraine

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The Russian Federation war against Ukraine has become a major source of environmental, demographic and economic disruption in Ukraine and neighbouring Carpathian territories. These effects interact with climate change, biodiversity loss, demographic decline, land-use change, energy insecurity and uneven institutional capacity, generating compound risks (UNEP, 2022; Carpathian Convention, 2022b; European Commission, 2026; Melnykovych et al., 2026a). For the Carpathian Research Agenda, the war is both a source of direct damage and a stress test for regional social–ecological resilience. The challenge is to identify recovery pathways that strengthen resilience without reinforcing territorial inequalities or long-term development lock-ins.

At the 2022 Carpathian Ministerial Conference, the Parties adopted declarations on the post-2020 global biodiversity framework and on the environmental consequences of the war in Ukraine (Carpathian Convention, 2022a, 2022b). These declarations reaffirmed cooperation with Ukraine and invited stakeholders and partners to contribute to green recovery and reconstruction. The Lugano Principles provide a complementary framework centred on partnership, participation, inclusion, sustainability and building back better (Ukraine Recovery Conference, 2022).

Forum Carpaticum in September 2023 provided an early science–policy–practice assessment. Two panels, "Understanding uncertainties and needs for resilience and post-war recovery: Voices from the Ukrainian Carpathians" and "Future of the Carpathians in a time of critical transition: Exploring triggers for sustainability in the post-war era" developed messages for the Carpathian Convention COP7 (Melnykovych et al., 2023; Mitrofanenko et al., 2024). Participants described the environmental capacity of the Ukrainian Carpathians as being "stretched to its limits" by displacement, business relocation and interacting climate and resource pressures (Melnykovych et al., 2024b). This identified a key research gap – the need for cumulative assessment of ecological, social and infrastructural pressures. Forum Carpaticum 2023 also called for green recovery and stronger collaboration on natural-resource governance, wildfire, biodiversity, and social and socio-ecological innovation.

The Seventh Meeting of the Conference of the Parties to the Carpathian Convention (COP7) in October 2023 embedded cooperation with Ukraine within Convention implementation. The Carpathian Biodiversity Framework includes Strategic Objective 8 on direct and indirect war effects, while COP7 decisions span biodiversity, rural development, forests, transport, infrastructure and energy, environmental assessment and monitoring,

climate change, and the science–policy–practice interface (Carpathian Convention, 2023a, 2023b). The EU accession of Ukraine and reconstruction architecture reinforces this direction. The EU Ukraine Facility links recovery to environmental resilience, territorial cohesion, local participation, capacity building and gender equality (European Union, 2024). The European Commission has also stressed effective environmental impact assessments and strategic environmental impact assessments (EIA and SEA) for relevant reconstruction plans and projects and progress on circular economy, biodiversity and environmental governance (European Commission, 2024, 2025c). Research is needed on what the pathways will be for implementation of these principles in mountain (rural and remote) municipalities with uneven capacities.

War-related transformations have a strong territorial and urban–rural dimension. Western Ukrainian cities and small towns have become nodes for displaced populations, relocated enterprises, services and investment, while surrounding rural and mountain municipalities provide land, housing, food, biomass and ecosystem services (Lozynskyy & Zubyk, 2022). These changes intersect with longer-term outmigration, ageing and uneven development (Niewiadomski & Maryskevych, 2022). Research should distinguish direct war impacts, territorial spillovers and pre-existing trends and examine whether recovery strengthens urban–rural relations or reinforces territorial inequalities (Bertram et al., 2024). Forum Carpaticum 2025 highlighted pressures on infrastructure, ecosystems and municipal capacities associated with population and business relocation (Mitrofanenko et al., 2025).

Natural-resource governance is integral to these dynamics (see Chapter 5 on integrated landscape management). Forests are among the key social-ecological systems underpinning ecological and socio-economic resilience in the Carpathians providing habitat for biodiversity, carbon storage, water and climate regulation, slope stability, timber and non-timber forest products, energy and rural livelihoods, although they are increasingly exposed to climate-related disturbance, fragmentation and growing pressures on natural resources (Keeton et al., 2025; Melnykovych et al., 2026a). Research should therefore approach Carpathian forests as multifunctional social–ecological systems (Melnykovych et al., 2018, 2026b) linking ecosystem condition, biodiversity conservation and restoration with climate adaptation, multifunctional management, institutional capacity and community participation. Participatory governance, knowledge co-production and benefit sharing can help reconcile competing forest uses and ecosystem-service demands with local needs, but require institutional change, integration of local knowledge and attention to the values shaping forest-governance transitions (Melnykovych et al., 2018; Sarkki et al., 2019a, 2019b; Nijnik et al., 2021; Brnkalakova et al., 2022). For Ukraine, post-war recovery provides a critical setting for examining complementary pathways based on sustainable low-carbon forest-resource use, close-to-nature and "close-to-people" forest management supported by technological and social innovation, and anticipatory governance and socio-ecological innovation (Melnykovych et al., 2026b).

This agenda has become particularly timely as Ukraine prepares to move away from clear-cutting as the main final-harvest approach in Carpathian mountain forests and expand close-to-nature forestry (Cabinet of Ministers of Ukraine, 2024). Research is needed to assess the ecological effectiveness, economic feasibility, institutional requirements and practical implementation of this transition, including how close-to-nature approaches can be adapted to different ownership, management and site conditions. provides an applied setting for testing these approaches through forest demonstration sites, training, knowledge-sharing hubs and science–practice–policy exchange. Research and investment are also needed to restore and strengthen forest

and nature-protection infrastructure, monitoring systems, management capacity and professional expertise that has been damaged, lost or disrupted during the war, and to increase preparedness for climate-related extremes (Melnykovych et al., 2026b). Wildfire represents an important emerging research priority for the Carpathians (Zibtsev et al., 2023b). Although direct war-related fire impacts are concentrated mainly outside the Carpathian region (Zibtsev et al., 2023b), climate change, drought, changing land use and land management and fuel accumulation may increase future fire risk and require a stronger shift from reactive suppression towards prevention, preparedness and rapid response (Soshenskyi et al. 2021; Zibtsev et al., 2023a, 2023b, 2024; Melnykovych et al., 2024b, 2026b). Research in the Carpathians should support spatial and temporal assessment of fire regimes and future risk; appropriate fuel management and fuel-break systems; preparedness linked to fire-weather danger; mapping and improvement of detection coverage, forest roads, water sources and response infrastructure; fire-behaviour modelling; and community-based "living-with-fire" approaches in areas of increasing risk. Understanding how conservation and restoration, close-to-nature and close-to-people forest management, participatory governance and climate-risk preparedness can combine to strengthen the long-term resilience of Ukrainian Carpathian forest social–ecological systems is vital to "build back better".

Green recovery indeed creates opportunities and trade-offs for the circular bioeconomy and energy transition. Higher-value wood products, non-timber forest products, cascading biomass use, agricultural residues, biogas, repair and reuse may diversify rural economies and retain value locally. Yet biomass and bioenergy can increase ecosystem pressure where resource efficiency, biodiversity safeguards, ownership and equitable benefit sharing are neglected (Soloviy et al., 2019; Melnykovych et al., 2026b). The EU Bioeconomy Strategy similarly links circular biological-resource use with competitiveness, resilience and rural development while stressing sustainability of the resource base (European Commission, 2025a, 2025b). Research should identify when circular bioeconomy pathways create local value and energy resilience and when they generate extraction pressures or dependencies. Yet, particular attention should be paid to balancing increasing demand for timber and biomass for reconstruction with the protection of irreplaceable forest ecosystems, including primary and old-growth forests. Research is needed to identify pathways that meet post-war recovery needs while safeguarding biodiversity and ecosystem integrity in the long term.

Social and socio-ecological innovation provide a complementary resilience pathway. In Carpathian mountain communities, collective action, new governance arrangements and entrepreneurship can mobilise local knowledge and resources and address needs insufficiently met by markets or public institutions (Melnykovych et al., 2018; Nijnik et al., 2019, 2022). Such innovations depend on institutions, finance, facilitation, networks and sustained learning (Melnykovych et al., 2024a). For example, methodology on setting up multi-actor rural innovation ecosystems were developed in the RURACTIVE project (RURACTIVE, n.d.; Bravaglieri et al., 2025). According to this methodology, public authorities, communities, businesses, civil society and knowledge broker organisations co-design place-based solutions, while capabilities to empower transformative change are enabled via competencies of multiple actors (Melnykovych et al., 2024a). In Ukraine, in the Zakarpattya oblast (Synevyr community), the NGO FORZA is testing this approach which could potentially be scaled up elsewhere. Research on post-war resilience should therefore examine participation, knowledge, benefit distribution, durability and transferability.

Forum Carpaticum 2025 sharpened the implementation challenge. The session "Empowering local communities to act for change" identified gaps in environmental-law enforcement, strategic planning, EIA/SEA, access

to finance, technical expertise and coordination among municipalities, ministries, universities, civil society, and donors (Mitrofanenko et al., 2025). Smaller municipalities were considered particularly constrained by the costs of feasibility studies, energy and waste plans, environmental assessments and project preparation. Participants therefore emphasised municipality–university partnerships, twinning, peer learning, multi-actor processes and timely scientific expertise; capacity building should thus be treated as recovery infrastructure. CAS Rebuild Ukraine (n.d.) practice-oriented training programme at Bern University of Applied Sciences provides an applied example linking professional learning with sustainable reconstruction, circular economy, energy efficiency, urban and rural planning, digitalisation, governance and gender equality. Research should test whether such approaches generate durable organisational capabilities and improve access to finance and implementation capacity.

Equity cuts across these pathways: internally displaced people and other groups with limited influence over local decision-making may experience different risks and opportunities from recovery. Research should examine participation, access to resources and finance and distribution of benefits and costs. This aligns with emerging EU research priorities: the Horizon Europe 2027 topic "Strengthening rural communities' resilience to shocks" emphasises participatory and anticipatory governance, involvement of women, youth and vulnerable groups, and a multi-actor approach (European Commission, 2025b, 2025c).

The 2025 S4C recommendations to the Carpathian Convention Implementation Committee translate these findings into proposals for biodiversity- and climate-sensitive reconstruction, stronger EIA/SEA and monitoring, municipal project preparation, cross-border cooperation, energy communities, municipality–university partnerships and timely scientific expertise (Mitrofanenko et al., 2025). These are recommendations of the scientific network, not decisions adopted by the Parties. Carpathian COP8, scheduled for the end of 2026 in Ukraine, provides a science–policy window to assess progress since 2022 and inform future Convention priorities.

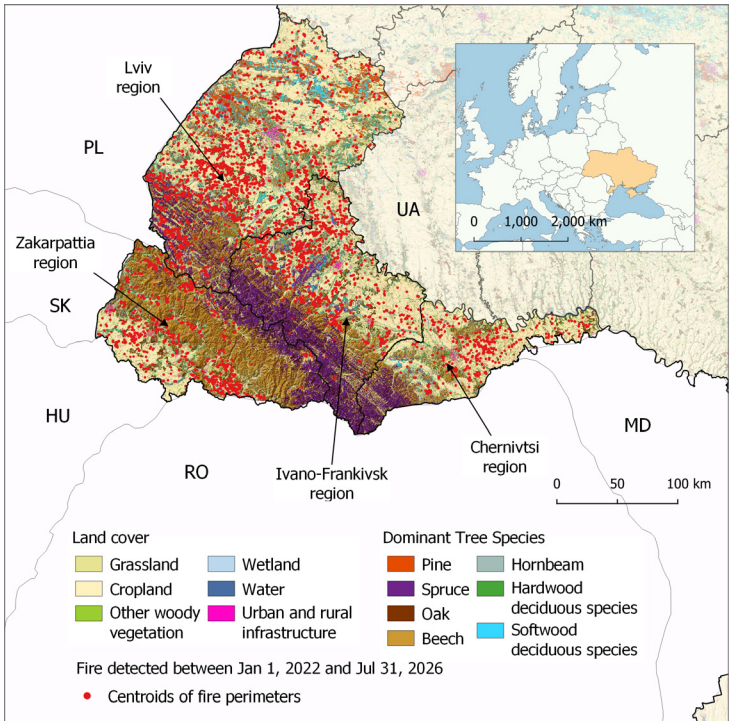
For the Carpathian Research Agenda on Ukraine, the priority is comparative, longitudinal and transboundary analysis of resilience pathways. The Carpathians can function as a regional living laboratory for examining how ecological restoration, territorial development, circular bioeconomy, social innovation, finance and governance interact under uncertainty (Melnykovych et al., 2026a). The key question is which combinations work, for whom, under what ecological and institutional conditions, and with what consequences across places and scales.

Recommended topics

- War-related demographic, settlement and urban–rural transformation
- Cumulative environmental, social and infrastructural pressures
- Green recovery, biodiversity safeguards and ecosystem restoration
- Participatory natural-resource governance and close-to-nature management
- Circular bioeconomy, bioenergy and local value creation for resilience
- Knowledge and capacity for community-based innovative solutions
- Social and socio-ecological innovation and multi-actor governance
- Youth, gender, displacement and equitable participation
- Spatial planning, EIA/SEA, monitoring and rapid science advice
- Forest socio-ecological system as infrastructure for long term resilience

Ukrainian Carpathians: land cover, dominant forest species and recorded fire detections across the region in 2022– 2026

Credit: Myroniuk Viktor, Zibtsev Sergiy, Oleksandr Soshenskyi



- Cross-border governance and science–policy–practice cooperation
- Efficient approaches for rebuilding critical environmental and natural-resource-related infrastructure

Recommended research questions

- How are war, displacement and business relocation reshaping settlement systems, urban–rural relations, local economies and resource demand across the Carpathians?
- Where and through which mechanisms are cumulative environmental, social and infrastructural pressures approaching critical thresholds?
- Which combinations of ecosystem restoration, participatory natural-resource management, energy, infrastructure and local development support recovery without creating new ecological or socio-economic lock-ins?
- Under what conditions can circular bioeconomy and bioenergy retain value locally while respecting ecological limits and equitable access?
- Which institutional, financial and human capacities enable municipalities to plan, finance and implement green recovery?
- When do social and socio-ecological innovations and multi-actor approaches strengthen local agency, and when do they reproduce inequalities or fail to persist?

- How do recovery pathways affect participation and livelihood opportunities for youth, women, displaced people and other groups at risk of exclusion?
- Which place-based innovation, learning and partnership models are effective and transferable across different Carpathian contexts?
- How can EIA/SEA, monitoring and rapid scientific expertise better anticipate cumulative and transboundary impacts?
- How can the Carpathian Convention and S4C strengthen science–policy–practice cooperation for Ukraine's recovery and resilience of the wider Carpathian region?

References

Bern University of Applied Sciences, School of Agricultural, Forest and Food Sciences (BFH-HAFL). From crisis to resilience with close-to-nature forest management in Ukraine. Zollikofen: School of Agricultural, Forest and Food Sciences HAFL, Bern University of Applied Sciences. https://www.bfh.ch/en/research/reference-projects/from-crisis-to-resilience-with-close-to-nature-forest-management-in-ukraine/

Bern University of Applied Sciences. (n.d.). Certificate of Advanced Studies: Rebuild Ukraine. website. https://www.bfh.ch/en/continuing-education/cas/wiederaufbau-ukraine/

Bertram, D., Lambracht, M., & Chilla, T. (2024). Settlement systems in mountain regions: A research gap? Mountain Research and Development, 44(2), A1–A9. https://doi.org/10.1659/mrd.2023.00021

Bravaglieri, S., Åberg, H. E., Bertuca, A., & de Luca, C. (2025). Multi-actor rural innovation ecosystems: Definition, dynamics, and spatial relations. Journal of Rural Studies, 114, Article 103492. https://doi.org/10.1016/j.jrurstud.2024.103492

Brnkaľáková, S., Melnykovych, M., Nijnik, M., Barlagne, C., Pavelka, M., Udovc, A., Marek, M., Kovač, U. & Kluvánková, T. (2022). Collective forestry regimes to enhance transition to climate-smart forestry, Environmental Policy and Governance, 32(6), 492–5-3. doi: 10.1002/eet.2021.

Cabinet of Ministers of Ukraine. (2024). Some issues of forest management during martial law and amendments to Resolution of the Cabinet of Ministers of Ukraine No. 724 of 12 May 2007. Resolution No. 454 of 23 April 2024. Kyiv: Cabinet of Ministers of Ukraine.

Carpathian Convention. (2022a). Ministerial declaration of the Carpathian Convention on Carpathian commitments for the new post-2020 global biodiversity framework implementation. Carpathian Ministerial Conference, Rzeszów, Poland, 21–22 November 2022.

Carpathian Convention. (2022b). Ministerial declaration of the Carpathian Convention on impact of the war on the environment in Ukraine and the need for cooperation and assistance. Carpathian Ministerial Conference, Rzeszów, Poland, 21–22 November 2022.

Carpathian Convention (2023a). Decisions adopted at COP7 of the Framework Convention on the Protection and Sustainable Development of the Carpathians. Seventh Meeting of the Conference of the Parties, Belgrade, Serbia, 11–13 October 2023. Vienna: UNEP Vienna Programme Office, Secretariat of the Carpathian Convention.

Carpathian Convention (2023b). Carpathian biodiversity framework. Seventh Meeting of the Conference of the Parties, Belgrade, Serbia. Vienna: UNEP Vienna Programme Office – Secretariat of the Carpathian Convention. The framework was adopted at COP7 in Belgrade on 12 October 2023.

European Commission. (2025a). A strategic framework for a competitive and sustainable EU bioeconomy. COM(2025) 960 final. Brussels: European Commission.

European Commission. (2025b). Horizon Europe Work Programme 2026–2027: Food, Bioeconomy, Natural Resources, Agriculture and Environment. Brussels: European Commission.

European Commission. (2025c). Ukraine 2025 Report. SWD(2025) 759 final. Brussels: European Commission.

European Commission. (2026). Communication on the EU's eastern regions bordering Russia, Belarus and Ukraine: Strong regions for a safe Europe. COM(2026) 82 final. Brussels: European Commission.

European Union. (2024). Regulation (EU) 2024/792 of the European Parliament and of the Council of 29 February 2024 establishing the Ukraine Facility, Official Journal of the European Union. L, 2024/792. http://data.europa.eu/eli/reg/2024/792/oj

Keeton, W. S., McCallum, S., Kuraś, K., Fischer, E. & Egerer, H. (2025). Assessment of climate risks and adaptation options for Carpathian forest ecosystems and their services. Secretariat of the Carpathian Convention.

Lozynskyy, R. & Zubyk, A. (2022). Transformation of rural settlement network in the Carpathian region of Ukraine (1989–2020), European Countryside, 14(2), 281–301. doi: 10.2478/euco-2022-0014

Melnykovych, M., Nijnik, M., Soloviy, I., Nijnik, A., Sarkki, S. & Bihun, Y. (2018). Social-ecological innovation in remote mountain areas: Adaptive responses of forest-dependent communities to the challenges of a changing world, Science of the Total Environment, 613–614, 894–906. https://doi.org/10.1016/j.scitotenv.2017.07.065

Melnykovych, M., Nijnik, M., Rohner, T. & Waeber, P. O. (2023). Nurturing the future of the Carpathians in a time of critical transition: Exploring triggers for sustainability in the post-war era, [Conference presentation]. 7th Forum Carpaticum: Carpathian Futures – Critical Transitions, Kraków, Poland, 25–28 September 2023.

Melnykovych, M., Böttinger, E., Waeber, P. O., Bertuca, A., De Luca, C., Domínguez, X., Fuentemilla, S., Hernández, S., Heikkinen, H.I., Kottawa Hewamanage, L., Nijnik, M., Pilla, F., Sarkki, S., Selva, C., Wilson, R., Valero, D. & Miller, D. (2024a). Learning needs and gaps of rural communities. (Deliverable D3.1. Horizon Europe project RURACTIVE – Empowering Rural Communities to Act for Change, Grant Agreement No. 101084377).

Melnykovych, M., Sarkki, S., Rogelja, T., Kluvánková, T., Nijnik, A., Miller, D. & Nijnik, M. (2024b). Future of forest in the Ukrainian Carpathians in time of critical transition: Why social innovation might be a trigger towards sustainability, in 26th IUFRO World Congress: Book of Abstracts. Stockholm, p. 2983.

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkaľáková, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W. S., Kluvánková, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy, I., Waeber, P. O. & Zawiejska, J. (2026a). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda, Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Melnykovych, M., Nijnik, M., Soshenskyi, O., Zibtsev, S., Lobchenko, G., Sarkki, S., Voloshyna, N., Soloviy, I., Kravets, P., Khan, Y., Yaroshchuk, R., Keeton, W. S., Rosset, C., Pauli, B., Garcia, C.A. & Waeber, P. O. (2026b). Pathways for Ukraine's post-war nature recovery: Focus on forest socio-ecological systems, Ambio, 55, 817–843. doi: 10.1007/s13280-025-02263-0

Mitrofanenko, T., Melnykovych, M., Kubal-Czerwińska, M., Kuras, K., Vetier, M., Halada, Ľ., Zawiejska, J. & Nijnik, M. (2024). Bridging science, policy and practice for collaborations towards sustainable development in the Carpathian region. In S. Schneiderbauer, P. Fontanella Pisa, J. F. Shroder, & J. Szarzynski (Eds.). Safeguarding mountain social-ecological systems: Building transformative resilience in mountain regions worldwide. (Vol. 2, pp. 207–217). Elsevier. doi: 10.1016/B978-0-443-32824-4.00006-7

Mitrofanenko, T., Škovira, R., Kholiavchuk, D., Csabay, J., Keeton, W., Zawiejska, J., Matei, E. & Melnykovych, M. (Eds.). (2025). Key Messages and recommendations from Science for the Carpathians for the Carpathian Convention Implementation Committee. Science for the Carpathians.

Niewiadomski, Z. & Maryskevych, O. (2022). Impact of war on natural environment of the Carpathians in Ukraine. Ministry of Climate and Environment of Poland, Department of Nature Conservation.

Nijnik, M., Kluvánková, T. & Melnykovych, M. (2022). The power of social innovation to steer sustainable governance of nature, Environmental Policy and Governance, 32(6), 453–458. doi: 10.1002/eet.2018.

Nijnik, M., Kluvánková, T., Melnykovych, M., Nijnik, A., Kopiy, S., Brnkalakova, S., Sarkki, S., Kopiy, L., Fizyk, I., Barlagne, C., & Miller, D. (2021). An institutional analysis and reconfiguration framework for sustainability research on post-transitionforestry: A focus on Ukraine. Sustainability, 13 (8), 4360. https://doi.org/10.3390/su13084360.

Nijnik, M., Secco, L., Miller, D. & Melnykovych, M. (2019). Can social innovation make a difference to forest-dependent communities? Forest Policy and Economics, 100, 207–213. doi: 10.1016/j.forpol.2019.01.001.

RURACTIVE. (n.d.). RURACTIVE – Empowering rural communities to act for change. (n.d.). Horizon Europe project, Grant Agreement No. 101084377. RURACTIVE project website. Project and Grant Agreement No. 101084377 independently confirmed by CORDIS.

Soloviy, I., Melnykovych, M., Björnsen Gurung, A., Hewitt, R. J., Ustych, R., Maksymiv, L., Brang, P., Meessen, H. & Kaflyk, M. (2019). Innovation in the use of wood energy in the Ukrainian Carpathians: Opportunities and threats for rural communities, Forest Policy and Economics, 104, 160–169. doi: 10.1016/j.forpol.2019.05.001.

Ukraine Recovery Conference. (2022). Outcome document of the Ukraine Recovery Conference URC2022: Lugano Declaration. Lugano, Switzerland, 4–5 July 2022.

United Nations Environment Programme (UNEP). (2022). The environmental impact of the conflict in Ukraine: A preliminary review. United Nations Environment Programme.

Sarkki, S., Parpan, T., Melnykovych, M., Zahvoyska, L., Derbal, J., Voloshyna, N., & Nijnik, M. (2019a). Beyond participation! Social innovations facilitating movement from authoritative state to participatory forest governance in Ukraine. Landscape Ecology, 34, 1601–1618. https://doi.org/10.1007/s10980-019-00787-x

Sarkki, S., Ficko, A., Miller, D. R., Barlagne, C., Melnykovych, M., Jokinen, M., Soloviy, I., & Nijnik, M. (2019b). Human values as catalysts and consequences of social innovations. Forest Policy and Economics, 104, 33–44. https://doi.org/10.1016/j.forpol.2019.03.006

Soloviy, I., Melnykovych, M., Björnsen Gurung, A., Hewitt, R. J., Ustych, R., Maksymiv, L., Brang, P., Meessen, H. & Kaflyk, M. (2019). Innovation in the use of wood energy in the Ukrainian Carpathians: Opportunities and threats for rural communities. Forest Policy and Economics, 104, 160–169. https://doi.org/10.1016/j.forpol.2019.05.001

Soshenskyi, O., Zibtsev, S., Gumeniuk, V., Goldammer, J. G., Vasylyshyn, R., & Blyshchyk, V. (2021). The current landscape fire management in Ukraine and strategy for its improvement. Environmental & Socio-economic Studies 9(2), 39–51. https://doi.org/10.2478/environ-2021-0009

Zibtsev, S., Myroniuk, V., Soshenskyi, O., Sydorenko, S., Bogomolov, V., Kalchuk, Y., & Zibtseva, I. (2023a). Ukraine Fire Perimeters 2022 (Ver. 1) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8298835

Zibtsev, S., Soshenskyi, O., Melnykovych, M., Blaser, J., Waeber, P. O., & Garcia, C. (2023b). Ukrainische Wälder im Fokus von Klimakrise, Krieg und Brandkatastrophen. Schweizerische Zeitschrift für Forstwesen, 174(2), 115–117. https://doi.org/10.3188/szf.2023.0115

Zibtsev, S., Myroniuk, V., Soshenskyi, O., Kalchuk, Y., & Zibtseva, I. (2024). Ukraine Fire Perimeters 2023 [Data set]. Zenodo. https://doi.org/10.5281/zenodo.10514571

22 Cross-cutting priorities for translating the S4C Research Agenda into action

Mariana Melnykovych

Alongside the thematic research domains presented in this S4C Research Agenda, four cross-cutting priorities are critical for strengthening the contribution of Carpathian research to policy and practice. Drawing on recurring challenges identified through recent S4C and Carpathian Convention processes, and synthesised by Melnykovych et al. (2026), these priorities address four interconnected implementation gaps: limited uptake of knowledge in decision-making, fragmented governance, uneven access to financial resources, and constrained institutional and human capacities. Accordingly, the priorities focus on (1) strengthening science–policy–practice interfaces; (2) advancing multi-level, cross-border, and cross-sectoral governance; (3) connecting research, policy, and financing for implementation; and (4) strengthening institutional and human capacities. They represent enabling conditions for translating knowledge across the S4C Research Agenda into coordinated action and sustained impact across the Carpathian region.

1. Strengthening science–policy–practice interfaces

How can shared monitoring, interoperable data, knowledge co-production, and sustained science–policy–practice interfaces improve the timely use of knowledge in decision-making across the Carpathians?

Effective decision-making requires knowledge that is accessible, comparable, policy-relevant, and responsive to emerging challenges. Priorities include coordinated environmental and socioeconomic monitoring, interoperable datasets, common indicators, regional assessments, and stronger integration of scientific, local, traditional, and practice-based knowledge. To make this operational, priority should be given to:

- Creating mechanisms for rapid access to scientific expertise when new policy questions, hazards or development pressures emerge;
- Establishing a shared Carpathian monitoring framework with a minimum set of comparable environmental and socioeconomic indicators;
- Improving interoperability of national datasets through common metadata, standards and open-data protocols;
- Producing regular regional synthesis reports and short policy briefs targeted to Convention Working Groups and national authorities;
- Linking S4C researchers more systematically with Convention Working Groups, national focal points and subnational authorities; and
- Documenting whether and how scientific recommendations are taken up in strategies, plans and decisions.

2. Advancing multi-level, cross-border, and cross-sectoral governance

Which governance arrangements (focusing on adaptive governance) most effectively coordinate action across sectors, governance levels, and national borders in relation to shared Carpathian challenges?

Many Carpathian challenges cross administrative, sectoral and national boundaries. The key issue is therefore not simply more cooperation, but how cooperation is organised around shared problems and functional territories. Priority should be given to:

- Establishing cross-sectoral working arrangements for issues that cut across several Convention Working Groups, such as ecological connectivity, water–forest interactions, tourism pressure, renewable-energy development or responses to polycrisis due to the war in Ukraine impacting the entire region (as seen in Melnykovych et al., 2026);
- Developing transboundary initiatives in shared functional areas, including river basins, ecological corridors, protected-area networks, and other cross-border landscapes;
- Strengthening formal links between regional commitments and national and subnational planning processes;
- Supporting networks of municipalities, protected areas and river-basin authorities to exchange methods and jointly address shared problems; and
- Developing and applying approaches for assessing policy coherence and identifying trade-offs among biodiversity, forestry, agriculture, transport, renewable energy, tourism, and other sectoral policies.

3. Mobilising and aligning financial resources for implementation

Which financing mechanisms can provide stable, accessible, and coordinated support for long-term research, monitoring, capacity development, and transboundary implementation in the Carpathians?

Long-term implementation of the S4C Research Agenda requires financing arrangements that provide continuity beyond individual project cycles and enable participation across countries, institutions, and governance levels. Existing European, national, regional, public, private, and philanthropic resources therefore need to be better connected with agreed Carpathian research and implementation priorities. Particular attention is needed to long-term activities – such as monitoring, research infrastructure, capacity development, restoration, and transboundary cooperation – that are difficult to sustain through short-term project funding. Priority should be given to:

- Linking scientific evidence and identified research needs more systematically with funding and investment decisions related to restoration, adaptation, and sustainable regional development;
- Strengthening links among research priorities, policy commitments, and financing instruments

is therefore essential for moving from knowledge generation to sustained implementation;

- Identifying long-term financing needs for monitoring, research infrastructure, capacity development, and transboundary cooperation;
- Exploring funding arrangements for activities that require continuity beyond individual research projects;
- Exploring and mobilising complementary and blended financing, including public, private, and philanthropic sources, for Carpathian initiatives;
- Improving coordination among European, national, and regional funding programmes around priority research areas in the Carpathians;
- Expanding access to small-scale and seed funding for municipalities, NGOs, protected areas, early-career researchers, and less-resourced research institutions;
- Supporting the preparation of joint transboundary proposals and investment pipelines; and
- Ensuring dedicated attention to financing the research, monitoring, and institutional capacities needed for recovery and resilient reconstruction in Ukraine.

4. Strengthening institutional and human capacities

Which institutional capacities, professional skills, networks, and learning mechanisms are most important for evidence-informed, adaptive, and inclusive action across the Carpathians?

Effective implementation of the S4C Research Agenda depends on institutions and people with the capacity to interpret and apply knowledge, coordinate across sectors and governance levels, develop and manage projects, engage stakeholders, and sustain long-term cooperation. Capacity development should therefore extend beyond one-off training to strengthen institutional learning, professional networks, knowledge exchange, and sustained expertise across the Carpathian region. Existing regional mechanisms, including the Carpathian Education for Sustainable Development Expert Network, provide a basis for supporting such processes. Priority should be given to:

- Regional training programmes and summer schools for early-career researchers and practitioners;
- Staff exchanges and short-term scientific missions among research institutions, public authorties, protected-area administrations and other relevant organisations;
- Mentoring and proposal-development support for institutions with limited access to European research funding and international research networks;
- Development of communities of practice connecting researchers, policymakers, planners, practitioners and local actors around shared Carpathian challenges;
- Strengthening institutional learning and continuity of expertise, including mechanisms for retaining knowledge, experience and professional capacities beyond individual projects and funding cycles;
- Strengthening the capacity of local communities to participate meaningfully in knowledge

co-production, priority setting and decision-making;
- Supporting multi-actor and transdisciplinary approaches that bring scientific, policy, professional, local and traditional knowledge together in the co-design, testing and implementation of solutions;
- Supporting social innovation, local partnerships, living labs and other forms of research-driven and community-led projects; and
- Strengthening links with European and global mountain research like Mountain Research Initiative (MRI), education and professional networks to facilitate peer learning, knowledge exchange and transfer of relevant approaches across regions.

Together, the four cross-cutting priorities define the enabling conditions needed to translate the S4C Research Agenda into coordinated action across the Carpathians: knowledge must inform decision-making; governance must enable coordinated action; financial resources must be available and aligned with priorities; and institutions and people must have the capacity to act. Their implementation requires sustained cooperation among S4C, Carpathian Convention bodies, research and education institutions, national and subnational authorities, protected areas, civil society, the private sector and local communities. Progress should be monitored systematically, including the use of scientific evidence in policies and plans, continuity and accessibility of shared monitoring systems, participation in transboundary and cross-sectoral initiatives, involvement of institutions across Carpathian countries, participation of early-career researchers and less-resourced institutions, and mobilisation of resources for long-term research and implementation. Such monitoring can identify persistent gaps, assess whether research is contributing to policy and practice, and inform future revisions of the Agenda.

Looking towards and beyond 2030, the S4C Research Agenda should be treated as a living strategic framework rather than a fixed list of priorities. Scientific knowledge, policy needs and regional conditions will continue to evolve, particularly in the context of interacting environmental, socioeconomic, governance and geopolitical pressures that characterise the emerging Carpathian polycrisis (Melnykovych et al., 2026). The Agenda should therefore be reviewed periodically through Forum Carpaticum, cooperation with Carpathian Convention bodies and continued engagement with regional stakeholders, allowing priorities to evolve in response to new evidence, emerging challenges and opportunities for regional cooperation.

References

Melnykovych, M., Mitrofanenko, T., Nijnik, M., Brnkalakova, S., Csabay, J., De Bortoli, I., Kholiavchuk, D., Keeton, W.S., Kluvankova, T., Matei, E., Martino, S., Sarkki, S., Škovira, R., Soloviy. I., Waeber, P.O. & Zawiejska, J. (2026). Navigating uncertainties for changing mountains in a time of polycrisis: Strengthening the Carpathian mountain agenda. Mountain Research and Development, 46(3). https://doi.org/10.1659mrd.2026.00099

Interested scientists, practitioners, policy-makers are welcome to join the S4C Network and contribute to its activities.

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