A Strategic Research Agenda for Biodiversity-Friendly Transport Infrastructure in Europe

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Transport ecology, which developed from road ecology *[1, 2]*, opens up a specific field of research at the crossroads between two major areas: transport research and biodiversity research. Amidst growing tensions surrounding this interface (often conflicting objectives of environmental preservation and economic development), one of the BISON project's objectives was to identify and prioritise research and innovation needs so that transport infrastructure can take greater account of biodiversity throughout its life cycle. As such, a Strategic Research and Deployment Agenda (SRDA) was developed, which can be implemented at different scales (EU Research Framework Programme; regional, national or local programmes). The SRDA defines the vision, overall objectives, key priorities, investment areas and a research and deployment roadmap for all stakeholders. One specific aspect of this agenda concerns short, medium and long-term research: the Strategic Research Agenda (SRA).

OBJECTIVE AND APPROACH FOR PREPARING THE STRATEGIC RESEARCH AGENDA

To conduct the broadest possible reflection, the methodology for developing the SRA was not only based on the knowledge and experience of BISON members and on scientific literature, it was also largely open to the views of the different stakeholders involved (bottom-up approach). The process began by collecting their expectations (needs, requirements) and their proposals for solutions: online consultation of voluntary individuals and institutions and of experts; research into publications by representative institutions (e.g. European and international professional associations). The research questions raised by these expectations and proposals were identified by a panel of multidisciplinary BISON experts. This cross-analysis of potential research questions provided the opportunity to reach agreement on their relevance. The questions were classified according to the infrastructure concerned (roads, railways, waterways, power lines, pipelines, airports, harbours) and the stages of the infrastructure life cycle: planning, design, adaptation, operation, decommissioning. The list of identified research actions (RAs) was discussed (interest, importance, formulation) with other BISON partners as well as a broad external audience: IENE Scientific and Expert Committee (*https://www.iene.info/*), BISON Advisory Group; workshops at international conferences (IENE 2022 and TRA 2023).

The result is intended for European and national authorities in charge of transport infrastructure and research, the scientific community, operational players and environmental agencies. Its objective is to improve and better target research programmes and projects in the field of transport ecology. It also aims to better define the funding mechanisms for this research, a well-identified cross-cutting issue that has so far been difficult to take into account.

This article presents the main results of this process which shows that roads are a major research topic, closely linked with questions concerning other types of transport infrastructure.

KEY RESEARCH CHARACTERISTICS FOR BIODIVERSITY-FRIENDLY ROADS

Number of research actions involving roads and other types of transport infrastructure

The Strategic Research Agenda puts forward 92 research actions (RAs), 97% of which (i.e. 89 RAs) involve the road sector *(illustration 1a)*. The vast majority of these RAs are not specific to the road sector but are shared with other types of infrastructure. This makes it possible to 'cross-fertilise' knowledge between different transport sectors. As such, even the infrastructures which are least considered in studies (e.g. pipelines, power lines) may share more than 76% of research objectives with the road sector *(illustration 1b)*. The latter shares almost all of its questions with the railway sector (99%) and secondly – and more unexpectedly – with airports (91%).

The SRA's research actions can be broken down into 14 major issues:

- Disturbance to species due to transport infrastructure;
- Limitation of impacts related to wildlife movement through risk management;
- Assessment of crossing arrangements for optimum implementation;
- Efficiency and consolidation of impact reduction measures;
- Efficiency and prospects for remote solutions (e.g. compensation, translocation, etc.);
- Global pressure on the biodiversity of transport infrastructure in space and time;
- Consideration of all landscape dynamics in transport infrastructure projects;
- Involvement of stakeholders from the territories crossed;
- Optimisation of the ecological potential of land;
- Control of the spread of invasive alien species;
- Adaptation to the impact of climate change;
- Characterisation of biodiversity-friendly performance with a view to continuous improvement;
- Control of monetary and non-monetary costs borne by biodiversity;
- Coherent framework of objectives and principles for coordinated initiatives.

Stages of the road life cycle in research actions

Among the research actions related to roads, the Operation stage is the most recurrent, affected by 92% of the RAs *(illustration 2a, OPE)*. This shows the progress still needed, even though it has been a major phase since the emergence of road ecology *[1, 2, 3]*. The same is true for the Design stage (DES: 79%). As a much more recent addition to the arena of concerns, the Adaptation to

TABLE 1 - TOPICS IDENTIFIED THROUGH THE RESEARCH ACTION CHARACTERISATION PROCESS

Title	Definition
Policy (POL)	Improve policies in order to ensure that biodiversity care guidance is properly targeted in transport infrastructure projects, from the decision-making stage and throughout the whole life of infrastructures
Law and regulation (LAR)	Improve laws and regulations in order to ensure that rights and duties of all stakeholders relative to biodiversity care are properly applied in transport infrastructure projects, from the decision-making stage and throughout the whole life of infrastructures
Planning of TI projects (PLP)	Improve the planning process in order to ensure that the status of biodiversity and its protection objectives are properly taken into account during the process, and will continue to be considered during and after infrastructure construction
Assessment of realised TIs (ASR)	Improve the process for assessing the effects of realised transport infrastructure on biodiversity, and for checking compliance with their biodiversity commitments.
Cooperation between TI stakeholders (COS)	Improve the process of cooperation between stakeholders (solving breaks, developing levers) in order to reach the maximum benefit for biodiversity care, from the decision-making stage and throughout the whole life of infrastructures
Awareness of TI stakeholders (AWS)	Improve awareness of all types of stakeholders on the diverse dimensions of biodiversity-friendly transport infrastructure in order mutual understanding lead to shared involvement for biodiversity
Reduction measures (REM)	Assess and improve the ecological relevance and effectiveness of reduction measures of transport infrastructure effects on biodiversity, and develop better solutions for biodiversity in this field.
Compensation measures (COM)	Assess and improve the ecological relevance and effectiveness of compensation measures of transport infrastructure effects on biodiversity, and develop better solutions for biodiversity in this field
Responses to effects of climate change (CLC)	Identify and understand all the phenomena due to climate change affecting biodiversity in infrastructure, their foreseeable effects and develop mitigation solutions, as well as nature based solutions against climate change
Responses to spread of invasive species (IAS)	Identify and understand all the phenomena bound to spread of invasive species in infrastructure, their foreseeable effects and develop mitigation solutions, as well as nature based solutions against dispersal of invasive species
Achieving ecological permeability of TIs (EPE)	Identify and understand the different aspects of the barrier effects caused by infrastructure on populations and develop solutions to restore ecological permeability by means of resources from all relevant fields
Restoring and enhancing ecological networks with TIs (REN)	Understand and improve the ecological potential of transport infrastructures and their associated raw-material production sites in order to make them contribute to restore blue and green networks and enhance their ecological functioning
Achieving TI network densities compatible with ecological capacities/interest (TIN)	Understand the various effects of transport network density and use intensity of infrastructures on population dynamic and ecological functions and services at landscape scale, in view to adapt transport development to landscape ecological capacities and interest
Controlling the specific pressures on biodiversity created by the transport sector (SPR)	Identify and understand the various effects on biodiversity due to the pressures specifically created by transport the transport sector (infrastructures and their use) and develop targeted mitigation solutions
Developing the biodiversity care culture in the transport sector (CAC)	Identify and understand all the breaks and possible levers for the diverse stakeholders' cultures regarding biodiversity-friendly attitude in order to develop and generalise a pro-biodiversity behaviour in the transport sector

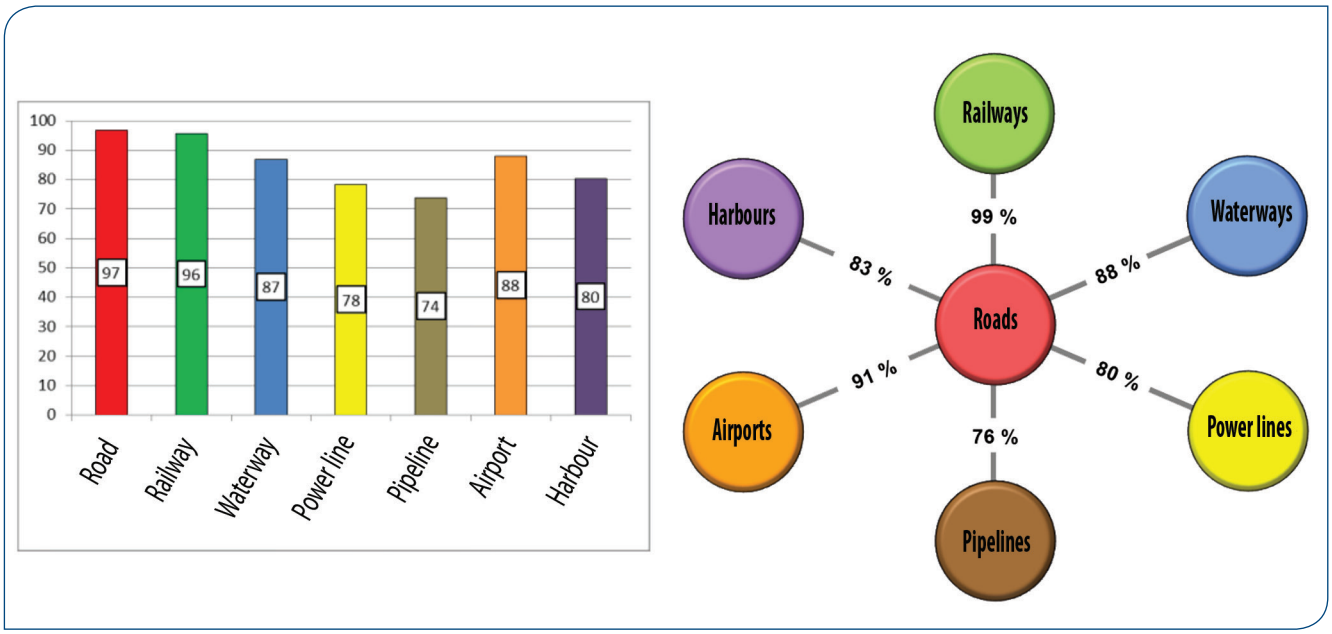

Illustration 1 - (a) Representation of transport infrastructures in research actions (%); (b) Sharing rate of research actions between roads and other infrastructures (%)

existing infrastructure stage also raises many questions today (ADA: 82%). In addition, the questions on these three stages are strongly interconnected (from 71 to 78%, see the Design-Operation-Adaptation triangle in *illustration 2b*).

Although fewer, the occurrences of Planning (PLA: 52%) and Decommissioning (DEC: 49%) nevertheless demonstrate a renewal of research questions. Today, infrastructure planning is approached according to a broader vision that takes into account all of the dynamics of the crossed territories (integrated planning). Until now, the decommissioning stage has been rarely taken into account by stakeholders. The shortest Construction (CON) stage is linked to fewer questions but reflects the logic of life cycle analysis and integrates the impacts of upstream and remote processes.

Main topics associated with the research actions

Each research action is characterised by its relationship to one or more major topics highlighted by the general analysis of needs and proposals *(table 1)*. Depending on the complexity of the issues addressed in the research actions, they have been linked to one, two or three topics. The relative significance of each topic for all road-related research actions is presented in *illustration 3*.

The most recurrent topics are impact reduction measures (REM = 16%), achieving ecological permeability[1] of transport infrastructures (EPE = 13%), controlling the specific pressures on biodiversity created by the transport sector (SPR = 11%) and restoring and enhancing ecological networks with transport infrastructures (REN = 10%). These account for 50% of occurrences alone, expressing the high degree of questioning on these aspects. The topics REM and EPE have been at the heart of road ecology since its origin *[1, 2]*. In many cases, they are also linked within the same research action: questions are opened by the solutions provided so far. The topics SPR and REN are more recent, opening up a wide range of new questions.

The topics CLC and IAS (2% each) address important and well-known biodiversity conservation issues. Their occurrence rate is low because in the road sector and the transport industry in general these two problems and the way to deal with them are already clearly identified.

TOOLS TO SUPPORT R&D ACTIVITIES IN TRANSPORT ECOLOGY

Data collection for regulatory monitoring of transport infrastructure

Regulatory monitoring of the ecological impacts of roads (and other types of transport infrastructure) after their commissioning and for several years produces vast quantities of data. At present, due to a lack of organisation and cooperation, this data cannot be exploited by research. Opportunities for deeper analysis, large-scale vision, improved feedback and cross-referencing with research projects are lost, to the detriment of all present and future stakeholders.

The scientific community is able to pinpoint the data (nature, quality, format, etc.) that

1 An infrastructure's ability to allow passage to organisms, plants and animals.

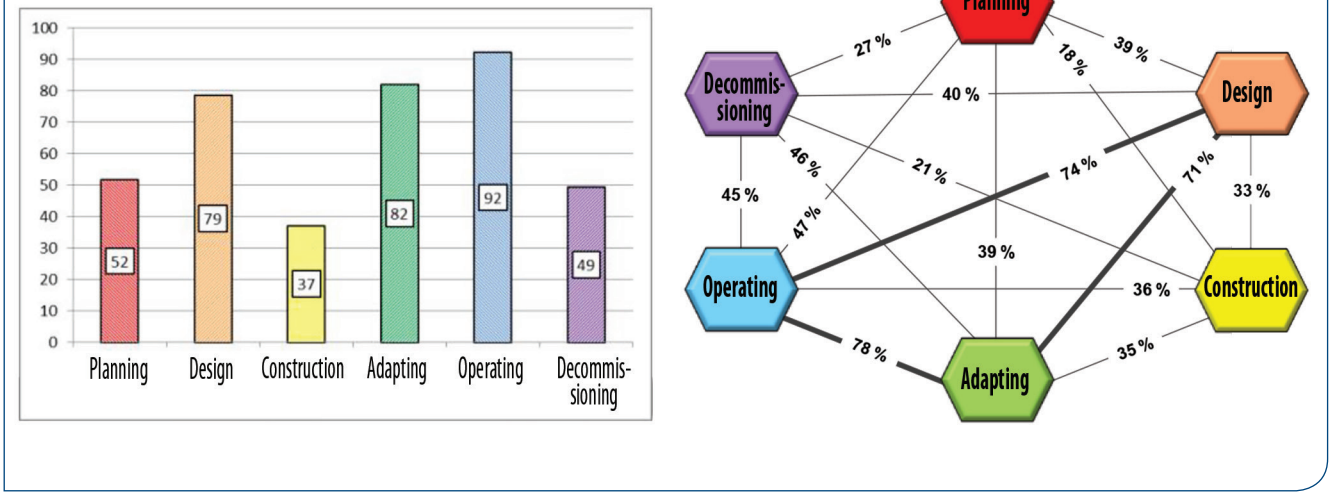

Illustration 2 - (a) Life cycle stages in road-related research actions (%); (b) Relationships between the life cycle stages in these research actions (%)

it would be necessary to obtain through this monitoring to contribute to research for more biodiversity-friendly transport infrastructure. The implementation of this research resource also includes defining the communication system needed to collect and provide data to the scientific community.

Full-scale experiments to test hypotheses and solutions

Research and development activities in transport ecology are often slowed down (or sometimes prevented) by the impossibility of testing hypotheses or innovative solutions in full scale. Opportunities are few and far between. They only occur in the context of calls for collaborative research projects with operators (complex assemblies) or as part of real infrastructure projects (which can limit the sharing of information).

The possibility of implementing and offering operators full-scale experimentation projects should be introduced as a common research tool in transport ecology. This could be in the context of new projects or, more broadly, through the multiple opportunities offered by all existing infrastructures. In addition, this would facilitate multidisciplinary studies, and strengthen and accelerate feasibility studies.

A European network of long-term study areas

A major challenge for transport ecology research is understanding and managing the effects of long-term and landscape-scale infrastructure networks, taking into account the various types of infrastructure, the density of their interconnections, their effects on anthropisation and any additional effects induced by the latter. Until now, the means available for research have only been able to address this issue through partial initiatives, which are dissociated from one another, preventing the integration and transferability of results. Developing this research requires the mobilisation of researchers from all of the disciplines involved in common study fields and over a long enough period (decades) to be able to interact and observe the same subjects, stakeholders and their respective developments.

The wide variety of situations across Europe (ecoregions, land use, transport network interconnections) makes it possible to identify a set of diversified and complementary study areas on which European researchers could focus their efforts. The transport ecology scientific community could propose the perimeters of such areas that would be discussed with all relevant stakeholders. Such a tool would allow more efficient investment in research as well

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as cross-analysis on each area and between regions of Europe, including cross-border regions. Operational lessons would benefit all regions regardless of their situation, for management and planning.

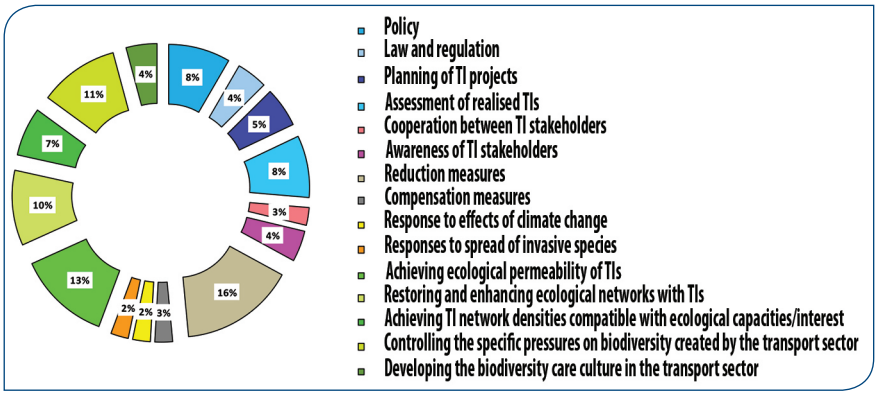

Illustration 3 - Occurrence of topics among road-related research actions

A FRAMEWORK FOR IMPLEMENTING RESEARCH ACTIONS

The polymorphic, dynamic and stochastic dimensions of biodiversity are directly opposed to the desire for standardisation which is characteristic of transport engineering. This inherently makes transport ecology a subject of tension that is still emerging in institutional and research spheres. However, research needs, as well as the realisation and structuring of scientific work, can only emerge in an environment that is mature enough to formalise and express them. Transdisciplinary research in transport ecology which takes into account all stakeholders (applied research) must meet strong societal expectations today: to halt the decline of biodiversity and design sustainable mobility in the context of climate change. Investigating new leads to identify avenues for improvement and innovation involves increased risk-taking from the perspective of research investment. The current system must therefore be adapted to allow the reintegration of this dimension into the whole process: call design, project development, assessment and use/exploitation of the results. To supporting this ambition, it is necessary to *[4, 5, 6]*:

- Develop a dynamic long-term vision (> 10 years) of expectations and funding;
- Support new approaches for assessing nature-related ancillaries and impacts with the entire scientific community;
- Manage risk-taking through a rigorous process of scientific excellence;
- Support the research ecosystem with stakeholders able to establish connections between funders/users and researchers (knowledge brokers);
- Strengthen the development of indicators based on scientific evidence and data sharing.#