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2	MTES	MINISTERE DE LA TRANSITION ECOLOGIQUE ET SOLIDAIRE	France
3	CERTH/HIT	CENTER FOR RESEARCH AND TECHNOLOGY HELLAS	Greece
4	CDV	CENTRUM DOPRAVNÍHO VÝZKUMU- TRANSPORT RESEARCH CENTER	Czech Republic
5	UGE	UNIVERSITÉ GUSTAVE EIFFEL	France
6	SPW	SERVICE PUBLIC DE WALLONIE – DIVISION MOBILITE – INFRASTRUCTURES	Belgium
7	UPGE	UNION PROFESSIONNELLE DU GENIE ECOLOGIQUE	France
8	UIC	INTERNATIONAL UNION OF RAILWAYS	France
9	CEREMA	CENTRE D'ETUDES ET D'EXPERTISE SUR LES RISQUES, L'ENVIRONNEMENT, LA MOBILITE ET L'AMENAGEMENT	France
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12	UKF	FAKULTA PRÍRODNÝCH VIED - UNIVERZITA KONŠTANTÍNA FILOZOFA V NITRE	Slovak Republic
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15	FRB	FONDATION POUR LA RECHERCHE SUR LA BIODIVERSITE	France
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34	NTIC	NETIVEI ISRAEL - NATIONAL TRANSPORT INFRASTRUCTURE COMPANY LTD	Israel
35	NCA	NATURE CONSERVATION AGENCY OF THE CZECH REPUBLIC	Czech Republic
36	RWS	MINISTERIE VAN INFRASTRUCTUUR EN WATERSTAAT - MINISTRY OF INFRASTRUCTURE AND WATER MANAGEMENT	Netherlands
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TABLE OF ACRONYMS

BI	Blue Infrastructure
EEA	European Environment Agency
EC	European Commission
ES	Ecosystem Services
GBI	Green and Blue Infrastructure
GI	Green Infrastructure
IAS	Invasive alien species
NbS	Nature-based Solution
TI	Transport infrastructure
IoT	Internet of Things
C-ITS	Cooperative intelligent transport system
C&AD	Connected and autonomous driving
GHG	Greenhouse gas
TES	technological-ecological synergies
CEA	Cumulative Environmental Assessment
CE	Cumulative Effect(s)
EIA	Environmental Impact Assessment
HTI	Habitats related to Transport Infrastructures

TABLE OF FIGURES

TABLE OF TABLES

EXECUTIVE SUMMARY

The BISON project is led by a consortium of 39 European members and associated countries. It aims to tackle the integration of biodiversity with the development of infrastructure, including roads, railways, waterways, airports, harbours, or energy transport networks.

The BISON project will meet the above aim through the following objectives:

- Identify future research and innovation needs for a better integration of biodiversity with infrastructure.
- Identify the construction, maintenance and inspection methods and materials which are long-lasting and resilient and can be used by different transport modes to mitigate pressure on biodiversity.
- Support European Member States to fulfil their international commitments by engaging all stakeholders into biodiversity mainstreaming for infrastructure planning and development.
- Strengthen European Member States' leadership in sustainability, by showing the way to other countries, including developing countries.

This deliverable (D3.4) is produced in the context of BISON work package (WP) 3 – Existing and future synergy between Infrastructure and Biodiversity. WP3 has the overall objective to identify and describe current good practices and new approaches that may help mainstreaming biodiversity in the transport sector while emerging trends in technology and environment create new challenges and opportunities.

The present report is produced through the collaborative effort of the BISON working group for task 3.3 (see list of contributors) during January 2021 to May 2022. It is based on broad literature research involving scientific and non-scientific publications, websites, blogs, and governmental communications, and shall provide inspiration for the development of the future research agenda and the scenario building in other parts of the BISON project. The report explores selected trends in demography, economy, climate, biodiversity and technology, and discusses their repercussions on nature and the possibility to mainstream biodiversity in transport. It also proposes concrete actions and tools to deal with the emerging challenges and help on the way towards a sustainable transport system. The different chapters in this report can be read independently of the others and provide their own summary and a list of key points.

The central messages from the chapters are:

1. Transportation technology is at the brink to a revolutionary change that may lead to a more efficient, cleaner, equitable and resilient sector where mobility is replaced by accessibility and (unnecessary) transport demand is reduced. Still these benefits may not suffice to compensate for the needs of the growing world population and increased living standards. More and new infrastructure will be built and it will crave inclusive and holistic approaches for people as well as for nature to approach sustainability.
2. Climate change mitigation is now unquestioned and decarbonisation of the transport sector is central to the concept of sustainable development. However, to cope with the inevitable and existing impact on people and ecosystems, transport infrastructures as well as many other land use and engineering practices must adapt. These adaptation provide certain opportunities to improve conditions for

biodiversity, but as with new infrastructure, it requires a holistic and inclusive approach to benefit from these changes.

3. Nature-based Solutions provide a sustainable and economically viable alternative to conventional technical approaches for the environmental (and ecological) adaptation of infrastructure. They may not only assist in coping with climate change but also help to integrate infrastructure in the natural environment and reduce its negative impacts. Still, the concept is rather new and more development and experience is needed to obtain its full potential.

4. Triggered by climate change, habitat exploitation and expanding transport, but also thanks to Nature-based Solutions and restauration/conservation achievements, infrastructure managers will increasingly have to deal with alien and native wildlife species some of which may be of concern to infrastructure facilities or to biodiversity. To control the biological threat and simultaneously provide for desired species, cross-sector strategies for the monitoring and management of biodiversity need to be developed and adopted.

5. Traditional impact assessment is not sufficient to address the large scale and long term effects that accumulate from the various direct and indirect effects of infrastructure development, climate change and their repercussion on human societies. Evaluating the cumulative effects on nature and people alike requires a holistic approach but also a comprehensive monitoring system that also tracks the outcome of mitigation attempts.

6. Social and ecological values should be considered jointly in a holistic planning and design of transport infrastructure. To develop appropriate solutions and help people to adopt challenges and accept necessary changes in *e.g.*, transport behaviour, we need to rely on behavioural and psychological knowledge rather than technical solutions. Mainstreaming biodiversity and social concerns in the transport sector must call on emotional, cultural and recreational values.

7. Most of the above, however, is only achievable if it is economically defendable and yet aiming for sustainability will not produce attractive short term revenues. Priorities should hence be given to increased alternative funding, redirected incentives, and new regulation and transformation metrics. Internalisation of externalities of transport costs can be a key element in this approach. In addition, also demographic trends in populations affect national and global economy and must be considered when mainstreaming biodiversity in the transport sector.

In essence, the key objectives for a sustainable transport sector are:

- reduce the demand for (unnecessary) mobility and transport and instead aim for increased accessibility of resources,
- include non-transport related and non-monetary values in a holistic long-term planning that favours both people and biodiversity,
- internalise external costs of transportation for society and environment (polluter-pays principle), including long-term and cumulative effects.

Again, this requires strong governance and ambitious, aligned policies that involve the general public as well as stakeholders and businesses.

TABLE OF CONTENTS

GENERAL INTRODUCTION

The world we live in is not static. Climate change and its dawning impact on human living conditions, the growing human population with its increased energy consumption and depletion of natural resources, and the decline in biodiversity with its loss of existential ecosystem services, are well established trends that require urgent and comprehensive actions to prevent social and economic disasters (*e.g.*, IPBES, 2019). Yet, progress has been slow; and providing for a further 2 billion people by 2050 while improving living standards and satisfying increased transport demands while coping with climate change will severely limit our ability to manage and restore those natural assets on which all life depends (OECD, 2012). Unforeseen events like the COVID-19 pandemic and the Russian war on Ukraine shake our foundations but such crisis also offer the necessary incentives to question traditional paths and give way for new solutions and standards that may have been overdue since long (European Commission, 2020).

The transport sector holds one of the keys in this development (WWF & IISD, 2017). Transport is fundamental to the daily movement, trade and communication of people, organisations and goods across the globe. It is central to human societies, economies, yes in fact life itself. It is hence not surprising that developing a sustainable transport system that is resilient, clean, energy efficient, equitable and affordable, and environmentally adapted is a core objective of many governments around the globe. Recent advances in communication, vehicle and energy technologies provide hope and opportunities to reshape the way we transport (ITF, 2021). The changes may go even deeper than this and affect urban development, trade and land use. Institutions central to infrastructure finance and development are aiming at a shift to low-carbon, climate-resilient, “sustainable” investments. International agreements and conventions such as the Paris Agreement on climate change[1], the Convention on Biodiversity and its Post-2020 Framework[2], or the UN Sustainable Development Goals[3] already indicate that this shift has political momentum.

However, while organisations such as the World Road Association (PIARC, 2020), the Worldwide Railway Organisation (UIC, 2018), or the International Association for Air Transport (IATA, 2021) clearly identify objectives for decarbonisation, resilience, safety and accessibility, their ambition towards sustainability is mainly driven by energy and CO_2 emission constraints. They hardly acknowledge the need to integrate ecosystem and biodiversity concerns (Bartlett, 2019). Even at the recent ITS European Congress 2022[4], biodiversity is not mentioned at all.

In order to achieve a sustainable infrastructure and transportation, strategies need to be developed that internalise the impact on the natural capital such as species, habitats and ecosystem services (Georgiadis, 2020). We can build upon decades of best-practise experiences (as provided by the European expert network on Infrastructure and Ecology, IENE)[5] and take advantage of the opportunities offered by new technologies and Nature-based Solutions, but we also must claim a strong governance

[1] https://unfccc.int/process-and-meetings/the-paris-agreement/nationally-determined-contributions-ndcs/nationally-determined-contributions-ndcs
[2] https://www.cbd.int/article/draft-1-global-biodiversity-framework
[3] https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[4] https://itseuropeancongress.com
[5] The Infrastructure and Ecology Network Europe - https://www.iene.info

with ambitious, aligned policies and a cross-sector collaboration to mainstream biodiversity (Bartlett, 2019; Sperling *et al.*, 2018; WWF & IISD, 2017).

This report discusses important trends in environment, technology and socio-economy that define the premises in the development of sustainable infrastructure and challenge our progress in mainstreaming biodiversity in the transport sector.

The report is produced through the collaborative effort of the BISON working group for task 3.3 (see list of contributors). During January 2021 to May 2022, the task group has met biweekly to monthly to develop and discuss the content of the individual chapters. The chapters have been partly pre-defined (during the application phase) and partly initiated through collaboration within the task group. The main responsibility for each chapter resides with the main authors. A first draft of this report was presented and reviewed in October 2021 after which a seventh chapter (on economy) was added. Further input was provided through a workshop with other BISON working groups in January 2022.

The chapters are based on broad literature surveys involving policy documents, reports, scientific papers as well as websites and blogs. Many of the policy documents have been identified in the initial BISON stakeholder questionnaire (BISON deliverable 3.2), while other literature has been identified through communication within the BISON consortium and through regular literature research. The aim was to explore emerging trends and challenges without restriction to what has been published or officially proclaimed. The report therefore reflects the interpretation of the main authors and task group members, but not necessarily the opinion of the entire BISON consortium. It shall provide input to the development of future scenarios and the strategic research agenda within the BISON project.

Chapter 1 explores current advances in vehicle, energy, and communication technologies that can shift the focus from mobility towards accessibility. They have potential to reduce transport demand and thus the need for more infrastructure. Chapter 2 discusses the repercussions of climate change on infrastructures and the consequent need to adapt infrastructure assets to the new conditions. Such adaptation also provides opportunities to include biodiversity concern. Climate change and increased transportation may also increase the risk for spreading invasive species that may harm ecosystems as well as infrastructures. Chapter 3 outlines that transport organisations may increasingly be obliged to employ monitoring routines for the early detection and mitigation of invasive species. Such routines will also benefit the management and protection of native species that get into conflict with transportation activities and facilities. Chapter 4 focuses on Nature-based Solutions and their potential not only to support biodiversity linked to transport infrastructure but also to benefit from ecosystem-services replacing or complementing expensive built-up solutions. Chapter 5 highlights the need to evaluate the cumulative impact of infrastructure and transportation on biodiversity at a higher and more holistic level. Infrastructure projects cannot be considered as isolated events but must relate to the existing and emerging context that includes social, economic, historical (cultural) and natural aspects. The inclusion of socio-psychological concerns in the planning of infrastructure and biodiversity adaptations is discussed in chapter 6. The success of the necessary changes in transportation will largely depend on the attitudes and motivations of planners and transport users, *i.e.*, the general public. Finally, chapter 7 looks into the economic dimensions and tools that may create important incentives to both individuals and organisations to adjust transport behaviour.

A common thread that links all chapters is the urgent need for governance, ambitious and aligned policies, and strong cross-sector collaboration. These must translate into holistic and long-term management for sustainability replacing the traditional, market-driven focus on short-term economic revenues. If business as usual is to prevail until 2050, we are likely facing a world with significantly deteriorated living conditions, with many wildlife species and ecosystem services irreversibly lost and human populations endangered by an uncontrollably changing climate (OECD, 2012).

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1 TECHNOLOGICAL INNOVATIONS IN TRANSPORT

Author: Andreas Seiler (SLU)

“What world-changing idea would you like to see implemented by humanity? – That’s easy: limitless clean energy (by fusion power) and a shift toward electric cars.” Stephen Hawking, in his final book ‘Brief Answers to the Big Questions’ (published by Hodder Stoughton in 2018)

Summary

Technological developments have the potential to radically transform the transport sector as we know it into a more energy efficient and safe, resilient and ecologically and socially sustainable system. However, this potential can only be achieved if we take advantage of the technology changes through strong and internationally aligned policies, fostering a behavioural change in transport demand and a more holistic approach to internalise environmental and social costs.

This chapter discusses major trends in vehicle, transport infrastructure (TI) and energy technologies linked with implications on transport behaviour and the possibly resulting effects on biodiversity. Starting with the so called three revolutions in urban transportation: i) electrification; ii) automation and communication, and iii) cooperation, it is discussed how transport, especially passenger road transport, may shift from mobility dependent on private car ownership to a safer, more equitable and affordable use of mobility services. This change will increase the efficacy of transport, reduce the number of vehicles in use and in consequence lower pollution and the need for additional TI.

Many countries in Europe struggle with aging and old-fashioned TI and operations that still produce significant environmental and health impacts. Where upgrades or replacements become necessary to oblige with current technical standards, opportunities may appear to improve conditions for biodiversity. Also new types of highways or high-speed railways especially magnetically levitated rail (Maglevs or Hyperloops) may provide better possibilities to minimize the carbon footprint and the impact on nature than ‘traditional’ TI. This is because their design can include most recent tools and methods and because they need to be sealed-off and isolated from their natural environment for pure safety reasons. New infrastructure is often elevated or tunnelled thus providing many opportunities to maintain wildlife movements and ecological processes. Finally, robotics and drone technology offer a new and potentially effective kind of transport-supporting ancillary activity that can help reduce both surface traffic and need for infrastructure, especially in still remote areas. However, more research is needed, and new regulatory frameworks must be developed in order to integrate autonomous drones in the future transport system.

Electrification is essential to the environmental adaptation of transportation – as long as electricity derives from renewable resources. Different approaches to overcome dependencies on fossil fuels will need to be combined to meet policy objectives on climate change. These will have significant repercussion on other sectors, eventually creating a new, decentralised and more resilient energy sector powered by sustainable and renewable resources.

Key factors for a sustainable transportation will thus be a) a reduced demand for (personal) transport, and b) the inclusion of non-transport related values in a holistic planning and design that favours both humans and wildlife.

Key messages

- Transportation technology is at the brink to a revolutionary change that may lead to a safer, cleaner, more equitable and resilient sector.
- Current technological advances offer huge opportunities to reshape transportation, upgrade or replace existing infrastructures – provided that these chances are backed up by strong governance and regulatory frameworks.
- Decarbonisation of transportation in conjunction with automated and connected modes of transport is likely to improve traffic safety, reduce energy consumption and air pollution, minimise congestion and space consumption through more efficient use of vehicles.
- Carpooling and ride sharing are important tools, facilitated by automated and especially driverless vehicles, that can improve accessibility without increasing mobility demands.
- Short-term benefits for biodiversity and ecosystem conservation must be expected small and insufficient to compensate for the continued increase in traffic. On a long-term basis, however, the outlook is rather optimistic if the many opportunities are seized.
- To achieve a sustainable transport sector in a viable environment, inclusive and holistic approaches must be employed that govern people as well as nature.

1.1 Introduction

The transport sector boldly anticipates a significant growth and expansion during the next decades. More than 2 billion cars (Sperling and Gordon, 2009) may populate the ever so expanding networks of roads and railroads to satisfy the quickly growing hunger for more transportation, trade and exchange. By 2050, more than 25 million road lane kilometres, 335 thousand rail track kilometres (IEA 2013), and many hundred airports and runways may be built globally (Francis, 2019), with the large majority (85%) expected in developing economies (IEA 2013). More than 75% of the infrastructure to be built by 2050 does not yet exist today. Likewise, transport energy consumption and emissions are projected to increase by nearly 40% by 2050, clearly surpassing the goals of the Paris Agreement on climate change (IEA, 2022). In addition, new infrastructure will further infringe on ecosystems causing additional fragmentation and disturbance of natural habitats and loss of biodiversity already suffering from climate changes. The conventional path forward is clearly not sustainable and it will require fundamental changes in many domains to build a brighter future (OECD 2012).

At the same time however, transportation technology is at the brink to a revolutionary change that provides opportunities to counteract the alarming growth in traffic and infrastructure and remedy its consequences for biodiversity and climate. After many decades of only incremental development, mostly dedicated to the refinement of existing technologies, new concepts for personal and public transportation gain foothold. The initial flirt with renewable energies has become the new normal and the divorce from internal combustion engines craving fossil fuels and pollution air and climate is imminent. If by 2035-2040, as proposed by the European Green Deal in July 2021[6] and several other countries in the world (BloombergNEF, 2021), all new vehicles rely on non-fossil energy only, automobile manufactures and in

[6] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#documents (last visited in September 2021)

fact the entire transport sector has finally got the necessary incentive to reshape transportation. This challenge provides opportunities for technical advances (*e.g.*, automation) and new mobility concepts (*e.g.*, combined mobility, car sharing) to be implemented and refined. However, the success will largely depend on a cultural shift in transportation overall, where behavioural, structural and policy changes need to go hand in hand (Fulton *et al.*, 2017). Ultimately, we may be able to reduce the demand for mobility while providing affordable and equitable access to resources that will benefit both people, economies, and nature. Transportation may increasingly be considered as a service that can be called upon rather than as a result of private car ownership (Flügge, 2020).

In their essence, these developments have been called the three revolutions in urban transportation (Sperling, 2018): i) electrification of transport; ii) connected, autonomous and intelligent vehicles that allow for iii) the collective sharing and pooling of vehicles. But these revolutions also apply to rural and inter-urban transportation, involving rail, air, maritime mobility, passenger as well as freight transport (Grazia Speranza, 2018). Autonomous trucks, trains, ships, drones and airplanes are no longer science fiction, much of the required technology is already in place to assist and even replace human drivers and pilots. Transport networks and vehicles are now rapidly electrified to cope with climate objectives and new legislative requirements (Searle, Bieker and Baldino, 2021). They are essential in the growingly connected, intermodal system of transportation in Europe and key in the marriage of the transport and the energy sector for a sustainable future.

This development goes hand in hand with the installation of new, innovative infrastructures such as Maglevs and Hyperloops. Yet it may take decades before these systems will become a prevailing feature in inter-urban or global transportation networks. In the meantime, European countries in particular will need to invest in comprehensive upgrade schemes for the majority of existing and aging TI that is impermeable to environmental conditions to accommodate for the anticipated growth in transportation, including heavier vehicles, denser traffic at higher speeds, and electric power distribution. In addition, necessary climate change adaptations of infrastructure will also require partial rebuilding and replacement of older components with more resilient features.

It is easily overseen in the excitement about future transportation possibilities, that all these anticipated changes will impact on the natural environment, on the landscapes we inhabit and coexist with wildlife (IUCN SSC HWCTF, 2022). There are obvious risks with the foreseeable changes in transportation, but also many opportunities to mainstream biodiversity concerns and lift the pressure on nature. This chapter discusses some of these trends and their possible repercussions on our environment.

1.2 Technological trends

The future of sustainable mobility appears to be ruled by technological developments in mainly three domains (Barceló, 2019):

a. applications supported by information and communication technologies,

b. vehicular and infrastructure technology,

c. energy sources and propulsion technologies.

Obviously, we are aiming for cleaner vehicles that use upgraded or new infrastructures in more efficient, inter-connected and intelligent ways. While air transport, especially by unmanned aircraft systems (*i.e.*, drones) will develop further into an integrated part of the sectors (Gupta *et al.*, 2021), surface transportation will remain the dominant way to transport people and goods. New type of TI (*e.g.*, Hyperloops) may allow for super-speed travel, but still, most of tomorrows infrastructure may not be fundamentally different from what we operate today. In other words, even in the longer run, there will most likely be roads, railways, canals, airports, and harbours, populated by cars, trains, airplanes and ships. And while the major technological advances may first be implemented in developing and fast-growing economies, Europe has to master its legacy of traditional road and railway systems and find solutions that integrate the existing stock of infrastructure with future sustainable transportation standards (European Commission, 2018b)

1.2.1 Automation and communication

The probably most influential and ground-breaking technological development that will reshape transportation in the near future is the implementation of artificial intelligence (AI) in the automation of vehicles and its capabilities to obtain, analyse and learn from Big Data (Marr, 2020). AI will govern traffic flows safely and operate individual vehicles, gather vast amounts of data on environment, infrastructure, and vehicles, and share data with others even outside the transport system. AI will further interpret, learn from, and respond to the joined flow of Big Data. The amazing and truly revolutionary thing is however, that these functions do not need highly complex coding or a centralized computation service but can self-develop from machine-learning algorithms and no-code AI platforms across the Internet of Things (IoT) (Dilmegani, Cem, 2021). In addition, these functions do not need expensive new infrastructures but can be integrated into or benefit from existing transportation networks, provided that efficient and fast communication is available.

One initial requirement for the automation of vehicles are multiple sensor networks that inform the vehicles' AI about all driving parameters such as *e.g.*, speed, distance to next vehicle ahead, proximity to objects near the vehicle, the presence of road demarcations or the detection of humans and larger wildlife next to the road (Verwoort *et al.*, 2017). This also creates immense opportunities for AI machine-based learning. For example, the car will remember events linked to GPS positions, learn to foresee risks, and hence pre-emptively counteract, such as by reducing travel speed at times and locations where risk factors are most frequently observed. When connected to the IoT, this experience could be shared with other vehicles, and they could adopt precautionary behaviours. This data also offers opportunities to aid biodiversity monitoring for conservation (see BISON deliverable D3.5).

Many of these sensors already exist in rail and road transport today and can be purchased and retrofitted as driver assistance suites in cars from *e.g.*, Volvo, Mercedes, Volkswagen, Tesla, Polestar, providing a level 1-2 automation (Figure 1-1). While levels 3-4 automation are already in the making by some automobile makers and IT-companies and can be expected to have its break-through in the very near future, it will require a broader political and technological consensus on the regulatory frameworks and an extensive, connected, and intelligent transport system to provide for a level 5 fully autonomous vehicle fleet[7].

Connected and autonomous driving (C&AD) will eventually free the driver from any responsibility allowing her to use transportation time for other tasks than monitoring vehicle and traffic. The question is not whether at all but to what degree L0-L2 vehicles will be entirely replaced by L4 or L5 systems during the next 20-30 years. How swiftly this transgression can be made depends on multiple sociological, psychological and economic factors, but the faster the change the greater the benefits for the economy – and for the environment (Sperling, 2018).

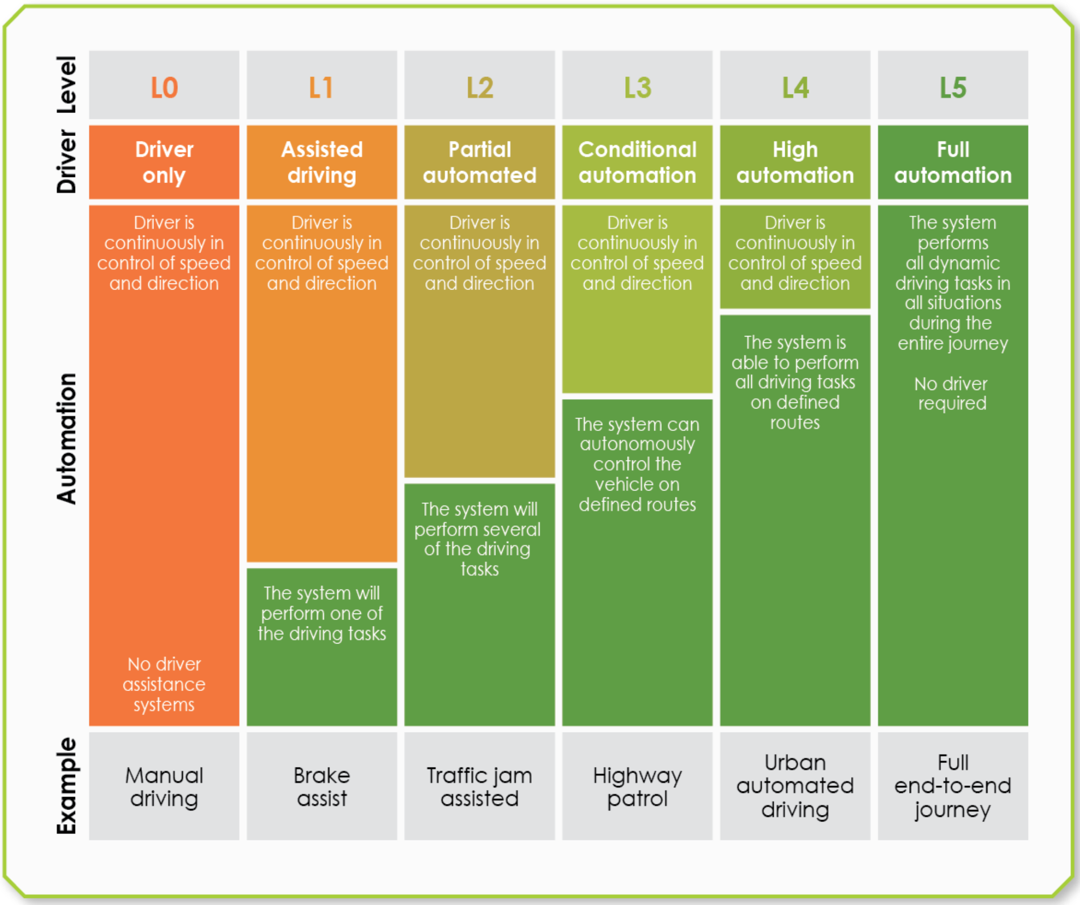

Figure 1-1: Six levels of automation in vehicular technology defined by the Society of Automotive Engineers in 2014. Redrawn from: (Verwoort et al., 2017).

Given the immense number of vehicles and the huge number of 'individual' experiences that could be shared, the benefits of "fleet learning" may appear almost instantaneously and without any central design or plan. It only requires that car manufactures are willing or obliged to share data across a common platform (Sperling, 2018). In such a cooperative intelligent transport system (C-ITS), automated vehicles communicate with other vehicles in the surrounding network to avoid collisions and congestion, with road information systems such as traffic lights or speed regulations, and with the internet at large supporting *e.g.*, delivery schemes, personal time schedules and intermodal connections. Combined with information provided by and distributed across social networks, these highly decentralised and complex

[7] COM(2018)283. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0283

communication networks have the potential to greatly increase traffic safety, enhance efficacy, and reduce energy consumption (Linse *et al.*, 2015). For example, vehicles controlled by connected AI's of L3-5 could be virtually linked in a car-train, benefit greatly from reduced air resistance and respond to unforeseen events in unison.

As a result, automated and connected traffic will become significantly safer – for both passengers and people, and maybe also for larger wildlife. This may significantly help to achieve the European Vision Zero, *i.e.*, no road fatalities on European roads by 2050[8]. Fewer fatalities, fewer accidents, less congestion and more efficient use of energy and infrastructure assets, are expected to produce higher financial revenues for both states and companies (Verwoort *et al.*, 2017). For instance, the revenues for the EU automotive industry alone may exceed EUR 620 billion by 2025 and EUR 180 billion for the EU electronic sector. The overall cost savings and benefits for the society at large are expected to be so large that they alone are reason enough for stakeholders to push this development forward. It requires, however, that private players, regional and local authorities, Member States and the EU work together on a common vision of connected and automated mobility and swiftly develop and deploy the necessary regulatory frameworks[9,10].

What applies to cars and road transportation, also applies of course to trains, airplanes, and ships. On railways, connected and intelligent trains are more closely tracked by the centralised traffic control centres, allowing for overall increase in transportation by performing infrastructure and operational analysis that will occur with the increase in traffic density (IEA, 2019). Since December 2021, four autonomous trains created by Siemens and Deutsche Bahn are in service in the city of Hamburg, Germany, as part of a €60 million modernisation project for its S-Bahn urban rail system[11]. In France, the first fully autonomous SNCF trains are expected in traffic in 2023[12], while in cities like Paris, Barcelona and Copenhagen driverless subways (Metro) are already in use for years. Airplanes are already in autopilot mode during most of their operations and automation will increase (SKYbrary Aviation Safety, 2021), while fully automated and connected shipping is under development (Cassauwers, 2020; Siemens, Schnitiger Corp., 2021).

1.2.2 Car sharing, ride-hailing and public transport

The deployment of automated, AI driven and connected vehicles is likely to empower and speed up the long-needed change in human transportation from individual car ownership towards the use of joint mobility services (Shaheen, 2018). This trend may not only change our way of life but entail significant benefits to biodiversity. Public transportation is of course nothing new in Europe and has been essential to urban mobility for long over hundred years. The concept of mobility as a Service (MaaS) that integrates various forms of transport and transport-related services into a single, comprehensive, and on-demand mobility service, has already grown into a multi-corporate alliance[13]. Still, for decades, societies around the world have been made increasingly dependent on individual car ownership, much to the profit of automobile manufacturers and oil companies (Sperling and Gordon, 2009). Even if initially car ownership

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[8] COM(2011)144; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52011DC0144
[9] The C-ROADS platform brings together all ongoing Cooperative Intelligent Transport Systems deployment activities across the EU to ensure interoperability of services. https://www.c-roads.eu/platform.html.
[10] COM(2016)766; https://eur-lex.europa.eu/legal-content/en/ALL/?uri=CELEX:52016DC0766
[11] https://www.euronews.com/next/2021/10/20/all-aboard-except-the-driver-a-fully-autonomous-train-takes-to-the-tracks-in-germany
[12] https://uic.org/com/enews/article/driverless-trains-towards-a-railway-revolution
[13] https://maas-alliance.eu/the-alliance/

has liberated many people from the mobility constraints of the past by widening the choice of jobs and living opportunities, it entails substantial and often obscured costs to households, especially as cars are parked for most of the time. Many if not most resources and services in both urban and rural areas have been located with the assumption that they will be accessed by cars. People without access or ability to drive cars have inevitably become marginalized, although also they pay for the externalities of the car-focused transport system, and suffer from noise, air pollution, and land consumption (Sustainable Development Commission, 2011). Clearly, this development has to be reversed in order to achieve a sustainable transport, a cleaner environment, and fairer societies. The International Transport Forum in its Outlook 2021 (ITF, 2021a) emphasizes the need to reshape transport, setting priorities for equitable transportation, policy alignment, collaboration by proposing a focus on accessibility rather than mobility. 'Sustainable accessibility' rather than 'sustainable mobility' should be the slogan of the future.

A more flexible, efficient, and affordable shared transportation will be the key in this development. While traditional public transportation is rather rigid (definite routes, time schedules), car sharing offers a more flexible and growingly attractive alternative to taxis and busses (Grazia Speranza, 2018). For small and medium-sized cities, it is conceivable that a shared fleet of self-driving vehicles could even eliminate the need for traditional public transport (Alessandrini et al., 2015). Companies such as Uber, BlaBlaCar, MIFAZ, ClickAPoint or ShareNow[14] have already established successful modes of shared car transport. Their major drawback is however that they rely on the willingness of car owners to welcome unknown passengers into their private vehicles and take over responsibility for their safety. With automated, driverless vehicles, the responsibility for safe driving is no longer with the human driver, but the car manufacturer. Hence the reluctance of car owners to invite unknown passengers – or of passengers to trust a private provider may be substantially lower. Companies like Uber[15] are already experimenting with driverless cars in USA that can be ordered on demand and shared during rides with others in areas where urban planning will allow and will not interfere with public safety. Also, public transport can be designed demand-responsive and flexible (Archetti, Speranza and Weyland, 2015) with the use of connected and autonomous vehicles (Pettersson, 2019). This could be of particular value to rural areas where lower population densities do not suffice to pay for traditional and static public transport.

Another important driving force in this development are personal economics. Costs for transportation are quickly rising as a result of increased taxes on fossil fuels, increased prices for oil and gas due to import limitations from Russia and the overall inflation caused by COVID19 pandemic and Russia's invasion of the Ukraine in February 2022. Travellers may by necessity start sharing rides or cars to save money and this change in attitude may foster commercially operated car sharing, especially if automated systems provide increased safety and flexibility. When automated, driverless cars can be easily hailed and shared, mobility providers could drive travel costs down to a fraction of what they are now and even much less costly than public transport (Sperling, 2018). In combination with other on-demand services such as rentable two-wheelers (bikes and scooters[16]), the need for private car ownership in urban areas will drop substantially (Weiss et al., 2015). This will not only reduce greenhouse gas emissions, noise, and congestion problems, but also free space from now unused parking facilities that could be used for Nature-based Solutions to create a healthier urban environment.

In rural areas, however, private car ownership may still remain attractive if not a necessity to ensure access to schools, jobs, shops. Key challenges for policy makers will be to reduce the demand for road

[14] https://www.blablacar.com, https://www.mifaz.de, https://www.clickapoint.com, https://www.share-now.com
[15] https://www.uber.com/blog/pittsburgh/pittsburgh-self-driving-uber/
[16] https://www.voiscooters.com, https://www.li.me/en-us/home, https://www.tier.app/sv/

travel through innovative use of C-ITS, establishing demand-responsive public transport, and providing juridical and economic incentives to develop private or commercial systems for ridesharing. Combined with a shift to virtual working spaces and home offices, extended options for online shopping with on-demand deliveries for small goods (as experienced during COVID-19 restrictions), car traffic even in rural areas may shrink significantly.

Overall, the trend from private car ownership towards using public, shared or corporate mobility services is not an automatic and guaranteed development but a process that may be triggered by economic factors and empowered by technological developments but will be accomplished only with a strong and ambitious policy that quickly changes peoples' behaviour and attitudes (ITF, 2021a). The power of attitude changes can be exemplified by the idea of 'flygskam' or flight shaming that emerged in Sweden in 2019 and led to a 9% drop in domestic air passengers (European Investment Bank, 2020).

1.2.3 Electrification of transportation

The third major trend already transforming transportation is the shift towards electrification. Electric vehicles (EV) on roads and rails have been around for almost 200 years[17], but the development of private EV has been stalled over many decades due to the predominance of fossil fuels (Sperling, 2018). Now, there is a surge in the development of new hardware, mechanisms, protocols, and policies to satisfy the growing demand for EV worldwide (IEA, 2020).

At the UN conference on climate change (COP26) in 2021[18], new goals for mitigating rising CO_2 levels have been defined, which clearly require an acceleration of the transition to zero emission vehicles. Road transport alone stands for about 10% of global emissions and its part is rising faster than emissions from other transport sectors. Hence the proposal by the European Commission in 2021[19], that in only 14 years, new passenger road vehicles in the EU must rely exclusively on non-fossil energy. Older vehicles with internal combustion engines (ICE) may require conversions to be able to run on ethanol or biodiesel. The new European legislative package 'Fit for 55'[20], aims at reducing net emissions by at least 55% by 2030 compared to 1990 and for being entirely climate neutral by 2050, making the shift to EV mandatory. Also, other countries such as the US, Canada, or China have set ambitious targets to phase out vehicles with internal combustion engines and electrify the vehicle fleet (Figure 1-2). Private EV sales are already accelerating quickly after COVID-19 and by 2040, the global market share of electric passenger vehicle sales may reach 70% (BloombergNEF, 2021). The real take-off in EV sales may happen from the second half of the 2020s when EV not only become cheaper to own on a lifetime-cost basis than ICE models but even cheaper to buy upfront. However, to meet the goals the Paris Agreement, and achieve a deep decarbonisation of the transport sector by 2050, this transition needs to happen even more quickly than today, and it must include not only cars and vans as in current directives, but also buses and trucks, trains, airplanes and ships (Searle, Bieker and Baldino, 2021).

Electrification of the transport sector relies on a combination of three different approaches:

a) battery driven electric vehicles with static charging at regular charging facilities;

[17] https://www.energy.gov/timeline/timeline-history-electric-car
[18] https://ukcop26.org/transport/
[19] https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/698920/EPRS_BRI(2022)698920_EN.pdf
[20] COM(2021)0550; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021DC0550

b) onboard fuel cells or combustion engines that produce electricity from hydrogen, renewable sources or biofuels;

c) electric systems that provide power to vehicles during transport (road or rail).

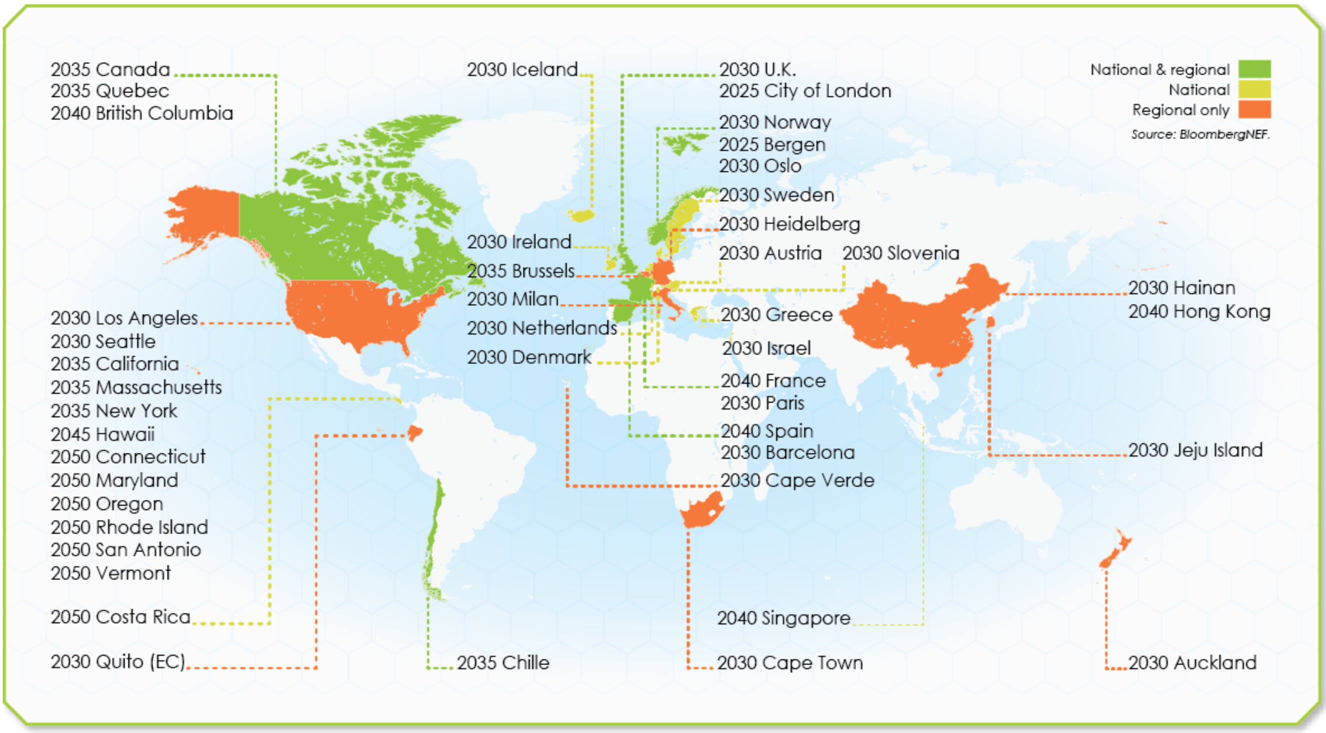

Figure 1-2: Government phase-out targets for vehicles with internal combustion engines. Redrawn after BloombergNEF (2021).

While electricity from static charging still suffers from low energy density of available batteries, it benefits from higher energy efficacy and technological simplicity in the longer run. Research must accelerate in battery technology, alternative and more environmentally friendly materials, lighter, flexible and rapid re-charging batteries (IEA, 2022). Charging stations must be installed at higher pace to become more widespread and accessible at shopping malls, schools, sport halls, and above all at offices and homes, thus offering a greater flexibility than traditional gas stations (ACEA, 2022). In addition, highways and urban roads may be electrified to allow for simultaneous charging while driving[21]. Experiments with dynamic on-road conductive and inductive power transfer are already ongoing in *e.g.*, Germany and Sweden (

[21] https://smartcitysweden.com/evolution-road-is-testing-the-next-generation-of-electric-roads/

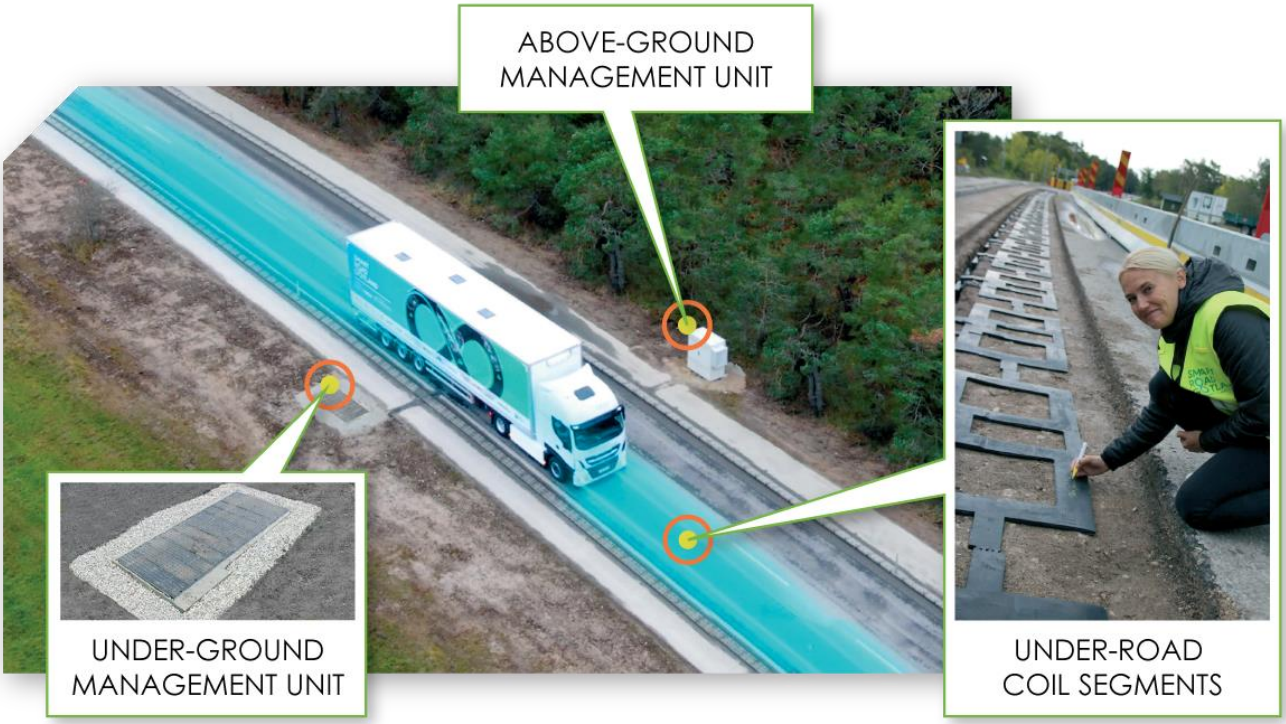

Figure 1-3) (Gustavsson, Hacker and Helms, 2019)[22] and the UK[23].

In the rail sector, electrification is already commonplace. The majority of trains in Europe is already electric and the electrified railway network steadily increases (IEA, 2019). Train engines powered by batteries or hydrogen are now tested in *e.g.*, Germany[24], Britain[25], to replace diesel engines on railway lines where full electrification is not yet feasible (Barrow, 2019). Similarly, also airplanes and ships are about to be electrified; either relying on batteries or using power from hydrogen fuel cells (CAA, 2022; FCHEA, 2022) and preferably complemented by solar and wind[26] power. Electric taxiing of aircrafts (*i.e.*, the electrification of ground operations in aircraft), for example, could immediately reduce CO_2 emissions as well as operational cost for airlines (IEA 2022).

[22] https://www.electricroads.org
[23] https://www.smithsonianmag.com/innovation/england-going-to-test-roads-that-actually-charge-electric-cars-180956336/
[24] https://www.electrive.com/2021/09/08/alstom-debuts-battery-electric-train-in-germany/
[25] https://www.networkrailmediacentre.co.uk/news/batteries-included-prototype-battery-powered-train-carries-passengers-for-first-time
[26] https://www.ecomarinepower.com/en/rigid-sails-and-solar-power-for-ships

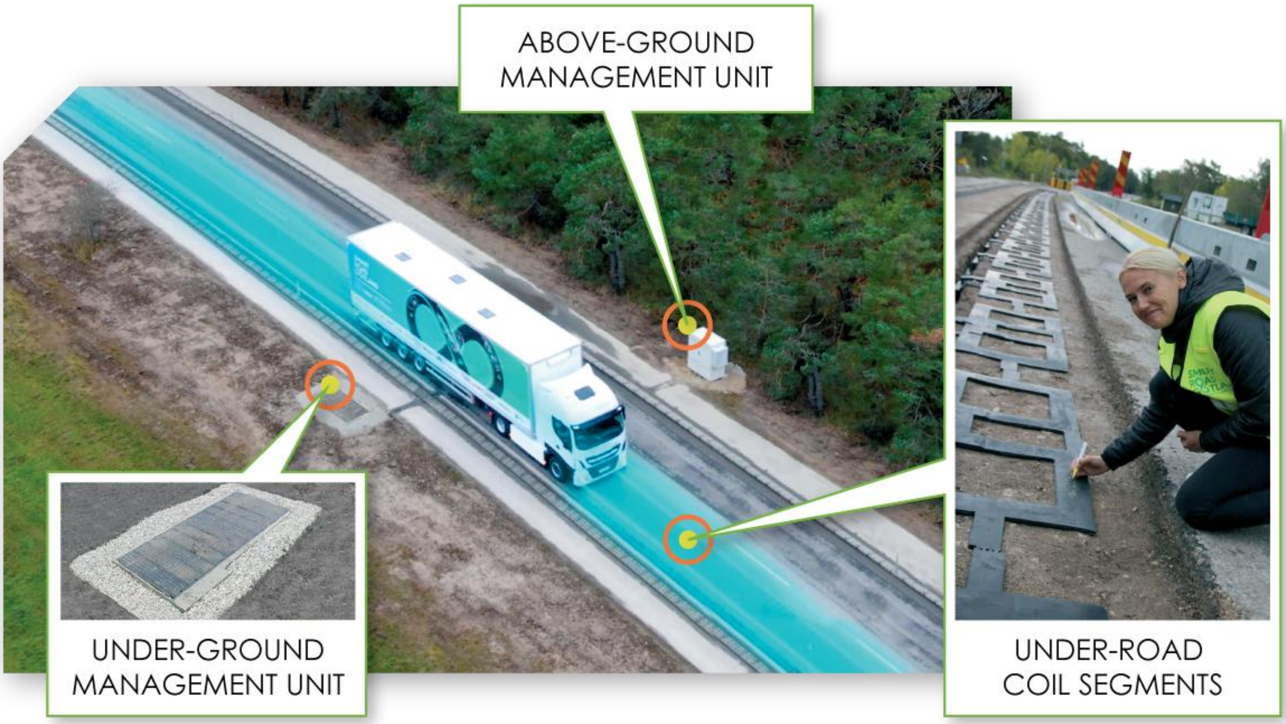

Figure 1-3: Electric Truck powered by Electreon wirelessly charging road in Gotland, Sweden. (Photo: Electreon.com)

Biofuels (ethanol, biodiesel) may play an important role to lower CO_2 emissions more quickly during the transition period. They provide “quick fixes” as they can utilise the same vehicle stock, infrastructure, and distribution networks as today, but are limited through the European Renewable Energy Directive[27] because they compete with land use for food production. Third generation biofuels (from *e.g.*, waste, algae plants) are more promising in this respect, but pose technical and geographical challenges that may limit their broad scale implementation (Lee and Lavoie, 2013). Similarly, hydrogen has practical advantages over batteries due to its high energy density and transportability but is overall less efficient as it first must be produced from electricity, be compressed, and transported to eventually generate electricity again. Research on production, transport and storage of hydrogen is however ongoing and supported by *e.g.*, the 2022 European Clean Hydrogen Alliance[28] (European Commission, 2020) and various corporate projects[29].

Electrification of transport will go hand in hand with the electrification in other sectors such as households or industry. In fact, it offers attractive synergies with decentralised systems for power production. Micro-power plants from household photovoltaics, small, local wind turbines and even water turbines could provide a significant part of the energy needed to power both smart homes and the fleet of electric cars, especially in rural environments (Erdinc, 2014). Vehicle-to-grid-transmission options that allow the electricity stored in car batteries to be used by other purposes, are under development. Since private vehicles are parked most of the time (95%), their battery capacity could be used to store excess electricity from household productions (Karlsson and Kullingsjo, 2013). In the long run, and given further research

[27] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001
[28] https://ec.europa.eu/growth/industry/strategy/industrial-alliances/european-clean-hydrogen-alliance_en
[29] https://greenhysland.eu

and development, a fleet of connected electric vehicles could provide a mobile and flexible storage for electricity and constitute a central component in a smart and resilient grid for electricity production and transmission that liberates countries from the politically disagreeable import of fossil fuels (Cuddy *et al.*, 2014; Fachrizal *et al.*, 2020).

1.3 Infrastructure development

1.3.1 Roads and railways

Roads and railways comprise not only the backbone of today's transport system but will certainly even in future carry most goods and people. Given the technological advances described above, the need for climate change adaptations in infrastructure (see chapter 2) and the increasing use of Nature-based Solutions (see chapter 4), tomorrow's road and rail infrastructure will most likely look different than what has been built during the past decades. A great challenge, especially in Europe, is to cope with the legacy of old infrastructures that have been designed for lesser traffic, lower speeds and different safety, technical and environmental standards. Several network elements are reaching the end of their working lives, some of which may be easy to reinforce or to replace, but others require substantial investments. Ageing infrastructure is an issue that demands innovative approaches for maintenance, adaptation and upgrading to ensure continued functionality while meeting future demands; or else for decommissioning to recover land (IEA, 2019; PIARC, 2020).

This provides opportunities but also the obligation to remedy the direct impact on humans, environment, and biodiversity. For example, roads and railways will increasingly need to be screened to reduce noise disturbance to lineside residents; take necessary prevention measures to reduce wildlife collisions; or be bridged to re-establish and enhance ecological connectivity for wildlife populations. Best-practice options for retrofitting existing infrastructure can be found in handbooks such as the upcoming BISON Online Handbook 'Good practice for mainstreaming biodiversity on transport' and alternative handbooks (Iuell *et al.*, 2003; van der Ree *et al.*, 2015; Borda-de-Água *et al.*, 2017; Hlaváč *et al.*, 2019). The overall need for ecological adaptation will grow further with increased traffic volumes, higher speed limits and heavier trucks. Inevitably, some of these retrofitted mitigation measures will be costly (such as ecoducts or tunnels), but many are more affordable and can benefit from synergies with other upgrading needs. For example, the discussed increase in maximum weight limits for trucks (Liimatainen *et al.*, 2020) will entail reinforcements or replacements of many older bridges by larger and stronger constructions. Where such upgrading is planned, ecological design enhancements might be integrated at only marginal costs. To take advantage of such synergies and prioritise among the multitude of mitigation needs, administrations need to develop comprehensive ecological adaptation strategies that are considered jointly with concerns for traffic safety, CO_2-emissions, and accessibility among others. Examples of such strategies can be found in *e.g.*, the Dutch and the German defragmentation programs (Rijkswaterstaat, 2004; BMUV, 2012).

For new infrastructure, there are many more options to minimise potential impacts and attempt a no-net loss in biodiversity – or even a net gain in biodiversity[30]. Clear policy directives, economic incentives and available funding (see chapter 7), as well as best-practice examples can help to integrate biodiversity

[30] https://www.iucn.org/theme/business-and-biodiversity/our-work/business-approaches-and-tools/business-and-biodiversity-net-gain

and landscape concerns already at the early planning stages in the design of future infrastructures (Bartlett, 2019). In principle, this may imply that most of the future primary infrastructure will need to be clearly isolated from the surrounding environment in order to protect and preserve natural processes as well as human values. High speed railways or highways may be either elevated or buried (tunnelled) to allow for sustained land use for agriculture, forestry or peri-urban development and to prevent unauthorised access by humans and wildlife that inhabit the landscape. Trains and cars, especially when automated and connected, could travel at higher speeds and with no risk to run into wildlife – or people. In fact, the gain in transport efficacy and traffic safety alone may provide sufficient incentive to develop the futuristic ‘Netway system’ (Forman and Sperling, 2014) where roads are encapsulated and populated by autonomous pods that run on electricity provided through the road surface. A similarly isolated system with automated transportation bots for cargo, the Swiss Cargo sous terrain[31] project, is already in planning and shall be opened in 2030. Examples of advanced and ambitious infrastructure projects with minimized surface footprint are the 1100 km long Highway E39 project in Norway with its submerged floating bridges and seafloor tunnels[32] that shall reduce travel time through Norway’s most productive coastal region by about 50% (Figure 1-4) or the 230 km long Brenner Base Tunnel system[33] improving connections along the Scandinavian-Mediterranean transport corridor, one of 9 core trans-European network corridors identified by the CEF-programme (Connecting Europe Facility)[34]. Such high-profile endeavours ought to provide ample opportunities to mainstream biodiversity concerns.

However, although decarbonisation, safety and accessibility are central objectives in these ambitious plans, the idea of ecological adaptation or biodiversity integration is not yet even mentioned. For example, the ‘Sustainable & Smart Mobility Strategy’ (European Commission, 2020)[35] only mentions ‘biodiversity’ once, as one of many impacts of infrastructure, but does not set goals or targets to limit the effects. Neither does the UK transport vision for 2015 (UKRI, 2021) acknowledge ‘nature’ nor ‘biodiversity’ in its outlook and ambitions. Also PIARC’s strategic plan for road infrastructure 2020-2023 fails to recognize broader biodiversity concerns, but at least addresses wildlife mortality and barrier effects in a specific task group (PIARC, 2020). The international railway union (UIC) maintains an expert group on sustainable land use that gives advice on biodiversity issues (UIC, 2018), and works with its railway infrastructure members within the project REVERSE[36] to publish a strategy with actions and guidelines for biodiversity. In addition, independent networks of experts, such as the Infrastructure and Ecology Network Europe (IENE)[2], can provide important assistance to practitioners, planners, and stakeholders to mainstream biodiversity in upcoming transport strategies, plans and projects.

31 https://www.cst.ch/en/what-is-cst/)
32 , https://www.vegvesen.no/en/road-projects/european-road/e39coastalhighwayroute/film/
33 https://www.bbt-se.com/en/
34 https://ec.europa.eu/inea/connecting-europe-facility/cef-transport/projects-by-transport-corridor
35 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020DC0789
36 https://uic.org/projects/article/reverse

Figure 1-4: The Coastal Highway Route E39 is the largest infrastructure project in Norwegian history and includes not only a submerged Floating Tube Bridge (SFTB) for some of the deepest and longest fjords but also the Rogfast sub-seafloor tunnel, the longest and deepest tunnel in the world today. Source: Norwegian Public Roads Administration.

1.3.2 Maglevs and hyperloops

Similar to what is described above, also high-speed trains (> 250 km/h), maglevs (> 400 km/h) and of course hyperloops (>700 km/h) have to be ‘sealed’ for technical and safety reasons to avoid potential disturbances from the surrounding. They are mostly elevated or tunnelled as a result of *e.g.*, their rigid curve-linearity and technological requirements (*i.e.*, vacuum tubes for hyperloops). This helps to maintain landscape connectivity and thus biodiversity across the infrastructure for a significant part of its length. Barrier and mortality effects on wildlife will be minimised, but disturbances from noise and vibrations may still prevail (Chen et al., 2007). In addition, they require secondary infrastructure (roads, tunnels) for construction, maintenance and service, power lines for electricity provision, and train stations with access roads and parking facilities, connecting conventional trains, and commercial development. Thus, the overall ecological footprint of these systems will be substantially larger than what may appear at first, but probably still less than compared to traditional highways or railways.

Maglevs and hyperloop systems comprise an attractive new mode of transportation similar to high-speed rail but competing with air transport at medium to long range distances. Independent multicriteria analyses indicate the high potential of these system and the competitive advantage over air travel, despite high initial investment costs and further need of technical development (Janic, 2003; Yavuz and Öztürk, 2021; Sane, 2020). Over time they will likely connect in hubs to expansive networks, just as railways did 100 years ago, but for the nearer future they may remain rather isolated facilities with little or no exchange in between, except through new highways or railway lines, which are approached with concern in the European transport market.

To cover high investment costs and in competition with air travel, transport by hyperloops and maglevs may presumably be rather exclusive and expensive. People and communities with lesser income may hence not afford to travel with these new transport systems or fail to be connected to them and instead be those that are “travelled upon”. They will bear the externalities of travel that include communities severed by infrastructure, noise and air pollution, and traffic incidents (Sustainable Development Commission, 2011; Barnes, Chatterton and Longhurst, 2019). In that they suffer from very much the same impacts as wildlife and nature (habitat fragmentation, pollution and mortality), and indeed, mitigating the impacts on social and natural values can and should go hand in hand (Bartlett, 2019). Internalisation of external effects and mainstreaming of social as well as ecological concerns are recognised as key objective in the development of a future sustainable transportation (ITF, 2021a) (see chapter 6).

1.3.3 Air transport and drones

Air transport plays a vital role in economies and will probably continue to do so despite the COVID-19 aviation crisis (EGIS, 2021), and despite the growing concern about the unproportionally high (13.9%) contribution of air travel to CO_2 emissions by the transport sector[37]. However, this requires comprehensive and ambitious plans for decarbonisation of the sector (CAA, 2022). As with road and rail traffic, biofuels offer a competitive short-term alternative to fossil fuels as they require little adaptation of existing infrastructure. Hydrogen driven airplanes will be more promising in the longer term but require new facilities and distribution systems. Battery driven planes are especially attractive for short-range flights, but here they also compete with high-speed and magnetically levitated rail. To achieve a net-zero aviation however and remain competitive with other transport modes, also airports, ground operations and suppliers must be included in the process and agree on a long-term goal consistent with the Paris Agreement on climate change (IEA, 2022).

Air travel does not free transportation from its inevitable surface impacts since air transport must use facilities for take-off and landing. For example, bird-strikes, *i.e.*, collisions of airplanes with birds, occur mostly during take-off and landing. They are not only an increasing hazard to commercial air transport (EGAST 2013) but can also affect migratory bird populations (Hu *et al.*, 2020; Nilsson *et al.*, 2021). In addition, air travel requires secondary connecting infrastructure to provide access for people and goods. As with hyperloops or maglevs, the evaluation of air travel must also consider this secondary infrastructure and its impact on the environment.

In this respect, the new drone technology may revolutionize air transport and deliver substantial economic, social, and environmental benefits. Unmanned, automated drones could be used to deliver food, medicine or even people without requiring new infrastructure or adding to urban congestion (ITF, 2021b). As drones are (mainly) battery driven, they do not directly contribute to CO_2 emissions. Delivery by drones could be especially valuable in areas that are not yet accessible by road or rail, both for people living remotely and wildlife as they would reduce the need for new linear infrastructures. Drones will not compete with long-distance air cargo transport, but open up a new niche, complementing and competing with mostly short-range road transport (Gupta et al., 2021). Before drones will be fully integrated in the transport system, however, there are yet substantial gaps in knowledge to be addressed concerning safety, privacy, and environmental impacts. Also, little is known on how much drones may affect biodiversity through e.g, collisions with and disturbance of animals (Mulero-Pázmány et al., 2017), but it is likely that certain flight restrictions will be needed to protect wildlife in critical areas and periods. Implementation of drone technology hence requires a whole set of new policies and regulatory frameworks (European Commission, 2018a).

1.4 Implications for biodiversity mainstreaming

Electrification and automation are likely to produce a safer, cleaner, and more sustainable transportation, with improved air quality, reduced CO_2 emissions and a more efficient use of transport assets that, at

[37] https://ec.europa.eu/clima/eu-action/transport-emissions/reducing-emissions-aviation_en

least partially, compensates for the anticipated overall growth in transportation. The politically enforced switch to zero-emission vehicles is already stirring up automakers, battery manufacturers and energy providers, the socio-economic benefits in form of new jobs, new industry branches and increased domestic production are expected to be significant.

Obviously, electrification of transport will significantly reduce the emission of tailpipe exhausts with the primary goal to mitigate climate change and its effects on life on Earth. Beside this overarching agenda, however, the immediate benefits for biodiversity are less evident. For example, traffic mortality in wildlife is unlikely to be affected by the choice of the propulsion technology. It will not matter to the animal if it is hit by a zero-emission vehicle or an old diesel truck. Electrified vehicles tend to be quieter at low speed and thus might be more hazardous to people and wildlife as they lack the alarming rumble of the motor. But at higher speeds, the major part of the noise a car produces derives from the friction between tire and asphalt and from air resistance but not the engine (Rybakowski, Dudarski and Kowal, 2014; Farooqi *,* 2020). Electrified aircrafts also produce less noise especially during take-off and landing (Riboldi et al*.,* 2020). This may increase the risk for bird strikes as quieter airplanes (large-bodied planes) more often collide with birds than noisier planes (Burger, 1983).

Thus, there may be only little gain in traffic noise pollution at large and noise protection facilities will be needed still, especially if traffic volume further increases. Electrification also implies reduced emissions of other noxious gases and will hence improve air quality and the spread of fertilizing nitrogen on adjacent habitats (Vestreng et al., 2009; Xu, Xiao and Wu, 2019). However, the spread of toxic, carcinogenic microplastic and nanoparticles from *e.g.*, abrasion of asphalt, rubber and brakes remains and poses a growing threat to human health and environment (Molden, 2022).

Likewise, automated and connected driving may only have limited influence on biodiversity at large. Of course, an automated driving system with its better sensors and faster responses than human drivers will be able to detect potential collision risks with animals (and humans) even at night and low visual conditions[38]. Wildlife-vehicle collisions are unfortunately common issue on roads, railways and even in airports (Rytwinski & Fahrig, 2015; Grilo *et al.*, 2020), and entail substantial socio-economic costs for vehicle repairs, traffic delays, human injuries and loss of animals (Seiler & Bhardwaj, 2020). Thus, vehicle AI can be expected to be trained to avoid collisions with larger bodied wildlife (*e.g.*, moose, deer, wild boar, etc.) as much as with human pedestrians. Smaller species, on the other hand, such as amphibians or reptiles, that do not harm traffic safety may not benefit from the vehicle's accident-avoidance software. Yet, intelligent traffic systems with ecologically oriented algorithms or wildlife-friendly driving mode could be informed about where and when to circumvent accident hotspots or reduce speed to prevent animal mortality during especially critical periods (such as reproductive or seasonal migration periods).

Overall, the major benefits to wildlife will not be through advances in automation or electrification but rather through enhanced traffic efficacy and changes in transport behaviour that may come alongside these changes. If people share rides and cars, use public transport, shift to rail or work from home offices and do daily grocery shopping locally or online, it will need fewer vehicles on the road to accommodate the anticipated growth in transportation and economy. Less road traffic means less pollution by noise and particles, less mortality in wildlife and diminished barrier effects. For example, during the strict travel restrictions of the COVID-19 pandemic in 2020, most European countries experienced a reduction in wildlife roadkill (Bíl *et al.*, 2021). When restrictions were lifted again and traffic volume was back at pre-COVID levels, one study reported that also wildlife roadkill numbers returned to baseline (Driessen,

[38] See e.g., https://www.volvocars.com/uk/support/topics/use-your-car/car-functions/large-animal-detection

2021). Less road traffic may also reduce the need for new infrastructure as long as existing roads suffice. This would counteract the growing fragmentation of landscapes and, through upgrading of existing assets, even provide opportunities to enhance current conditions for biodiversity. For example, roads may need to be upgraded with new bridges to support heavier trucks or faster trains, or to prevent hazards from increased water levels and flooding events. The new bridge design will be able to integrate biodiversity adaptations such as *e.g.*, wider bridge spans that include the entire stream ecosystem with shorelines and adjacent vegetation rather than only the current water volume (see BISON Online Handbook 'Good practice for mainstreaming biodiversity on transport'). In consequence, both terrestrial and aquatic wildlife may benefit from the technical upgrade and once again be able to migrate along with the stream corridor.

Similarly, any new infrastructure development, be it motorways, high-speed railways or airports, should also provide opportunities to mitigate the impact on biodiversity. In many cases where old infrastructure will be upgraded, improvements can be made that may enhance conditions for wildlife. To achieve a no-net-loss or even a net-gain in biodiversity values, ecological concern and knowledge about solutions must be incorporated in the entire life-cycle process of infrastructure. The same actually applies to human values as well and it is not surprising that social and environmental impacts are often mentioned jointly. In fact, the internalisation of external effects on social and ecological properties are recognised as key objective in the development of a future sustainable transportation (ITF, 2021a).

1.5 Conclusions

It is apparent that most scenarios for future transportation may not always be environmentally or socially sustainable. It will need substantial political effort, strong governance and aligned policies to counterbalance the quickly growing demand for mobility and transportation, especially at a global scale. Current developments in energy production, vehicle and communication technology will contribute to the increase in mobility but offer likewise opportunities to counteract its adverse effects and even foster a safer, cleaner, fairer and more sustainable transport system (ITF, 2021a).

This requires firstly a change in behaviour of transport users, triggered by strong policy incentives and facilitated by new technologies, towards a reduced demand for mobility while accessibility is improved. Secondly, transport must internalise the concern for those that are "travelled upon", including people and wildlife, and who bare the externalities of those who travel (Sustainable Development Commission, 2011).

What is yet needed is a holistic, large scale and integrative approach that jointly considers the cumulative impacts of growing transportation on natural capital, biodiversity habitat, ecosystem services and Nature-based Solutions - in the face of an already warming climate (Bartlett, 2019).

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2 CLIMATE CHANGE ADAPTATION AND MITIGATION OF TRANSPORT INFRASTRUCTURES AND RELATED EFFECTS ON BIODIVERSITY

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Summary

Climate change poses a fundamental threat to life on Earth. It does not only directly affect ecosystems and species; its effects also interact with other human stressors such as transportation and transport infrastructures. While numerous measures are put in place through national or global policies to mitigate global warming, other adaptive actions are still needed to prepare our society to the upcoming changes.

Limiting emissions from the transportation sector will not only help to contain the rising temperature, but it will also reduce pollution, one of the main drivers of biodiversity loss and ecosystems degradation. At the same time, these ecosystems can assist in the struggle with climate change as “sinks” that accumulate and store gases. Meanwhile, adaptation of transport infrastructure to climate change effects involves a two-pronged approach: nature-based solutions and engineered-technological solutions. Climate change adaptations also provide new opportunities for biodiversity to be better included in infrastructure projects. Still, these adaptations can be expensive, and stakeholders need to prioritize the primary areas of concern in their territory. This can be aided by better decision support-tools that highlight the vulnerabilities, risks, and exposures to climate change hazards.

Key messages

- Climate change is already impacting human societies and ecosystems;
- Public policies play a key role in mitigation and adaptation measures;
- Mitigation (to prevent further acceleration of climate change) and adaptation (to reduce its impact on transport and environment) are essential;
- Adaptation offers opportunities to mainstream biodiversity in the transport sector by means of technical as well as nature-based solutions;
- Decision-makers should employ tools to identify specific vulnerabilities in their territory and prepare adaptations measures accordingly.

2.1 Introduction

In its 6th Assessment Report published in 2021, leading scientists of the working group on the Intergovernmental Panel on Climate Change (IPCC) expressed consensus that human activities have warmed the atmosphere, ocean and land leading to widespread and rapid changes affecting both biodiversity and human themselves. A new report released in 2022 by this same working group details the impacts of climate change on ecosystems, biodiversity and human communities at numerous levels (IPCC WGII, 2022). Regardless of the effectiveness of climate change policies and measures, the European Strategy on Adaptation to Climate Change indicates that climate change hazards will increasingly affect TI (European Commission, 2021).

Improving transport infrastructures resilience to climate change effects should be brought up in line with efforts to make transportation less carbon intensive, while minimizing impacts on the environment and the climate system.

To reach that goal, adaptations must be made at local level, while mitigation is carried on at a larger scale. The European Environment Agency (EEA) distinguishes very precisely adaptation and mitigation measures[39]. Adaptation means anticipating the adverse effects of climate change and taking appropriate actions to prevent or minimise the damage climate change can cause (infrastructures direct changes and/or behavioural shifts), while mitigation is about making the impacts of climate change less severe by preventing or reducing emission of greenhouses gases (GHG) (cleaner mobility system, increasing renewable energies).

Mitigation takes decades to affect climate change impacts, so immediate actions must be taken in order to prepare for changes that are already upon us. While adapting transport infrastructure to climate change, it is also necessary to integrate biodiversity into these projects. Indeed, measures focusing on protection and restoration of biodiversity have generally important knock-on benefits for climate mitigation and adaptation. That is why treating climate, biodiversity, and human quality of life (including transportation and TI) as coupled systems is a key to successful outcomes (Figure 2-1).

This chapter will highlight the consequences of climate change in the coming decades on transport infrastructures and the associated transportation and outline possible solutions for mitigation and adaptation while promoting synergies between biodiversity and transport infrastructures.

[39] https://www.eea.europa.eu/

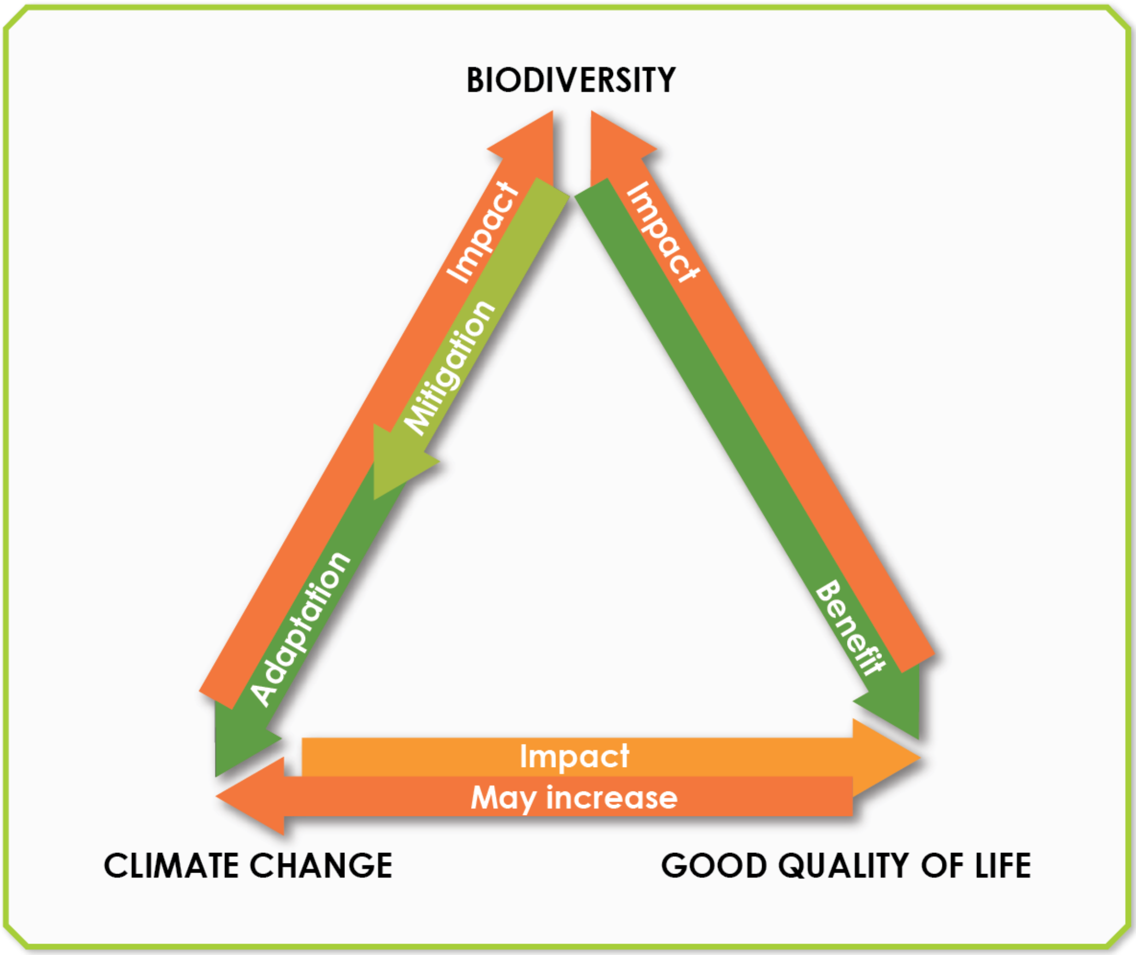

Figure 2-1: Relationship between climate change, biodiversity, and good quality of life. Blue arrows represent interactions that are predominantly threats and white arrows are predominantly opportunities. Source: Pörtner et al., 2021

2.2 Main adverse effects of climate change on TI

As climate changes continue, extreme weather phenomena are likely to occur more frequently and become more intense. The impacts of extreme weather events can be particularly severe on transport infrastructures and therefore transportation itself and the safety of users. Yet we are still in the nascent stages of understanding how climate change might affect transportation systems (Markolf *et al.*, 2019), and every possible key impact should be evaluated. Despite the uncertainty and complexity of weather phenomena, an understanding of their associated hazards and their possible adverse effects on infrastructures could produce considerable cost savings in the long term.

The different phenomena along with their associated hazards and main impacts on infrastructures and transportation are listed below (Table 2-1).

Table 2-1: Example of the physical relationship between a given phenomenon, its associated hazards, and their possible adverse effects on transport infrastructures; inspired by (Palin et al., 2021).

Phenomenon	Associated weather hazard	Secondary associated hazard(s)/ impact(s)	Impacts on TI / consequences on transportation
Temperature	High temperature	Heatwaves; wildfires	Softening and expansion of pavement (Figure 2-2); rutting and potholes; expansion and buckling of rail tracks; air cargo restrictions; destruction of electric pipelines; damages to vehicles; damages to runways.
	Large seasonal temperature range	Permafrost thaw	Roadway, railway and bridge damages; thermokarst and/or formation of icing along roads.
	Low temperature	Snow; ice; frost; freeze-thaw action	Snow-covered rail or road portions; iced track; frozen section; damage to overhead lines and signalling equipment; freezing of tunnels; destruction or malfunction; short circuit.
Precipitation	Excess precipitation	Flooding (surface water, groundwater, fluvial); infiltration; landslide	Wet road-surfaces; softened track bed; track under water (Figure 2-3); collapsing of roads/racks/pipelines; damages to cargo/equipment; damages to assets such as culverts, drainage, structure, tunnels; infrastructure slope failure; reducing of speed; ports and airfields flooding.
	Precipitation deficit	Drought; drying of soil; shrinkage cracking; landslide	Subsidence of ground; sinkholes.
Wind	Windstorms/gales	Tree fall; wind-blown objects; sand and dust storms	Direct damages on every structure; obstructions of rails or roads by heavy objects (Figure 2-4); increase of clear air turbulences; malfunction on switching and crossings; derailment of trains.
Sea level rise and atmospheric pressure	Short- and long-term changes to extreme coastal water levels	Coastal flooding; wave overtopping; tidal river floods	Direct damages on every structure; obstructions of rails or roads by heavy objects (Figure 2-4); increase of clear air turbulences; malfunction on switching and crossings; derailment of trains.

Figure 2-2: Melted road surface due to high temperature in New Delhi, India, on the 27th of May 2015. Source: ©Harish Tyagi/EPA

Figure 2-3: Rail tracks under water, Kupferdreh, Essen, Germany. Source: ©Michael Neuhaus/DB AG, provided by UIC.

Figure 2-4: Rail tracks blocked by wind-blown trees and electric pipelines, Germany. Source: ©Michael Neuhaus/DB AG, provided by UIC.

2.3 Biodiversity and transport infrastructure: a conjoint effort

Climate change is expected to have direct and indirect effects on biodiversity, from individual to biome level, most of which are currently observed: direct destruction caused by extreme weather events (flash floods, wildfire, storms), unsuitable habitat, change of migration route and fitness decrease are just a few of these effects (WWF UK, 2018). Either way, climate change is only adding more pressure on biodiversity as it was already facing habitat loss and fragmentation, poaching and unsustainable land use, leading to a huge extinction rate especially for species having limited dispersal abilities.

While mitigation has been the dominant policy response to climate change in the global community, scientists have argued that significant climate change will occur even in the event of dramatic emissions reduction in the near term, thus adaptation is vital to address these impacts. Nonetheless, mitigation efforts should be carried on, as they will benefit both biodiversity and transportation. In any case, an overhaul of existing infrastructure will be required. This offers new opportunities to include design changes that will benefit biodiversity as well.

The goal of this subchapter is to explore the challenges faced to mainstream biodiversity conservation in the context of other priorities, specifically transport infrastructures' resilience to climate change and how climate change adaptation and mitigation can affect biodiversity.

2.3.1 Climate change mitigation

Climate change mitigation is necessary in order to stabilize GHG levels in a timeframe sufficient to allow ecosystems to adapt naturally and to enable economic development to proceed in a sustainable manner. Among the EU-28, the transport sector is responsible of 27% of total GHG emissions (EEA, 2020), that is why climate change mitigation in the TI field is necessary and will benefit both biodiversity and human society in the long term. Furthermore, a decrease in traffic and fuel combustion will reduce air, water and soil pollution which are ones of the main direct drivers of biodiversity loss (Pörtner *et al.*, 2021).

2.3.1.1 The importance of policy

Previous policies have largely tackled the problems of climate change and biodiversity loss independently, and yet their mutual reinforcing means that satisfactorily resolving either issue requires consideration of the other. A significant reduction in forest degradation and destruction can contribute to lowering annual anthropogenic greenhouse gas emissions, with emission-saving estimates ranging from 0,4-5,8 $GtCO_2e\ yr^{-1}$ (Pörtner *et al.*, 2021). What's more, forest destruction accounts for around 20% of global carbon emissions, which is more than the world's entire transport sector (Greenpeace, 2018). And yet, 15% of the deforestation can be attributed to new infrastructures that serve current human lifestyle in different ways: transportation, transformation and energy generation (Youmatter, 2020).

That is why, even though the EU has set climate and energies targets (in regard to the UNFCCC's Kyoto Protocol, 1997) which have been met by most of the European countries in 2020, the national targets should also consider other factors such as the net loss of natural spaces for instance (EEA, 2021).

In order to achieve climate neutrality by mid-century, as established in the European Green Deal, a comprehensive policy approach addressing travel choices, vehicles technologies and fuels is necessary (for further details, see chapter 0), and every project should assess its impact on climate (through GHG emissions) as well as its vulnerability to climate change (Directive 2014/52/EU). At a national scale, politicians and professionals should promote educational behaviour change programs and encourage different practices:

- Minimising unnecessary travel activity;
- Compensating the carbon footprint of any travel activity;
- Improving active transportation (any self-propelled, human-powered mode of transportation: bicycle, walking);
- Using public transports;
- Carpooling.

Obviously, these behavioural changes will only happen if the educational programs are held jointly with actions from governments:

- Improving public transport (quality, frequency, network, affordability);
- Urban planning (parking and traffic restraints and fees);
- Providing bicycles and scooters as well as bicycle-related infrastructure;
- Fuel taxing.

2.3.1.2 Transport technology and/or practice

So far, fuel economy regulations have been effective in slowing down the growth of GHG emissions, but the growth of transport activity has overwhelmed their impact. Along with fuel taxing, an array of transport demand management strategies has been employed to manage traffic congestion and reduce air pollution. While these strategies can be effective in reducing private vehicles travels, they may not be enough to prevent growth in transport emissions and technological developments in fuel and engine will be key to effective mitigation strategies (Auerbach *et al.*, 2016):

- Supporting the use of public and electrified transport (through sustainable energy);
- Supporting door-to-door actions/solutions;
- Using of alternative fuels (biofuels, hydrogen, natural gas);
- Improving batteries for electric and hybrid vehicles.

Fuel switching has been a much-promoted component of decarbonizing strategies, especially in the transport industry. Fossil-fuel derived liquid fuels have been replaced by bioethanol, electricity and hydrogen (Pörtner *et al.*, 2021). These new energies derive from different sources as the use of wind power, solar power, hydropower, growth of bioenergy crops or even biological processes (microbial biomass conversion). They offer a seemingly sustainable resource while reducing carbon emissions. A European Alliance has even kicked off in 2022 to ensure that aviation and waterborne transport have sufficient access to renewable and low carbon fuels in order to reduce the transport sector's GHG emissions by 90% in 2050.

The railway sector, while already being one of the most efficient and lowest emitting modes of transport, is actively trying to reduce its GHG emission by implementing battery-powered and hydrogen-powered freight trains (IEA, 2019). Still, in order to make rail transport more attractive to car users, one of the main levers for governments is to improve and support digital door-to-door actions. Even though digital solutions concerning journey from a train station to another are widely used, the part concerning the trip from home until these stations (and backwards) still need to be developed. Citizens may find it inconvenient to walk from their home until the train station, or they don't have access to public transports information, and they resort to using their car instead. Making available an app/website providing all the information about physical continuity of the journey when moving from one mean of transport to another, may encourage citizens to use more environment-friendly modes of transport (International Union of Railways (UIC), 2021).

Concerning electric and hybrid road vehicles, the main challenges are to improve the lifespan of batteries, as well as the driving range while reducing the mining (Cano *et al.*, 2018). Indeed, for lithium batteries, the total lifecycle material resources required can exceed the weight of the battery by nearly 200 times (Kosai *et al.*, 2021). A charging stations network across countries should also be improved in order to encourage users to travel in electric and hybrid cars.

Many challenges related to mitigation measures demand large land areas (development of bioenergy crops, solar plants, wind turbines etc.). The concept of technological-ecological synergies (TES) has thus begun to emerge as an integrated systems approach that recognizes the potential co-benefits that exist in combining technological and nature-based solutions (Hernandez *et al.*, 2019). For instance, it is possible to employ solar panels on contaminated lands that would otherwise be extremely costly to restore or to utilize transpiration of vegetation underneath solar panels to cool the panels.

2.3.2 Climate change adaptation

Even if the humanity successfully limits the global temperature increase to within 1.5 °C, feedbacks and inertia in the global climate system mean that phenomena such as sea-level rising for instance will continue to increase, making adaptation essential.

2.3.2.1 Nature-based solutions

Nature-based Solutions (NbS) are defined by IUCN[40] as "actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits". NbS can have multiple purposes such as, carbon sequestration to address climate change, disaster risk reduction in relation to natural hazards or provision of benefits by green spaces in cities (Dorst *et al.*, 2019). In this subchapter, some NbS concerning disaster risk reduction will be addressed (for further details about NbS, see chapter 4).

For instance, coastal protection from sea-rising level and storms could be provided by the rehabilitation of natural barriers such as coastal wetlands (Figure 2-5), dunes and coral reefs. In the same way, inland wetlands restoration could help reduce flooding. The management of green verges along roads and railways tracks could reduce risks of flooding and landslides by stabilizing the soil and retaining water thanks to plant roots.

[40] https://www.iucn.org/commissions/commission-ecosystem-management/our-work/nature-based-solutions

Figure 2-5: Example of a natural barrier from sea-level rising and storms: coastal wetlands.

In both cases, the coral and flora management in the face of climate change can focus on maintaining current species communities, promoting native species better adapted to changing conditions (Morecroft *et al.*, 2019) or even reintroducing native species that have been driven out, mostly due to humans. Indeed, this latest conservation strategy called rewilding, can help struggling ecosystems to self-regulate and fight climate change. Either way, introducing or reintroducing species as part of a NbS should be considered very carefully in order to prevent the spreading of invasive alien species (IAS, for further details, see chapter 3).

Evidence from 13 initiatives in 12 countries shows that NbS can provide important, wide-reaching, cost-effective and long-term benefits relating to climate change adaptation, biodiversity as well as social issues (IIED & IUCN, 2019). Yet, prioritizing one of these three pillars can cause detrimental effects on the others. That is why, every dimension of a NbS project should be taken into account (for further details, see chapter 4).

2.3.2.2 Engineered and technical solutions

In this part, both engineered and technological solutions to mainstream biodiversity in TI and to adapt TI to climate change will be addressed.

When the TI are already existing, biodiversity can be directly mainstreamed in them (notably roads and railways) with actions such as building fauna passages (Figure 2-6) (underpasses or overpasses) at the same time as their overhaul. By restoring habitat connectivity, these fauna passages will allow species to migrate more easily with the changing climate.

Figure 2-6: Example of an overpass in France, allowing fauna to cross the highway RN2. Source: © O. Pichard/ Cerema.

Concerning TI adaptation to climate change, any NbS can be replaced by an engineered and/or technological solution, but these are often more expensive and are less understandable in the long term in terms of ecological coherence. Adaptation solutions are numerous and vary depending on the TI type and weather hazards, that is why the solutions mentioned in this chapter are not exhaustive.

Some measures of coastal infrastructure protection can be achieved through the construction of dikes, sea walls, and relocation or elevation of vulnerable seaports and/or airports. Based on high-end projections for sea level rise in 2100, infrastructure of coastal ports should be elevated two meters (Becker *et al.*, 2017). These measures shall go with an elevation of surrounding connections in order to ensure freight transportation.

Other measures like burying electric lines to avoid storm damages or building avalanche and landslides protection barriers can be set up. Dams can help reduce risk of flooding, as water management through an improvement of drainage system and water storage. For both roads and railways, digging a flood diversion channel will help rooting excess water away from the infrastructure (Palin *et al*., 2021). Landslide and soil erosion near infrastructure can be prevented by soil pinning, which will strengthen unconsolidated material, especially wet (Payne *et al.*, 2018).

In any case, a big part of the climate change adaptation concerns weather early warning systems. They will allow adapting transportation according to announced weather hazards, thus limiting accidents, and infrastructure destruction.

2.3.3 Main outcomes on biodiversity in regard to climate change risk mitigation and adaptation options

2.3.3.1 Positive outcomes

As mentioned earlier, ecosystems and climate are intrinsically linked, and that explains why most of the mitigation and adaptation actions benefit both the climate and biodiversity:

- Reducing air and water pollution;
- Enhancing habitat connectivity;

- Protecting habitats and individuals;
- Decreasing direct destruction and mortality.

Among the mitigation measures, one of the most obvious benefits for biodiversity is the reduction of GHG emissions, which leads to a reduction of pollution and temperature. This limits the loss of suitable habitats and coral bleaching. In addition, ocean-based renewable energy installations offer artificial reef creation, fish aggregation and basically act as marine protected areas (Inger *et al.*, 2009).

Obviously, the embedding of fauna passages in TI and the management of habitats related to TI (*e.g.*, green verges) offers habitat corridors, facilitating species range shifts under climate change. The NbS will always have positive impacts on biodiversity. They constitute positive, “no regrets” actions since they bring combined benefits at environmental, economic and social levels (UICN, 2016).

According to the report of the IPCC in 2019, wind energy development also helps reducing air pollution, combatting desertification and land degradation. Vegetation growing under solar panels provide habitats for pollinators, allowing a double-use of land and positive spill over effects (Dhar *et al.*, 2020). In addition, adaptations such as buried power lines to reduce the damages caused by windstorms, could be a solution to preventing bird electrocution and collision.

2.3.3.2 Harmful outcomes

Some climate change mitigation and adaptation can be harmful to biodiversity in different ways, in either the short or the long term:

- Direct mortality;
- Competition for land;
- Pollution;
- Habitat loss and degradation.

Mitigation actions rely a lot on the implementation of renewable energies as well as on bioethanol, which necessitate large land areas. These large areas of monoculture bioenergy crops can displace other land covers or uses (Arneth *et al.*, 2019), and have negative biodiversity implications either in the same region or elsewhere (Hof *et al.*, 2018). The same effect can be applied for implementation of solar plants. Besides, nitrogen fertilizer and pesticide used on bioenergy crops could also affect biodiversity negatively in adjacent land, freshwater and marine ecosystems (Maxwell *et al.*, 2020). In addition, N_2O emissions associated with current biofuels production practices can substantially reduce the climate mitigation potential (Yang *et al.*, 2021).

Inland and offshore wind turbine also have direct effects on biodiversity by *e.g.*, causing mortality in birds and bats population because of their blades, interfering with migration routes or with acoustic signals of marine mammals during construction (Madsen *et al.*, 2006).

Furthermore, their implementation requires specific minerals, and mining for these minerals, either in the ocean or on land, have detrimental impacts on biodiversity, especially by intruding into protected areas and remaining wilderness (Sonter *et al.*, 2020).

Overall, adaptation and especially mitigation measures should be carefully thought in order to take the best course of action regarding biodiversity conservation, climate change, TI and transportation (Figure 2-7). Each project has to be evaluated in order to reach the best trade-off between impacts and benefits.

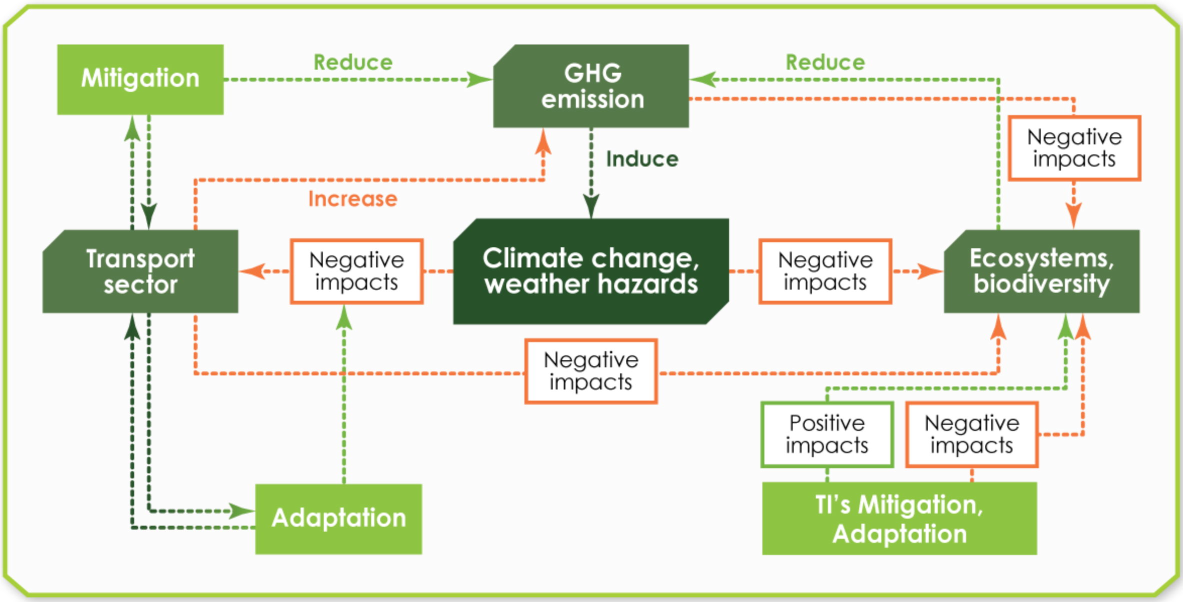

Figure 2-7: Diagram depicting the complexity of the relationships between the transport sector, biodiversity and climate change. ©Manon Teillagorry/Cerema.

2.4 Planning: challenges and opportunities

Projected climate impacts are not expected to be the same in every region of Europe, and there is not a single approach fitting all community to anticipate, plan and adapt to climate change. There is a broad array of climate change impacts and yet, available resources to assess and adapt, both financial and technical vary. One of the main challenges is to give access to stakeholders to planning and modelling tools, in order to anticipate measures to be taken both for existing TI and those to come. These tools can take numerous forms, from websites to handbooks as it has been done for the railway sector (Quinn *et al.*, 2017). At the same time, the need to plan measures to reduce climate change impacts, gives the opportunity to include biodiversity in projects where it was previously disregarded. The possibility to reduce climate change impacts on TI while enhancing biodiversity should thus be carefully assessed every time.

2.4.1 Planning and modelling tools

Planning and modelling tools exist to help institutions and governments to identify whether they should be concerned by all-weather hazards expected or just a few of them for instance. These tools raise awareness of what there is to lose (both ecosystems and transportation), leading to an anticipation of pressures to come, and then to taking actions (Figure 2-8). Delaying actions on climate change will lead to higher cost investment and higher risks exposure.

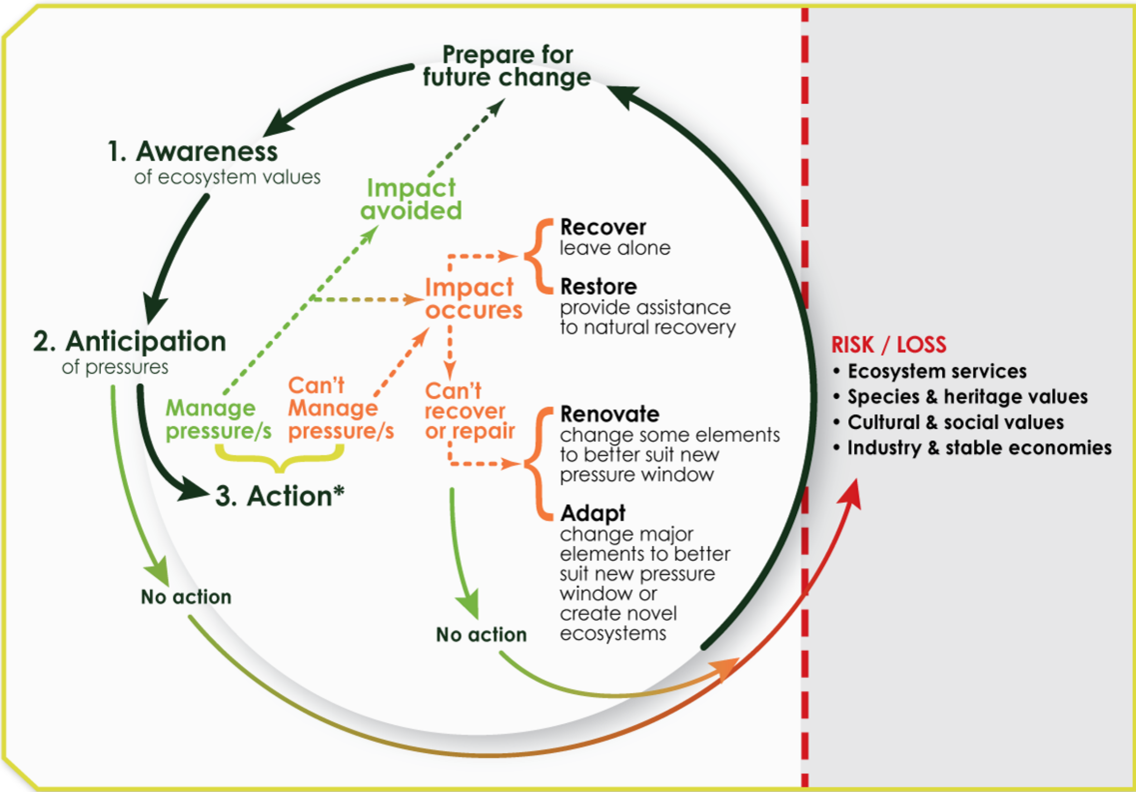

Figure 2-8: The 3A's (Awareness, Anticipitation, Action) pathway from Bergstrom et al., 2021.

In Europe, the website Climate adapt[41] proposes several tools on adaptation, risks, impacts, monitoring, reporting, etc. Several climate services are available, and information can range from seasonal forecasts (*e.g.*, forest fire, floods) to long-term projections (*e.g.*, sea-level rise).

Through the European Union's Earth Observation Program, Copernicus, many derived services are provided:

- Copernicus Climate Change Service (C3S) supports information about Essential Climate Variables (ECV) and climate observation, reanalyses projections and impact indicators;
- Copernicus Emergency Management Service (CEMS) provides information on floods, drought and wildfires for emergency response and disaster risk management;
- Copernicus Marine Environment Monitoring Service (CMEMS) provides information about the current state, natural variations and changes in the global ocean and European regional seas;
- Copernicus Atmosphere Monitoring Service (CAMS) provides consistent and quality-controlled information related to GHG (Figure 2-7), solar energy and climate forcing.

[41] https://climate-adapt.eea.europa.eu

2.4.2 Vulnerability, risks, and exposure maps

The three terms vulnerability, risks, and exposure, are defined by the IPCC as follow:

- Vulnerability is the degree to which a system is susceptible to, and unable to cope with adverse effects of climate change;
- Risk is the potential for adverse consequences on the system;
- Exposure is the nature and degree to which a system is exposed to significant climate variations.

For the three of them, the "system" refers to a human or an ecological one. By using data sets coming from various climate stations during a long period, it is possible to draw maps according to different aspects. The purpose of these maps is to highlight areas with elevated vulnerability and/or risks and/or exposure. By doing that, specific mitigation and adaptation strategies can be designed to reduce the likelihood of an event-related impact such as damage to infrastructure (Wolf & McGregor, 2013). Every map is unique, seeing as it both answers to a very specific area, problematic and public, and depends on the availability and accuracy of the data (Figure 2-9**Error! Reference source not found.**).

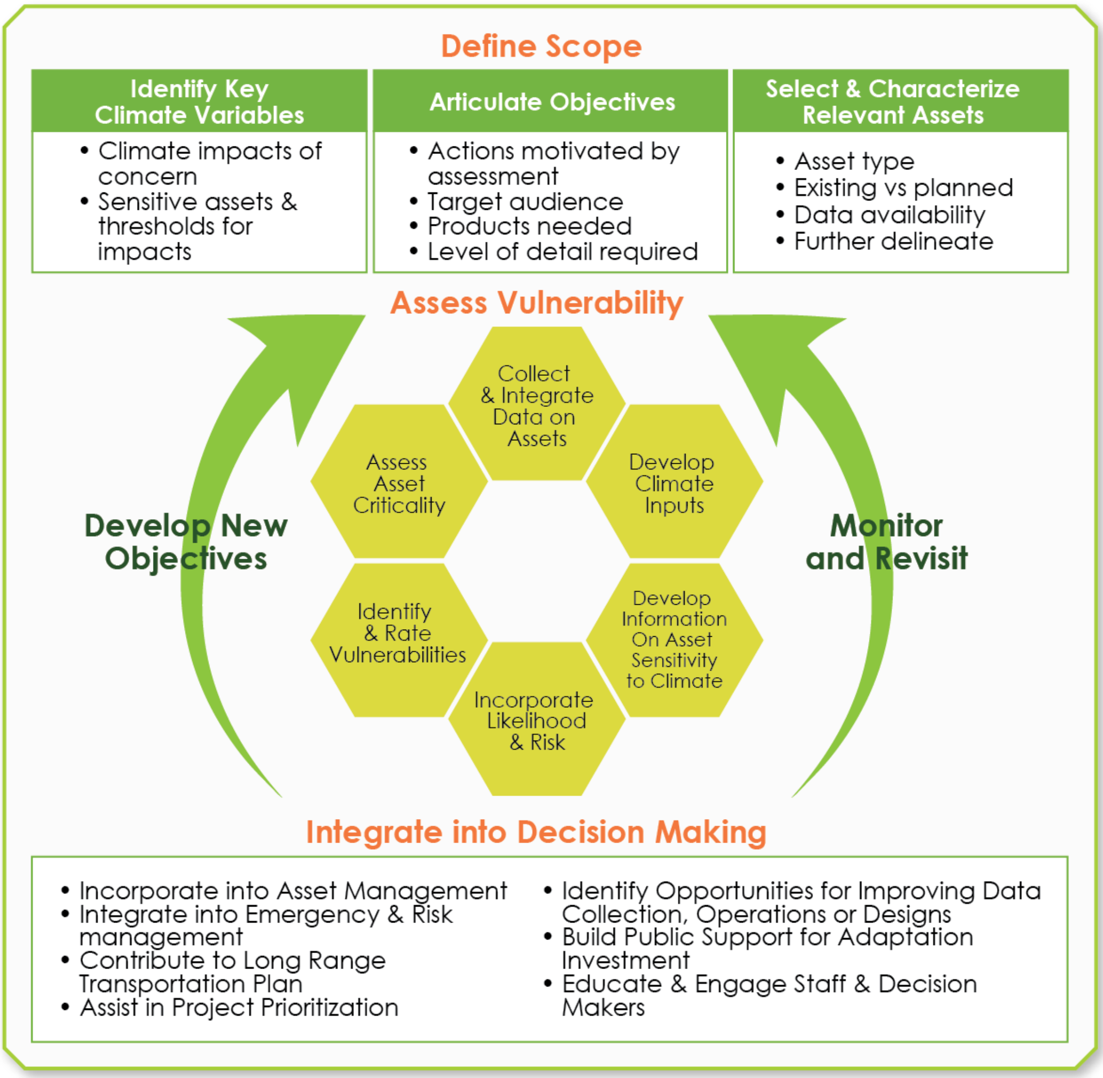

Figure 2-9: Climate change vulnerability assessment framework. Source: Valenzuela et al., 2017.

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3 INVASIVE ALIEN SPECIES AND OTHER SPECIES OF CONCERN TO TRANSPORTATION INFRASTRUCTURE

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Summary

Transport and infrastructure facilitate the spread of species around the globe that can be harmful to the new ecosystems, cause material damage to infrastructure or impose a risk to human health. These species reach places that they could not have reached on their own. Increasing human mobility and growing trade around the world, now aided by a changing climate, will accelerate the introduction of invasive species and other species of concern and thus require intensified counteraction by the transport sector.

Although for some of the most invasive species regulatory frameworks are already in place and efforts are made to control their spread, the legal situation regarding control liability is inconsistent among the EU Member States. Furthermore, due to differences in *e.g.*, climatic conditions, land use and biodiversity management, national lists of invasive species vary between countries. However, the number of species of concern, listed as invasive or not, is growing in most countries. It is indispensable to further develop the knowledge base about these species so that colonisation of new areas can be prevented, and already invaded areas can be better controlled. As the transport sector is an important pathway for the introduction and spread of species that are invasive or of other concern, the risks must be considered in the management of transport infrastructure and outbalanced by the benefits from enhancing infrastructure habitats to support native fauna and flora. This requires more holistic and internationally aligned management plans for all biodiversity.

In this chapter, we discuss the ramifications of this development with a focus on plant species linked to road and rail infrastructure.

Key messages

- Infrastructure managers will increasingly have to deal with wildlife species that cause concern to infrastructure facilities or to biodiversity.
- Risks and benefits in the management of infrastructure habitats and the employment of Nature-based solutions must be well balanced.
- Policy and legal frameworks need to be adjusted and harmonized among countries, while considering geographic differences among countries and ecosystems.
- Strategies in the control of invasive species should merge with or include strategies for the management of biodiversity in general and apply a more holistic approach.

3.1 Introduction

Our transport system benefits humans, but also a variety of other species that are actively or passively moved over long distances. Species are transported by vehicles, people or with goods find new footholds in often disturbed areas alongside transport infrastructure (TI) corridors or move actively along infrastructure in road and rail verges, canals, and natural waterways. These species can be alien to the native flora and fauna, and some are harmful as they quickly spread into adjacent habitats, outcompete and prey upon native species and restructure food webs (Gallardo *et al.*, 2016). Other species may not only impose functional damage to ecosystems in their new environment, threatens and destroys biodiversity but also damage TI facilities such as embankments (*e.g.*, Japanese knotweed*, Reynoutria japonica)* or affect human health (*e.g.*, Giant hogweed, *Heracleum mantegazzianum*). Already, the transport sector is the third largest source of such invasive alien species (IAS) (see Figure 3-1), only preceded by agriculture and horticulture. However, the introduction by the transport sector is to a very high extent made unintentionally which differs compared to horticulture and agriculture. Nevertheless, the transport sector must take on the responsibility to reduce the pathways of unintentional introduction and spread of IAS.

In Europe, there are legal and economic incentives to control the spread and survival of IAS that are of concern to TI. As transportation growths and infrastructures connect globally even further, transport authorities will increasingly have to consider alien and invasive species in their design and management plans. Some of these species might also benefit from measures that aim to protect native fauna and flora and enhance biodiversity. Some species will take advantage of the new pathways provided by Nature-based solutions (NbS), while others will advance from reduced application of conventional pesticides, and still others might establish more easily due to climate related changes in temperature and water levels. The apparent conflict between promoting NbS, enhancing native biodiversity and a possible spread of IAS and other 'problematic' species makes monitoring and maintenance central to the establishment of a functional green and blue infrastructure. Thus, improved routine measures and monitoring concepts must enable a cost-efficient maintenance of TI that promotes biodiversity while controlling IAS.

This chapter focuses on invasive plant species linked to surface infrastructures such as roads and railroads. Animal species, especially larger wildlife, are specifically linked to habitats provided by infrastructure and hence the responsibilities of the transport sector are less pronounced. We also allude to the significance of the problem with invasive species in aquatic systems, that move along canals and rivers or a spread by shipping activities (Gallardo *et al.*, 2016). Most legal constraints apply to aquatic settings as well, but the means to control and prevent IAS may be different.

3.2 Defining species of concern

In the European Union[42], IAS are defined as 'species that are introduced by human activity in modern time and that significantly harm native biodiversity, add significant costs to the economy, or jeopardises human health'. This definition puts focus on the vector of introduction, a timeframe, and the costs

[42] http://extwprlegs1.fao.org/docs/pdf/eur140066.pdf

associated with introduced species (as defined in Stohlgren & Schnase, 2006; see below). This means that species that change their natural range without human intervention are by definition considered neither as an alien nor invasive species – and do hence not legally require mitigation.

Terminology used in this chapter:

- **Alien species –** have been introduced in modern times by human activity to a new area/region/country.
- **Exotic species –** synonym to alien species.
- **Invasive species –** are alien and cause harm to native species, human health, or economy.
- **Expansive species –** are native to a country but have started to expand into new ecosystems due to changes in climate, land use, or other human activities.
- **Invasive alien species of Union concern –** are listed by the EU and entail legal obligations to prevent their introduction and spread and to control population development.
- **Species of special concern to infrastructure –** cause either legal or practical problems to the use or maintenance of transport infrastructure but are not necessarily invasive or alien species.

The European Union has established a list of IAS of Union concern in 2016 which has since been updated with new species and that currently includes 66 invasive alien plant and animal species (European Commission, 2019; see Appendix 3.1 and 3.2).

According to Regulation (EU) No. 1143/2014 (European Commission, 2014) all EU member countries are legally obliged to prevent introduction, establishment and spread of IAS included on the list of Union concern. For those IAS that are already established in a country, measures must be taken to control and eradicate their populations. In addition to this list of Union concern, EU countries may have their own complementary list of IAS that require legal action in respective countries.

In addition to the list mentioned above, there are more, native, species of particular concern to the transport sector that require management strategies and eventually specific adaptations of infrastructure. These species include species that expand their range within a country due to changes in climate or that grow and expand their populations due to restoration and rewilding programs.

Changes in biodiversity due to climate change are expected as species enter regions that were previously not inhabitable due to colder temperature or lower water level. With a changing climate, formerly benign species that inhabit lower regions may move to or be accidentally transported to higher altitudes or northern latitudes where they now survive and compete with native communities.

Restoration and regeneration of native ecosystems, reduced hunting pressure and the restricted use of pesticides, supports and promotes many native species, especially carnivores and large herbivores. Some of these species may have oppressed by human activities or been eradicated entirely from areas for decades (for example ungulates and large carnivores). As these species recover, new conflicts may occur with farming, husbandry, as well as with traffic safety simply because these human activities have been developed without considering the formerly native wildlife. Now, and especially for the coming decades, as efforts are made to enhance biodiversity, better ways to allow a sustainable human-wildlife coexistence are requested (HWCTF, 2022). The rewilding of formerly human dominated areas has clear benefits to native biodiversity and natural processes (Carver *et al.*, 2021), but may also entail costs for new mitigation measures, accident prevention and population management.

For example, wild boar populations in Sweden were eradicated historically but recover and expand currently due to the intentional re-introduction of individuals for hunting purposes. The growing number of wild boar cause significant crop damage (annual costs in Sweden about 12,3 million €; (Hedmark *et al.*, 2021) and thousands of vehicle accidents per year (Seiler *et al.*, 2019). These problems play a prominent role now, since current agricultural and road safety practices developed without consideration of the species when it was largely absent. Another example is the recovery of wild geese populations that, taking advantage of open grass habitats at airports, are increasingly involved in bird strikes with airplanes during take-off and landing (Christensen *et al.*, 2015). Here, new technologies need to be developed to detect and defer risks, adjust flight plans and manage bird populations (EGAST, 2013; Nilsson *et al.*, 2021).

Similar holds for many other native species that recover in the wake of restoration and rewilding processes. In principle, the transport sector has to resolve conflicts due to the recovery and natural range expansion of native species are similar to those caused by invasive alien species, but the intended outcome and hence the necessary means for mitigation are different (Seiler & Bhardwaj, 2020). While invasive species must be controlled and eradicated, native species that recover shall be protected and supported. Hence, both invasive and native species ought to be considered in the management of infrastructure and infrastructure habitats – be it for legal or practical reasons.

3.3 Pathways for introduction of IAS

There are several different pathways of introduction of IAS (Figure 3-1) and the number of introductions for IAS species in EU are listed as intentionally, unintentionally or for unknown reason as indicated in the European Network on Invasive Alien Species (NOBANIS) data in 2021. Not all introductions result in the establishment of a species. As a rule of thumb, about 10 % of all introduced alien non-native species succeed to survive and reproduce in a new environment and about 10% of those become invasive (*NOBANIS - European Network on Invasive Species*, 2021), also see (Arianoutsou *et al.*, 2021). Horticulture is the most prominent introduction pathway, followed by agriculture. Transport is the third largest introduction pathway. Since an introduction via ballast water and hull fouling (biofouling) are also components of the transport sector, the whole transport sector combined almost introduces as many IAS as agriculture. Horticulture and agriculture as the two most prominent introduction pathways, are almost always intentional whereas introductions via the transport sector are almost always unintentional. Naturally, an unintentional introduction is hard to control, and the impact of the introduction is often difficult to predict.

Although IAS might have originally been introduced via one pathway, it might be further spread via another pathway. The transport sector plays a central role as a vector of dispersal. In particular, verges adjacent to roads, railways, and waterways represent suitable habitats and corridors for spread for many IAS. Common examples are the knotweeds (*Reynoutria sp.),* Giant hogweed *(Heracleum mantegazzianum)* and Himalayan balsam that have been introduced by horticulture and subsequently spread by transport. Unfortunately, the responsibility to control IAS is directed consequently to the landowner, in this case, the owner of the TI.

Therefore, in order to minimise the high number of unintentional introduction of species, it is necessary for the transport sector to work together with other stakeholders to define the problems, understand the issues, and determine actions to take necessary measures.

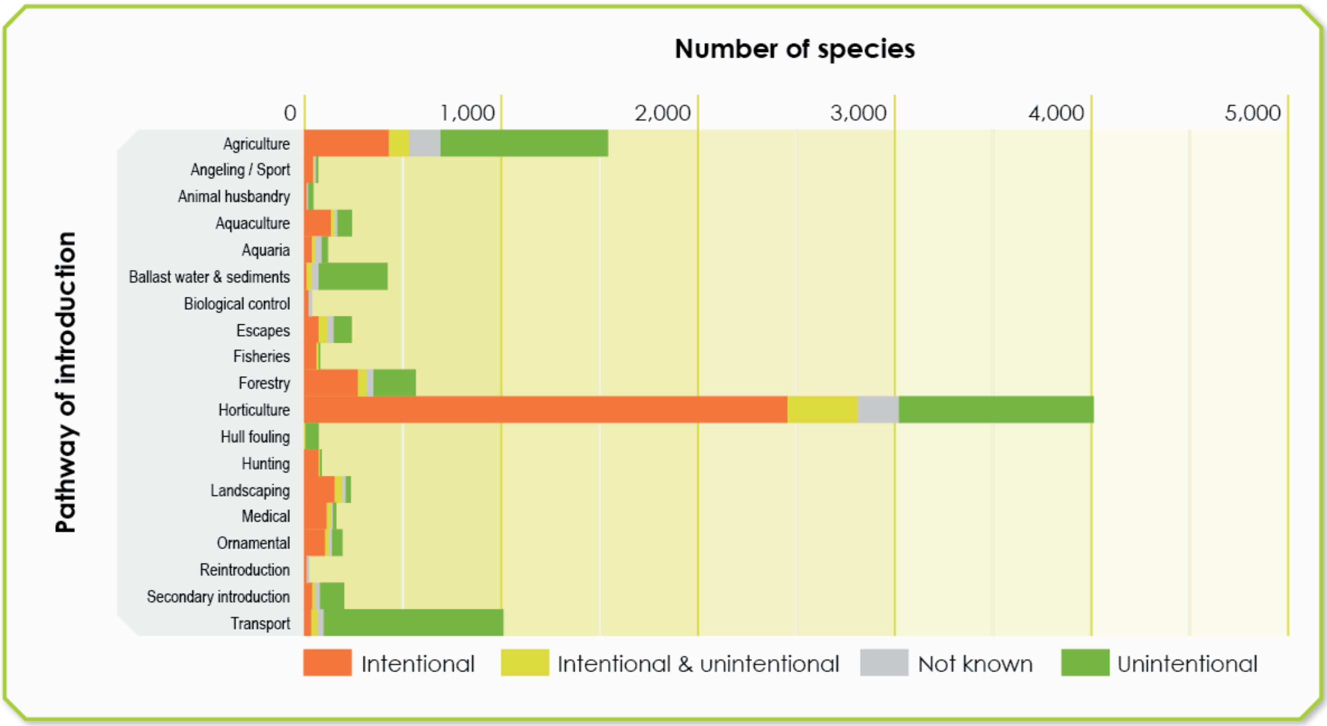

Figure 3-1: The relation between different pathways and cause of introduction on number of species introductions of alien species in Europe (for the member states of The European Network on Invasive Alien Species (NOBANIS), data from (NOBANIS - European Network on Invasive Species, 2021).

The transport sector is an efficient pathway for invasive and expansive species because of the following reasons:

- Spread along areas adjacent to roads, railways and waterways is promoted through wind, water and maintenance activities.
- Construction of TI (*e.g.*, via the movement of soils) and exploitation of new areas.
- In the marine environment, new structures that are installed in the course of TI development can be used as steppingstones for dispersal (hard substrate on naturally soft bottom environments can be used by sessile organisms).
- Construction of water canals as short cuts and connections between formerly unconnected water bodies (Geburzi & McCarthy, 2018).
- Ports act as hot spots for exotic species, to be transported to another destination (Briggs, 2012).

3.4 Transport-specific problems exceeding the EU-legislation

The list of Union concern does not include all species that are relevant to the transport sector. It is important to recognise that other plant and especially animal species may cause challenges and conflicts (see above). The main challenges related to plants that the transport sector faces are:

1. Fast and high growing plants that pose a safety risk for operation/service due to line-of-sight obstruction and cause increased maintenance efforts
2. Harmful plants that cause a health risk for maintenance and construction staff
3. Plants with strong root or rhizome systems that damage or destabilise the TI itself
4. Plants that loose above-ground biomass over winter and thus destabilize embankments through an increased erosion risk (especially along waterways)
5. Contamination of soil material with invasive species
6. Changes in regulations of the use of conventional chemical herbicides

One of the most prominent examples are the knotweeds that cause severe problems for maintenance along roads, railways, and waterways (Figure 3-2) but they are not included in the list of Union concern. Knotweed populations can cause line-of-sight obstructions along roads, damage to track beds, and erosion problems along waterways (Figure 3-3). Control of knotweeds thus demands higher effort for personnel, time, and money. As there is no legal obligation of controlling the species that are outside the list of Union concern, it is essential to raise road authorities´ awareness for the problem.

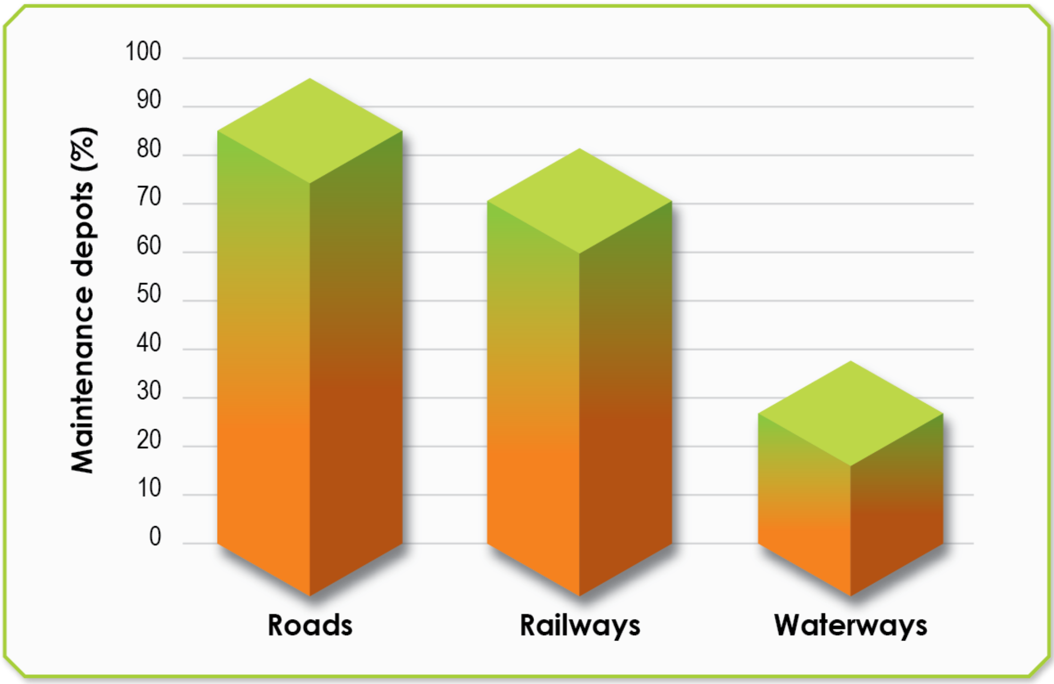

Figure 3-2: Percentage of maintenance depots for different types of transport systems that specified problems with Japanese knotweed (Reynoutria japonica) according to a representative survey in Germany (data from BASt, 2018).

Maintenance depots often deal with species of special concern regularly but often are restricted by resources. The lack of consequent management possible exacerbates problems in the transport sector. In contrast, many species included on the list of Union concern might not be seen as problematic for TI maintenance but need to be controlled according to the EU-legislation. For example, yellow skunk cabbage (*Lysichiton americanus)* does not cause a huge obstruction along TI but has to be eradicated by removing plants before they set seed. These actions are additional cost for the TI sector, and which are expected to increase in the future as more species are introduced and potentially listed.

Figure 3-3: Knotweed on the middle strip of a German highway causes high maintenance efforts as it regularly needs to be controlled (Photo © P. Bartels).

One of the most important challenges is to increase awareness of authorities to the problem independent of whether species are listed as invasive or not and to develop and provide solutions, management and monitoring concepts (UIC, 2021a). For this, offering educational training for maintenance and construction staff would be of importance. For those species that are not listed but are particularly problematic for the TI sector, other concepts should be developed. Some countries have already done this and hopefully others may follow. There are three steps that have to be fulfilled:

- Determine species that are of concern to the transport sector. Furthermore, establish an inventory of species in each member state and estimate associated costs regarding control of these species.
- Develop a central-based management concept to control those species in TI habitats.
- Establish a transnational monitoring concept and develop partnerships between stakeholders.

Naturally, such course of action requires additional resources that are currently not considered in the transport sector.

3.5 Challenges in controlling invasive species

The increasing acknowledgement of problems due to IAS may be explained by several factors *e.g.*, there is an amplified establishment of IAS when people are traveling and transport increase globally. Secondly, the general knowledge of IAS has increased and with that our attention to problems caused by IAS. These problems may therefore be a bigger threat than we up until now have realized (Brunel *et al.*, 2013). The third factor is the EU legislation (European Commission, 2014) that demands prevention, early detection, monitoring and eradication of IAS (European Commission, 2014).

3.5.1 Action list for managing IAS

Generally, as the control of invasive species is very resource-consuming, most efforts should be put into prevention (Figure 3-4). Although mitigation measures for IAS populations along TI are cheaper than extermination, not controlling them usually has consequences for adjacent biodiversity as well as TI maintenance. In the aquatic sector, prevention is the only measure as eradication is beyond means of available resources (Olden *et al.*, 2022). Exterminating an IAS from an area may be expensive, but it will also eliminate the cost of regularly managing the populations and all other measures that have to be considered when IAS are present. The most effective and most cost-efficient way to control IAS is consequently to exterminate the population rapidly when it first occurs before it expands. This, however, requires a comprehensive and continuous monitoring and reporting system that identifies and locates IAS upon their arrival.

Thus, in order to manage invasive species, the following actions need to be taken:

1. Development of an early warning system by utilising multiple approaches (*e.g.*, citizen sciences)
2. Establish a monitoring system to map already established populations of IAS and detect new arrivals.
3. Intensify control efforts near established populations of IAS to prevent their further dispersal.
4. Develop routines and priorities to eradicate stablished populations of IAS
5. Develop rapid eradication measures of newly introduced species.

Therefore, early detection and awareness of species causing problems in neighbouring countries or regions will be important to prevent further introduction of problematic species into new areas. This is not only a responsibility for TI but all sectors (see Figure 3-4). In the planning of new TI and accompanying landscape design attention should be given to measures, especially NbS, to prevent an initial establishment of IAS (Byun *et al.*, 2020; Park *et al.*, 2021).

Establishment of invasive species can be prevented through an appropriate design of habitats related to the TI (HTI). For instance, some IAS are shown to spread less rapidly in complex ecosystems that are in good ecological status (*e.g.*, Byun, Blois and Brisson, 2020). Ideally, TI related areas should thus be designed (including their management) at the step of TI planning with the goal of being as similar as possible of a complex ecosystem. Ecological engineering and NbS could provide some technical answers, like using diverse native species for early greening and soil stabilisation (Park *et al.*, 2021). In particular the integration of green and blue infrastructure into already existing structures should be a major objective as well as challenge.

According to the list above, action 2, 3, and 5 rely heavily on knowledge about single species. Therefore, knowledge about ways to prevent establishment, eradication/control methods, vectors for dispersal and how to control those vectors have to be constantly reviewed (Online handbook (forthcoming)). Attention should also be drawn to standards and guidelines of transport vehicles as given in the 2011 Guidelines for the Control and Management of Ships[43.]

[43] https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/RESOLUTION%20MEPC.207[62].pdf

3.5.2 Estimated cost of IAS

It is very hard to accurately estimate the costs that are caused by IAS. On the one hand, it is almost impossible to translate the ecological impact of IAS on biodiversity and ecosystems into economical terms (Crystal-Ornelas *et al.*, 2021). On the other hand, economic costs that are directly caused by IAS, such as costs of crop failures, costs in health care due to harmful species, are rarely accounted for nor centrally registered. Expenditures for management of IAS by the transport sector are often embedded in general maintenance costs and reliable estimates are rare (Diagne *et al.*, 2020). Nevertheless, Haubrock *et al.* (2021) recently estimated that the overall costs of biological invasions in Europe between 1960 and 2020 have increased exponentially and may sum up to 116,61 billion Euros. Annual costs per country exceed several billion euros (Kettunen *et al.*, 2008) and thus the national GDP of several countries (Haubrock *et al.*, 2021).

Due to climate change, construction of new transportation corridors and increasing global trade flows, problems with IAS and thus associated costs are expected to increase substantially in the future (Early *et al.*, 2016; Kleinbauer *et al.*, 2010; Lenda *et al.*, 2014; Seebens *et al.*, 2017; van Valkenburg *et al.*, 2014).

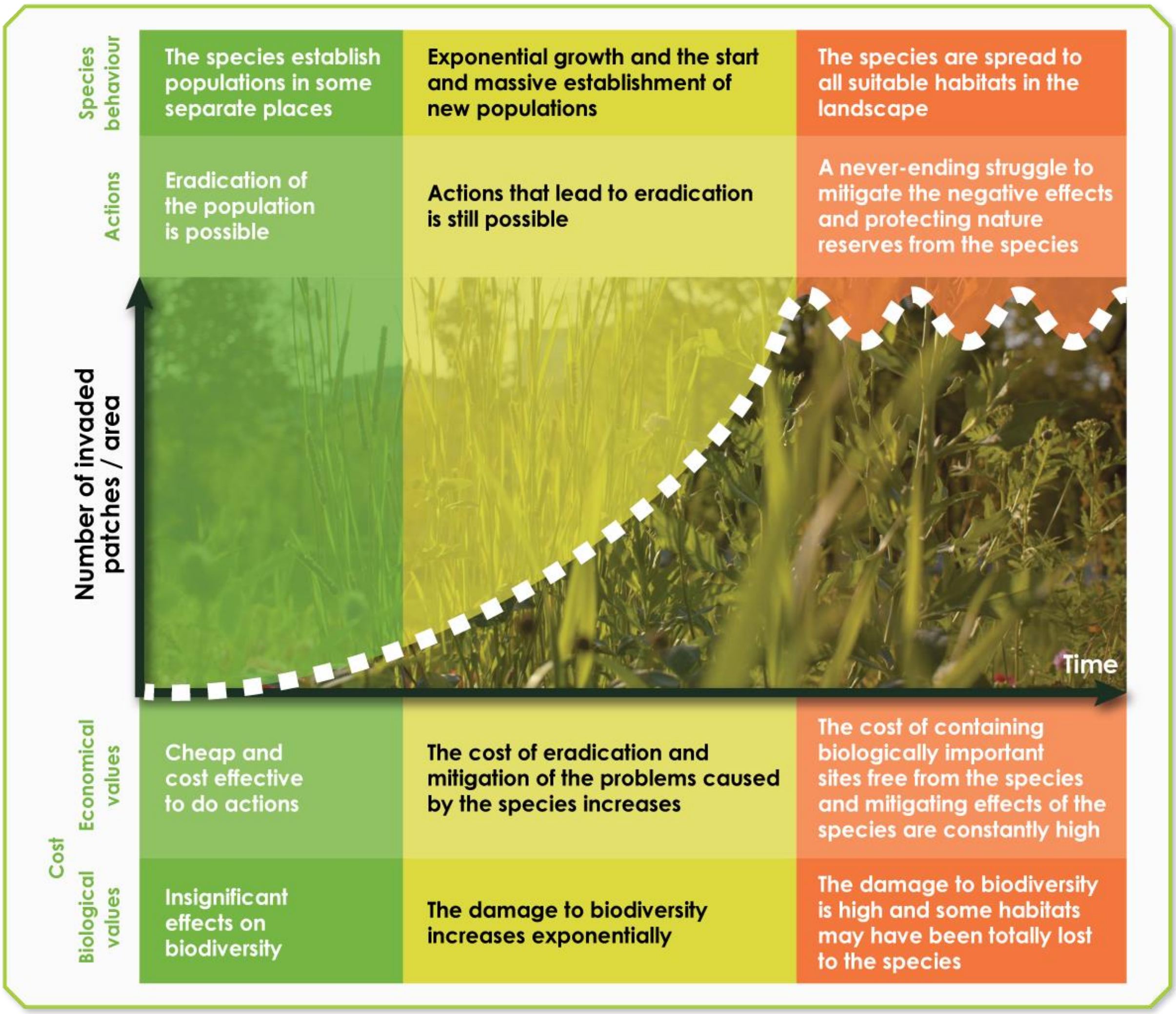

Figure 3-4: A general model for the accumulated cost in monetary and biological terms for the management of invasive alien species during different stages of their establishment.

3.6 Trends and challenges

- In the coming decades, many new species of concern to the transport sector will appear all over Europe. Global trade, travel and transport will introduce species that may act as IAS. Early warning systems and a fast onset of control programs will save money and biological values in the long run.

- Nature-based solutions (see chapter 4) must be carefully designed to prevent and control IAS across all transport sectors. Many solutions are species- and site-specific thus there is more research and effective monitoring needed to develop appropriate actions.

- There is a trend to employ alternative methods and use natural compounds instead of conventional herbicides and pesticides to eradicate IAS. Methods include *e.g.*, intense grazing by animals, mechanical methods, digital tools and preventive methods by geotextiles or anti-vegetation mats (UIC, 2021b).

- The future of chemical control agents for road and rail verge management is debated heavily by the member states and some countries acting prior to any restrictions by EU legislation.

- Concerns over the usefulness of alternative chemical control agents like organic acids have sparked lively debate among member states due to the transition toward a phase-out of conventional chemical methods.

- Caution has to be taken in landscaping along TI to adapt to climate change (see chapter 2). For example, tree species should not only be selected for water efficiency but also checked for their potential to functionally damage ecosystems.

- Both the EU list of invasive alien species of Union concern and national IAS-lists are legally binding. Thus, the transport sector, including administrations, operators and entrepreneurs, is obliged to employ methods preventing reproduction, propagation and dispersal of IAS.

- It is important that species that are not listed as species of Union concern but still cause problems to biodiversity and infrastructure are included in management programs to avoid future costs and harm to biodiversity.

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3.8 Appendix 3.1. A consolidated list of invasive alien plant species of Union concern (including the species in the updates 2017 and 2019) (European Commission, 2019).

Scientific name	English name	Entry into force
Acacia saligna (Acacia cyanophylla)	Golden wreath wattle	15-aug-19
Ailanthus altissima	Tree of heaven	15-aug-19
Alternanthera philoxeroides	Alligator weed	02-aug-17
Andropogon virginicus	Broomsedge bluestem	15-aug-19
Asclepias syriaca	Common milkweed	02-aug-17
Baccharis halimifolia	Eastern baccharis	03-aug-16
Cabomba caroliniana	Fanwort	03-aug-16
Cardiospermum grandiflorum	Balloon vine	15-aug-19
Cortaderia jubata	Purple pampas grass	15-aug-19
Eichhornia crassipes	Water hyacinth	03-aug-16
Elodea nuttallii	Nuttall's waterweed	02-aug-17
Ehrharta calycina	Perrenial veldt grass	15-aug-19
Gunnera tinctoria	Chilean rhubarb	02-aug-17
Gymnocoronis spilanthoides	Senegal tea plant	15-aug-19
Heracleum mantegazzianum	Giant hogweed	02-aug-17
Heracleum persicum	Persian hogweed	03-aug-16
Heracleum sosnowskyi	Sosnowsky's hogweed	03-aug-16
Humulus scandens	Japanese hop	15-aug-19
Hydrocotyle ranunculoides	Floating pennywort	03-aug-16
Impatiens glandulifera	Himalayan balsam	02-aug-17
Lagarosiphon major	Curly waterweed	03-aug-16
Lespedeza cuneata (Lespedeza juncea var. sericea)	Chinese bushclover	15-aug-19
Ludwigia grandiflora	Water-primrose	03-aug-16
Ludwigia peploides	Floating primrose-willow	03-aug-16
Lygodium japonicum	Vine-like fern	15-aug-19
Lysichiton americanus	American skunk cabbage	03-aug-16
Microstegium vimineum	Japanese stiltgrass	02-aug-17
Myriophyllum aquaticum	Parrot's feather	03-aug-16
Myriophyllum heterophyllum	Broadleaf watermilfoil	02-aug-17
Parthenium hysterophorus	Whitetop weed	03-aug-16
Pennisetum setaceum	Crimson fountaingrass	02-aug-17
Persicaria perfoliata	Asiatic tearthumb	03-aug-16
Prosopis juliflora	Mesquite	15-aug-19
Pueraria lobata	Kudzu vine	03-aug-16
Salvinia molesta (Salvinia adnata)	Salvinia moss	15-aug-19
Triadica sebifera (Sapium sebiferum)	Chinese tallow	15-aug-19

3.9 Appendix 3.2. A consolidated list of invasive alien animal species of Union concern (including the species in the updates 2017 and 2019) (European Commission, 2019).

Scientific name		
Acridotheres tristis	Common myna	15-aug-19
Alopochen aegyptiacus	Egyptian goose	02-aug-17
Arthurdendyus triangulates	New Zealand flatworm	15-aug-19
Callosciurus erythraeus	Pallas' squirrel	03-aug-16
Corvus splendens	Indian house crow	03-aug-16
Eriocheir sinensis	Chinese mittencrab	03-aug-16
Herpestes javanicus	Small Asian mongoose	03-aug-16
Lepomis gibbosus	Pumpkinseed	15-aug-19
Lithobates catesbeianus	American bullfrog	03-aug-16
Muntiacus reevesi	Muntjac deer	03-aug-16
Myocastor coypus	Coypu	03-aug-16
Nasua nasua	Coati	03-aug-16
Nyctereutes procyonoides	Raccoon dog	02-Feb-19
Ondatra zibethicus	Muskrat	02-aug-17
Orconectes limosus	Spiny-cheek crayfish	03-aug-16
Orconectes virilis	Virile crayfish	03-aug-16
Oxyura jamaicensis	Ruddy duck	03-aug-16
Pacifastacus leniusculus	Signal crayfish	03-aug-16
Percottus glenii	Amur sleeper	03-aug-16
Plotosus lineatus	Striped eel catfish	15-aug-19
Procambarus clarkii	Red swamp crayfish	03-aug-16
Procambarus fallax f.*virginalis*	Marbled crayfish	03-aug-16
Procyon lotor	Raccoon	03-aug-16
Pseudorasbora parva	Stone moroko	03-aug-16
Sciurus carolinensis	Grey squirrel	03-aug-16
Sciurus niger	Fox squirrel	03-aug-16
Tamias sibiricus	Siberian chipmunk	03-aug-16
Threskiornis aethiopicus	Sacred ibis	03-aug-16
Trachemys scripta	Red-eared, yellow-bellied and Cumberland sliders	03-aug-16
Vespa velutina nigrithorax	Asian hornet	03-aug-16

4 NATURE-BASED SOLUTIONS & GREEN INFRASTRUCTURE

Authors: Marine Pasturel and Sylvain Moulherat (UPGE)

Summary

Adaptation of existing and future mobility systems increasingly requires innovative solutions to adapt to face climate change and prevent the loss of biodiversity. Nature-based Solutions (NbS) is an “umbrella concept” of solutions addressing social challenges such as climate change and disaster risk reduction, supporting major EU policy priorities. NbS are expected to contribute to people inclusiveness thanks to their governance system thought both with stakeholders and users. Moreover, NbS is not only the technical intervention but develop other aspects, *e.g.*, the process to achieve it, its monitoring, or the fair distribution of its benefits. Yet, NbS is a young concept which appropriation by researchers and stakeholders is still an ongoing process, and very few studies about NbS related to transport infrastructures exist to date. NbS benefits are clearly understood, however, the current lack of explicit evaluation of the biodiversity aspect in NbS would be particularly detrimental when associated to the transport infrastructure context. Indeed, transport infrastructures could act either as a barrier or a corridor for biodiversity. NbS play a major role which has to be adequately understood and enriched with further research, development, and innovations to improve their comprehensive efficiency for climate adaptation and biodiversity conservation.

Key messages

- NbS are sustainable and economically viable alternative to conventional approaches.
- NbS is still a blurred concept under refinement and appropriation by researchers and stakeholders.
- Very few studies relate NbS to transport infrastructures.
- Explicit evaluation of the biodiversity aspect in NbS is lacking.

4.1 Introduction

Ecological adaptation of existing and future mobility systems increasingly requires innovative solutions to adapt to climate change and prevent the loss of biodiversity. NbS in their conceptual form are expected to be a sustainable and economically viable alternative to traditional approaches needed to adapt the human made systems to global changes. Preventing the loss of biodiversity and even achieving a net-gain for nature is also an expectation of NbS deployment. In this respect, NbS are expected to be inspired or supported by Nature and cover a large range of actions (*e.g.*, Figure 4-1). For example, restoring and improving corridors alongside other grey infrastructures[44, 45], and under electricity network with development of new types of pylons in order to avoid bird electrocution[46].

Figure 4-1: Habitat creation for vulnerable pollinators in Irish railway stations. Partner in the All-Ireland Pollinator Plan to create suitable habitats for vulnerable pollinators throughout the entire railway network across the 145 stations in Ireland[47].

Nature-based Solutions support major EU policy priorities in particular the European Green Deal, the Biodiversity strategy for 2030 and the Adaptation strategy to climate change[48] (Figure 4-2). The European commission has promoted the development and use of NbS as well as Green and Blue Infrastructures, enhancing knowledge, evidence, creating spaces where experience feedbacks can be shared (Raymond *et al.*, 2017), and creating awareness (European Commission, 2015; Faivre *et al.*, 2017).

Despite the fact that the recent concept of NbS seems to be a relevant tool to contribute to the EU adaptation face to global warming and biodiversity loss, recent systematic reviews point out difficulties to adequately promote the concept due to a lack of rigour in the use of NbS concept and of clear efficiency evaluation on its different aspects (Faivre *et al.*, 2017; Giordano *et al.*, 2020; Melanidis & Hagerman, 2022; Nelson *et al.*, 2020). In this section, based on a non-systematic literature review, we analysed how the NbS concept has been used to address the biodiversity preservation issue expected by NbS with an additional focus concerning the use of NbS for transport infrastructure. Based on these results, we identified the past and expected future trends concerning the deployment of NbS for transport infrastructure sustainability improvement. The expected co-benefits for biodiversity conservation have also been considered in order to identify future needs for research, development and innovation (RDI) improving the mainstreaming of biodiversity with transport infrastructure management.

[44] http://www.lifelines.uevora.pt

[45] http://www.life-elia.eu

[46] https://lifebirds.eu/en/lifebirds/

[47] https://pollinators.ie/wp-content/uploads/2019/10/Transport-Corridors_actions-to-help-pollinators-2019-WEB.pdf

[48] https://ec.europa.eu/info/research-and-innovation/research-area/environment/nature-based-solutions_en

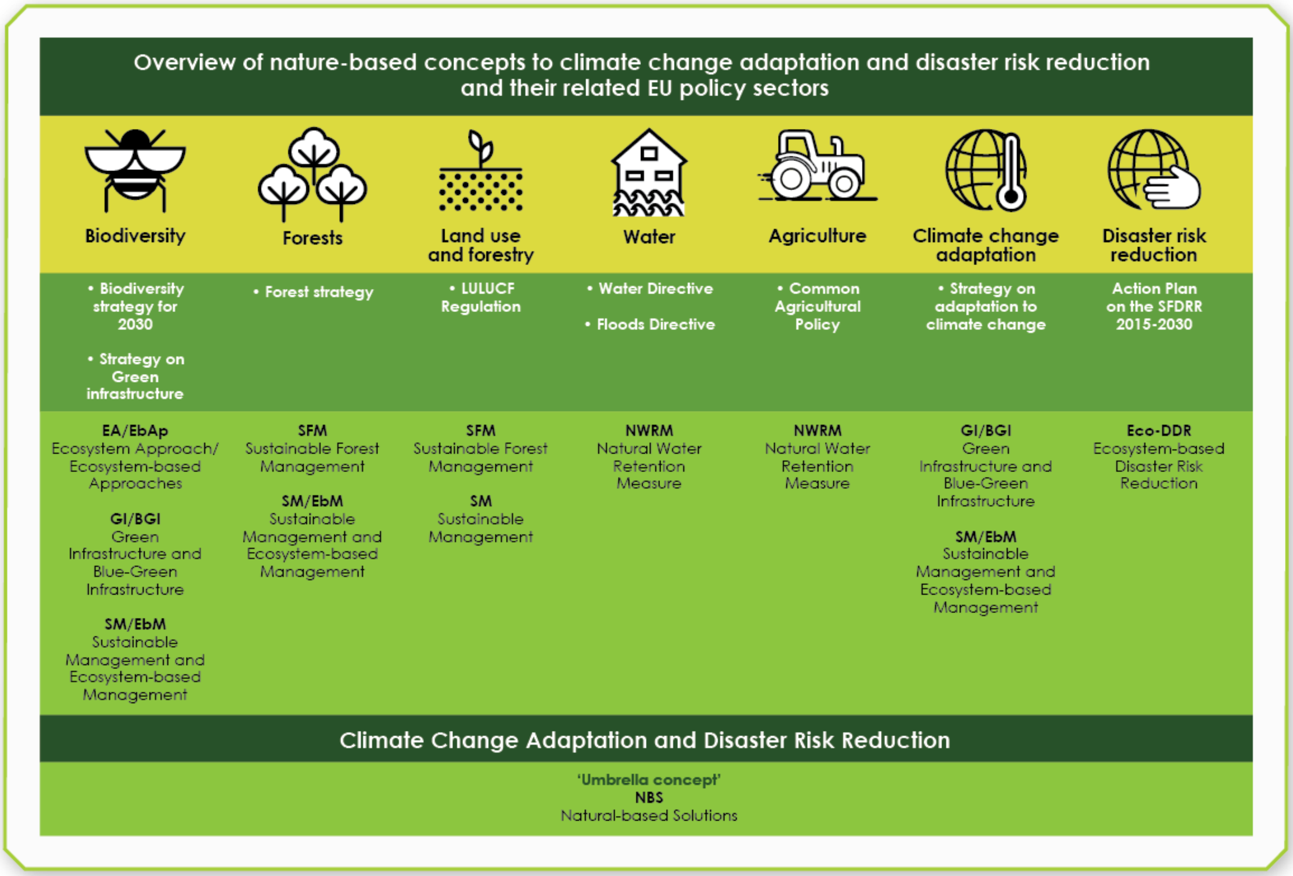

Figure 4-2: Nature-based Solutions concept from EEA for climate change adaptation and disaster risk reduction and their related EU policy sectors. Source: EEA (2021).

4.2 Current context of Nature-based Solutions and Green Infrastructure deployment

4.2.1 Definitions

Nature-based solutions (NbS) are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems, that address societal challenges effectively and adaptively, simultaneously providing human well-being and biodiversity benefits (IUCN, 2016). The EU Commission defines NbS as solutions "inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient, and systemic interventions" (European Commission, 2015). In order to support stakeholders in the design and application of NbS, IUCN edited a global standard, including eight criteria and 28 indicators (Figure 4-3 from (IUCN, 2020)). For now, the EU commission and the IUCN definitions are not fully in line, IUCN definition axing more on biodiversity and ecosystems, and EU commission more on economic and social services. Yet, current work of the EU commission tends to align the EU definition on the IUCN one.

Green and Blue Infrastructure (GBI often simplified as GI) is understood as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as water purification, air quality, space for recreation and climate mitigation and adaptation. This network of green (land, GI) and blue (water, BI) spaces can improve environmental conditions and therefore citizens' health and quality of life. It also supports a green economy, creates job opportunities, and enhances biodiversity (European Commission, 2015). GBI can therefore be considered as a specific type of Nature-based solutions with a strong focus on biodiversity conservation objectives. In addition, thanks to its strategical objective of biodiversity conservation planning, GI could be of prime interest in the design of NbS of smaller scale (Catalano *et al.*, 2021).

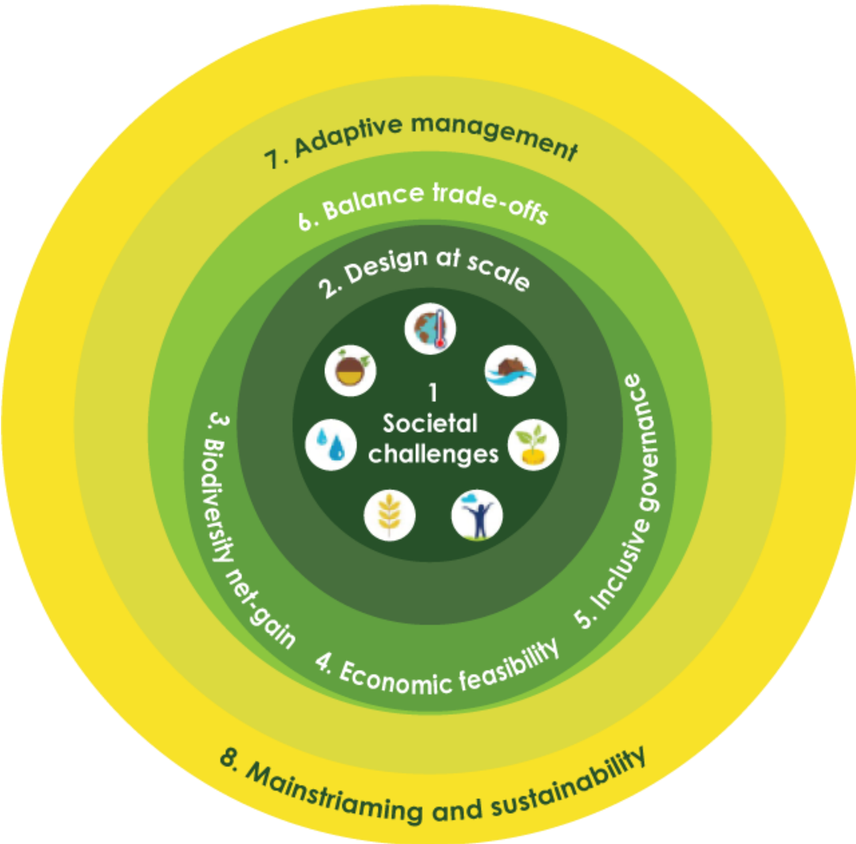

Figure 4-3: Criteria and indicators of Global Standard for NbS (IUCN, 2020).

4.2.2 Continuum from grey infrastructure to Nature-based Solutions

Nature-based Solutions is an “umbrella concept” of solutions for *e.g.*, climate change and disaster risk reduction, encompassing several established approaches, inter alia GI. In this context of climate change and disaster risk reduction, NbS are also expected to contribute to the biodiversity protection and to provide services to human being. In addition, NbS are expected to contribute to people inclusiveness thanks to their governance system (Figure 4-3). Thus, usual practices in ecological engineering like technical interventions cannot systematically be considered as an NbS. Indeed, if such practices are definitely inspired from nature, they do not necessarily provide co-benefits to human well-being nor contribute to climate change adaptation or disaster risk reduction. For example, a solution of river renaturation may not be considered as a NbS if only thought and applied by stakeholders, whereas a same solution with user involvement and monitoring effects on biodiversity could be one. Despite the Global Standard list of inclusion criteria and indicators for NbS (Figure 4-3), their understanding and application can be dependent of the project scale or involved parties. Yet, some criteria of exclusion are well-defined (Sowińska-Świerkosz & García 2022), like negative or no impact on biodiversity, same benefits as grey infrastructure alone, or unfair distribution of benefits. The use of NbS to mainstream biodiversity in transport infrastructure is one tool along a gradient of solutions which should be deployed depending on the challenges an action has to manage.

4.2.3 Literature survey concerning the use of Nature-based Solutions to mainstream biodiversity in transport infrastructure

Ecosystems and biodiversity, considered as sustainability goals, were often addressed in publications mentioning NbS, and regularly as a by-product of other goals (Figure 4-, Hanson *et al.*, 2020). However, biodiversity is barely monitored (before and after the NbS development), and it is usually considered as de facto improved by NbS (Andrés *et al.*, 2021). Very few studies concerned NbS and transport infrastructures, yet NbS are developed in order to mitigate vehicular pollution for example (Pearce *et al.*, 2021; Przybysz *et al.*, 2021).

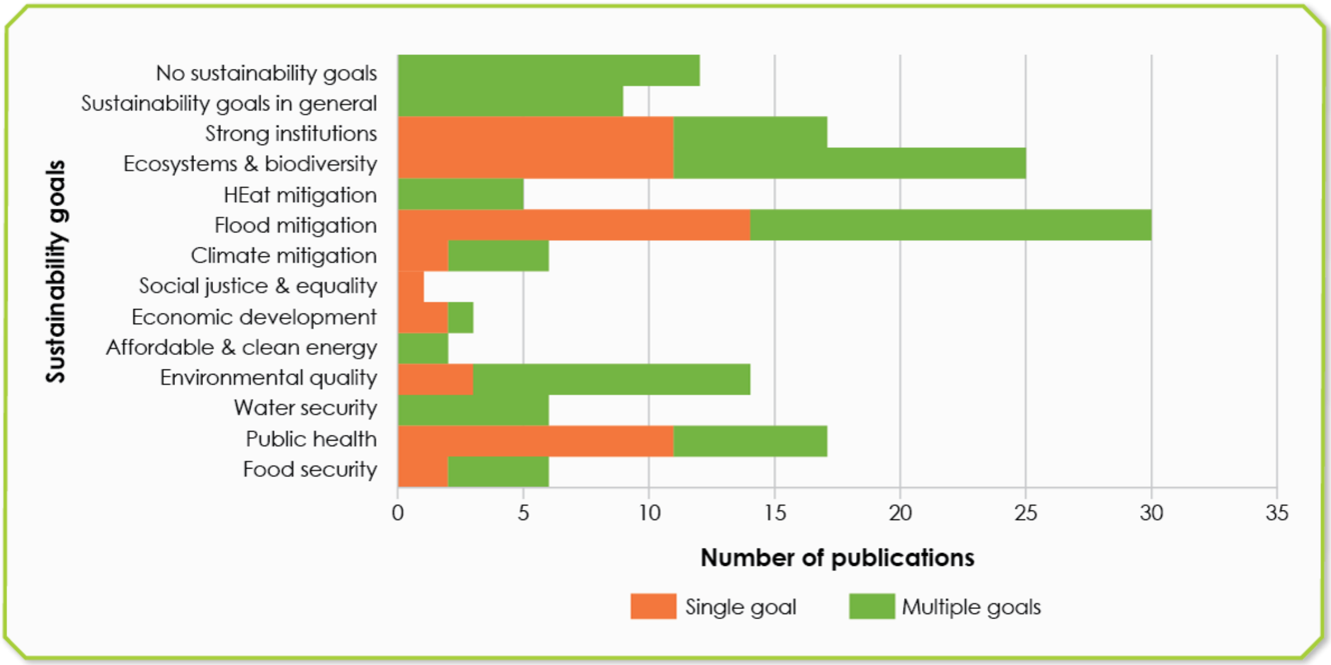

Figure 4-4: Number of nature-based solution publications addressing the sustainability targets reviewed by Hanson et al., (2020).

4.3 Trends in the use of Nature-based Solutions to mainstream biodiversity with transport infrastructure

4.3.1 Past trends

NbS is a young concept which appropriation by researchers and stakeholders is still an ongoing process (Baraldi *et al.*, 2019; Hanson *et al.*, 2020; Nelson *et al.*, 2020; Nesshöver *et al.*, 2017; Sowińska-

Świerkosz & García 2022). In the transport sector, integration of transport and GI is expected to enhance scenic value and connectivity resulting in increased benefits from leisure and tourism. (European Commission, 2015). The European Commission enhances research and use of NbS and GI (EEA, 2021), identifying knowledge gaps that need to be fulfilled, including better evaluation of the effectiveness of NbS in several aspects like environmental ones, using strategic approaches, and highlighting the synergies between NbS and grey infrastructure. Building evidence of the effectiveness of NbS should help to secure funding and use .

The recent Horizon 2020 call had mobilised EUR 1 billion funding for research and innovation on climate change and biodiversity crises, including solutions like NbS. The H2020 project Nature-based Urban Innovation[49] (NATURVATION) explored European and Member State (MS) policy support for NbS, showing that the current policy frameworks provide a basis for NbS implementation, yet highlighting the lack of quantitative and measurable targets for NbS employment.

While NbS impacts on biodiversity, social, and economic domains can be well perceived, their definition and concepts can still be mixed up with GI or ES ones, and evaluating tools still need developments (but see development of standards by IUCN (2020)). EEA (2021) highlighted the absence of NbS mention in multilateral agreements (*e.g.*, Paris Agreement) or in the conventions, and the lack of a roadmap and measurable targets for promoting the use of NbS at the EU level. Beyond the appropriation of the NbS concept, Baraldi *et al.* (2019) suggest that the use of the NbS, GI or ES terms is not so important facing the crucial role of communication about their significance for climate change adaptation.

In several studies, the term NbS is used as a key word or a final postponed goal of the research topic that could concern only GI or ES. Some authors focused either on one or two of NbS aspects (*e.g.*, ecosystem services and well-being, stakeholder engagement and inclusiveness, etc.), and only mentioning that the other ones would be de facto improved, yet the benefits of NbS are clearly recognized (Chen *et al.*, 2018; Neri-Flores *et al.*, 2019; Pearce *et al.*, 2021; Zari *et al.*, 2020). Nesshöver *et al.* (2017) highlighted the need of including other views than just market driven approaches and cash flows, and EEA (2021) asked for fulfilling knowledge gaps.

Eggermont *et al.*, as soon as 2015, highlighted the potential fear of natural scientists that NbS could address biodiversity conservation mainly (or only) in a cosmetic manner, which could generate even more pressure on natural systems. Indeed, the lack of evaluation of the whole impacts of NbS and GI sometimes, *i.e.*, not correctly applied, may lead to a negative benefit-risk balance. For example, in some studied areas, the creation of green roofs showed an increase in air pollutant concentrations due to a decrease of the horizontal flow, leading to a lower general air quality in the area. The presence and location of trees, the 3D configuration of streets and meteorological conditions must be well-studied and considered to lead to an increased air quality from GI creation (Rafael *et al.*, 2018).

4.3.2 Future trends

The nature-based solution deployment is strongly supported by the UE adaptation as well as the Biodiversity strategy and the Green deal. Thus, EEA (2021) identifies several European funds promoting NbS or GI projects (*e.g.*, Natural Capital Financing Facility, LIFE programme, Horizon 2020, and Horizon Europe call) in the frame of climate change adaptation and disaster risk reduction. Nature-based

[49] https://naturvation.eu/

solutions are therefore expected to be widely implement across the EU in the next decade to face the climate changes adaptation needs.

The transport sector would have to implement more and more NbS regardless the infrastructure life-cycle stage (*e.g.*, GI used as master plan tool for transport infrastructure design, transport infrastructure adaptation and upgrading including NbS, transport infrastructure decommissioning as green space in cities[50]). Transport and the energy transition of the sector coupled to NbS will be part of a main strategy for helping decarbonisation and promoting social, ecosystemic, and economic processes in tomorrow's cities (Cosola *et al.*, 2021).

Biodiversity conservation is also a crucial part of climate change adaptation and disaster risk reduction, that could not be removed from the NbS framework and must be included and well evaluated especially in GI projects. This is particularly true putting this last statement in perspective of the current growing population dynamic of large mammals and the rewilding trends supported by EU biodiversity strategy (Jepson & Schepers, 2016). Indeed, future NbS deployed in relation with transport infrastructure should be appropriately designed to ensure security and safety in transport in a context where large animals responsible for a large part of severe animal-vehicle collisions would be more and more increasingly present.

4.3.3 Research, development, and innovation needs to mainstream biodiversity with transport infrastructure

The strong support for NbS at the EU scale is expected to speed-up their deployment. However, this deployment must be appropriately designed to avoid counterproductive effects. In this respect, a very strong research, development and innovation need exists in order to deploy efficient NbS in the transport sector with an appropriate integration of biodiversity issues. Future research has a key role in the future of NbS concept, summarized in three potential pathways: broader and deeper, biased with stickiness to older green concepts, and an empty buzz word (Nesshöver *et al.*, 2017; Hanson *et al.*, 2020; Melanidis & Hagerman, 2022).

4.4 General need on NbS knowledge

The term GI is a general term to refer both to natural and semi-natural areas, that are strategically planned to provide ES. However, when it comes to its direct application, uncertainties are met in terms of scale, specificity, and applicability. For instance, both a single tree and a large forest could be considered GI if they are strategically planned to deliver certain benefits to people and the environment. However, it is obviously possible the fact that natural elements deliver ES without a planning strategy behind, therefore, the term GI can become less appropriate when used outside the context of planning / policymaking.

Most of NbS projects have so far explored solutions of climate change mitigation in cities, but have not evaluated their biodiversity aspects, or integrated the eight factors displayed by IUCN. Mainstreaming comprehensive biodiversity aspect (not only the ES) in NbS evaluation would be of prime requirement to benefit from the full potential of NbS in contributing to climate adaptation and biodiversity conservation.

[50] https://www.paris.fr/pages/la-petite-ceinture-et-ses-promenades-ecologiques-7855

In research papers, usually one or two criteria are used but not the whole ones making set that involves a NbS or GI (Hanson *et al.*, 2020). The timescales for implementing NbS and indicators showing its benefits must be well-defined in order to meet stakeholders' expectations. Future research must ensure the evaluation and consideration of biodiversity aspects in both urban, rural, or natural environment, as well as developing a framework that integrates the whole factors defining NbS.

Most of the NbS publications concern the urban context, nearly a quarter consider no specific land-use context, and less than 6 % forested area (Hanson *et al.*, 2020). The authors suggest that these proportions show an attempt to develop frameworks and operationalisation of NbS through conceptual and reflection papers, in order to advance the concept. However, refining the concept may also lead to a standardized interpretation into a single approach.

In Europe, too few studies concern southern countries, yet which are in the forefront of climate changes. In addition to the very few studies that concerned African and South American countries, this lack of studies in such vulnerable areas precludes the participation processes from these areas during the several steps of development and interpretation of the concept of NbS, biasing the comprehensive theoretical and empirical knowledge (Ferreira *et al.*, 2020; Whelchel *et al.*, 2018).

Future research should evaluate the improvement of public trust in the decision-making process and NbS implementation and impacts when including participatory processes. Collaboration and participation of stakeholders and citizens in the creation, development, and application of NbS is recognized as promising in order to enhance the acceptance and good use of NbS, but research must be pursued for example to adjust and mitigate the frustrations from difficulties and expectations of citizens and stakeholders (Ferreira *et al.*, 2020).

4.5 Nature-based solutions, transport infrastructure and biodiversity

Existing research on NbS, mostly conducted in cities, can benefit to ports and airports because these transport infrastructures can be part of cities, or can, at some points, be considered as “small cities”. However, the disequilibrium of NbS associated research towards urban environment makes their results of limited impacts for linear transport infrastructure. Indeed, linear transport infrastructures are largely developed in rural and natural environment rendering their interaction with biodiversity issues particularly important in the context of efficient NbS deployment. Therefore, further research on NbS would benefit from specific development adapted to the understudied transport infrastructure system. In addition to enlarging the scope of targeted built environment in NbS research, their implementation in a more natural landscape with a developed sensitivity toward biodiversity conservation issues, will constitute an interesting opportunity for an improvement in the biodiversity aspects integration in the global NbS design and evaluation.

The current lack of explicit evaluation of the biodiversity aspect in NbS would be particularly detrimental when associated to the transport infrastructure context. Indeed, transport infrastructures (particularly linear ones) are known to drive complex interactions with ecological networks sometimes acting like a barrier, sometimes like a corridor depending on species and context (Clark et al 2010, Villemey et al 2018, Ouédraogo et al 2020, Remon et al submitted). In such a complex context, further research on NbS adapted to transport infrastructure would need to adequately integrate the biodiversity management aspect in order to:

- Manage the invasive species spreading which could occur with massive NbS implementation and may have consequences on human health (*e.g.*, diseases spreading by invasive fauna vectors, allergy troubles due to invasive flora, chapter 3).
- Manage the safety and security issue which may arise with the large mammal population increase.
- Ensure the coherence between NbS deployment and conservation strategies such as the Natura 2000 network development or the rewilding initiatives.

Thus, in this context, GI would play a major role which has to be adequately understood and enriched with further research, development, and innovations to improve their comprehensive efficiency for climate change adaptation and biodiversity conservation.

4.6 References

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5 CUMULATIVE EFFECTS

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Summary

Cumulative effects of transport and infrastructure on the environment have been acknowledge over many years, but a global view considering different spatial and temporal scales is needed to deal with the upcoming challenges from climate change, invasive alien species and future transportation trends. The demand for passenger and freight transport is increasing in Europe and substantial investments are expected to be made in new and upgraded infrastructures. While the European Commission focuses on the control and regulation of the more immediate effects of transportation projects, the accumulated impacts on biodiversity are generally ignored.

To properly tackle cumulative effects of infrastructure and transportation on biodiversity, a holistic approach is needed that includes social, economic, historical (cultural) and (natural) landscape aspects. Tools and methodologies are needed to allow a follow up on the steps and concepts essential for the consideration of cumulative effects. Cumulative effects must be assessed and monitored throughout a project, at different scales, using appropriate monitoring and evaluation indicators. This should also involve building a collaborative governance and strengthen regulatory frameworks, all overseen by independent agencies. Finally, both stakeholders and the general public need to be better informed about the risks and challenges related to cumulative effects in order to be able to take informed decisions.

Key messages

- Environmental impact assessment studies should address a project's contribution to the cumulative impact - not only the immediate effects of the project itself.
- The assessment of cumulative effects must consider future challenges such as increasing demand for mobility and new transport infrastructure or adaptation to climate change and resilience to invasive species. This requires a better cooperation between all stakeholders.
- Cumulative Environmental Assessment (CEA) should be done at local, regional, and national scales applying a holistic approach that includes social, economic, historic, and cultural aspects.
- Monitoring at both overarching level and project level is essential to track outcomes in relation to critical cumulative thresholds and tipping points. This requires better guidelines and tools but also a definition of critical thresholds.
- Efficient mitigation measures addressing cumulative impacts are needed to move towards a target of net gain on biodiversity, at least a zero net loss of biodiversity and environmental values.

5.1 Introduction

This chapter defines what cumulative effects are and describes some types of them, such as growth inducing effect or cascade effects.

Before discussing cumulative effects, it is useful to redefine what are called direct and indirect effects. Direct impacts occur through direct interaction of an activity with an environmental, social, or economic component. Indirect impacts on the previous component are these which are not a direct result of the project, often produced away from or as a result of a complex impact pathway. The indirect impacts are also known as secondary or even third level impacts.

Cardinale and Greig (Cardinale & Greig, 2013) give the following definition of cumulative effects (CE): they "result from the successive, incremental, and/or combined effects of an action, project, or activity […] when added to other existing, planned, and/or reasonably anticipated future ones". In the case of Transport Infrastructure, it can be for instance the reduction of a wildlife population due to the added effects of habitat loss, its fragmentation, and the disturbance of migratory or dispersal corridors.

In the United States, the National Environmental Policy Act (NEPA[51]) regulations changed the definitions, merging direct and indirect and eliminating cumulative. The new regulations state that: "Effects means changes to the human environment from the proposed action or alternatives that are reasonably foreseeable and have a reasonably close causal relationship to the proposed action or alternatives, including those effects that occur at the same time and place as the proposed action or alternatives and may include effects that are later in time or farther removed in distance from the proposed action or alternatives." (new CEQ 2020 – 40 CFR 1508.1[44]). It is also important to highlight that the NEPA talks about 'human environment' specifically and not to biodiversity.

It is interesting to note that 40 CFR 1508.1 clarifies what the definition of environmental effects includes: "*Effects include ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic (such as the effects on employment), social, or health effects. Effects may also include those resulting from actions that may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial".*

Cumulative effects (CE) can include: i) different effects from a single project; ii) effects from other projects (past, current or future); iii) effects from other changes or actions; and iv) accumulation of insignificant effects that become significant together.

The action of cumulative effects can be of different types:

- Physicochemical transport;
- Nibbling loss of habitats and lands;
- Spatial and temporal crowding;
- Growth-inducing potential (Krausman & Harris, 2011).

[51] NEPA was signed into law on 1970 to establish a national policy for the environment, provide for the establishment of the Council on Environmental Quality (CEQ), and for other purposes. NEPA requires federal agencies to assess the environmental effects of their proposed actions prior to making decisions.

Cumulative effects can also be characterized by their scope, the speed at which a threshold is reached, but also regarding expectations from the population towards socioeconomic factors considered important and "potentially irreversible". Social, political, economic and trade choices also contribute to cumulative effects (Sadler *et al.*, 2012).

There are numerous kinds of cumulative effects, Blakley and Franks presented no less than 40 types of cumulative effects that have been discussed in EIA literature (Blakley & Franks, 2021). Examples of effects are additive, aggregative, ameliorative, antagonistic, combined, compensatory, compounding, cross-boundary, discontinuous, exponential, growth-induced, indirect, induced, integrative, linear, nibbling, secondary, sequential, space-crowded, time-delayed...

The notion of cumulative effects is not a new concept but is currently an emerging topic because of their strong impact on biodiversity. The cumulative effects of projects on biodiversity can be assessed in terms of changes to the physical and chemical conditions of the environment. Depending on the nature of these modifications, the effect on biodiversity may be positive or negative. Figure 5-1 illustrates how cumulative effects occur in the area of transport infrastructures.

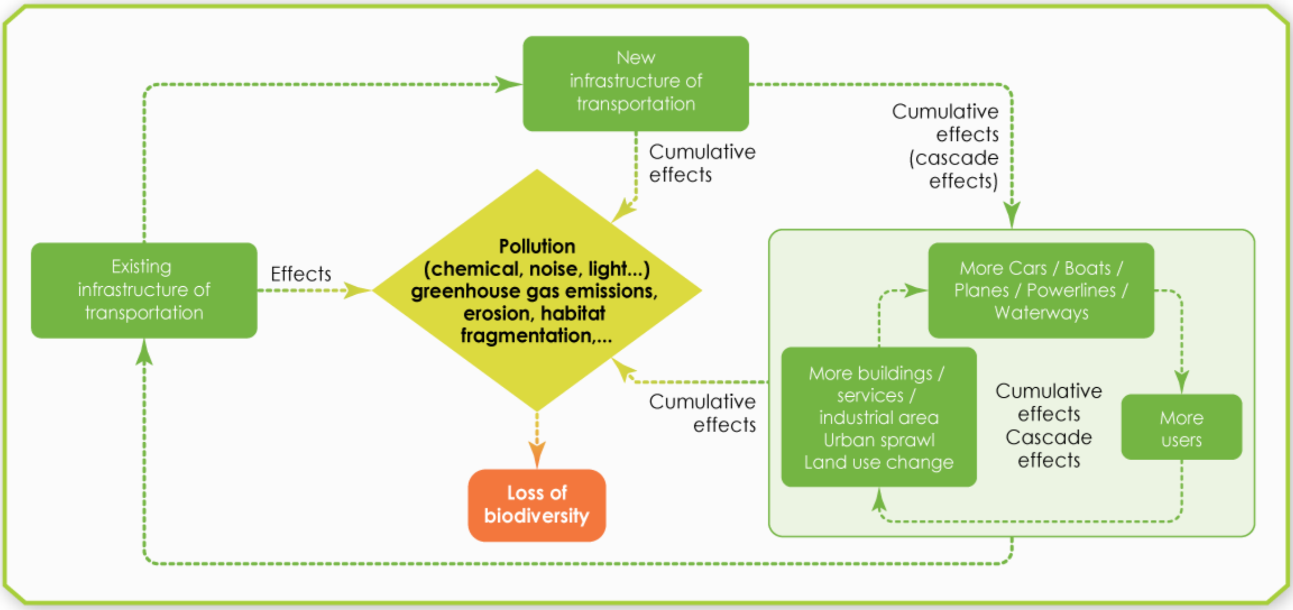

Figure 5-1: Illustration showing how cumulative effects occur within the context of infrastructure and transportation. Source Olivier Pichard adapted by John Alertas.

The European efforts to provide a legal framework for the consideration of cumulative effects should be highlighted. The European parliament and the Council have adopted the Directive 2001/42/EC on the assessment of the effects of certain plans and programmes on the environment. This text specifies that "*These effects should include secondary, cumulative, synergistic, short, medium and long-term permanent and temporary, positive and negative effects.*" Nevertheless, it is necessary for the legal texts of each Member State to define a certain level of requirement for the consideration of cumulative effects.

The purpose of this chapter is to identify some cumulative effects related to transport infrastructures, especially in relation to emerging trends discussed in the other chapters of this report.

The consideration of cumulative effects requires first and foremost an assessment and management methodology that can be applied to any emerging trends. The important thing is to take all of them into account.

5.2 Example of cumulative effects in transportation infrastructure and transportation

5.2.1 Cumulative effects with damaging consequences on environments

There are countless examples of cumulative effects. We can identify cumulative effects of two transport infrastructures (see Figure 5-2), whether close together or not, but also the cumulative effects of a transport infrastructure with the effects of other projects of any kind: housing, agglomerations, industrial zones, wind farms, etc.

There are also cumulative effects with climatic events such as droughts or floods which will be accentuated by climate change. The most important effects caused by cumulative impacts and their consequences are known to depend on various factors (*i.e.*, climate change, invasive species, public health…); not all factors are listed in this section and only the impact of transport infrastructures on biodiversity will be considered.

Figure 5-2: Examples of different combination of infrastructures of transportation. Left: Construction of the LGV Est (high-speed line) and the A4 motorway © Bernard Suard / Terra. Right: powerline and railways in Ennetières en Weppes, France. Cc-by-sa 4 Olivier Pichard, Cerema.

Cumulative effects are not limited to the accumulation of different infrastructures. A single infrastructure leads to many cumulative effects. This is particularly the case with a growth inducing effect which sees the construction of buildings, housing, artificial lights… As illustrated in Figure 5-3, there is also chemical or light pollution linked to the operation of transport infrastructures. Project cumulation often sees cumulative effects on all types of pollution by exceeding thresholds, especially air- and noise-pollution (**Error! Reference source not found.**). Fortunately, the European Noise Directive of 2022 had already foreseen the inclusion of cumulative noise from transport infrastructures (road, rail, or air traffic) in European noise mapping.

It is not possible here to detail all of these types, but we will present two important ones, which are emerging issues as they are too often forgotten in EIA: growth-inducing and cascade effects.

Figure 5-3: Cumulative effects of roadside management (chemical and noise pollution) or traffic safety (light pollution). Photos: Olivier Pichard.

5.2.2 Growth-inducing effects

Transportation infrastructures are typically intended to induce and promote growth as they provide access to resources, industrial, commercial activities and connect areas. It can thus contribute to their development, to an existing commercial area, or even create new ones (Johnson *et al.*, 2020). Growth-inducing infrastructure lead often to the growth of spin-off developments, including secondary access through rail or roads, areas of settled or agricultural lands (see example on Figure 5-4). Moreover, deforestation occurs mostly in the first few km along roads (Johnson *et al.*, 2020).

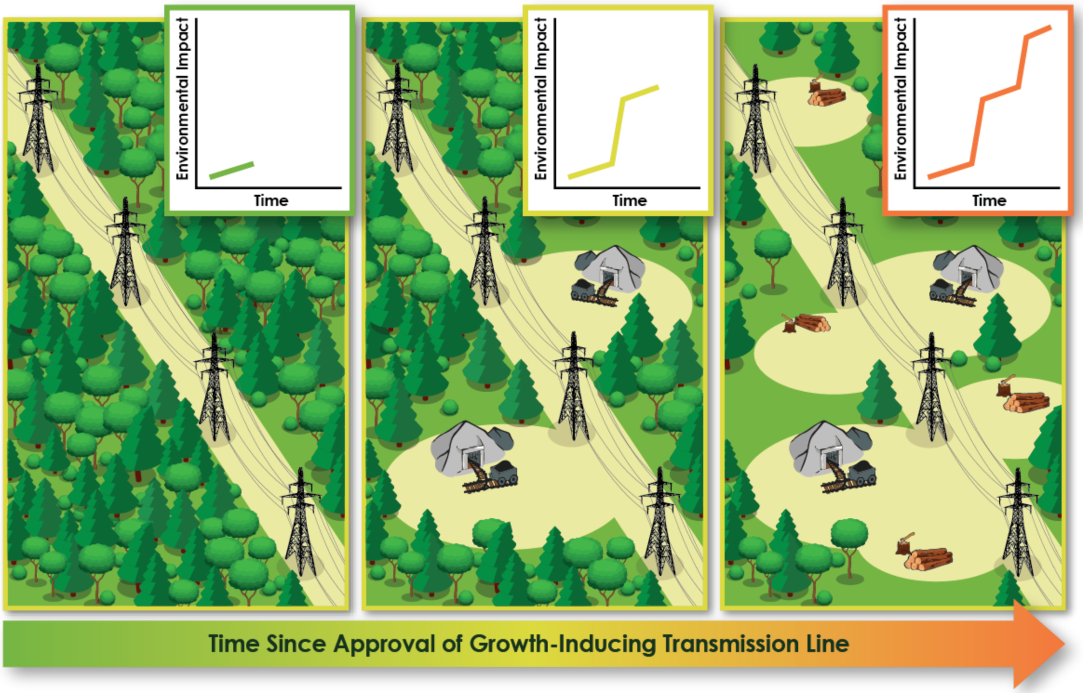

Figure 5-4: Cumulative environmental impacts resulting from the keystone decision to approve growth-inducing infrastructure. In this example, an electrical transmission line provides inexpensive energy, inducing the development of mining and the resulting mines provide new road access for forestry. Width of red line indicates development's zone of influence and the magnitude of impact (Johnson et al., 2020) adapted by John Alertas.

Table 5-1. Example of different types of infrastructure with their some direct impacts and cumulative effects

Infrastructure type	Example of direct impacts	Example of cumulative effects
New modes of transport, such as hyperloops  Source: www.transitionsenergies.com	- Alteration of natural habitats during the construction phase - visual pollution, loss of social values of the area - risk of collision with flying fauna	- creation of roads serving the infrastructure - creation of power lines to supply the infrastructure - reorganisation of the territory (housing, offices, services) according to the stations served.
Development of small airfields  Source: www.internationalairportreview.com (Palanga Airport, Lithuania)	- destruction of natural habitats, fragmentation - air pollution, especially noise pollution - light pollution	- creation of roads serving the infrastructure - reorganisation of the territory (housing, offices, services) according to airport localisation. - increased risk of animal-vehicle collision such as “bird-strikes during the operational phase (air safety)
Development of electrical powerline (linked with wind farms)  Source cc by sa 4 John Ferguson	- loss of natural habitats (hunting and breeding grounds for animals) - risk of collision with flying fauna - noise and light pollution - visual pollution, loss of social values of the area	- creation of roads serving the infrastructure - development of industrial activities taking advantage of the energy supply - loss of landscape value leading to encourage the development of industrial and commercial activities

Ng *et al.* (2019) indicated that road infrastructure development, export, education, and physical capital stock per worker contributed substantially to economic growth. This implies that policies to improve road infrastructure development, export, education, and physical capital stock should be carried out hand-in-hand in order to sustain higher economic growth (Ng *et al.*, 2019). Besides socioeconomic factors, empirical research also shows that improvements in other transport facilities and infrastructures such as telecommunications or Integrated Internet of Things (IoT) technology contributed substantially to economic growth (Ng *et al.*, 2019).

This growth inducing effect is often neglected in impact studies. It must be acknowledged that predicting the impact of transport infrastructure construction is very difficult as the impacts occur over several decades and involves unpredictable trajectories. However, growth induce effect is often caused by none or poor spatial planning, which should be limiting factor of such effect when properly conducted and with strong legal power.

5.2.3 Cascade effects

Cascade effects refer to "a sequence of events in which each produces the circumstances necessary for the initiation of the next" (Allaby, 2010).

Transportation infrastructures have an impact on their surrounding environment from their construction to their eventual decommissioning. It is the goal of EIAs to assess every possible impact, including cascade effects, while taking into account what risks the infrastructure can pose to the environment. The territory adjacent to the infrastructure may be subject to cascading effects, due to its socio-economic characteristics, which should be anticipated. For example, cascade effects of highways are the building of highway intersections, light pollution and the almost inevitable establishment of businesses and other services. But for these last two effects, they can fall under the growth inducing effect if they are not directly necessary to the built infrastructure. This also applies to airports, ports, and railways.

5.2.4 Possible positive effects of the bundling of transportation infrastructures

Habitats related to transport infrastructure (HTI) are green and blue areas associated with transport infrastructures and usually managed by transport authorities and stakeholders. These areas include verges, resting sites, water retention ponds and other drainage elements, as well as wildlife crossings (such as ecoducts). In some case, although less visible and highlighted, HTI can have some positive effects for biodiversity. However, they must be managed and maintained properly to not become ecological traps and to provide the full potential of its benefits Regular mowing and clearing of verges and maintaining grassland habitats are favourable for many plant and animal species (Figure 5-5). In areas of intensive agriculture such as fertile floodplains, are sometimes the roadside verges the only remaing green in the landscape allowing to survive to many species.

Figure 5-5: Example of possible positive effects of rail verges: regular mowing maintains a grassland habitat, sometimes relict. Source: ÖBB-Infrastruktur AG - Pano Radweg March Mhoier 2011.

Positive cumulative effects are in some cases possible in environments embedded by several infrastructures, notably when it is the result of the twinning of linear transport infrastructures (LTI), that can concern different types of LTIs, such as a highway and a high-speed line (Deshaies *et al.*, 2016).

The interstitial area between the two infrastructures can constitute interesting environments for many species (as semi-natural habitats), and act more as a filter than a barrier. Some species thrive also under conditions without predators or human disturbance.

5.3 How to better assess/evaluate cumulative effects

Given the scale and scope of a Cumulative Effects Assessment (CEA), it is often beyond the technical and financial responsibility of a single project developer and collaboration is often needed (Cardinale & Greig, 2013). One of the main difficulties in CEA is indeed the definition of the scale (time and distance), which is often minimized, especially the to evaluate landscape-scale impacts (Johnson *et al.*, 2020). For a good CEA it's better to advance it from the project level to regional scale (Seitz *et al.*, 2011) and even to national scale. Meaningful analyses and corresponding decision-making will require a shift in mindset, moving away from approaches that simply consider the individual project footprint to ones that evaluate the sustainability, management, or conservation of broader regional areas over decadal time periods (Johnson *et al.*, 2020).

5.3.1 How cumulative effects are currently dealt with in planning?

A study commissioned by the European Commission aimed to investigate the assessment of indirect and cumulative impacts, and interactions between impacts within the Environmental Impact Assessment (EIA) framework of the European Union (EU) (Parr & Johnston, 1999). This important study leads to the publication of the *"Guidelines for the Assessment of Indirect and Cumulative Impacts as well as Impact Interactions*" (Walker & Johnston, 1999). These recommendations have enabled Member States to take cumulative effects into account in impact assessments. This is notably the case in France in 2010 with the "Grenelle 2" law. This law stipulates that the impact study must include a study of the effects of the project on the environment or health, including cumulative effects identified in other projects.

Unfortunately, although cumulative effects must be analysed and studied in the dimensioning of mitigation measures, no real methodological proposal has been made to apprehend them and integrate them into the application of the mitigation sequence. In an analysis of twenty-one French EIA following the application of this law (Bigard *et al.*, 2017) showed that seventeen studies mentioned cumulative effects, twelve included an assessment of cumulative effects, nine detected cumulative effects with other projects and only two proposed to take them into account in the compensation measures. This shows that despite the fact that cumulative effects are now an almost systematic paragraph in EIAs, they are not always analysed, quantified and taken into account in the further reasoning on the equivalence between losses and gains (Bigard *et al.*, 2017). Cumulative effects must be taken into account in the process from the design to route plan of transport modes.

5.3.2 Different tools to assess cumulative effects

Though different assessment methods exist, none is universally accepted and thus several are often used. We present below some tools to better assess cumulative effects.

- **Rapid Cumulative Impact Assessment**

For emerging markets, Cardinale and Greig (Cardinale & Greig, 2013) proposed the Rapid Cumulative Impacts Assessment (RCIA), a simplified CIA (Figure 5-6). It is based on six steps, including the identification of Valued Environmental and social Components[52] (VECs) or to socioeconomic and cultural aspects; they should reflect public and scientific concerns.

- **Scenario planning**

Scenario planning in cumulative effects assessment is very useful to develop a small suite of reasonably narratives of future development and activity patterns (N. Duinker & L.A. Greig in Blakley & Franks, 2021). A scenario is "*an internally consistent view of what the future might turn out to be – not a forecast, but one possible future outcome*" (Porter, 1985).

- **Casual-Loop-Diagrams**

Another solution is to use Causal-Loop-Diagrams (CLDs) (Berariu *et al.*, 2015). CLDs are generated in order to provide useful information for decision makers. CLDs clearly visualize cascade effects which enable one to identify non-linear critical feedback processes and to analyse the behaviour of the considered system. See Figure 5-7 showing a CLDs to concrete natural disaster events, the European flood of 2002, and the European heat wave of 2003.

- **The Threshold concept**

One important tool to assess cumulative effects is to use the threshold concept (C.J. Johnson & J.C. Ray in Blakley & Franks, 2021). Thresholds are considered objective measures that define when a harmful activity should cease, because further human activities will result in an unacceptable risk to some environmental or ecological value (Johnson, 2013).

- **The safe-to-fail approach**

Scenarios in which the infrastructure fails because of its conception, intern characteristics or its environment, are rarely if not never considered. The "safe-to-fail" approach goes further by anticipating these possible failures of infrastructures, mainly in relation to climate change, and how it will affect people, to ensure that if and when they fail, the impacts on the surrounding environment will be as limited as possible or at least manageable (Kim *et al.*, 2019).

- **Innovative solution with emerging technologies**

Remote sensing and drone technologies could greatly improve to identify hot spots, the assessment of cumulative effects and to take additional precautions and mitigation measures the assessment of cumulative effects (Blakley & Franks, 2021). Prediction models could even be used to study ecological continuities[53]. In this way of prediction models, artificial intelligence could be used to improve the assessment of cumulative effects. These new tools are discussed in BISON deliverable D3.5.

[52] Valued environmental components (VECs) are defined as fundamental elements of the physical, biological or socio-economic environment, including the air, water, soil, terrain, land use and fauna and flora that may be affected by a project.

[53] Pegase project: https://www.u-picardie.fr/edysan/pegase

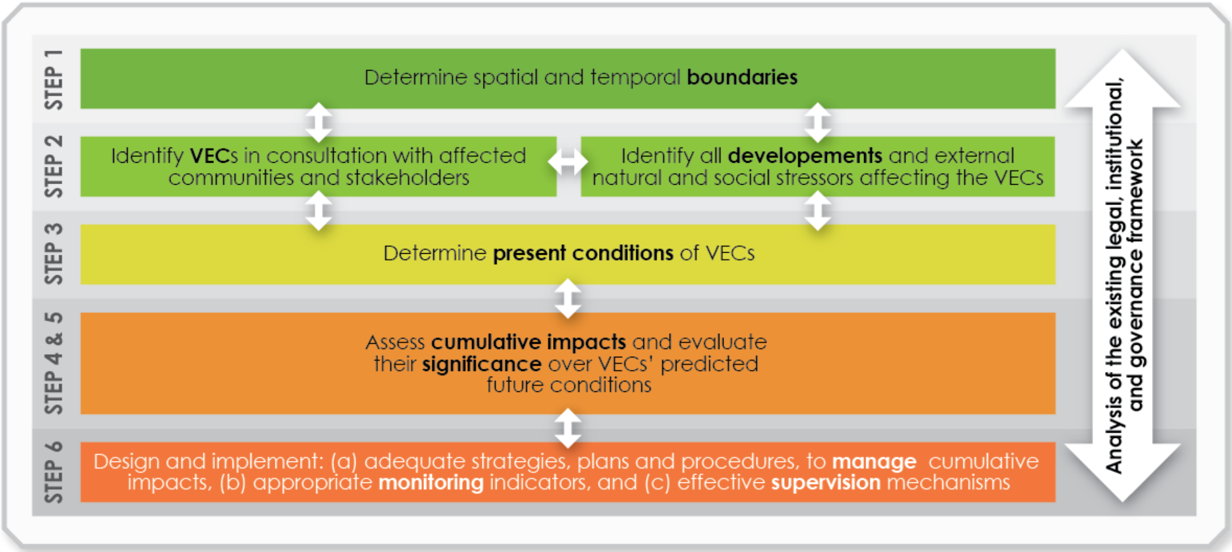

Figure 5-6: Rapid Cumulative Impacts Assessment (RCIA) (Cardinale & Greig, 2013) adapted by John Alertas.

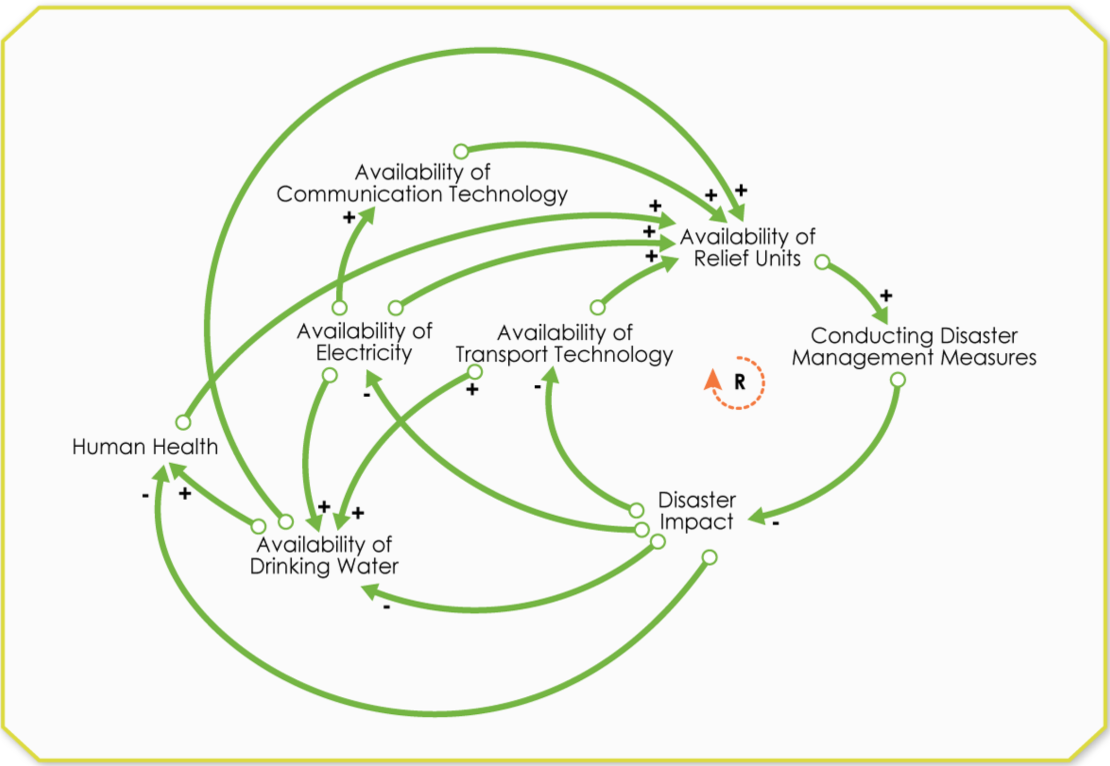

Figure 5-7: CLD of the Disaster Impact on Relief Operations—expanded with human health. Arrows are drawn to describe cause-and-effect interactions. If this interaction is positive (negative), the arrows are supplemented by a "+" ("–") sign. CLDs can be either balancing or reinforcing. Reinforcing loops strengthen change, while balancing loops are self-correcting. Source: (Berariu et al., 2015) adapted by John Alertas.

5.3.3 How to manage cumulative effects by indicators

There are several methods for defining indicators for monitoring cumulative effects, but they are often dedicated to the social, economic or biodiversity compartment without having a global vision of the cumulative effects on an infrastructure project for example (Morgan, 2009; Canter & Atkinson, 2011).

It is necessary to define indicators at different scales (local, regional, and national), for several valued environmental components (VEC) such (EAO, 2013) :

- Physical environment (atmosphere, geology, soils, surface water, groundwater...);
- Aquatic environment (Fish habitat defined by numerous parameters: biophysical and water quality including temperature, pH...);
- Terrestrial environment (plants and habitats, wildlife…)...);
- Socio-economic environment (land and resource use, population, infrastructure and services, economy, community life.…

To be effective and useful, indicators must be relevant, practical, measurable, responsive, accurate and predictable (EAO, 2013). Other frameworks use the acronym SMART for Specific, Measurable, Attainable, Relevant, and Time-Bound (Global Reporting Initiative, 2016).

There is also a need to develop tools that support the sharing of information between different modes of transport and that allow to assess the collective cumulative impact as well.

5.3.4 Cumulative effects of abandoned infrastructure

While the EIA may consider all the impacts of one or more projects combined in operation, the impact of a project left abandoned, either during construction or at the end of its life, is quite never mentioned. There are many reasons for abandonment: safety reasons, profitability, abandonment of a project that should use the infrastructure, route changes depending on demand and need etc.

EIA should also address the effects of a possible project if it ceases to operate, both positive and negative. This may involve, for example the rent or allow access to abandoned network to other private users such as on railways (*e.g.* testing sites for technical universities, beekeeping, and husbandry (grazing), transforming old freight lines in the city to green walkways).

In these cases where the land still belongs to the transport sector, the EIA should not ignore the cumulative effects of these lands that support social activities and contribute to the economy.

5.4 Main challenges for mainstreaming cumulative effects evaluation

- **Build a collaborative governance**

In most cases, the consideration of cumulative effects is hampered by a problem of governance and coordination. In addition, the large number of actors involved in a project often leads to a dilution of responsibilities. Environmental management issues need a collaboration involving government and nongovernment entities, and community participation (Margerum in Blakley & Franks, 2021). There is a need for projects collaborative governance to involve transport infrastructure and biodiversity management.

Collaborative governance responds to increasing demand for more participatory and inclusionary approaches to decision making, embracing the knowledge, concerns, and participation of citizens and interest groups as a key component of its approach (Rongerude & Sandoval, 2016). Collaborative governance recognizes that information comes not only from scientific study and assessment but from citizens and interest groups too because they are also observers and information collectors who can augment scientific information (Margerum in Blakley & Franks, 2021).

- **Promote independent agencies dedicated to evaluating cumulative effects**

The implementation of collaborative governance for all kinds of effects is hampered by many legal policy and structural barriers. To improve governance, one solution would be to create an independent agency, financed by public or private funds but with no links of interest to a specific project or group.

Governance must also allow project leaders to have the most complete vision possible of the feasibility and possible impacts of their project before they invest money in it. Indeed, once money has been invested, it will be more difficult to give up on a project.

- **Strengthen regulatory obligations and collaborations**

The cumulative effects of all modes of transport that may interact with each other should be considered together before and during the design phase.

A decentralised and liberal system often leads to each partner seeking the highest return on its investment, often at the expense of detailed analysis about cumulative impacts. This could be changed only by strong and ambitious legal decision, or by external pressure from a citizen's collective, a non-governmental organisation or others that create a demand for a response.

- **Setting up an observatory of cumulative effects**

There is a need for a national and international tool or organisation for monitoring program on the state of the environment and biodiversity to provide a background of data against which cumulative effects can be detected and evaluated. Establishing such a monitoring system cannot be the responsibility of the transport sector but must be governed at an overarching level. The creation of monitoring indicators is a good support for an observatory of cumulative effects and a prerequisite for defining thresholds.

- **Setting thresholds and mitigation measures**

It is important to define the different types of thresholds. These are thresholds beyond which the cumulative effects are too great on biodiversity and society for a project to be acceptable. If the project is acceptable, it is then important to define the mitigation thresholds to be reached to achieve net gain or at least no net loss of biodiversity and social value.

- **Improve awareness of cumulative effects among the general public and stakeholders**

Local populations are impacted by the cumulative effects of several projects rather than by the impacts of one project., *i.e.*, by an accumulation of “small impacts rather than a few big ones” (Sadler *et al.*, 2012).

The terms “cumulative effects” or “cumulative impacts” are little known, despite the fact that they are the cause of the most well-known environmental problems, such as global warming, acid rain or biodiversity loss (Krausman & Harris, 2011).

Folkeson *et al.* (2013), pointed out a number of issues regarding the consideration of cumulative effects in the environmental impact assessment of transport infrastructures, on social, economic and methodological aspects. There is indeed, generally, a lack of consideration and awareness of cumulative effects by transport infrastructure planners. Their perception and definition of cumulative effects is not homogeneous, and neither is the method to assess the threshold and/or the relevant impacts (especially the qualitative ones, and for small projects) that make up cumulative effects.

There is also a need to better aware general public and stakeholders about cumulative effects.

5.4.1 Cumulative effects of new infrastructure and new transportation mode

As we saw in section 1, new modes of transport such as High-speed trains, hyperloops or others will lead to the design of new infrastructures. Some of these will have characteristics similar to existing infrastructure and it will be possible to transfer knowledge about their cumulative effects. Some infrastructures will have no equivalent, such as hyperloop infrastructures. The assessment of cumulative effects for these new modes of transport will then have to be particularly considered at all stages of their deployment. The methods presented above will still be applicable, but the new characteristics of these will have to be incorporated.

The future of transport opens up new challenges for cumulative effects and reinforces the need for a cumulative effects observatory to collect as much feedback and methodology as possible to deal with them appropriately.

5.4.2 Key research point

While it is sometimes relatively easy to identify the impacts of a project, such as the loss of habitat for the construction of an airport, it can be very difficult to understand all the impacts correctly, whether direct, indirect, or cumulative. The study of cumulative effects makes this work even more complex because it is sometimes impossible to predict how different projects will evolve and interact with each other. Beyond that which is not foreseeable, we study everything that can be "reasonably" studied from our point of view. Known, easily measurable effects. But there are effects which impacts on biodiversity are difficult to measure, whether on a local or regional scale. We could mention, for example, the impact of a project on local hygrometry, the consequences on aerology, on the distribution of soil microfauna or even genetic competition. On this last point, the fragmentation or, on the contrary, the restoration of ecological continuities can have a direct impact or cumulative effect on the genetic drift of populations that have become isolated or respectively to the endemic diversity of remnant populations. This could be a field of research to explore.

Response times of wildlife populations to habitat loss and fragmentation induced by linear infrastructures (and other land uses), *i.e.*, the delay after which a species is affected (in terms of population size, genetic structuration, etc.), are not well known and should be considered in CEA (Blakley & Franks, 2021).

5.5 Conclusions

Cumulative effects are not sufficiently integrated throughout the life of a project, from the strategic planning to its decommissioning. The many emerging issues mentioned in the previous chapters, such as climate change, invasive alien species, future transportation trends, and so on are all new issues to be integrated into the assessment of cumulative effects. Successful integration of these issues will necessarily require tools and procedures that still need to be better defined. Finally, it is essential that strong and restrictive regulatory measures are enacted to oblige project managers to take full ownership of this issue.

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6 SOCIAL PSYCHOLOGY DIMENSION

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Summary

The social dimension of transportation has many facets linked to biodiversity and the challenges imposed by changes in technology, demography, economy as well as climate. To achieve a public understanding of these challenges and yield acceptance for the urgent adaptations, we must better understand the key psychological mechanisms that drive alter individual behaviour and attitude.

As the COVID-19 pandemic demonstrated, people are capable of adapting fairly quickly to new constraints: some people relied on bicycles to avoid public transport while others favoured teleworking, resulting in fewer journeys, less traffic and thus less pollution. But this response was triggered by the feeling of an immediate and controllable danger to personal health. The loss of biodiversity and climate change have large-scale and long-term consequences that may appear out of reach to an individual and hence are less likely to affect transport behaviour. Modern neuroscience, behavioural and evolutionary psychology help to better develop actions to contemplate emerging challenges and responses. This applies to the general public, for example by employing participatory science, but also to stakeholders by encouraging a holistic approach in sustainable infrastructure projects. For a proper consideration of the social-psychology dimension, it is important that planning and impact assessments integrates both ecological aspects (biodiversity, ecosystem services) and psychological, social, and cultural aspects.

New vehicular and communication technologies will change transportation and (hopefully) reduce the need to travel, while still providing opportunities to maintain social ties, obtain goods and services, or enjoy leisure activities - that do not require access to a personal car. Economic constraints and policy incitements will change travel pattern towards increased shared and public transportation and challenge the need to further upgrade and expand traditional infrastructures.

In this chapter, we discuss some new challenges and solutions related to psychology and human behaviour for mainstreaming biodiversity in the transport sector.

Key messages

- Behavioural sciences, psychology and evolutionary psychology tell us that the human brain, by design, has difficulty in relating to complex and large-scale issues such as loss of biodiversity or climate change, and instead rather focuses on short-term concerns.

- Behavioural sciences allow us to better understand how to make the general public as well as stakeholders responsible actors of change, allowing them to better adopt challenges and accept necessary changes.

- Social values and ecological values need to be considered jointly in the planning and design of transport infrastructure and in parallel to technical, economic, and environmental concerns.
- People are likely to consider biodiversity mostly in relation to other more personal values such as cultural heritage or recreational activities.
- Any solution based on environmental morality, encouraging solidarity and cooperation will make it easier for the public to engage in environmentally friendly projects

6.1 Introduction

The social psychology dimension is a cross-cutting issue in almost every chapter of this document. In this chapter, we wanted to take a step back and highlight new knowledge on how to approach the issue of the relationship between people and transport in relation to biodiversity. Social psychology issues are also addressed in relation to the topics covered in the other chapters.

The social psychology dimension of transportation and biodiversity is also addressed, being another emerging challenge for stakeholders and society as a whole. These transport needs will have to deal with emerging issues such as climate change, air and water pollution, noise, and the sharing of travel space.

In this chapter we will look at the main challenges facing the public in the fields of travel and infrastructure in relation to biodiversity and how they will be able to adapt to them, particularly by taking into account new knowledge in the field of human psychology.

6.2 Individual response to emerging trends

As science focused on the exploration of human cognition, behaviour and wellbeing, psychology has an important role to play in understanding human responses to emerging trends.

Emerging issues such as climate change or new technologies are not easy to grasp without a minimum of education on all these concepts. The discourse can be too factual and abstract (*e.g.*, the number of species or biomass disappearing), which poses again another problem beyond comprehension for the public, and another one to attract its interest. A good understanding of the issues involved for complex subjects like biodiversity requires a long time to acquire and a certain scientific rigour. Humans are not good at coping with uncertainty, and routinely misperceive probabilities. They are also inclined to focus on the short-term rather than long-term developments, engaging in temporal discounting that assigns less weight to the future than to the present (Clayton, 2019).

We should also consider strong tendency of human beings to resist scientific evidence and to cling to beliefs of all kinds, such as religious, political, or ideological. We see this regularly in the climate sceptic movement in the United States and in the COVID-19 pandemic, which saw a large number of people adhere to the conspiracy theory. In some ways we have the same problems with people who do not believe in the loss of biodiversity or who believe that progress is the solution to everything. Furthermore, social psychological studies have demonstrated that people in groups often fail to respond to emergencies. In a manifestation of collective ignorance, everyone assumes that other people are not taking action because they know no action is needed — whereas in fact they are all looking to each other for cues (Clayton, 2019). Table 6-1 **Error! Reference source not found.**below is an example of the main barriers to accurate perceptions of climate change but this is transposable to a large number of emerging issues.

Table 6-1: Some barriers to accurate perceptions of climate change (Clayton, 2019).

Limits on cognition	Ideology	Interpersonal relations	Perceived risks
Ignorance and uncertainty	Worldview	Social norms	Financial investment in status quo
Temporal discounting	System justification	Collective ignorance	Social costs of unpopular position
Difficulty with abstractions	Politicisation	Mistrust of messenger	Unexpected costs from making changes, for example in adopting new technologies

Temporal devaluation is the concept that the further away the benefits are in time, the less valuable they are considered: it is a survival instinct (Bohler, 2020). This can be why trade-offs made to protect the biodiversity (ARC measures, etc.) are sometimes difficult to understand and to accept for people, who can lack a long-term vision. The latter is yet essential for infrastructure planning and biodiversity protection. Awareness of these issues is therefore important but cannot be raised by stakeholders alone.

The wording used to sensitize are important, just like the temporal and spatial scales, and the units used: it is once again a matter of perception, and therefore of adjustment to the level of knowledge and the socio-cultural context. On the other hand, the discourse must not be too ‘emotional’ either; it is all about finding a balance. Biodiversity loss, like climate change, is rarely understood or felt in a physical way, but rather intellectual; the threat is perceived as more remote (Sturm, 2019). Indeed, in public consultations, the people present are mostly those directly affected by a project and/or those already highly sensitized to biodiversity issues. Moreover, there are other challenges: the habituation phenomenon (to ‘bad’ news, negative effects, etc.); the fact that people are either not confronted by biodiversity on a daily basis, or are not paying attention to it, or only to certain species; cognitive dissonance and denial, etc. (Sturm, 2019). Finally, the public is rarely aware of the biodiversity loss at its own local scale, and can have misconceptions about some species (distribution, population, level of vulnerability, native or not, etc.) and habitats (Bednar-Friedl *et al.*, 2011).

All of this can explain partly why there is such a low ‘social awareness’ of the challenges specific to transport infrastructures and biodiversity, and low public participation, but it also shows the limits of the involvement of the public in decision-making and monitoring.

6.3 Challenges and opportunities for mainstreaming biodiversity in the infrastructure of transportation sector

6.3.1 Using behavioural science to engage the public

Evolutionary psychology teaches us that human beings are conditional co-operators, capable of immense sacrifices provided they are convinced that everyone is involved. The need for social justice is a good example. Experiments on human behaviour at the Max Planck Institute in Leipzig have shown that children can resist the urge to eat a sweet in front of them if it is explained to them that resisting is a collective project, which can only succeed if all their peers make the effort together (Kirschner, 2013). This is a question of morale, but also of preserving one's social status in relation to one's fellow human beings.

Environmental morality, by legitimising a sacrifice on the part of all in the pursuit of a common cause, will therefore support and justify a moral and social system in which the most deserving person will not be the one who accumulates more than the others but the one who sacrifices as much as the others (Bohler, 2020). All this also helps to give meaning to life, which is necessary for good mental health of the human being. The difficulty is that people are willing to compromise. For example, not using a private car can be seen as a deprivation of freedom. Only the perfect integration of the need for a collective effort, which can be combined with increasing the social status of a person, can make it possible to accept this "deprivation of freedom".

It is interesting to use any solution based on encouraging solidarity and cooperation. For example, people can now cooperate by sharing their car journey with others, especially through dedicated applications. These applications often have an additional financial incentive that allows for better acceptance (sharing of transport costs).

Acting on the driver of social status to enhance the individual can also change the value of that status. For example, owning a car, especially a large one, could degrade that social status. In the same way, with the rise of environmental consciousness and the 'slow travel' ethos, we are seeing some shift from aviation for night trains, having quite a revival in Europe.

It is necessary for public policies to find the right measure to encourage change. Human beings need to feel good in order to live in harmony in their environment and in society. If the forecasts are too pessimistic and the measures to be taken too restrictive, the population will react with rejection to the measures to be taken. Moreover, the changes in behaviour that are induced by a vital necessity such as climate change are then accompanied by emotional response including guilt, grief, anxiety, and depression.

6.3.2 Developing participatory science

Participatory science is a relevant means of involving the general public in environmental preservation which makes it possible to act on environmental morality but also on social status. Public participation in transport-related projects, particularly through public enquiries, also makes it possible to factor in social issues in the choice of transport modes and in the choice of transport infrastructure.

Given the length of roads to monitor, participatory science (also called “volunteer” or “citizen” science) represents an emerging opportunity to complete the data gathering of wildlife information in road ecology, such as roadkills. Now some smartphone applications allow citizens to survey their surroundings on their own. The applications allow citizen scientists and volunteers to complete environmental monitoring activities and easily share the data with ecologist and conservationists (Bíl *et al.*, 2017).

To be extended on a larger scale and provide additional and accurate data to scientists, the goal(s) and method(s) should be identified as precisely as possible, and it would be beneficial to have standardisation of protocols, and automation of identification of species (Shilling *et al.*, 2020; Vercayie & Herremans, 2015). This might not be a substitute for systematic inventories necessary for impact studies, but numerous and reliable data can still be obtained with less effort. Moreover, it is important to keep the participants informed and motivated to encourage their continued participation. Feedback and communication are thus essential, including through the media, which can also enable to 'recruit' new volunteers (Vercayie & Herremans, 2015).

Citizen science is also an emerging tool to include emerging trends, such as invasive alien species monitoring, especially for early detection (Larson *et al.*, 2020), and for the monitoring of light pollution (Hecker *et al.*, 2018), to which transport infrastructures contributes by public lighting. Invasive alien species issues are discussed in greater extent in chapter 3.

Beyond the data contribution that citizen science can make, it encourages better local knowledges (and their recognition), feedbacks with stakeholders (including about managements methods), and the acquisition of data "over broad geographic areas", while "balancing the role of expert and local knowledge". This potentially leads to better management (of biodiversity, territories, risks, local resources), and even resolution of conflicts and better resilience towards disasters such as extreme climate events, that can cause loss of infrastructure. It could even tend towards identification of 'pollution hot-spots', disaster risk assessment, and 'civic ecology' (participatory science community-driven instead of by scientists) (Dickinson & Bonney, 2012; Jordan *et al.*, 2019).

Different tools useable for participatory science are discussed in greater extent in BISON deliverable 3.5.

- **Include ecosystem services and the social value of biodiversity**

The inhabitants of a territory perceive the environment very differently according to their cultural origin, their education, their sensitivity to their environment, their attachment to places... All these elements allow the public to attribute a certain value to their environment.

- **Ecosystem services**

The Common International Classification for Ecosystem Services (CICES) summons ways the science community has sought to describe ecosystem services, and following common usage, recognises that the main categories of ecosystem outputs to be provisioning (mostly food), regulating (filter water, pollinators...), and cultural services (development, knowledge, recreation...) (Haines-Young & Potschin-Young, 2018). Unlike the Millennium Ecosystem Assessment[54] (MA) the latest version of the CICES (5.1) did not retain the "supporting services" (water cycle, nutrient cycling...) as ecosystem service.

All these categories are closely related to the social dimension and must be taken into account in any project. Topics related to cultural ecosystem services are often neglected in impact assessments. This could be improved if these issues were identified in legislation. This is particularly the case in France, as

[54] The MA is a major UN-sponsored effort to analyse the impact of human actions on ecosystems and human well-being

shown by the recent law that aims to protect the smells and sounds ('sensory') of the countryside (Law n° 2021-85 of January 29th, 2021).

- **Social values**

The definition of social values is ambiguous (Hansjürgens *et al.*, 2017), and it can differ from one researcher to another (Kenter *et al.*, 2014). It can refer to the values and norms of the society or culture or the values of a community, and also can refer to public interest or public goods and so on (Kenter *et al.*, 2015). Although the definitions and expressions are different, they can reflect the cognition or belief of a particular scene, behaviour, and object, etc.

We will focus here on the definition from Sherrouse and Semmens (Sherrouse & Semmens, 2014) as “nonmarket values of ecosystem perceived by stakeholder, and which correspond to cultural ecosystem services to a large extent such as aesthetic, therapeutic, and recreation”. Social values are also the equivalent of “landscape values” and opposite of monetary (or economic) valuations (Kenter *et al.*, 2015). The consequence is that social values are not an additional concept on top of ecosystem services. Social values are not something different from ecosystem services but the result of an assessment of ecosystem services from a social point of view.

There are many social dimensions that can be used to assess ecosystem services (Table 6-2), but all of them should be considered when addressing the topic of biodiversity and transport. Indeed, both stakeholders and the general public may be confronted with several of these social dimensions, whether during transport or in the face of a transport infrastructure development project. A single site often accumulates ecosystem services related to many types of social dimensions, such as places with centuries-old trees, meditative landscapes, historical references (Figure 6-1).

Figure 6-1: Example of area with many types of social values. Barbieux’s park. Cc-by-sa 4 O. Pichard, Cerema.

Table 6-2: Description of the ten social value types of ecosystem services (Zhang et al., 2019).

Social value dimension	Social value description
Aesthetic	I value these places because I enjoy the scenery, sights, sounds, smells, etc.
Biodiversity	I value these places because they provide a great deal of animals, plants and so on.
Cultural	I value these places because they provide basic materials for formal and informal education and transfers wisdom and knowledge.
Economic	I value these places because they provide timber, minerals, fishes, medicinal materials, and tourism opportunities, etc.
Future	I value these places because they allow future generations to know and experience these scenes as they are now.
Historical	I value these places because they maintain important historical landscapes (nature and /or human), or preserved folk customs, historical traditions, etc.
Life sustaining	I value these places because they help produce, preserve, clean, and renew air, soil, and water.
Recreation	I value these places because they provide a space for a range of outdoor recreation activities.
Spiritual	I value these places because they are a sacred, religious, or spiritually special place to me or I feel reverence and respect for nature there.
Therapeutic	I value these places because they make me feel better, physically and/or mentally.

- **Integrate social assessment of ecosystem services in the transport field**

It is very important to conduct a social valuation of the full range of ecosystem services with both stakeholders and the general public in any project involving changes in transport. This should be done through literature reviews, but also by outreach to populations through surveys, interviews, etc.

Social dimensions also play a role in Environmental Impact Assessment (EIA), from the early steps of mitigation to last steps of compensation (Dutta & Bandyopadhyay, 2010). It is important to include cumulative effects, as discussed in chapter 5, and even social cumulative effects.

- **Examples of links between biodiversity, transport, transport infrastructure, and social valuation of ecosystem services**

The concept of ecological continuity could "be extended to also include cultural heritage in functional manner", as a "cultural heritage connectivity", and be used in Environmental Impact Assessment (Antonson *et al.*, 2010). Cultural heritage connectivity is defined "*as a functional, economic or social connection of human processes between two points in the landscape, which can be manifested in tangible or non-tangible features and has an historical dimension*" (Antonson *et al.*, 2010). Its analysis can indeed give a good picture of the historical and/or present function of the landscape and its ecological characteristics, as well as socio-economic characteristics, which impacting conservation of biodiversity locally (Paloniemi *et al.*, 2012).

As seen previously, transport infrastructures can provide interesting ecological environments. This is particularly true for transport infrastructure that is not intensively managed. This is often the case for secondary roads, but it is not always the case. As relict environments, they "provide important refuge and connectivity for many threatened species, particularly in low populated rural areas" (Spooner, 2015), which is also related to cultural heritage. Maintaining or restoring biodiversity on railways and rural road verges could also have positive socio-economic effects such as tourism or contributing to aesthetic values and visual screening: it thus would be worthwhile to value these environments by changing public's perception.

Greenways are a non-motorised transportation infrastructure (see examples in Figure 6-2), found both inside and outside cities, but transport is not their only purpose: it is also ecological, recreational, cultural, aesthetic, etc. (Ahern, 1995). According to Zhao (Zhao *et al.*, 2019), like many other subjects related to transport and/or biodiversity, the public's perception of greenways has not been much studied. They are not used only for recreational purposes but also for transportation, especially if they "overlap with transportation corridors and therefore primarily serve as transportation infrastructures rather than recreational and ecological greenways". Neither the public nor the professionals are usually aware that greenways can act as ecological corridors similarly to other linear transport infrastructures if they include vegetation strips (trees, meadows...).

Figure 6-2: Examples of greenways that could be developed. Cc-by-sa 4 O. Pichard, Cerema.

- **Acceptance of rewilding**

Rewilding is the process of rebuilding, following major human disturbance, a natural ecosystem by restoring natural processes as a self-sustaining and resilient ecosystem with high biodiversity. This will involve a paradigm shift in the relationship between humans and nature. The ultimate goal of rewilding is the restoration of functioning native ecosystems containing the full range of species at all trophic levels while reducing human control and pressures (Carver *et al.*, 2021). Rewilding helps landscapes become wilder, whilst also providing opportunities for modern society to reconnect with such wilder places for the benefit of all life (Pereira & Navarro, 2015).

6.3.3 Involving society in biodiversity-friendly transportation mode

- **Changing attitudes and transport behaviour**

Reducing the impact on biodiversity also involves sustainable mobility. New challenges required for sustainable mobility include (Holden, 2016):

- Improving public transport;
- Improving the feeling of well-being;
- Increasing the use of public transport and the used of shared transportation per se;
- Encouraging ‘green’ attitudes;
- Improving the mobility of ‘low-mobility’ groups.

Technological innovations of mobility, traffic increase and transport mode are discussed in greater extent in chapter 0.

The increase in urban populations may lead to a reduction in the use of private vehicles in favour of public transport, particularly for reasons of traffic flow, noise, and pollution. If people manage to reduce individual travel, this will reduce the need to create new infrastructure or parking areas, thus indirectly contributing to preserving biodiversity.

The choices made by both public policy and the general public about transport modes will have consequences in terms of transport infrastructure, with more infrastructure dedicated to public transport. However, the issue of transport modes and infrastructure is closely linked. The Campbell paradigm suggests that travel behaviours and habits are also shaped (by constraint or support) by the transport offer available on the territory, and this “irrespective of [the] environmental attitude” of the users. For example, if we want to encourage the general public to cycle in cities, we must first offer them a dedicated bicycle infrastructure. However, the offer alone is not enough. A change in the choice of transport modes will be more acceptable if people have a direct benefit from their behaviour (in terms of money, time spent, general wellbeing).

- **Improve the feeling of well-being**

The feeling of well-being determines mainly the choice of transport mode, but we have to define what is well-being. The Organisation for Economic Co-operation and Development (OECD) defined the subjective wellbeing as “good mental state, including all of the various evaluations, positive and negative, that people make of their lives and the affective reactions of people to their experiences” (OCDE, 2013). This definition incorporates, according to OECD, three aspects of subjective wellbeing:

- Life evaluation: a reflective assessment on a person’s life or some specific aspect of it.
- Affect: a person’s feelings or emotional states, typically measured with reference to a particular point in time.
- Eudaimonia: a sense of meaning and purpose in life, or good psychological functioning.

It’s also important not to compromise on people’s perception. We ought never to say: this is good for you, even though it will never make you or others feel better. On the contrary, if you want to measure the quality of life, then you have to study what people feel themselves (Alkire, 2008).

When different criteria of a strategic transportation planning are proposed to users, they give more value to the following criteria: accessibility, safety, and environment; and less value to the landscape and comfort criteria. According to Mouter *et al.* (2019), people generally are willing to make compromises on travel-time savings to protect the environment, whether it is linked with their own personal interests like noise pollution or protection of species. However, travel time is crucial: people are less likely to make compromises if they can save 20 minutes or more (Mouter *et al.*, 2019). People are willing to walk much greater distance to the nearest public transport stop if the green, pleasant, environment is provided in comparison to car-oriented environment (PIARC, 2019)

The challenge is to find all possible solutions so that people can adapt well to this change, and willing to interchange shorter travel times with better wellbeing. That being said, with the development of wireless networks, it is also possible to count transport time as working time, especially in public transport, provided that satisfactory working conditions are offered.

Transforming stations into the liveable (green surroundings, restaurants, shops), safe and logistic hubs to attract more people could be a solution to make public transport more attractive and enhance well-being. Economics aspects are discussed in greater extent in chapter 7.

- **Finding ways to encourage people to use environmentally friendly modes of transport**

To support the shift towards more environmentally friendly modes of transport, public policies will therefore need to put in place a comprehensive system based on welfare and economy by providing incentives (*i.e.*: time savings, taxation of polluting transport and financial support for non-polluting transport). The challenge facing public policies is to find a system of incentives based on solidarity in order to avoid penalising the most disadvantaged, at the risk of leading to social unrest, as was observed in France in 2019 during the "yellow waistcoat crisis". The European Union's Green Deal is a step in this direction (European Union, 2022).

One solution to engage people in eco-friendly modes of transport are nudges. Nudges are indirect suggestions to change a behaviour, originating from the behavioural sciences. They can encourage people to adopt new behaviours, such as changing their transportation habits (Figure 6-3). Green infrastructures can also be considered as nudges because they induce incidental experiences of nature and biodiversity (Beery *et al.*, 2017). However, it is far from being enough and economic incentives are often much more effective (Gravert & Olsson Collentine, 2021).

Figure 6-3: Rental bikes in Bucharest, Romania – cc by sa 4 Babu.

Changes of behaviour – *e.g.*, shifting to less individual trips by car and more public transportation use – are difficult with the habituation to the living standards, such as having your own car and driving every day (Sturm, 2019).

- **Education on environmental issues**

It is obviously necessary to underline the role of education on environmental issues such as biodiversity. Changing in behaviour could start at an early age. For example, by creating more nature orientated playgrounds, nurseries, and schools. Sometimes children can teach their parents better than any legislation or knowledge transfer. The media also play an important role in providing reliable and easily accessible information throughout people's lives. It is important to bring the message across that biodiversity should not be perceived as a risk and that its protection should not be seen as an additional burden but rather as a common good that we all share.

- **Leisure, tourism and “need of nature”**

Daily commuting must be distinguished from journeys made for leisure and tourism. The latter are increasing in frequency and cars are the usual transport mode. The “pull and push factors” in travel decisions are indeed not the same according to the type of travel, and less rational: usual sustainable transport policies are thus less relevant for leisure and tourism travels (Holden, 2016). These types of travels are indeed often to natural areas, and so, far from urban areas and their “high-capacity public transport hubs”. Ideally, the transport management should be demand-driven to be more flexible and sustainable, but leisure activities are highly variable according of the time of the year, weekday, and to meteorological conditions; which complicates such an implementation. People have a “need of nature” but they are less inclined to use public transport in natural areas although they exist, or they are not aware of it, or the public transport is only on a restricted area (often in the last kilometres). Developing public transport towards natural areas would also benefit the local communities and rural areas (Orsi, 2015). However, even in urban areas, the need for nature remains important. A study has shown that 80% of French people consider that living near a green space is an important criterion (UNEP, 2016).

6.3.4 Involving society in biodiversity-friendly infrastructure of transportation

Biodiversity perception and biodiversity management perception are closely related. While there tends to be a general agreement that biodiversity needs to be conserved and protected, the ways it is done can be contested, as the methods can be seen as harmful. Biodiversity management methods themselves influence in return the perception of the public, especially when they directly impact local people. There are many different views on biodiversity, reliant on value judgments and conceptual and cultural contexts, and they should be taken into account and accepted to open debate and gain public acceptance (Fischer & Young, 2007).

People affected by a new airport, road or rail project near their home, and who consider it mainly as a source of negative impacts (on ecological and cultural values), usually feel useless in influencing the planning process (Henningsson *et al.*, 2014). However, some people are very motivated to defend their quality of life. This is known as the phenomenon of “Not in My Backyard (NIMBY)” (WEXLER, 1996). This phenomenon occurs when residents of a neighbourhood consider a new project as inappropriate or unwanted for their local area. Although this phenomenon may have described excessive intolerance on the part of the inhabitants, it should not be perceived negatively because the people affected by a project play a very important sentinel and monitoring role, such as whistle-blowers. The vigilance of citizens is also expressed well beyond their "backyard", notably through their involvement in environmental protection associations. Local associations (mostly environmental organizations) can de-escalate conflicts by getting directly involved in projects (Shan *et al.*, 2021). These associations can act as mediators between planners and the public. One of their particularities is that they often insist on risks posed by a project and link it to spatial development (Lolive & Tricot, 2005). Their mobilization therefore contributes to the general interest.

The Arnstein ladder (Figure 6-4) was created in 1969 by Sherry R. Arnstein to measure citizen involvement in planning programs (Connor, 1988). According to Bailey (Bailey *et al.*, 2011), the Arnstein gap refers to a “deficit in public participation” and is often observed during projects. The public and the professionals both aspire to a level of cooperation “slightly higher than ‘partnership’”. Though it means that disagreement and conflicts are not inevitable, consensus is often the goal of the planners and thus does not appeal to the public who do not always find their diverse aspirations in a compromise. The use of advanced technologies (*e.g.*, computer visualization, decision theoretic methods) can be seen only as a way for planners to reach public acceptance and thus consensus, but it rarely achieves that goal, and should rather encourage feedback between all stakeholders. It is even harder to reach this consensus when the project is on a large scale or even transboundary, where the cultural context also comes into play.

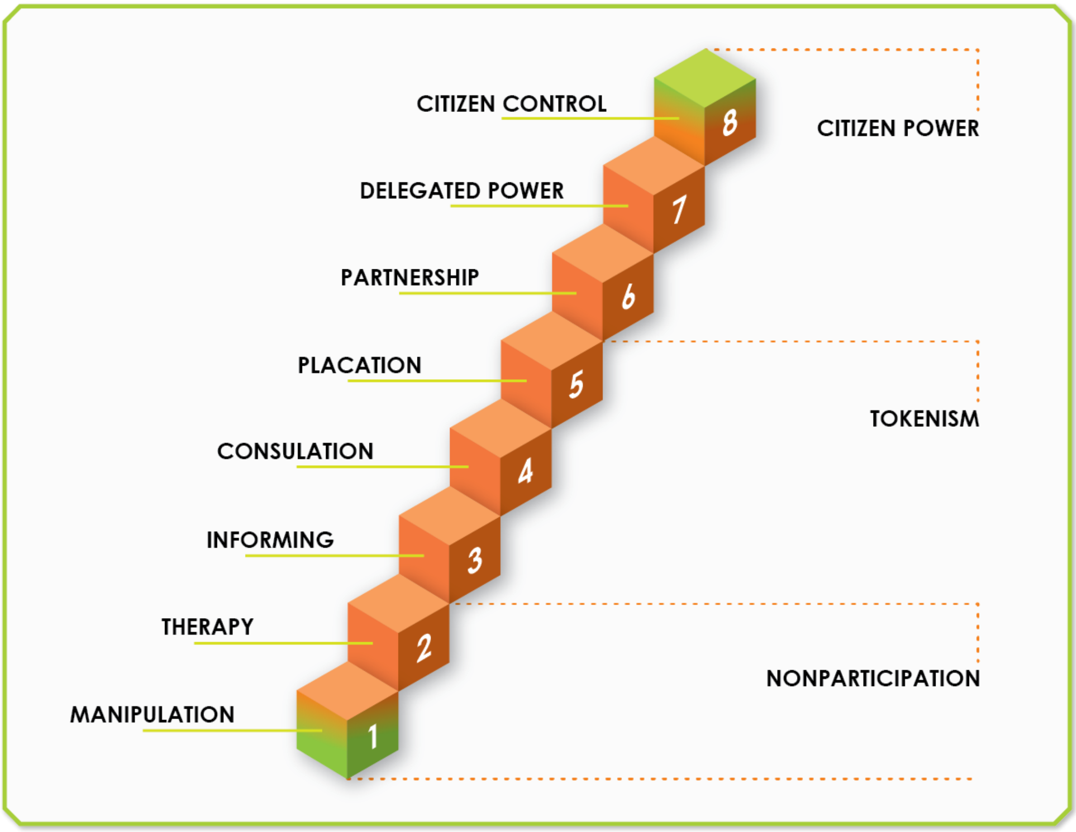

Figure 6-4: The Arnstein ladder Source: Connor, 1988, adapted by John Alertas.

Poor or non-existent public participation or involvement can cause conflict in transport infrastructure projects, particularly regarding biodiversity. There are different types of biodiversity conflicts (Young *et al.*, 2010):

- Related to beliefs and values;
- Related to the process of decision-making;
- Related to information;
- Conflicts of interest;
- Structural conflicts;
- Inter-personal conflicts (between individuals or groups).

Offset (or compensation) measures are the last implemented in the mitigation hierarchy, to tackle residual impacts. Just like other ARC measures (avoid, reduce, compensate) aim to mitigate the environmental impacts of a new infrastructure, they greatly contribute to the social acceptance of a project; provided, that they are themselves accepted. This could be improved if the residual impacts of the project at stake are better known, so that the people do not feel like they were not informed thoroughly (Villarroya & Puig, 2013). Besides, on-site and in-kind offsets are usually more socially acceptable than off-site and out-of-kind offsets (Villarroya *et al.*, 2014), since the latter are located further away and of a different nature, and act as a last resort. It is indeed less understandable to an unfamiliar audience, and when there is a strong knowledge of local biodiversity and/or cultural values associated – and thus a strong movement to protect it. Specific conservation measures can be highly contested even though there is a general agreement about a need of biodiversity conservation (Buijs *et al.*, 2006). This happens when the project leads to negative consequences on the human level, well-being, health etc.

Wildlife passages are one of these ARC measures to reduce the impacts on landscape and habitats fragmentation due to infrastructures of transportation. The social acceptability of its integration into the territory concerned is thus also important. The aesthetics of the structure impacts every user or the structure, road users and thus must be considered; different alternatives should be proposed for each project, to ensure its social acceptability as much as possible (Ahern *et al.*, 2009).

It is also important to pay attention to the perception of the value of compensation: the level of compensation can never "identically" compensate all the values of a site. It will all be a question of compromise, of evaluating the 'acceptable' threshold of compensation from a human point of view, not without a certain level of subjectivity. It is also a question of dealing with society's view of nature. Paradoxically, the public will be more willing to protect an invasive species such as the grey squirrel in London's gardens than a threatened native mollusc species that lives further away (Dunn *et al.*, 2018).

The roadside vegetation not only contributes to the safety of the road but also to the landscape, which is important in territories that depend on tourism (Lucey & Barton, 2011). There is also positive links of people using 'transport' infrastructure with biodiversity issues. This environment is valued by road users, who generally prefer diversified and native vegetation (Akbar *et al.*, 2003). Figure 6-5 is an example of touristic road in Norway. This argues to mainstream biodiversity into spatial planning.

Figure 6-5: Scenic road in Norway (cc-by-sa 4 O Pichard).

In conclusion, any intervention on a territory within the framework of a project is subject to the context of the territory, both institutional and socio-cultural, and its values, particularly concerning natural resources. Hence, it is important to question the potential effects of policy interventions on the socio-cultural components of the territories; are they requested by the populations, what is their degree of involvement – actual and desired (see the Arnstein ladder), etc. A “locally desirable stable equilibrium” should be aspired (Pörtner *et al.*, 2021).

Project managers or contractors are sometimes not sufficiently trained on these subjects. For example, state wildlife agencies and departments of transportation do not always have the same perception and opinion on the effectiveness of mitigation measures for deer-vehicle collisions because of their different cultures and expertise (Sullivan & Messmer, 2003). This highlights the difficulty in understanding the social perception of measures for biodiversity.

In short, it appears that there is a growing need of collaboration, coordination, training on certain subjects, and exchanges among not only general public but also all stakeholders involved in infrastructure management and planning.

6.4 Need for knowledge

To better manage infrastructures and reduce their negative impacts on biodiversity, there are still knowledge gaps to be filled.

There is a lot of new research in the field of behavioural ecology including social network analysis, gene-by-environment interactions, landscape genetics, metapopulations organisation, spatially explicit models, ethology, neurosciences... This research is oriented towards animal communities, but also has many echoes in the understanding of human communities. This research is essential to better understand how to make biodiversity measures more effective. It is also important to promote social acceptance of measures by providing a better understanding of the objectives to be achieved among the general public.

Biodiversity conservation can be improved by enhancing these models by better integrating the feedback between wildlife dynamics and people's behaviour (Bro-Jørgensen *et al.*, 2019). It is now essential to combine the different research fields of biodiversity, transport ecology and the social dimension to find solutions to the challenges facing our societies. If the size of wild animal populations changes, then this will have an impact on ecosystem services, which in turn will have an impact on people's behaviour. This will also affect natural resource management and consequently biodiversity. (Bro-Jørgensen *et al.*, 2019).

There is a research gap in relation to the opportunities that local people have in order to participate in decision-making processes related to biodiversity offsetting. Biodiversity offsetting can cause the displacement of local people and negatively affect their livelihood, but there is little literature on that aspect of the offsetting procedure (Tupala *et al.*, 2022).

Cumulative effects often ignore cumulative effects related to social issues. Cumulative social impacts are particularly present in the context of regions where resource-based industries dominate the economy. These "resource regions" tend to be distant from metropolitan centres. The growth of industries is often faster than the provision of services and infrastructure with impacts on the population (Grace & Pope in Blakley & Franks, 2021). There is a need for more knowledge on the social consequences of cumulative development.

The subject of cumulative effects is discussed in greater extent in chapter 5.

6.5 Conclusions

As we have seen, the challenges of integrating the social dimension to mainstreaming biodiversity in the field of transportation require good cooperation between the general public and all actors involved in spatial planning, whether public or private. These stakeholders must be able to set a framework for the harmonious development of transport and the infrastructure necessary for its proper functioning, integrating biodiversity and any emerging issues such as climate change. On the other hand, society must take part in this evolution by being as much as possible an actor of these transformations. Public policies must take hold of the behavioural sciences to involve society in the new challenges.

Research on communication strategies has identified several key recommendations:

- To overcome cognitive limitations and put information into a narrative form.
- Make the information locally relevant and to present it in multiple modalities, such as in lists, through images, and with statistics.
- To overcome emotional limitations, balance fear with hope.
- To overcome or at least address group-based polarization, seek trusted messengers to deliver the message. Successful communication must be geared to its audience.

In order to engage the general public in change, it is necessary to create psychosocial resilience to cope with adversity or significant stress. Research has shown that maintaining social connections, becoming informed, flexibility, a feeling of self-efficacy, and a sense of optimism are associated with resilience (Clayton, 2019; Rotherham, 2015).

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BIODIVERSITY AND INFRASTRUCTURE SYNERGIES AND OPPORTUNITIES FOR EUROPEAN TRANSPORT NETWORKS

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7 ECONOMIC TRENDS

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Summary

Economic activities including the transportation sector have strong impacts on biodiversity, but at the same time are directly dependent on biodiversity and ecosystem services. This chapter discusses important emerging economic trends, their expected influence on infrastructure (including energy transmission infrastructures) and mobility, and how they may affect possibilities to mainstream biodiversity in infrastructure projects.

Tomorrow's economy will have to deal with an increasingly urbanized but aging European population, as well as to increasing inequality. Tomorrow's infrastructures will therefore have to meet the challenges of access to mobility: access to cities for rural citizens, mobility of the elderly, access to transport for all. Low economic and demographic growth rates will most likely slow down the necessary investments in infrastructure (maintenance and adaptation of existing infrastructures to meet environmental objectives, creation of infrastructure for low-carbon mobility, recycling of obsolete infrastructures), unless appropriate policies and specific economic and financial instruments are put in place.

Stopping the erosion of biodiversity means acting on existing transport infrastructures and designing new infrastructures that are carbon-free and respectful of life. Because transportation and economy are closely intertwined, a metamorphosis of the economy will contribute to a transformation of the transport sector and its infrastructure. Four specific areas must be prioritized: national, private and blended financing, economic incentives, regulatory measures and metrics.

Key messages

- Transportation and economy are closely intertwined, both depending on each other.
- Future economic trends will affect transport behaviour and infrastructure development, but also vice versa. Mainstreaming biodiversity in infrastructure projects therefore also means considering both factors.
- Economic development is subject to many external factors, especially demographic trends (such as continued urbanisation, aging of the population, migrations), and can change rapidly if external shocks happen.
- To better mainstream biodiversity and reach a change of the global economic system in the post-2020 agenda, priority must be set on four areas of transformation: increased funding, redirected incentives, enabling regulation and transformed metrics.

7.1 Introduction

Economy and transport are intimately intertwined. Roads, railways, waterways, air and sea routes, as well as powerlines and pipelines are essential to the functioning of the society and to meeting human needs. Infrastructures are essential to move energy, resources, and commercial goods, as well as to connect people to each other. The European economy and society also rely heavily on the transport industry: according to the European Commission's figures, the transport sector provides 10 million jobs in Europe, and 5% of total European Gross Domestic Product (GDP) (Ali *et al.*, 2018). Between 1990 and 2016, investments in transport infrastructures have positively impacted economic growth in the EU-28 countries (Ghergina *et al.*, 2018). Transport costs are important for companies (an average of 10-15% of the cost of a finished product for European companies is linked to transport and storage costs according to the European Commission).

Because of the interconnections between transportation and the economy, future economic trends will affect infrastructure development, and vice versa, and thus biodiversity. Along with changes in population (ageing, migration, urbanization), energy (fuel price), technology (Information Communications Technology, new infrastructures) and other human activities (tourism, lifestyle changes), economy is one of the five drivers of transport demand (Sessa and Enei, 2009). Transportation supply is determined by European, national and local regulations (regulations, environmental standards), the supply of transport infrastructure and services, the price of energy (including taxes), energy availability, technological progress (Lamblin, 2005) and infrastructure funding (Fisch-Romito and Guivarch, 2019).

Prediction in economic trends is both useful and uncertain (Sen, 1986). One the one hand, economic trends depend on many non-economic factors such as demographics, energy supply, natural resources availability, climate and biodiversity, evolution of social behaviours, geopolitical context, scientific and technological discoveries. On the other hand, exogenous shocks can happen and abruptly change economic trends: natural hazard, financial crisis (*e.g.*, the subprime crisis), biodiversity loss and human behaviour (*e.g.*, the COVID-19 pandemic), political and geopolitical conflicts (*e.g.*, the Ukrainian war).

This chapter explores how main economic trends will most likely influence transportation infrastructures and mobility in the next decades, recognizing that any of these trends can change rapidly if external factors change. This chapter also gives some insights in how changes in the economic system contribute to mainstream biodiversity in infrastructure projects.

7.2 Demographic and economic trends

7.2.1 Demographic growth and continued urbanisation

According to the United Nations (World Urbanization Prospect, 2018), the European population may have reached its peak in the 2020s and begin to decline noticeably up to 2050 (from 743 million people in 2018 to 716 million people in 2050) (Figure 7-1).

Yet, there are wide differences in national population trends. Some European countries will continue to have a demographic growth, like Spain, Sweden, or France (UN, 2019a).

Concomitantly to this decline due to lower birth rates, urban populations are still expected to grow although at lower rates than during the 20th century (Figure 7-1) and mainly due to a process mixing rural exodus and growing urbanization. As rural populations move to work in cities, about 80 per cent of the global gross domestic product (GDP) is generated in cities (Grübler and Fisk, 2013), the rural population needs access to cities to work. Therefore increasing an urbanization need and process.

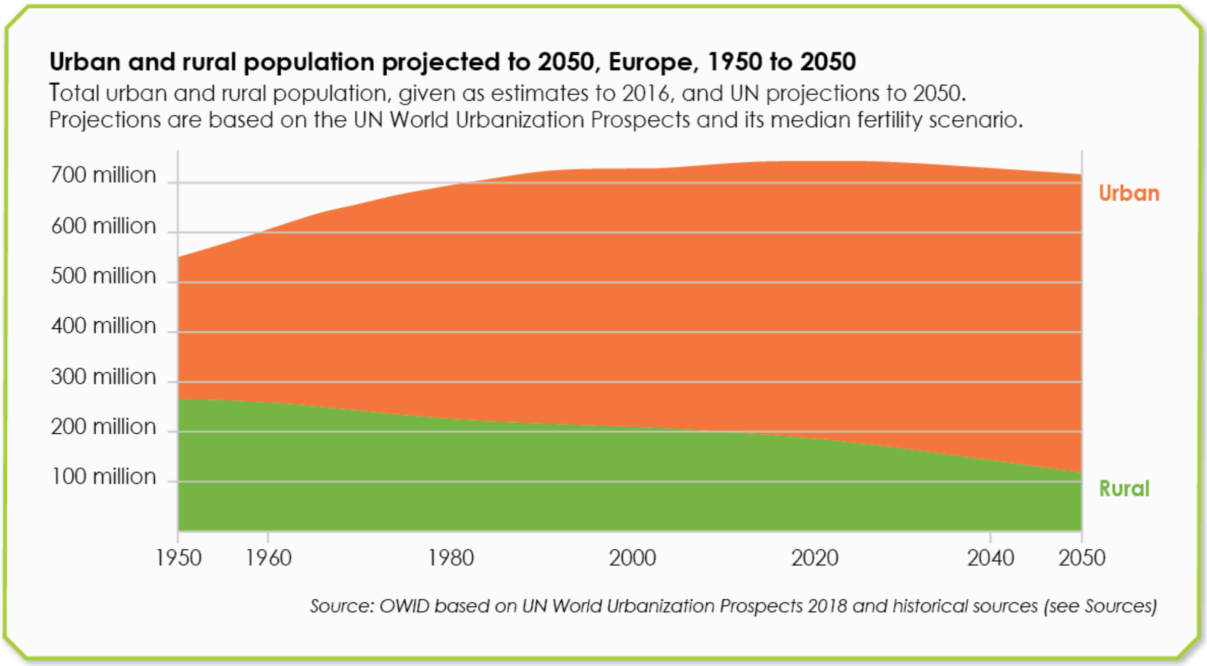

Figure 7-1: Urban and rural population projected to 2050, Europe, 1950 to 2050 (OWID, based on UN World Urbanization Prospects 2018 and historical sources, 2022)

7.2.2 Aging of the population

Together with the overall decline in population, Europe will most likely experience an aging of its population in the 21st century (Figure 7-2, European Commission, 2021). This result is based on an analysis of the total fertility rates (slight increase expected, from 1.52 in 2019 to 1.65 by 2070 for the EU as a whole), the life expectancy (from 78.7 in 2019 to 86.1 in 2070), and the annual net migration inflows (from about 1.3 million people in 2019 to about 1 million in 2070 that is 0.2% of the EU population).

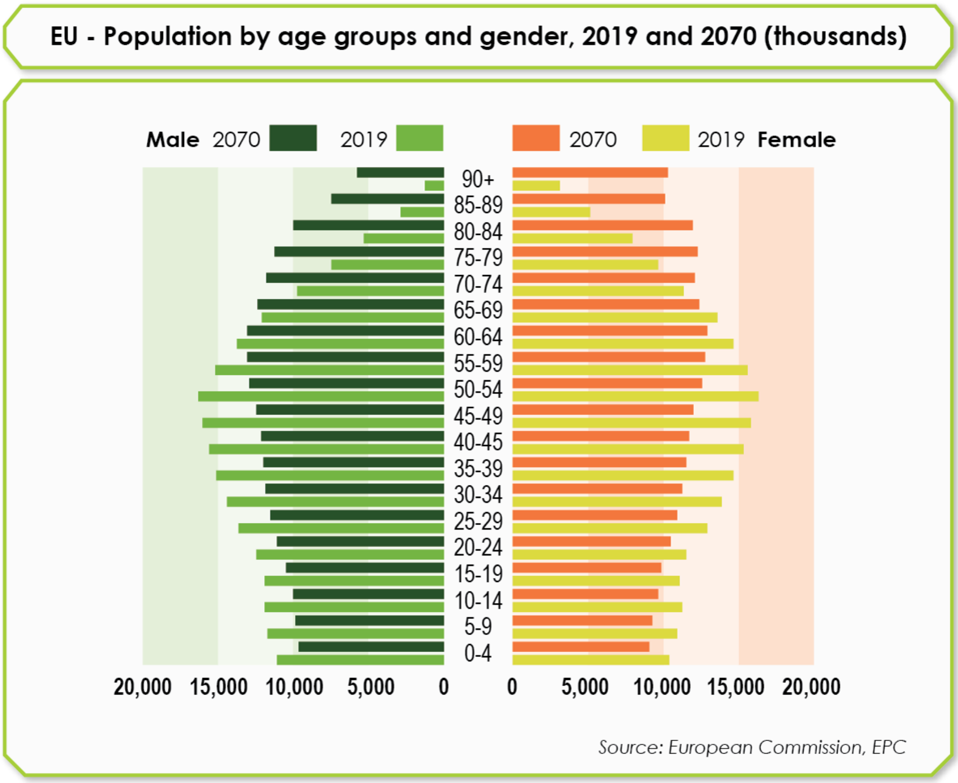

Figure 7-2: Population by age groups and gender, 2019 and 2070 (thousands) Source: European Commission, EPC (2021).

7.2.3 Migrations

Next to birth rates and age, immigration (and emigration) flows are important but difficult trends to anticipate because of their high volatility over time (Figure 7-3, European Commission, 2019) and differences among countries. Based on previous trends, the latest Eurostat population projections (EUROPOP2019, Eurostat 2020) foresee a decrease in net migration inflows into the EU, from 1.3 million people in 2019 (0.3% of the population) to around 1 million people in 2070 (0.2% of the population).

On the other hand, but different scenarios also suggest a global increase in migration, partly induced by a deterioration of human living spaces due to climate change (Lutz et al 2018). The International Migration 2019 Report states that the share of international migrants in the global population has increased, from 2.8 per cent in the year 2000 to 3.5 per cent in 2019.

Net migration flows (including statistical adjustment; 1960-2018)

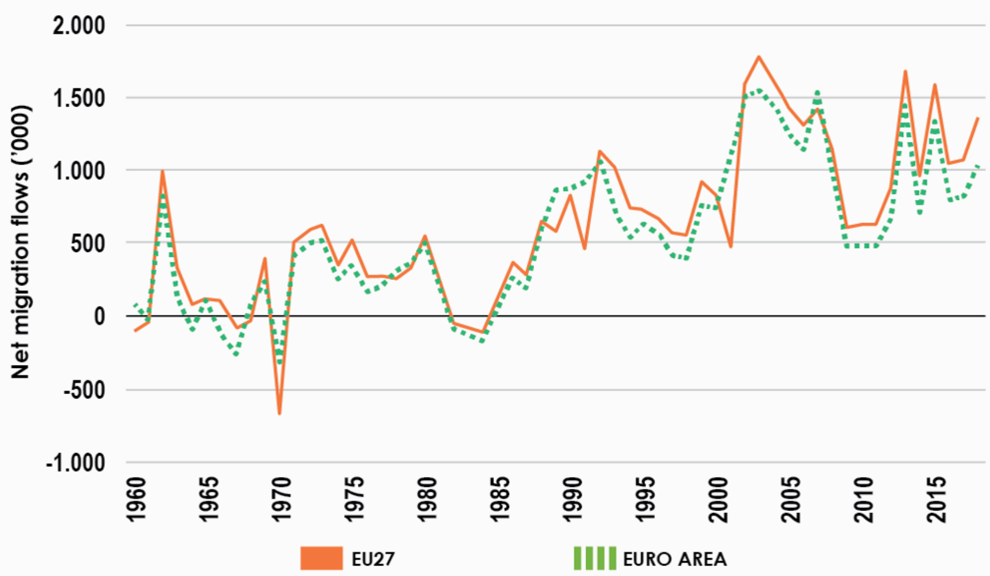

Figure 7-3: Net migration flows 1960 – 2018 (Source: European Commission, 2021 based on Eurostat Data).

7.3 Economic growth

Gross domestic product (GDP) is a measure of the economic activity, defined as the value of all goods and services produced less the value of any goods or services used in their creation. Since the beginning of the 21st century, real growth rates per capita have been stable as one considers standardized and actualized data (Eurostat, 2022)). Predict economic growth on the long run is difficult, because of the risk of exogenous shocks like the 2008 subprime crisis, the COVID-19 pandemic, or the Russian invasion war on Ukraine in 2022. The World Bank and the International Monetary Fund only provide growth estimates only for the next two years (Euro Area and EU Economic Snapshot - OECD). The Organization for Economic Co-operation and Development (OECD) uses the ENV-Linkages model[55] and the ENV-Growth model[56] model and forecasts growth of about 1.5% per year by 2050 (OECD, 2019).

During the 20th century, the strong economic growth has been feasible because of the use of cheap energy that accompanied it (Giraud and Kahraman, 2014). The evolution of growth rates in Europe may therefore depend on changes in energy price levels. Decarbonisation of transport and raised prices for fossil fuels will provide incentives to change behaviour towards less or different mobility, but this could also affect negatively economic growth and worsen inequalities (Saujot, 2012).

[55] An economic model that links economic activity to drivers of environmental pressure.
[56] A two-sector model that aims at projecting GDP and per capita income levels for all major economies in the world.

7.3.1 Inequalities

Because of the slowdown in growth and the liberalization of the economy, inequality in income has increased in Europe over the last forty years, although less than compared to the rest of the world (World Inequality Lab, 2022; L. Chancel and T. Piketty. 2021). The share of national income going to the top 10 percent of taxpayers increased from 31 percent to 35,8 percent in Europe between 1980 and 2016 according to the World Inequality Lab (Figure 7-4).

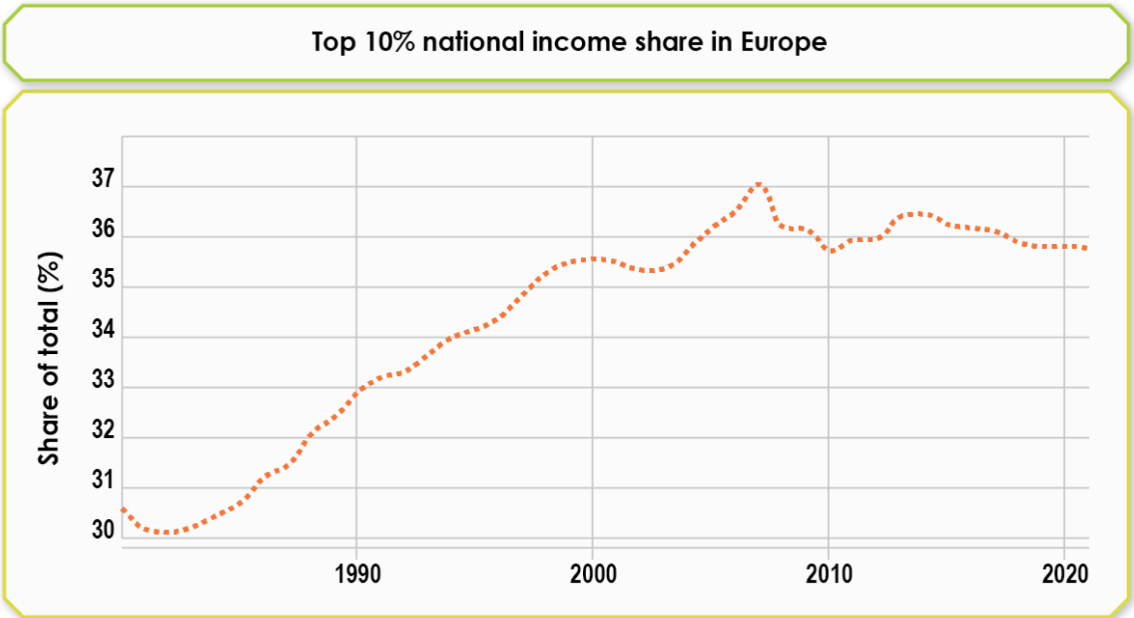

Figure 7-4: Top 10% national income share in Europe.

7.3.2 Technological progress, digitalisation of the economy

The digitization of the economy refers primarily to the development and diffusion of information and communication technologies (ICT). Digitization also refers to the substantial development or transformation of activities enabled by the rise of these technologies, including the development of digital platforms and transports, online commerce, or telecommuting. In the coming years, the digitization of the economy will continue in Europe and worldwide (France Stratégie, 2015; OECD, 2020; Qureshi and Woo, 2022), but it will also be confronted with sustainability issues (Halloy, 2017; Ademe, 2022).

7.3.3 Transformation of the European energy mix

European economies will most likely increase their share of renewable energy used in their energy mix (IRENA, 2019; Institut Montaigne, 2021), because of its objectives in terms of greenhouse gas emissions, the increasing competitiveness of renewable energies compared to fossil fuels, and the potential long-term increase in fossil fuel prices over the next few decades.

7.3.4 Summary of the relationship to transport and infrastructures

As the table 7-1 shows, economic and demographic trends will have different impacts on transportation and infrastructure, and an overall trend is not identifiable.

Table 7-1: Summary of trends in demography and economic and their expected effects on biodiversity and transportation.

TRENDS	EXPECTED IMPACT ON TRANSPORTATION AND INFRASTRUCTURE
DEMOGRAPHICS	
Slight decrease in population rates	Slight decrease in transportation demand
Urbanization	Growing need to connect cities to rural and urban areas
Ageing of the population	More mobility assistance, adequate accessibility
Steady migration rates	No significant effect
ECONOMICS	
Low growth rates	Slight increase in transportation demand
Transportation sector: technological change, digitalisation	Adaptation of existing infrastructures More telecommuting: stable or growing demand for mobility? Effect on transportation demand: potential opposite effect with regards to energy consumption and emissions (Noussan and Tagliapietra, 2020)
Increasing inequality	Inequalities in access to transport
Increasing frequency of crisis	Effects on transport supply, demand, and financing
Transformation of the European energy mix	More renewable energy infrastructures in Europe

7.4 Perspectives: implications for mainstreaming biodiversity and infrastructure

To mainstream biodiversity in TI a transformative change of the global economic system in the post-2020 agenda is needed. To do so priority must be set on four areas or “actions for transformation” (Turnhout and al., 2021), Figure 7-5: funding, incentives, regulation, and metrics. Deepening the knowledge on these subjects is essential to better mainstream biodiversity and infrastructures. Special attention should be paid on these four actions:

1. Funding: blended finance[57].

2. Incentives: economic instruments on infrastructures that mainstream biodiversity and internalise external costs.

3. Regulation: international trade policies, control of the application of regulations by economic actors (for example, of mitigation hierarchy).

[57] Defined as the strategic use of development finance for the mobilisation of additional finance towards sustainable development in developing countries according to the OECD.

4. Metrics: environmental accounting, economic and social valuation of biodiversity and ecosystem services, measure of biodiversity net gain, measure of the biodiversity footprint of companies for all the value chain, economic and social valuation of ecosystem services.

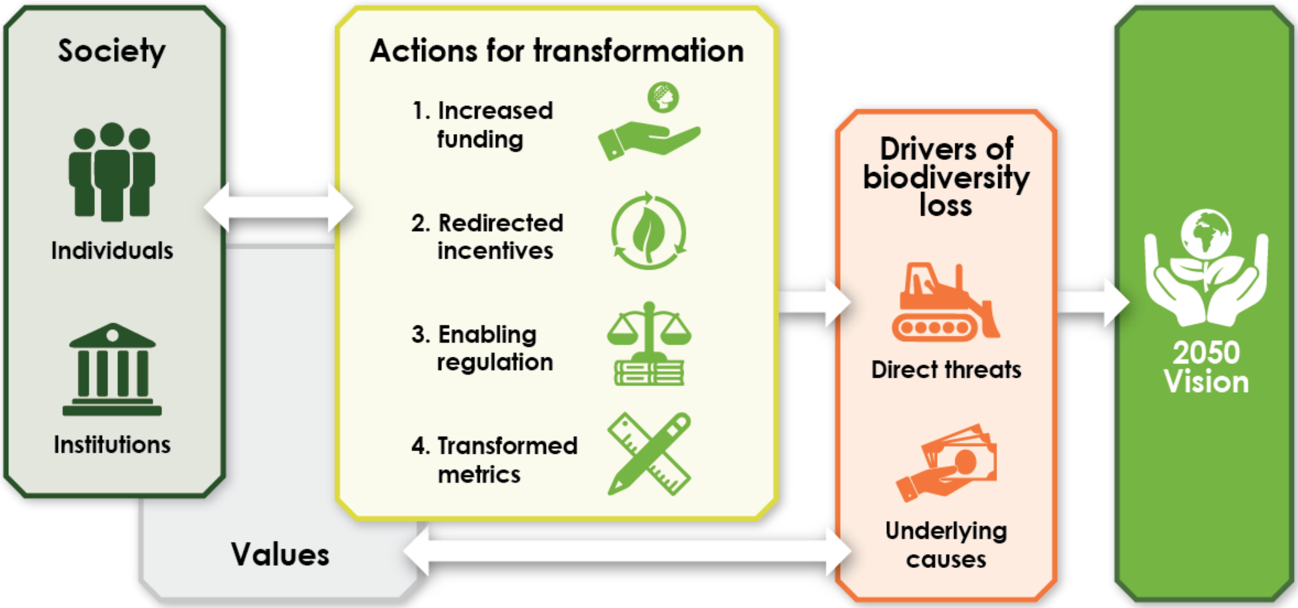

Figure 7-5: Action across four priority areas can affect values and institutions, address the drivers of biodiversity loss, and catalyze the transformative change needed to achieve the 2050 biodiversity vision (Turnhout and al., 2021).

Based on these areas of priority, and considering that all of these have economic implications and can trigger economic trends, we propose the following list of economic “actions for transformation” to mainstream biodiversity and infrastructures:

National funding

- Establish eco-conditionality of financial support to infrastructures projects
- Align investors criteria with criteria of European recommendations
- Establish long term funding (including preventive expenditures)
- Maintain European competitiveness

Private funding

- Enhance endowment of funds to eco-friendly projects
- Require payment for impacts on ecosystem services (Polluter-pays-principle, ECA 2021)

Blended finance

- Develop a joint public/private approach to ensure the flexibility of the private sector and the security of the public sector

Redirected incentives

- Raise awareness among economic actors
- Cease grants for and increase taxes on environmentally harmful businesses
- Redirect financial flows, consumption and production toward nature-positive options using nudges and quotas
- Establish biodiversity friendly organisations (such as *e.g.*, Transport 4 Nature[58], The Tree Council)

Enabled regulation

- Prioritise biodiversity loss and climate change, regardless of the geopolitical/economic/social context
- Improve a 'command and control' approach
- Require extra-financial reporting for all infrastructures and transportation companies
- Develop an overarching policy on land use
- Reduce of traffic and transport demand (especially for non-essential transport)
- Promote using public and shared transport and increase accessibility
- Internalise external costs (real costs of transportation integrated in the prices of goods and services)

Transformed metrics

- Implement structural changes in values and paradigms
- Improve measuring of non-transport values such as *e.g.*, natural capital, biodiversity net gain and biodiversity footprint of companies (see the Global Biodiversity Score[59])
- Enhance environmental accounting to integrate biodiversity issues into the accounting of transport and energy companies
- Require and allow for more transparency in data sharing

7.5 Conclusions

Economic growth in the 20th century has been dependent on transport infrastructure development, and the level of transportation mobility is conditioned by the nature and scale of economic activities. The challenge today is to guarantee sustainability, both in the economy in general and in the infrastructure transport sector. This requires a better understanding of what is most likely to happen in the economic sphere in the decades ahead, and to take these trends into account when mainstreaming biodiversity in transport infrastructure projects and maintenance.

Economic tools and instruments, such as funding, investment, or incentives, can help to account for biodiversity in infrastructure projects and can be used to direct development towards ambitious

[58] https://www.iene.info/projects/transport4nature/
[59] https://www.globio.info/global-biodiversity-score

environmental objectives. Structural changes in the economy are needed to guarantee efficient preservation and restoration of biodiversity in the long run.

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GENERAL CONCLUSIONS

It is well acknowledged that the current path of development, the growing human population with increased demands for energy, natural resources, trade and mobility is unsustainable. The warming climate and declining biodiversity will inevitably alter living conditions for future generations. Transportation is intimately linked to this development as it provides central functions to human societies while affecting its foundations. The sector is well aware of this and has started to take responsibility. Optimistic visions for the development until 2050 clearly suggest a potential and willingness for change towards sustainability. Triggered by necessary adaptations to climate change and obligations to depart from fossil fuels, and enabled by advances in communication and technology, this could lead to a sustainable, equitable, clean and energy efficient transport system where biodiversity and human values are internalised parts of a holistic design.

In the previous chapters, we have discussed trends in demography, economy, climate, biodiversity and technology, and proposed detailed actions and tools to deal with the emerging challenges and aim at an optimistic future. These include *e.g.*, redirected economic incentives and funding alternatives, socially inclusive communication, cumulative impact assessment, Nature-based Solutions, biodiversity monitoring schemes and climate change vulnerability maps. Some of these actions can be conducted within the responsibility of transport agencies, while other require a cross-sector collaboration.

In essence, however, the key actions that can break the historic trend and lead toward sustainable development are much broader and aim to:

- reduce the demand for (unnecessary) mobility and transport and instead aim for increased accessibility of resources,
- include non-transport related and non-monetary values in a holistic long-term planning that favours both people and biodiversity,
- internalise external costs of transportation for society and environment (polluter-pays principle), including long-term and cumulative effects.

To accomplish these tasks, however, requires a stronger governance and more ambitious, aligned policies than what has been accomplished so far. Departing from the natural path of growth and expansion towards circular economy and long-term strategies requires a huge effort that must be rooted in and accepted by the public and by business – and it may be here where the greatest obstacles can be found.

It seems that we have the knowledge and the tools at hand – we just need to make up our mind.

Note:

It may be worth mentioning that little of the above is actually new. Most, if not all has been proposed, acknowledged, and highlighted in one way or another already decades ago. As an example, at the Conference on habitat fragmentation and infrastructure in 1995[60] *that founded the European expert network on Infrastructure and Ecology (IENE)*[61] *and the COST341-action on the same topic*[62]*, the need for holistic approaches in the assessment of cumulative environmental impacts has been highlighted – as the need for cross-sector collaboration to deal with landscape fragmentation and its effects on humans and biodiversity. Progress since then has been rather slow despite the blooming of international research in road and rail ecology that has produced the robust empirical experience in mitigation now combined in the upcoming BISON Online Handbook 'Good practice for mainstreaming biodiversity on transport'. It remains to hope, that the new public awareness of climate change and the current economic crisis triggered by the COVID-19 pandemic and the ongoing war in Ukraine, will have sufficient leverage to accomplish the necessary change in transport demand and transport behaviour to enable the mainstreaming of biodiversity in the transport sector.*

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