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Indicators for monitoring the Strategic Transport Research and Innovation Agenda

The TRIMIS indicator framework to assess transport research and innovation progress

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Abstract

The European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS) maps and analyses research trends and innovation capacities across the European transport sector. The Strategic Transport Research and Innovation Agenda (STRIA) was adopted by the European Commission in 2017 as part of the "Europe on the move" package, which highlights main transport research and innovation priorities for a clean, connected and competitive mobility.

This report presents the methodological approach and a first list of indicators that TRIMIS proposes to measure progress in European Union transport research and innovation. These indicators provide input to the further development of STRIA roadmaps and will be used to support the planned TRIMIS interactive scoreboard that will be available on the TRIMIS online platform and will be periodically updated.

1 Introduction

In 2017, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) as part of the "Europe on the move" package, which highlights main transport research and innovation (R&I) priorities for a clean, connected and competitive mobility while complementing the 2015 Strategic Energy Technology Plan (European Commission, 2017a, 2015a).

Transport R&I is key to address current transport challenges. For example, in order to decarbonise transport and mobility, the EC has identified the need to overcome barriers and seize opportunities by promoting European transport R&I. Towards this goal, STRIA identified seven priority areas with specific actions for future R&I, outlined in seven roadmaps:

1. Connected and automated transport (CAT)
2. Transport electrification (ELT)
3. Vehicle design and manufacturing (VDM)
4. Low-emission alternative energy for transport (ALT)
5. Network and traffic management systems (NTM)
6. Smart mobility and services (SMO)
7. Transport infrastructure (INF)

The development of STRIA needs to be underpinned by an effective monitoring and reporting scheme to support its development and implementation. In September 2017, the EC launched the Transport Research and Innovation Monitoring and Information System (TRIMIS) to monitor the implementation of STRIA and its seven roadmaps (European Commission, 2017b).

The EC Joint Research Centre (JRC) is responsible for the development of TRIMIS under the supervision of the Directorate-General for Mobility and Transport (DG MOVE) and the Directorate-General for Research and Innovation (DG RTD) that are co-chairing STRIA.

TRIMIS is a monitoring and information mechanism that assists the development of STRIA and supports transport R&I. It focuses on the priority areas outlined in the seven STRIA roadmaps, where public intervention at European Union (EU) level can create added benefits. Being an open-access information and knowledge management system, it comprises a database of transport projects and programmes, as well as an inventory of transport technologies and innovations. Moreover, information on the status of transport-related R&I is being collated and disseminated along with a systematic horizon scanning scheme, while the progress on the implementation of the STRIA roadmaps will be monitored using a set of relevant indicators and an interactive scoreboard (Tsakalidis et al., 2020).

The development of TRIMIS is based on a step-by-step process that includes the necessary input identification and collection of data, the setting up of an assessment framework and the provision of policy support. TRIMIS tracks the status and developments in the field of transport, identifies innovative technologies and assesses their potential future impact through (Tsakalidis et al., 2018):

1. Updating and maintaining a transport R&I database that includes data on transport related projects and programmes, technologies and innovations
2. Monitoring and assessing transport sector technology performance using a set of indicators to monitor the European innovation capacities with reference to the STRIA roadmaps and the progress of European R&I, in order to support the assessment of the transport sector performance and maturity status
3. Identifying new technologies and opportunities that may have an impact on the transport sector through the development of an inventory of relevant scientific developments and new and emerging technologies with a potential impact on the future of the EU transport sector and horizon scanning
4. Highlighting mature technologies that are close to market introduction

This process provides continuous support to the STRIA implementation and update process. Seven working groups responsible for the roadmaps' development were set up, each corresponding to one of the roadmaps. After the adoption of the seven initial roadmaps, the status of each roadmap varies. As of March 2020, three roadmaps have been updated and a new version is available (CAT, INF and SMO), while the update process

has been initiated for ALT. TRIMIS has provided support to the update process -inter alia- by developing an initial set of indicators and by providing analyses to the active working groups.

In this framework, this report presents the methodology that TRIMIS has developed to evaluate the status and implementation of the STRIA roadmaps through selected indicators. The indicators measure progress in transport R&I across Europe and enable TRIMIS to monitor progress against roadmap targets as appropriate and subsequently report the results to the benefit of policy makers and other stakeholders involved in transport R&I. This report describes the selection and use of a set of indicators focusing at different levels of the STRIA intervention logic covering the challenges, objectives, inputs, outputs and impacts linked to each roadmap as introduced in Tsakalidis et al. (2018) and further analysed in the methodological chapter of this report.

This report contains five chapters. Following this introductory chapter, Chapter 2 provides an overview of the existing innovation assessment tools and current practice. Chapter 3 presents the role of indicators within TRIMIS and the methodology used to determine a set of indicators. Chapter 4 presents the set of proposed TRIMIS indicators for the assessment of STRIA. Finally, Chapter 5 provides conclusions and outlines future priorities.

2 Overview of indicators and tools as a means of monitoring and assessing innovation progress

This chapter provides an overview of the main existing indicators and assessment tools used to analyse innovation. Their overall objective is to monitor technological and socio-economic progress and thereby to support innovation-related policies. Furthermore, the approach of TRIMIS to identify appropriate indicators to monitor the progress of STRIA is presented.

2.1 Technology development assessment

Technology development has been measured traditionally using the Technology Readiness Level (TRL) scale. The National Aeronautics and Space Administration (NASA) developed the TRL scale to assess the maturity level of a particular technology. Nine readiness levels exist, ranging from TRL 1 to TRL 9. A technology project can be evaluated against the parameters defining each technology level and can therefore be assigned a TRL according to its progress (Mai, 2017). Although the TRL scale was introduced in the early 1970s for space systems development, it has been implemented in other fields, often adapted to the needs of different organisations (EARTO, 2014). For example, the EC definitions of the TRL are outlined in the general annexes of European Framework Programmes for Research and Technological Development, such as Horizon 2020 (H2020) (European Commission, 2014a).

Yet the use of the TRL scale for innovation policy has been criticised (Héder, 2017). A limitation of TRL is that they only indicate whether the technology is available and provide no indication on market maturity or (widespread) market uptake. To overcome this limitation, other indicators have been proposed. However, their diffusion is limited or relevant to specific areas.

The Manufacturing Readiness Level (MRL) is a measurement scale developed by a joint United States Department of Defence / industry working group under the sponsorship of the Joint Defence Manufacturing Technology Panel (JDMTP). The MRL provides a common metric and vocabulary for assessing and discussing manufacturing maturity and risk. The MRL scale comprises 10 distinct readiness levels ranging from MRL 1 to MRL 10. While the MRL provides a knowledge-based standard for the evaluation of manufacturing maturity, it must be supplemented with expert professional judgment (OSD Manufacturing Technology Program and The Joint Service/Industry MRL Working Group, 2017).

Other examples of indicators include the Innovation Readiness Level, which assesses the innovation readiness of a technology, product or service along five dimensions: technology readiness level, Intellectual property (IP) readiness level, market readiness level, consumer readiness level and society readiness level (Darmani and Jullien, 2017) and the Investment Readiness Level, which defines the fitness and intrinsic risks of the investment (Blank, 2014). The Demand Readiness Level (DRL) was introduced as an assessment tool, hybridising Market Pull and Technology Push approaches (Paun, 2011), while the System Readiness Level (SRL) index is an index of maturity applied at the system-level with the objective of correlating this indexing to appropriate systems engineering management principles (Sauser et al., 2006). Moreover, the Commercial Readiness Index (CRI) has been proposed in order to address the commercial uncertainty and the remaining risk in the demonstration and deployment phases (i.e. above TRL 6) (Australian Renewable Energy Agency, 2014).

2.2 Socio-economic, financial and organisational assessment

The concept of innovation is not only linked to technological development but covers a range of activities and processes influenced by socio-economic factors, availability of financial resources and the organisational framework in which a company or a country operates. The Organisation for Economic Co-operation and Development (OECD) (2009) identified the need for a comprehensive list of innovation indicators and highlighted that "*technology-based activities … are only a subset of what is included in the broader concept of innovation*". In order to gather additional information on innovation, the list of aspects to be investigated increases to cover innovation, collaborations among companies, skills, knowledge transfer, etc.

The distinction between technological (product and process) and non-technological (marketing and organisational) innovations is useful for data collection and analysis. However, it does not reflect industrial practice, where innovation is the result of a number of factors.

The measurement framework for non-technological indicators follows an approach where different dimensions are included: framework conditions; level of engagement in innovation activities by private firms; and the innovation impacts or outputs.

A framework to measure social innovation was developed following this overall approach (Bund et al., 2015, 2013), which includes a list of indicators' categories considering: financial resources, intellectual property rights, information and communication technology (ICT), knowledge, collaboration and networks, entrepreneurial activities and innovation culture.

The European Innovation Scoreboard follows a similar measurement framework in which the indicators used are clustered under the following categories: framework conditions, investments, innovation activities and impacts (European Commission, 2019):

- *Framework conditions* identify the main drivers of innovation performance external to the company (i.e. human resources, attractive research systems and innovation-friendly environment)
- *Investments* look at investments made in both the public and business sector (i.e. finance and support and firm investments)
- *Innovation activities* captures different aspects of innovation in the business sector such as product and process innovations as well as marketing and organisational innovations and small and medium enterprises (SMEs) that innovate in-house. Innovation activities also include linkages among firms and intellectual assets measuring Patent Cooperation Treaty (PCT) patent applications, trademark applications and design applications
- The *Impacts* category includes the effects of companies' innovation activities that examines employment and sales impacts and measures the economic impact of innovation

The TRIMIS analysis uses socio-economic, financial and organisational indicators that are aligned with this measurement framework.

2.3 Use of innovation assessment tools and indicators within the EU policy framework

A series of innovation assessment tools and indicators are used to analyse innovation and monitor progress to define EU innovation-related policies. The main EC tools are available online at the portal of the Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), namely (European Commission, 2018a):

- European Innovation Scoreboard
- Regional Innovation Scoreboard
- European Public Sector Innovation Scoreboard
- Innobarometer
- Regional Innovation Monitor Plus
- Business Innovation Observatory
- Digital Transformation Monitor

— European Cluster Observatory

— European Service Innovation Scoreboard

— Key Enabling Technologies (KETs) Observatory

— Key Enabling Technologies (KETs) Technology Infrastructure Mapping

Additional initiatives within the area of innovation and use indicators for technological assessment include:

— Intelligent Europe Energy (IEE) Common Performance Indicators

— Strategic Energy Technologies Information System (SETIS)

— Research and Innovation Observatory (RIO)

A detailed overview of the above-mentioned R&I monitoring tools is available in Annex II. The review and assessment of these tools support the selection of the appropriate approach and indicators to achieve the objectives of TRIMIS, outlined in the following section.

2.4 TRIMIS as the European transport R&I monitoring mechanism

TRIMIS aims to ensure the continuous monitoring of the status of EU transport R&I by:

— monitoring the STRIA development progress

— providing and regularly update 'technology mapping'

— defining and regularly update 'capacity mapping'

— assessing EU-funded research in the field of transport

— assessing STRIA progress and its actions against defined indicators and through scoreboards

— highlighting opportunities for new STRIA roadmaps or restructuring of the existing ones

— monitoring socio-economic developments and assess their influence on transport and innovation

— facilitating the effective functioning of an extensive network of transport stakeholders

To achieve these objectives, a set of appropriate indicators has been developed at the general level and in accordance with the specific characteristics of each roadmap that will be used for the assessment of their implementation by TRIMIS. Moreover, these indicators will provide the basis for an interactive transport R&I scoreboard that will be available through the online TRIMIS platform. The following chapter provides an overview of the indicator development process.

3 Methodology

This study aims to define a set of indicators that have a twofold role, namely to:

a. Streamline the monitoring process of STRIA and ensure coherence in the transport R&I assessment

b. Provide a metric to support the implementation and update of STRIA roadmaps

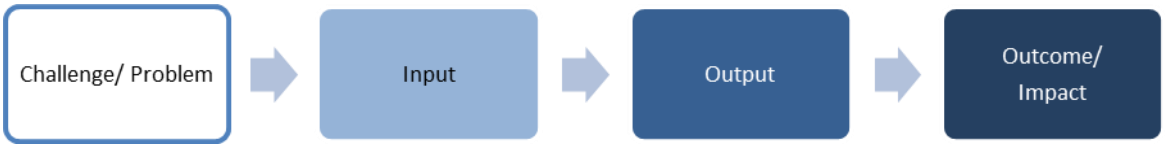
Four principles guide the development of an appropriate set of indicators:

1. Indicators must be grounded in the content of the roadmaps
2. Indicators must monitor the entire results chain that is set out in the roadmap
3. Indicators must be informative, useful and durable, so that they can be tracked over time
4. Indicators must be efficiently retrievable

Following this logic, it is important to align TRIMIS with EU principles for better regulation and good governance (European Commission, 2015b). STRIA determines the needs and sets the objectives of what needs to be achieved within the European transport R&I sector. TRIMIS provides the monitoring and evaluation support to identify relevant activities undertaken and to assess R&I activities. A comprehensive monitoring and assessment approach is used, which is aligned with the STRIA intervention logic as defined in Tsakalidis et al. (2018).

Figure 1 presents the generic intervention logic of the STRIA roadmaps, including the initial challenges / problems that emerge and the objectives linked to them, followed by the input, output and outcome / impact levels. Although with simplifications, this logic is based on corroborated literature (see for example World Bank, 2012; OECD, 2013) on the "results framework" or "results chains" that provide causal pathways from the planned interventions to the envisioned outcomes.

Figure 1. Generic intervention logic (results chain) of the STRIA roadmaps.



Source: Adapted from Tsakalidis et al., 2018.

With reference to Figure 1:

— An input covers everything that goes into an action, including resources (e.g. financial) and activities (e.g. research and development - R&D)

— An output comprises the direct (or short-term) effects of the input (e.g. number of publications, patent applications, technology level upgrade)

— An outcome (impact) refers to the high-level or long-term changes that the action is intended to achieve (e.g. improved road safety, pollution mitigation)

Even though it is more difficult to measure outputs and outcomes / impacts than inputs, it is important that such indicators be included to evaluate roadmap progress and identify R&I areas where potential interventions may be required. To this aim, the elements in the results chain are identified for each roadmap and indicators are selected.

Nevertheless, unlike the standard results chain analysis, the scope of the TRIMIS intervention logic remains more limited. The ultimate aim of the methodology is not to establish strict relationships between inputs and outputs, but to analyse and compare the trends of these variables. To this aim, more tangible, measurable results will be preferred and prioritised in the analysis, while others that are difficult to quantify will be omitted.

For instance, improvements in road safety is a specific and enduring transport challenge. While investments in R&D help to address this issue, road safety can also be improved by several other factors, such as improving infrastructure, appropriate policies or regulation etc., that are beyond the scope of this task and thus omitted.

Since some roadmap descriptions do not provide indicators, while others focus solely on input / output indicators, a harmonised set of indicators is proposed to address the STRIA roadmaps. The indicators belong to one of the following types:

1. Inputs
2. Outputs
3. Impacts

Chapter 4 provides a detailed list of the initial set of proposed indicators, based on the contents of the roadmaps. It should be noted that most indicators are not accompanied by set targets; since it is outside of the scope of TRIMIS to set targets, if the roadmaps do not contain any, then none will be set.

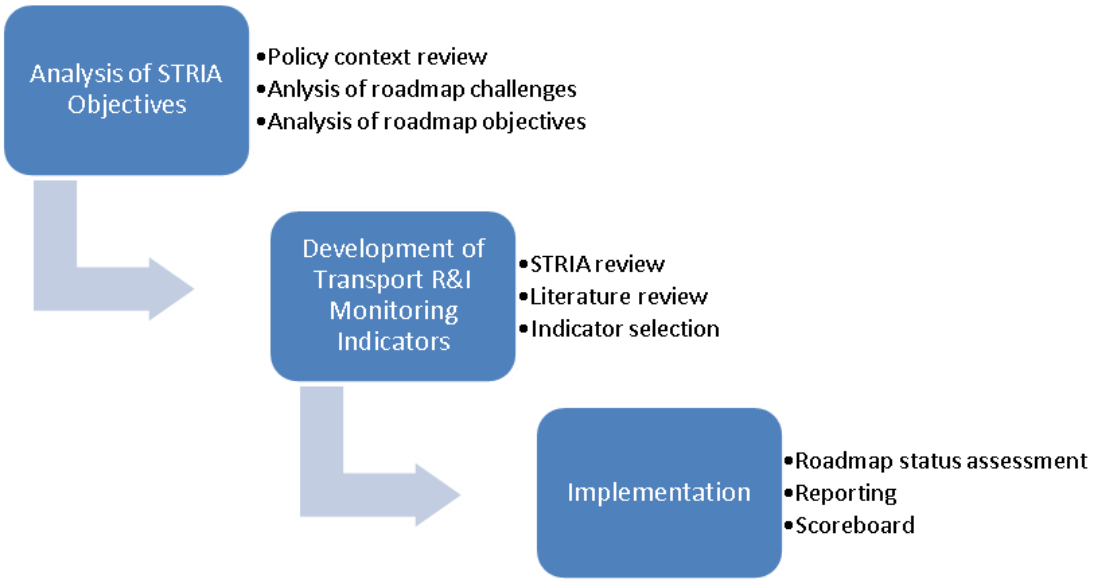
3.1 Development and implementation steps

The TRIMIS assessment process covers both technological and socio-economic elements related to the transport sector. The technological assessment addresses technical aspects, while the socio-economic assessment covers the social and economic impacts that influence relevant transport R&I capacities.

The technological assessment includes the analysis of all transport R&I data available in the TRIMIS database and requires technological indicators to be developed. In parallel with the technological assessment, the aim of the socio-economic assessment is to monitor and assess private and public transport R&I investments: economic, financial and human resources. A series of relevant indicators in this area has been presented in the TRIMIS technical report by Grosso et al. (2019). Only a limited number of those has been included in this report, since here the main focus is the development of a set of indicators directly linked to the STRIA roadmaps and the three assessed layers, i.e. inputs, outputs and impacts.

The TRIMIS methodological approach regarding indicators includes three steps: (i) the analysis of STRIA objectives; (ii) the development of a set of transport R&I monitoring indicators; and (iii) the implementation of this set of indicators for the roadmaps' status assessment, as presented in Figure 2.

Figure 2. Indicators development and implementation methodological steps.



Source: Own elaboration.

3.1.1 Analysis of STRIA objectives

The STRIA objectives as outlined in the seven roadmaps and their policy context are analysed.

In the TRIMIS assessment process, indicators are used to cover the STRIA objectives, accompanied by relevant thresholds and timeframes, if applicable.

3.1.2 Development of transport R&I monitoring indicators

The qualitative aspects related to the STRIA objectives in each of the roadmaps have to be quantified in order to be assessed. Hence, appropriate indicators are necessary, which in some cases are provided in the existing roadmaps, whereas in other cases they are not. In order to be consistent, a complete set of indicators is required.

An important criterion for the selection of indicators is the ability to identify data sources, the availability of data and an adequate update frequency. Lack of one of the above may be an elimination factor for candidate indicators.

Therefore, the indicators suggested in the roadmaps –if available- are used as a basis. They are complemented by indicators found in the relevant literature and by others based on the TRIMIS database that could be used to assess quantitative aspects related to challenges / objectives / actions for each roadmap.

3.1.3 Implementation

The selected STRIA indicators will be used to assess technological and socio-economic impacts of transport R&I. Specifically, a series of assessment reports focusing on STRIA will be produced to support policy making and provide insights to transport stakeholders:

- STRIA status assessment and roadmap-specific reports
- Thematic reports

Furthermore, an interactive scoreboard will be developed to visualise R&I progress based on the proposed indicators. This scoreboard will be available on the TRIMIS online platform and will include data visualisations and interactive functionalities to assess the status of R&I related to STRIA.

3.2 Indicator attributes

The indicators that are used by TRIMIS cover the main aspects of transport R&I.

These indicators are used to measure the effect of a targeted action and are included in the TRIMIS database. Each indicator should be defined, the measurement unit set, along with the target value and whether the indicator measures an input, output or impact. The target values can be outlined for all future years or a selection, depending on the timeframe of the action, if applicable. A data source should be identified to monitor progress. Table 1 presents the specific information collected for each of the indicators.

Table 1. Overview of information collected per indicator.

Element	Description
Level	Section of the results chain that is monitored
Indicator	Description of the indicator
Mode	Specific mode(s) of transport to which the indicator applies
Unit	Unit of measurement
Scope	Geographical scope
Timeframe	Start and end date of the measurement
Source	The source of information on which the indicator is based
Link / API	When non-TRIMIS data is used, a link is provided to an external source
Roadmap	One or more corresponding roadmaps
Frequency	Frequency with which the indicator is updated

Element	Description
Target value	Target value as defined by the STRIA roadmap
Target year	Year in which defined target is to be achieved as defined by the STRIA roadmap
Scoreboard	Shows if the indicator will be used for the online monitoring scoreboard
Remarks	Final written comments

Source: Own elaboration.

4 Development of TRIMIS indicators

This section presents the new set of indicators selected for the seven STRIA roadmaps. The contents of each roadmap are analysed in detail in order to identify the respective challenges, inputs, outputs and impacts. This analysis allows the definition of indicators to be used for the STRIA monitoring and assessment.

4.1 STRIA roadmap overview

The following sections provide a brief description of each roadmap. A list of indicators either provided in the roadmaps or obtained after a thorough assessment, together with a more detailed overview of challenges and objectives is provided in Annex II. The selection of indicators was based on the ability to identify data sources, the availability of data and an adequate update frequency. The list of indicators will be reviewed and updated when necessary. Moreover, targeted expert reviews could be used in the future as an additional means to further improve the selection or update of the indicators used.

4.1.1 Connected and automated transport

Connected and automated transport technologies can contribute to increasing the efficiency and safety of the transport system. The introduction of these new technologies and services can improve traffic flows, optimise the use of infrastructure, lower noise levels, shift greater volumes of passenger traffic towards public transport, increase the efficiency of goods transport and foster the emergence of multi-modal transport solutions.

The updated STRIA Roadmap on "Connected and Automated Transport: Road, Rail and Waterborne" was published in April 2019. It defines future research needs for developing and deploying connected and automated transport technologies and systems. The roadmap builds on and develops the 2017 CAT roadmap for the various transport modes. The 2019 CAT roadmap does not cover aviation (given the advances in recent year in the sector); the chapter on cross-modal cooperation and synergies, however, considers aviation.

The roadmap does not specify indicators for monitoring the R&I initiatives, since, although there has been significant effort in developing indicators for monitoring the progress of connected and automated road mobility (see for example Vermesan et al., 2017; Innamaa et al. 2018), including Intelligent Transport Systems (ITS) (Payne, 2015), it will not be possible to measure most of the indicators before the demonstration, implementation or future deployment of CAT.

4.1.2 Transport electrification

Transport electrification can contribute to breaking transport dependency on oil and decrease carbon dioxide and pollutant emissions. The increasingly decarbonised electricity generation will provide cleaner electricity to propel electric vehicles. Electric vehicles will be able to provide storage services to the grid, favouring further expansion of renewables.

The development of energy storage technologies and devices remains the cornerstone of a fully electrified transport system, integrated in a clean energy network. Decreasing battery costs while increasing their energy density and lifetime will speed up the electrification of road transport. The deployment of a network of recharging points covering the whole EU road network is another key enabling condition for transport electrification.

The STRIA Roadmap on Transport Electrification aims to bring forward, the developments carried out in the framework of the European Green Vehicles Initiative and encourage multi-sectorial and multi-disciplinary research and innovation activities on new materials, advanced propulsion systems and information computer technology.

With regard to the indicators provided, they are available only for road transport and aviation with a varying level of precision and vary from abstract terms such as 'range' and 'customer trust' to defined technical performance specifications. No specific data sources are provided in the roadmap or found available, which would meet the TRIMIS indicator selection criteria. Therefore, a set of adequate indicators have been identified for the assessment purposes.

4.1.3 Vehicle design and manufacturing

Transport vehicle design, development and manufacturing is a collaborative, integrated and complex set of processes and tools that consider the whole vehicle life cycle and is a key element for the competitiveness of the European transport industry.

Continuous research and innovation are necessary for the seamless integration of digital and physical vehicle design and manufacturing processes, tools and infrastructures.

The STRIA Roadmap for Vehicle Design and Manufacturing aims to develop successful marketable transport vehicles with shorter development times.

No specific indicators were provided in the roadmap but 35 actions were clearly identified and defined. These actions can be easily associated with indicators, but some of them are too general and/or difficult to assess (e.g. incorporate mechanism for dialogue with the community).

4.1.4 Low-emission alternative energy for transport

Electric battery and hydrogen fuel cell powertrains are viable options for many road vehicles. However, aviation, waterborne transport and certain heavy-duty road vehicles are likely to rely on combustion engines and liquid fuels for the foreseeable future.

In order to decarbonise the transport sector it is therefore essential in the short- and medium-term to increase the use of renewable energy sources and improve the overall energy efficiency of the transport system. This will have the benefit of not only reducing greenhouse gases (GHG) but also pollutants that are responsible for poor urban air quality.

Nevertheless, increasing the share of alternative low-emission energy in the transport sector poses a number of technical and environmental challenges.

The development of a new generation of powertrains will require research and innovation efforts to be focused on a step change in technology. One that allows greater and more efficient use of alternative energies to reduce GHGs. For energy production, R&I efforts will need to focus on novel low-emission alternative energies based on renewable and sustainable sources.

The STRIA Roadmap for Low-emission Alternative Energy for Transport focuses on renewable fuels production, alternative fuel infrastructures as well as the impact on transport systems and services of these technologies for road, rail, waterborne transport and aviation. In order to obtain the challenges, some interpretation from the authors of this report has been required, so refinements can be included in future versions of the research, particularly after experts' consultation and workshops updating the roadmap. One of the main problems from this roadmap is that objectives were not explicitly defined; therefore, they are obtained following an interpretation of the roadmap, with all the risks previously mentioned in other roadmaps. The roadmap also identifies R&I needs, linked to challenges and opportunities. No specific actions or indicators were provided in the roadmap and therefore 75 actions were identified based on the stated needs.

4.1.5 Network and traffic management systems

Network and Traffic Management systems are used for the optimisation and management of transport networks' operation. Bottlenecks across air, rail, road and water can result in system-wide capacity constraints, traffic jams, increased pollutant emissions, and environmental impacts.

The transition towards an advanced multi-modal transport system requires better coordinated and organised traffic flows to optimise the entire transport network. This involves devices to detect real traffic conditions, traffic information sharing, optimisation processes and the distribution of control actions via end-user devices.

Digital technologies and the emergence of the connected traveller can influence real-time demand by encouraging off-peak travel and use of alternative routes through intelligent applications and user information services. Integrated urban traffic management and mobility information systems can therefore contribute to optimising transport flows both through cities and in rural regions.

The STRIA Roadmap for Network and Traffic Management Systems aims to develop an advanced multi-modal transport system by effectively optimising the entire transport network across several areas.

Each objective is linked to a number of actions, which are connected with one or more indicators. The indicators do not relate to one specific action or the output level. They focus on impacts, such as the 'Share of travellers using mobility services instead of private car'.

4.1.6 Smart mobility and services

Smart mobility systems and services have the potential to contribute to the decarbonisation of the European transport sector. Changes in transport behaviour and lifestyles such as the use of smart phones, mobile web applications and social media together with the trend to *use* rather than *own* a particular transport mode have opened up new pathways to sustainable mobility.

A critical link exists between new technologies, services and transport decarbonisation. However, policy and innovation efforts have focused on small changes to improve car technology rather than on integrated transport and mobility strategies. Breaking this path-dependency remains a key innovation challenge.

Future transport and mobility services will need to be part of smart and sustainable city strategies to improve urban resource efficiency, decarbonisation and ensure an integrated transport system.

The STRIA Roadmap for Smart Mobility and Services aims to assess emerging new technologies such as multi-modal, electric and autonomous vehicles, drone technology and on-demand mobility services. It establishes and assesses the impacts of such technologies on transport and mobility systems and services.

In October 2019, a revised version was published, building on the 2017 roadmap and further developing the research and innovation strategy. It is based on consultation with a wide range of European stakeholders and experts.

Even though, challenges, target and innovation actions are defined and allocated in the roadmap, there are no specific indicators mentioned.

4.1.7 Transport infrastructure

Transport infrastructure includes physical networks, terminals and intermodal nodes, information systems, as well as refuelling and electrical supply networks. It is essential for the safe, secure operation of road, rail, civil aviation, and inland waterways and shipping and is crucial to the EU economic growth and social development.

Unlike other transport operations, public sector organisations at country or regional level own transport infrastructure. Where the private sector manages infrastructure, it is subject to economic regulation to comply with policies set by the member state (MS).

An issue of concern arises from the growing pressure on existing transport systems, combined with underfunded maintenance activity, growing digital connectivity, infrastructure vulnerabilities to human-made or natural disasters and the carbon efficiency of infrastructure reuse. Life-cycle optimisation and integrated efficient operation can lead to improvements in the existing and future infrastructure stock.

Furthermore, innovation that influence user's behaviour such as mobility-as-a-service and cooperative connected and automated mobility impact the optimal use of existing infrastructure and require a discussion on future standards and requirements.

The 2019 STRIA Roadmap for Transport Infrastructure identifies several research needs, where consumer or user acceptance will be needed, divided in eight thematic areas. The roadmap provides a short list of indicators divided by thematic area (for which however, no list of sources is provided), and a cross-cutting list of indicators that has been provided by TRIMIS (van Balen et al., 2019).

4.2 Roadmap conclusions

Each roadmap has followed a different development approach, a process resulting in varying structures, contents, lengths and outputs. Moreover, the lack of a harmonised timeframe between the various STRIA working groups leads to some inconsistencies between the roadmaps, as some of them have recently been updated and revised, while others not. An overall conclusion from the analysis of the STRIA roadmaps was the lack of specific or easy to monitor indicators. Moreover, there were inconsistencies between different roadmaps and lack of harmonisation in roadmap structure, providing specific challenges, objectives and targets. Therefore, a new set of indicators creates proposed, taking into account the STRIA roadmaps and using the TRIMIS database as a source. This list is presented in the following section.

4.3 List of proposed indicators and their specifications

The proposed set of indicators takes into account indicators included in STRIA roadmaps, as well as literature reviews and information available in the TRIMIS database. The list describes for each indicator the level (i.e. input, output and impact), the unit (e.g. passenger-km (pkm), hours, count) and whether it is general or roadmap-specific. Table 2 shows the full list of proposed indicators and their attributes. Even though some indicators do not measure exclusively innovation (for example the Trans-European Transport Network - TEN-T completion indicators), they reflect the outcome of R&I initiatives that foster innovative, ready-to-implement and cost-effective solutions.

Table 2. List of proposed indicators and their specifications.

ID	Level	Indicator	Unit	Source	General	CAT	ALT	ELT	VDM	NTM	SMO	INF
1	Input	Number of projects	Count	TRIMIS	1	1	1	1	1	1	1	1
2	Input	Number of projects per mode	Count	TRIMIS	1	1	1	1	1	1	1	1
3	Input	Total funding	Value (€)	TRIMIS	1	1	1	1	1	1	1	1
4	Input	MS Participation index. Normalised rate (based on the Gross Domestic Product - GDP) of transport R&I project participation per MS	Rate	TRIMIS	1	1	1	1	1	1	1	1
5	Input	MS Financial success index. Normalised rate (based on the Gross Domestic Product - GDP) of transport R&I project funding per MS	Rate	TRIMIS	1	1	1	1	1	1	1	1
6	Input	Projects funding timeline according to funding scheme	Number of projects	TRIMIS	1	1	1	1	1	1	1	1
7	Output	Projects at each development phase[1]	Count	TRIMIS	1	1	1	1	1	1	1	1

[1] In order to measure technology development, TRIMIS focuses on the monitoring of technology maturity in technologies identified in European R&I projects. In doing so, the nine TRLs have been consolidated into four development phases (Gkoumas and Tsakalidis, 2019). These development phases are used in a similar way to the original TRLs.

ID	Level	Indicator	Unit	Source	General	CAT	ALT	ELT	VDM	NTM	SMO	INF
8	Output	Number of patents linked to technologies	Count	TRIMIS	1	1	1	1	1	1	1	1
9	Input	Total business R&I expenditures	Value (€)	TRIMIS (Macro indicator)	1	0	0	0	0	0	0	0
10	Input	Total number of transport R&I researchers classified according to their gender	Full-time Equivalents (FTE)	TRIMIS (Macro indicator)	1	0	0	0	0	0	0	0
11	Impact	Carbon dioxide (CO_2) emission levels from all transport modes per year	million tonnes	DG MOVE based on European Environment Agency (EEA) data EU Transport in Figures - Statistical Pocketbook	1	0	0	0	0	0	0	0
12	Input	Sum of money spent on Transport R&I projects according to the beneficiary names and transport modes	Value (€)	TRIMIS	0	1	1	1	1	1	1	1
13	Input	Technology funding timeline according to roadmap	Number of projects	TRIMIS	0	1	1	1	1	1	1	1
14	Input	Level of international cooperation in transport R&I (Correlation matrix based on collaborations between organisations in the MS)	Coefficient	TRIMIS	0	1	1	1	1	1	1	1
15	Output	Number of scientific publications related to each roadmap	Publication count	Scopus	0	1	1	1	1	1	1	1
16	Impact	Number of road accidents	Count	Community Road Accident Database (CARE)	0	1	0	0	0	1	0	1
17	Impact	Number of rail accidents	Count	European Union Agency for Railways (ERA) European Railway Accident Information Links (ERAIL)	0	1	0	0	0	1	0	1

ID	Level	Indicator	Unit	Source	General	CAT	ALT	ELT	VDM	NTM	SMO	INF
18	Impact	Number of waterborne accidents	Count	European Maritime Safety Agency (EMSA) European Marine Casualty Information Platform (EMSIP)	0	1	0	0	0	1	0	1
19	Impact	Number of aviation accidents	Count	European Union Aviation Safety Agency (EASA) Occurrence Database	0	1	0	0	0	1	0	1
20	Impact	Hours lost in road traffic	Hours	JRC / DG MOVE	0	0	0	0	0	1	1	1
21	Impact	Hours lost due to delays in rail transport (passenger / freight)	Hours	Rail Market Monitoring Report	0	0	0	0	0	1	1	1
22	Impact	Hours delayed flights	Hours	Eurocontrol	0	0	0	0	0	1	1	1
23	Input	5G coverage in MS	%	5G scoreboard	0	1	0	0	0	0	0	0
24	Impact	Ratio of Alternative Fuel vehicles to total fleet	%	European Alternative Fuels Observatory (EAFO)	0	0	1	0	0	0	0	0
25	Impact	Growth of Alternative Fuel vehicles fleet	%	European Alternative Fuels Observatory (EAFO)	0	0	1	0	0	0	0	0
26	Impact	Growth of Alternative Fuel Infrastructure	%	European Alternative Fuels Observatory (EAFO)	0	0	1	0	0	0	0	1
27	Impact	Electric vehicle market share - new registrations	%	European Alternative Fuels Observatory (EAFO)	0	0	0	1	0	0	0	0
28	Impact	Growth of Recharging Infrastructure	%	European Alternative Fuels Observatory (EAFO)	0	0	0	1	0	0	0	1
29	Impact	Plug-in electric vehicles per public charging point	%	European Alternative Fuels Observatory (EAFO)	0	0	0	1	0	0	0	1
30	Impact	Fast chargers per 100 km highway	Count	European Alternative Fuels Observatory (EAFO)	0	0	0	1	0	0	0	1

ID	Level	Indicator	Unit	Source	General	CAT	ALT	ELT	VDM	NTM	SMO	INF
31	Impact	European share in world motor vehicle production	%	European Automobile Manufacturers Association (ACEA)	0	0	0	0	1	0	0	0
32	Impact	Carbon dioxide (CO_2) emissions from car production	t/car	European Automobile Manufacturers Association (ACEA)	0	0	0	0	1	0	0	0
33	Impact	Development of country market shares in compensated gross tonnage (CGT) deliveries	%	The OECD Council Working Party on Shipbuilding	0	0	0	0	1	0	0	0
34	Impact	European Rail Traffic Management System (ERTMS) equipped vehicles	Count	Association of the European Rail Industry (UNIFE)	0	0	0	0	0	1	0	0
35	Output	Deployment activities currently completed or in progress (Pilot Common Project – PCP implementation status per Air Traffic Management -ATM functionality)	%	Single European Sky ATM Research (SESAR)	0	0	0	0	0	1	0	0
36	Impact	Completion of TEN-T Road Core Network	%	DG MOVE TENTec	0	0	0	0	0	0	0	1
37	Impact	Completion of TEN-T Conventional Rail Core Network	%	DG MOVE TENTec	0	0	0	0	0	0	0	1
38	Impact	Completion of TEN-T High Speed Rail Core Network	%	DG MOVE TENTec	0	0	0	0	0	0	0	1
39	Impact	Completion of TEN-T Inland Waterways Core Network	%	DG MOVE TENTec	0	0	0	0	0	0	0	1

Source: Own elaboration.

Table 3 presents the current overview of proposed indicators. They are organised per roadmap and indicator focus. It can be noted that all roadmaps and all stages of the results chain are covered.

Table 3. Availability of initial indicators per roadmap and indicator focus.

Stage	Sum of General	Sum of CAT	Sum of ALT	Sum of ELT	Sum of VDM	Sum of NTM	Sum of SMO	Sum of INF	TOTAL
Input	8	10	9	9	9	9	9	9	72
Output	2	3	3	3	3	4	3	3	24
Impact	1	4	3	4	3	8	3	15	41
Grand Total	11	17	15	16	15	21	15	27	137

Source: Own elaboration.

This set of indicators will be used by TRIMIS for reporting purposes and the scoreboard that will be available on the TRIMIS online platform. Further effort is required to update indicators to support the STRIA development and implementation process.

5 Conclusions

For each STRIA roadmap, a set of indicators is proposed to provide a basis for the assessment of technological and socio-economic performance of European transport R&I. The proposed indicators will facilitate TRIMIS's monitoring and assessment process and will be included in the TRIMIS scoreboard as appropriate. Moreover, the use of quantitative metrics will assist the STRIA Governance Group and roadmap-specific working groups to assess the progress of achieving roadmap objectives and of implementing R&I actions.

The TRIMIS indicator development process is based on the identification of challenges / problems, objectives, and proposed actions in the STRIA roadmaps. However, definitions of these different factors are not always present in the roadmaps and therefore, the process has required further literature review and expert judgement. Therefore, additional effort is required to identify, interpret and extract information. Dedicated expert reviews could be used in the future as an additional means to further improve the selection or update the list of indicators used.

The initial analysis of the STRIA roadmaps highlights a certain lack of harmonisation among them. In this sense, harmonisation and / or standardisation across the roadmaps and the identification of indicators within the development and update process of STRIA will allow for better monitoring and assessment of each roadmap's progress.

Thus, the key challenge of monitoring the STRIA roadmaps will be to standardise the roadmaps; that is, their level of detail, challenges, objectives and actions. In addition, the connection between indicators and actions should be improved, as well as the link between challenges and objectives with actions.

References

Australian Renewable Energy Agency, *Commercial Readiness Index for Renewable Energy Sectors,* 2014; available at: https://doi.org/10.1007/BF02696941 (last accessed 02 March 2020).

Blank, S., *How Investors Make Better Decisions: The Investment Readiness Level,* 2014; available at: https://blogs.berkeley.edu/2014/07/01/how-investors-make-better-decisions-the-investment-readiness-level/ (last accessed 27 April 2020).

Bund, E., Hubrich, D., Schmitz, B. and Mildenberger, G., *Blueprint of social innovation metrics: contributions to an understanding of opportunities and challenges of social innovation measurement, 2013; available at:* https://archiv.ub.uni-heidelberg.de/volltextserver/18700/1/D2.4_final.pdf (last accessed 02 March 2020).

Bund, E., Gerhard, U., Hoelscher, M. and Mildenberger, G., 'A methodological framework for measuring social innovation', *Historical Social Research*, Vol. 40, No. 3, 2015, pp. 48–78. https://doi.org/10.12759/hsr.40.2015.3.48-78.

Darmani, A. and Jullien, C., *Innovation Readiness Level report: Energy Storage Technologies,* 2017; available at http://www.reeem.org/wp-content/uploads/2017/09/REEEM-D2.2a.pdf (last accessed 02 March 2020).

EARTO, *The TRL Scale as a Research & Innovation Policy Tool, EARTO Recommendations,* 2014; available at: https://www.earto.eu/wp-content/uploads/The_TRL_Scale_as_a_R_I_Policy_Tool_-_EARTO_Recommendations_-_Final.pdf (last accessed 04 March 2020).

European Commission, *European Innovation Scoreboard*, 2019; available at: http://ec.europa.eu/growth/industry/innovation/facts-figures/scoreboards_en (last accessed 02 March 2020).

European Commission, *Monitoring innovation*, 2018a; available at: http://ec.europa.eu/growth/industry/innovation/facts-figures_en_en (last accessed 02 March 2020).

European Commission, *Regional Innovation Scoreboard*, 2018b; available at: https://ec.europa.eu/growth/industry/innovation/facts-figures/regional_en (last accessed 02 March 2020).

European Commission, *Innobarometer*, 2018c; available at: http://ec.europa.eu/growth/industry/innovation/facts-figures/innobarometer_en (last accessed 02 March 2020).

European Commission, *Regional Innovation Monitor Plus*, 2018d; available at: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/ (last accessed 02 March 2020).

European Commission, *Business Innovation Observatory*, 2018e; available at: https://ec.europa.eu/growth/industry/innovation/business-innovation-observatory_en (last accessed 02 March 2020).

European Commission, *State of play and key trends of digital transformation in Europe*, 2018f; available at: https://ec.europa.eu/growth/tools-databases/dem/monitor/ (last accessed 02 March 2020).

European Commission, 'Data explorer', *Digital Transformation Monitor, 2018g;* available at: https://ec.europa.eu/growth/tools-databases/dem/monitor/data-explorer (last accessed 02 March 2020).

European Commission, *European Cluster Observatory*, 2018h; available at: http://ec.europa.eu/growth/industry/policy/clusters/observatory_en (last accessed 02 March 2020).

European Commission, *Cluster Mapping Tool*, 2018i; available at: https://ec.europa.eu/growth/smes/cluster/observatory/cluster-mapping-services/mapping-tool_en (last accessed 02 March 2020).

European Commission, *The European Service Innovation Scoreboard*, 2018j; available at: http://ec.europa.eu/growth/tools-databases/esic/scoreboard/index_en.htm (last accessed 02 March 2020).

European Commission, *ESIS online tool*, 2018k; available at: http://ec.europa.eu/growth/tools-databases/esic/scoreboard/esis-database/index_en.htm (last accessed 02 March 2020)

European Commission, *KETs Observatory*, 2018l; available at: https://ec.europa.eu/growth/tools-databases/kets-tools/kets-observatory (last accessed 02 March 2020).

European Commission, *SMEs' Access to Key Enabling Technologies*, 2018m; available at: https://ec.europa.eu/growth/tools-databases/kets-tools/kets-tc/map (last accessed 02 March 2020).

European Commission, 'IRI - The EU Industrial R&D Investment Scoreboard', *Joint Research Centre - IRI - Economics of Industrial Research and Innovation,* 2018n; available at: http://iri.jrc.ec.europa.eu/scoreboard.html (last accessed 02 March 2020).

European Commission, *EUROPE ON THE MOVE - An agenda for a socially fair transition towards clean, competitive and connected mobility for all,* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM/2017/0283 final, 2017a.

European Commission, *TRIMIS Transport and Research and Innovation Monitoring and Information System*, 2017b; available at: https://trimis.ec.europa.eu/ (last accessed 05 March 2020).

European Commission, *EU transport Scoreboard*, 2017c; available at: https://ec.europa.eu/transport/facts-fundings/scoreboard_en (last accessed 02 March 2020).

European Commission, *SETIS Strategic Energy Technologies Information System*, 2017d; available at: https://setis.ec.europa.eu/ (last accessed 02 March 2020).

European Commission, *Innobarometer 2016 – EU business innovation trends*, 2012. https://doi.org/10.2873/791491.

European Commission, *Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation,* Communication from the Commission, *C/2015/6317 final*, 2015a.

European Commission, *Better regulation for better results - An EU agenda,* Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM/2015/0215 final, 2015b.

European Commission, *State of the Innovation Union 2015*, Publications Office of the European Union, Luxembourg, 2015c. https://doi.org/10.2777/74073.

European Commission, *Horizon 2020 – Work Programme 2014-2015, Annex G: Technology readiness levels (TRL),* Commission Decision C(2014)4995*,* 2014a.

European Commission, *Innovation Union Competitiveness report 2013*, Publications Office of the European Union, Luxembourg, 2014b. https://doi.org/10.2777/44320.

European Commission, *European Public Sector Innovation Scoreboard 2013 - A pilot exercise*, Publications Office of the European Union, Brussels, 2013. https://doi.org/10.2769/72467.

Fiorini, A., Georgakaki, A., Pasimeni, F. and Tzimas, E., *Monitoring R&I in Low-Carbon Energy Technologies*, Publications Office of the European Union, Luxembourg, 2017. https://doi.org/10.2760/434051.

Frietsch, R.; Kladroba, A.; Markianidou, P.; Neuhausler, P.; Peter, V.; Ravet, J.; Rothengatter, O. and Schneider, J., *Final report on the collection of patents and business indicators by economic sector: Societal Grand Challenges and Key Enabling Technologies*, Publications Office of the European Union, Luxembourg, 2017. https://doi.org/10.2760/39818.

Gkoumas, K., and Tsakalidis, A., 'A Framework for the Taxonomy and Assessment of New and Emerging Transport Technologies and Trends', *Transport*, Vol. 34, No. 4, 2019, pp. 455-466. https://doi.org/10.3846/transport.2019.9318.

Grosso, M., van Balen, M., Ortega Hortelano, A., Haq, G., Gkoumas, K., Tsakalidis, A. and Pekár, F., *Innovation Capacity of the European Transport Sector, A macro-level analysis,* Publications Office of the European Union, Luxembourg, 2019. https://doi.org/10.2760/581596.

Hardeman, S., Van Roy, V., Vertesy, D. and Saisana, M., *An analysis of national research systems (I): A composite indicator for scientific and technological research excellence*, Publications Office of the European Union, Luxembourg, 2013. https://doi.org/10.2788/95887.

Héder, M., 'From NASA to EU: The evolution of the TRL scale in Public Sector Innovation', *Innovation Journal*, Vol. 22, No. 2, 2017, article 3.

Hollanders, H. and Es-Sadki, N., *Regional Innovation Scoreboard 2017 - Methodology Report,* 2017; available

at: http://ec.europa.eu/docsroom/documents/23986 (last accessed 05 March 2020).

Hollanders, H., Es-Sadki, N., Vertesy, D. and Damioli, G., *European Innovation Scoreboard 2017 - Methodology Report*, 2017; available at: http://ec.europa.eu/DocsRoom/documents/25101 (last accessed 05 March 2020).

Innamaa, S., Smith, S., Barnard, Y., Rainville, L., Rakoff, H., Horiguchi, R. and Gellerman, H.., *Trilateral Impact Assessment Framework for Automation in Road Transportation*, 2018; available at: https://connectedautomateddriving.eu/wp-content/uploads/2017/05/Trilateral_IA_Framework_Draft_v1.0.pdf (last accessed 05 March 2020).

Lepori, B., *Analysis of National Public Research Funding (PREF) - Handbook for Data Collection and indicators production*, Publications Office of the European Union, Luxembourg, 2017. https://doi.org/10.2760/849945.

Mai, T., 'Technology readiness level - NASA', *Technology Readiness Level*, 2017; available at: https://www.nasa.gov/directorates/heo/scan/engineering/technology/txt_accordion1.html (last accessed 05 March 2020).

OECD, *Development Results: An Overview of Results Measurement and Management,* 2013; available at: https://www.oecd.org/dac/peer-reviews/Development-Results-Note.pdf (last accessed 05 March 2020).

OECD, *Innovation in Firms: A Microeconomic Perspective*, OECD Publishing, Paris, 2009. https://doi.org/10.1787/9789264056213-en.

OSD Manufacturing Technology Program and The Joint Service/Industry MRL Working Group, *Manufacturing Readiness Level (MRL) Deskbook Version 2017*, 2017; available at: http://www.dodmrl.com/MRL_Deskbook_2017.pdf (last accessed 05 March 2020).

Paun, F. (2011) ''Demand Readiness Level' (DRL), a new tool to hybridize Market Pull and Technology Push approaches: Evolution of practices and actors of eco-innovation', *ANR - ERANETWORKSHOP, Feb 2011*, Paris, France, pp. 1–6, 2011.

Payne, S., *Study on key performance indicators for intelligent transport systems: final report in support of the implementation of the EU Legislative Framework on ITS (Directive 2010/40/EU)*, 2015; available at: https://ec.europa.eu/transport/sites/transport/files/themes/its/studies/doc/its-kpi-final_report_v7_4.pdf (last accessed 05 March 2020).

Sauser, B., Verma, D., Ramirez-Marquez, J. and Gove, R., 'From TRL to SRL: The Concept of Systems Readiness Levels', *Conference on Systems Engineering Research, Los Angeles, CA, April 7-8, 2006,* Paper#126, 2006.

Tsakalidis, A., van Balen, M., Gkoumas, K., and Pekar, F., 'Catalyzing Sustainable Transport Innovation through Policy Support and Monitoring: The Case of TRIMIS and the European Green Deal', *Sustainability*, Vol. 12, No. 8, 2020, 3171. https://doi.org/10.3390/su12083171.

Tsakalidis, A., van Balen, M., Gkoumas, K., Grosso, M., Haq, G. and Pekar, F., *Towards an integrated monitoring and assessment framework for the Strategic Transport Research and Innovation Agenda - Using TRIMIS as a policy support mechanism*, Publications Office of the European Union, Luxembourg, 2018. https://doi.org/10.2760/788905.

van Balen, M., Grosso, M., Gkoumas, K., Tsakalidis, A., Haq, G., Ortega Hortelano, A. and Pekar, F., *Research and innovation capacity in transport infrastructure: An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)*, Publications Office of the European Union, Luxembourg, 2019. https://doi.org/10.2760/551629.

Vermesan, O., Bahr, R., Yeung, M., Ahmad, A., Cousin, P., Karagiannis, G., Brevi, D., Langheim, J., Firmani, C., Bastianelli, A. and Klaus, G., *Performance and KPIs for autonomous vehicles and IoT pilot impact measurement,* 2017; avaialble at: https://autopilot-project.eu/wp-content/uploads/sites/16/2018/10/AUTOPILOT-D5.3-Performance-and-KPIs-for-autonomous-vehicles-and-IoT-pilot-impact-measurement-v1.0.pdf (last accessed 05 March 2020).

Vertesy, D. and Tarantola, S., *The Innovation Output Indicator 2016 - Methodology Update*, Publications Office of the European Union, Luxembourg, 2016. https://doi.org/10.2788/836690.

World Bank, *Designing a results framework for achieving results: A how-to guide*, World bank, Washington, DC, 2012.

List of abbreviations and definitions

5G	5th Generation Mobile Communications Technology
ACEA	European Automobile Manufacturers Association
ALT	Low-emission Alternative Energy for Transport
ATM	Air Traffic Management
BERD	Business Research and Development Expenditures
CAD	Connected and Automated Driving
CARE	Community Road Accident Database
CAT	Connected and Automated Transport
CIP	Competitiveness and Innovation Framework Programme
CGT	Compensated Gross Tonnage
CO_2	Carbon Dioxide
CRI	Commercial Readiness Index
DG GROW	Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DRL	Demand Readiness Level
DTM	Digital Transformation Monitor
EAFO	European Alternative Fuels Observatory
EASA	European Union Aviation Safety Agency
EC	European Commission
EEA	European Environment Agency
EIS	European Innovation Scoreboard
EIS-IT	European Innovation Scoreboard Interactive Tool
ELT	Transport Electrification
EMSA	European Maritime Safety Agency
EMSIP	European Marine Casualty Information Platform
EPO	European Patent Office
EPSIS	European Public Sector Innovation Scoreboard
ERA	European Union Agency for Railways
ERAIL	European Railway Accident Information Links
ERTMS	European Rail Traffic Management System
ESIS	European Service Innovation Scoreboard
EU	European Union
FP7	7th Framework Programme for Research
FTE	Full-time Equivalent
GBAORD	Government Budget Appropriations or Outlays for Research and Development
GDP	Gross Domestic Product
GHG	Greenhouse Gas

H2020	Horizon 2020 Framework Programme for Research and Innovation
HMI	Human Machine Interface
HPC	High Performance Computer
HPDI	High Pressure Direct Injection
I3S	Innovation Union Information and Intelligence System
IAI	Innovator's Ability Indicator
ICI	Innovator Capacity Indicator
ICT	Information and Communications Technology
IEA	International Energy Agency
IEE	Intelligent Europe Energy
IEI	Innovator's Environment Indicator
IMI	Innovation Management Indicator
INF	Transport Infrastructure
IOI	Innovation Output Indicator
IP	Intellectual Property
IPI	Innovation Potential Indicator
IR	Innovation Radar
IRI	Innovation Readiness Indicator
IRIMA	Industrial Research and Innovation Monitoring and Analysis
ITS	Intelligent Transport Systems
IUCR	Innovation Union Competitiveness Report
IUS	Innovation Union Scoreboard
JRC	Joint Research Centre
JDMTP	Joint Defence Manufacturing Technology Panel
KET	Key Enabling Technology
KPI	Key Performance Indicator
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
MPI	Market Potential Indicator
MRL	Manufacturing Readiness Level
MS	Member State
NASA	National Aeronautics and Space Administration
NO_x	Nitrogen Oxide
NTM	Network and Traffic Management Systems
OECD	Organisation for Economic Co-operation and Development
PCP	Pilot Common Project
PCT	Patent Cooperation Treaty
pkm	Passenger-kilometre
PM	Particulate Matter

PREF	Public Research Funding
PSF	Policy Support Facility
R&D	Research and Development
R&I	Research and Innovation
RIM	Regional Innovation Monitor
RIO	Research and Innovation Observatory
RIS	Regional Innovation Scoreboard
SESAR	Single European Sky ATM Research
SET	Strategic Energy Technology
SETIS	Strategic Energy Technologies Information System
SME	Small and Medium Enterprise
SMO	Smart Mobility and Services
SPF	Synthetic Paraffinic Fuel
SRL	System Readiness Level
STRIA	Strategic Transport Research and Innovation Agenda
TEN-T	Trans-European Transport Network
TENtec	European Commission's Information System to Coordinate and Support the TEN-T Policy
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Level
UN	United Nations
UNIFE	Association of the European Rail Industry
VDM	Vehicle Design and Manufacturing

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Annexes

Annex I. European R&I monitoring tools

This annex provides an overview of the main European R&I monitoring and assessment tools that have been used, inter alia, as references for the development of the TRIMIS indicator framework.

European Innovation Scoreboard

The European Innovation Scoreboard[2] (EIS) is developed to provide a comparative analysis of innovation performance of the EU, other European countries, and regional neighbours through the assessment of relative strengths and weaknesses of national innovation systems, while assisting countries in the identification of areas requiring attention. Results are presented through the appropriate country specific reporting and the European Innovation Scoreboard Interactive Tool (EIS-IT) (European Commission, 2019). The European Innovation Scoreboard 2017 methodology is based on a series of relevant indicators (Hollanders et al., 2017).

Regional Innovation Scoreboard

The Regional Innovation Scoreboard (RIS) is a regional extension of the European Innovation Scoreboard that provides an assessment of the innovation performance of European regions on a limited number of indicators (European Commission, 2018b). The European Innovation Scoreboard 2017 methodology is based on a series of relevant indicators (Hollanders and Es-Sadki, 2017).

European Public Sector Innovation Scoreboard

Following the Europe 2020 Innovation Union flagship initiative, the European Commission launched a pilot European Public Sector Innovation Scoreboard (EPSIS) as a first attempt to better understand and analyse innovation in the European public sector. The pilot EPSIS 2013 belongs to the family of the European Innovation Scoreboards (European Commission, 2013).

Innobarometer

The Innobarometer is a survey on activities and attitudes related to innovation. Each year, it gathers opinions and feedback from the general public and European businesses and provides a unique source of direct information on innovation for policy makers. The survey is based on a standard questionnaire to help monitor change in how companies manage their innovation activities, plan investment to modernise their business, and tackle barriers to the commercialisation of innovation (European Commission, 2018c). The assessment is based on an extensive questionnaire used for collecting information on the innovation performance of businesses in Europe as presented in European Commission's Repost entitled "Innobarometer 2016 – EU business innovation trends" (European Commission, 2016).

Regional Innovation Monitor Plus

The Regional Innovation Monitor Plus (RIM Plus) is designed as a platform for sharing knowledge and know-how on major innovation and industrial policy trends in the EU regions in the context of the growth and investment package set out in the Investment Plan of the European Commission. RIM Plus supports sharing of intelligence on innovation policies in some 200 regions across 20 EU member states and it is based on the work of a network of experts, while it provides detailed information on regional innovation policies (European Commission, 2018d).

The core of the RIM Plus service is a knowledge base of information on the regions, including:

- An online inventory of regional innovation policy measures, policy documents, organisations
- A single access point for good practice dissemination on regional innovation policy in Europe
- Mapping out regional practices in support of advanced manufacturing and relevant pilot / demo projects

Business Innovation Observatory

The Business Innovation Observatory is designed to provide evidence on the latest innovative trends in business and industry, while presenting methods used by the industry to develop solutions, their transition to market, but also the impact of these innovations on the economy (European Commission, 2018e). Innovation trends and insights are investigated through:

- case studies, covering the success stories of a range of innovative companies

[2] Between 2010 and 2015 the EIS was published under the name Innovation Union Scoreboard (IUS)

— videos, showcasing a selection of the case study companies and the key lessons learnt

— reports, drawing on the case studies and workshop outcomes and providing related policy recommendations

— workshops to engage the business community, policymakers, industry experts and academia on key business innovation trends

Digital Transformation Monitor

The Digital Transformation Monitor (DTM) is a tool that aims to foster the knowledge base on the state of play and evolution of digital transformation in Europe. It is designed to provide a monitoring mechanism to examine key trends in digital transformation, while offering insights into statistics and initiatives to support digital transformation, as well as reports on key industrial and technological opportunities, challenges and policy initiatives related to digital transformation (European Commission, 2018f). The Digital Transformation Scoreboard is part of the DTM framework, aiming to contribute to the knowledge base on the state of play and evolution of digital transformation in Europe.

The information contained in the DTM is presented using a five-category 'enabler' indicator capturing the main framework conditions favourable to digital transformation in the EU, while two category 'output' indicators are used to capture the effects of digital transformation, namely the changes in the number of ICT start-ups and the integration of digital technologies by EU businesses (European Commission, 2018g).

European Cluster Observatory

The European Cluster Observatory is designed as a European single access point for statistical information, analysis and mapping of clusters and cluster policy. Its main focus includes European, national, regional and local policy-makers as well as cluster managers and representatives of SME intermediaries (European Commission, 2018h). Moreover, the Cluster Mapping tool is designed to provide sectoral and cross-sectoral regional data and visualisations of the European geographical concentration of cluster development (European Commission, 2018i).

European Service Innovation Scoreboard

The European Service Innovation Scoreboard (ESIS) provides data-based analyses presenting the potential impact of service innovation on sector transformations. A wide range of indicators is used to measure service innovation impacts both at national and regional levels, thus covering the EU member states and six other European countries as well as 280 EU regions (European Commission, 2018j). Along with the ESIS, the ESIS Online Tool is the online version of the Scoreboard providing interactive metrics on service innovations at national and regional level according to a series of relevant indicators (European Commission, 2018k).

KETs Observatory

Key Enabling Technologies (KETs) are a group of six technologies, namely micro and nanoelectronics, nanotechnology, industrial biotechnology, advanced materials, photonics, and advanced manufacturing technologies. The KETs Observatory is an online monitoring tool that provides the EU, national and regional policy makers and business stakeholders with quantitative and qualitative information on the deployment of KETs both within the EU and in comparison with other world regions. In the KETs Observatory frame, a wide set of indicators is used covering regional, national and international level in order to monitor the generation and commercialisation of new knowledge around these technologies, while providing a thorough analysis of how countries cover KETs deployment value chain from technology development to commercialisation (European Commission, 2018l).

KETs Technology Infrastructure Mapping

KETs Technology Centres are public or private organisations carrying out applied research and close-to-market innovation (Technology Readiness Levels TRL 3 to 8, not necessarily the whole range) in Key Enabling Technologies (KETs). They help SMEs go from lab to market and to develop and produce new KETs-based products, supporting companies reduce the time-to-market for new innovation ideas (European Commission, 2018m).

IEE Performance Indicators

The Intelligent Europe Energy (IEE) Programme advanced a set of performance indicators so that applicants for funding could provide an ex-ante evaluation on the expected impacts of a project. These projects covered several areas, including transport.

After several iterations the guidelines moved away from common performance indicators towards project specific performance indicators. The indicators are assessed per project and therefore largely dependent upon the methodology as applied by the applicant.

Research and Innovation Observatory (RIO)

The Research and Innovation Observatory (RIO) monitors and analyses research and innovation developments at country and EU level to support better policy making in Europe. The H2020 Policy Support Facility (PSF) offers practical support to member states and associated countries to design, implement and evaluate reforms that enhance the quality of their research and innovation investments, policies and systems.

A set of potential variables to measure research excellence and define a composite indicator is provided in (Hardeman et al., 2013).

The national Public Research Funding (PREF) project provides additional indicators, which allow characterising and systematically comparing national systems (Lepori, 2017).

Frietsch et al. (2017) provide indicators used to assess business R&D expenditures (BERD) and patenting structures within key enabling technologies and societal grand challenges focusing on three main areas, namely: a) main economic indicators, b) business demography, and c) R&D intensity and output.

Innovation Output Indicator (IOI)

The Innovation Output Indicator focuses on the extent to which ideas of innovative sectors reach the market. It is developed by the JRC and is complementary to the indicators provided by the Research and Innovation Observatory. It is a single compound indicator based on four components.

Table A1. Components of Innovation Output Indicator.

Component	Source
Patents	OECD Patent Statistics Patent Cooperation Treaty (PCT); Eurostat; OECD Gross Domestic Product (GDP)
Employment in knowledge-intensive activities as percentage of total employment	EU Labour Force Survey
Trade balance of high-tech and medium-tech products to the total trade balance, together with knowledge-intensive services as a share of the total services export	Products: Eurostat COMEXT (EU+ European Free Trade Association); United Nations (UN) Comtrade (Others) Services: Eurostat; UN Service Trade Statistics
Employment in fast-growing firms of innovative sectors	Eurostat – CIS2010 Microdata

Source: Vertesy and Tarantola, 2016.

Innovation Union Competitiveness report (IUCR)

The IUC report was last published in 2013. Nevertheless, it provided a large list of indicators, covering information on investments, reforms and transformations (European Commission, 2014b).

Innovation Union Information and Intelligence System (I3S)

The I3S system was launched in 2011 to inform various stakeholders on the implementation of the Innovation Union. It provided information on the nature and implementation of the 34 commitments that were put forward by the Commission's Innovation Union communication. Currently, the I3S website is defunct.

State of the Innovation Union Report

The latest State of the Innovation Union Report was published in 2015. An evaluation was given for each of the 34 Innovation Union Commitments, referring to a range of initiatives that were taken and using data as collected under the Innovation Union Scoreboard (European Commission, 2015c).

Innovation Radar

The Innovation Radar (IR) focuses on the identification of high-potential innovations in the ICT FP7, Competitiveness and Innovation Framework Programme (CIP) and H2020 projects and the key organisation in delivering these innovations to the market. The IR assesses the Innovation Potential and the Innovation Capacity through two composite indicators: the Innovator's Capacity Indicator (ICI) and the Innovation Potential Indicator (IPI). These indicators are compiled as an aggregate of additional sub-indicators, compiled deploying pre-defined questionnaires and assessment templates on the projects.

Innovation Potential Assessment Framework

The innovation potential assessment framework of the Innovation Radar includes a set of pre-defined criteria and relevant indicators that assess the strength of each innovation. The assessment framework considers the aspects of innovation readiness, innovation management and market potential through the use of composite sub-indicators:

1. Innovation Readiness Indicator (IRI)
2. Innovation Management Indicator (IMI)
3. Market Potential Indicator (MPI)

These three indicators are aggregated in an arithmetic composite indicator the Innovation Potential Indicator (IPI).

The above-mentioned sub-indicators were calculated using relevant questions of the Innovation Radar.

Innovation Capacity Assessment Framework

The innovation capacity assessment framework of the Innovation Radar includes a set of pre-defined criteria and relevant indicators that assess the ranking of innovators. The assessment framework takes into account the aspects of innovation performance of the organisations considered as key innovators. The assessment framework considers the aspects of innovator's ability and innovator's environment through the use of composite sub-indicators:

- The Innovator's Ability Indicator (IAI)
- The Innovator's Environment Indicator (IEI)

These two indicators are aggregated in an arithmetic composite indicator, the Innovator Capacity Indicator (ICI) and were calculated using relevant questions of the Innovation Radar Questionnaire.

EU Industrial R&D Investment Scoreboard

The EU industrial R&D investment scoreboard is published within the context of the Industrial Research and Innovation Monitoring and Analysis (IRIMA) activities that are jointly undertaken by the European Commission's JRC and DG RTD. IRIMA activities aim to improve the understanding of industrial R&D and Innovation in the EU and to identify medium and long-term policy implications.

The Scoreboard collects key information to enable the assessment of the R&D and economic performance of companies. The main indicators are: R&D investment, net sales, capital expenditures, operating profits and number of employees are collected following a consistent methodology, definitions and assumptions applied in previous assessments. This ensures comparability so that the companies' economic and financial data can be analysed over a longer period of time (European Commission, 2018n).

EU Transport Scoreboard

The EU Transport Scoreboard is an online tool created by DG MOVE whose purpose is to provide a clear overview of member state performances in relation to transport policy achievements, thought the support of Key Performance Indicators (KPIs) which monitor and evaluate their performances.

The tool provides member state performances in four main area of interest: Internal Market, Investments and Infrastructure, Energy Union and Innovation and People; the total number of indicators is 29, the data coverage varies among indicators, starting from 2012 until 2017. Each of the KPIs defines its content and a reference to the sources used is specified. It is possible to access the database by country or by topic category (European Commission, 2017c).

SETIS

The Strategic Energy Technologies Information System (SETIS) is an integrated reporting and effective monitoring tool to support EU governance (European Commission, 2017d). Fiorini et al. (2017) presented the methodologies and data sources that were used by SETIS for the evaluation of selected KPIs utilised in the State of the Energy Union report to measure R&I progress, namely: a) trends in patents, b) private investments in R&I, and c) public (national) investments in R&I.

PATSTAT is used as the data source for assessing trends in patents. It is the Worldwide Patent Statistical Database created and maintained by the European Patent Office (EPO). A full dataset for a given year is completed with a 3.5-year delay and therefore detailed data have a 4-year delay. Estimates with a 2-year lag are provided at EU28 level. The data address advances in low-carbon energy and climate mitigation technologies (Y02 scheme of the Cooperative Patent Classification), while datasets are processed in-house to eliminate errors and inconsistencies. Patent statistics are based on the priority date, simple patent families and fractional counts of submissions made both to national and international authorities to avoid multiple counting of patents.

In order to assess private R&I investments, data are estimated based on financial information from publicly available company statements and patent data from PATSTAT. As with patent data, complete data series have a 4-year delay. Estimates with a 2-year time lag are made at EU level.

The International Energy Agency (IEA) statistics are the main source of data for the assessment of public (national) R&I investments. They address 20 of the EU member states, but both the regularity of reporting and the granularity of technological detail vary. There is a 2-year time delay in reporting for most member states. Data gaps are supplemented by the member states through the Strategic Energy Technology (SET) Plan Steering Group and / or through targeted data mining. Additional estimates are provided based on the correlation of macroeconomic indicators such as Government budget appropriations or outlays for R&D (GBAORD) and / or GDP.

Annex II. Challenges, objectives, actions related to roadmaps

Connected and automated transport

Identified challenges and problems

The roadmap identifies six general challenges for Connected and Automated Driving (CAD):

— developing, validating and testing of technologies for environment perception, vehicle decision making and control, infrastructure support and data communication of people and goods

— addressing of societal needs and expectations towards CAD, particularly in terms of road and passenger safety as well as cyber security, including legal requirements

— understanding human factors in the interactions between drivers, passengers and other road users with connected and automated vehicles

— identifying business and operational models to exploit the opportunities of CAD to provide future integrated mobility services, and to avoid the risk of increased numbers of vehicles

— adapting the legal frameworks of road transport to CAD and addressing how liability issues are handled

— supporting the standardisation and harmonisation of solutions towards interoperability among different operational environments, road infrastructures and vehicles

These are integrated with policy objectives. Additional challenges and policy objectives are identified for rail and waterborne transport, not reported here for the sake of brevity.

Roadmap objectives

The roadmap identifies general and policy specific objectives for road, rail and waterborne transport, aiming to identify R&I initiatives and actions that are tangible and specific in terms of content, timing and responsibility. Initiatives are activities described in terms of objectives, state of the art challenges and impacts. Actions (summarised in actions sheets, one per initiative) describe in sequential order the content of all activities that have to be implemented within each of the R&I initiatives.

Definitions of actions

The updated CAT roadmap identifies R&I initiatives that cover different overarching thematic areas. The roadmap provides also an action plan (actions) that must be implemented within each of the identified R&I initiatives. The R&I initiatives include:

23 R&I initiatives in the following eight thematic areas for road:

— In-vehicle enablers

— Vehicle validation

— Large scale demonstration pilots to enable deployment

— Shared, connected and automated mobility services for people and goods, including long haul transports (persons, goods, public)

— Socio-economic impacts; user / public acceptance

— Human factors

— Physical and digital infrastructure and secure connectivity

— Big data, artificial intelligence and their applications

25 R&I initiatives in the following nine thematic areas for rail:

— Rolling stock enablers for remote control of train operation and autonomous train operation

— Environment and operational monitoring

— Large scale demonstrations to enable EU-wide deployment

— Railway network information, management, maintenance and control

— Socio-economic and environmental impacts; user / public acceptance

— Human factors

— Physical and digital infrastructure & secure connectivity

— Big data, artificial intelligence and their applications

— Safety

18 R&I initiatives in the following nine thematic areas for waterborne:

— In-vessel enablers

— Condition and operational monitoring

— Validation & large-scale demonstration

— Information exchange and certificates

— Socio-economic impact of CAT

— Changed working conditions

— Physical & digital infrastructure

— Big data, artificial and their applications

— Secure connectivity

Transport electrification

Identified challenges and problems

Transport electrification combines an energy efficient power train system with the opportunity to use any source of energy other than fossil fuels including those from renewable sources, therefore having the potential to contribute to the Energy Union challenges of decarbonisation and energy security.

Even though specific challenges and problems are not listed in the roadmap, strong emphasis is placed on the general opportunities and challenges arising in the fields of energy and climate, competitiveness and integrated transport.

Roadmap objectives

The roadmap includes a series of objectives targeting the improvement of the status in specific focus areas under each mode of transport as follows:

Road transport

— Deployment of electric vehicles

— Product development and operating models

— Research and innovation

Waterborne transport

— EU general waterborne transport

— International shipping

— Small vessels

Aviation

— Commercial aviation (50-70 seats and equivalent cargo <7 tons)

— Commercial aviation (>70 seats and equivalent cargo >7 tons)

— Personal aviation

— Drones

— Airport environment

Rail transport

— Climate change

— Energy consumption

— Nitrogen oxide (NO_x) and particulate matter (PM) emission

— Noise and vibrations

— Research and innovation

Definition of actions

Road transport

— Promote a +400 kilometres range for electric passenger cars

— Development of small and light smart electric vehicles

— Progress and demonstration in urban bus electrification

— Public and commercial procurement of electric vehicles

— Certification of electric vehicles performance

— Develop electro-chemical systems for future high-density electric batteries

— Support local production of batteries, components and electric vehicles

— Demonstration of electrified road systems for heavy duty vehicles

Waterborne transport

— Raise public awareness of benefits of electrified vessel

— Deploy new materials and technologies

— Innovative financing tools

— Support education and training

— Research and development

— New business models

Aviation - aeronautics

— Energy storage systems improvement

— High temperature superconductors

— Electric aircraft design

— Airport electrification: Support vehicles for zero emission and very low noise airports

— Airport electrification: Charging infrastructure for ultra-low emission and noise airports

— Skills and competence development for a specialised interdisciplinary work force

— Regulations to decrease cost and increase product development speed

Rail transport

— Electrification of secondary network to increase the potential of utilisation of electric motorisation

— Development of new motorisation

— Intensify electric freight rail transportation

— Develop intermodal hubs in cities

— Develop light vehicles

— Smart power grids for rail to minimise the losses in the electric railway infrastructure

— Increase energy savings

— Regulations to harmonise energy characteristics for rails in the EU

Vehicle design and manufacturing

Identified challenges and problems

Twenty challenges appear in the VDM roadmap, out of which 14 correspond to road related problems, whereas the remaining six are linked to other transport modes (i.e. five challenges are linked to aviation, one challenge related to waterborne transport and no challenge was linked to railways). Therefore, 70% of challenges were associated with road transport, which mean research efforts are directed towards this transport mode. Although many of the challenges were allocated to one transport mode within the STRIA roadmap, other transport modes face similar barriers making challenges easily interchangeable between transport modes. Some challenges although not identical are similar and could be merged in one. It would be beneficial if this task was undertaken during the STRIA roadmaps' updating process. The identified challenges are listed below:

— Growing competition from emerging economies

— Growing complexity and cost pressure

— Increasing number of environmental and safety regulations

— More companies competing

— Behavioural change in users and industry

Roadmap objectives

The VDM roadmap establishes three main cross-modal objectives:

— Advancements on Design Tools and Processes

— Advancements on New Vehicle Concepts and Architectures

— Circular economy – modular vehicle architecture and remanufacturing, greening industry.

Several other objectives are strongly related to these three. In some cases, additional cross-modal objectives are a direct consequence of the principal objectives. For the sake of clarity, these secondary objectives are omitted in this report.

Definition of actions

No indicators were identified in this roadmap. However, a total of 35 actions were clearly identified and defined. Among them, 18 are linked to the cross-modal roadmap objective, Advancements on Design Tools and Processes. The cross-modal objective Advancements on New Vehicle Design and Architecture is associated with 11 actions whilst the third cross-modal objective, Circular economy – modular vehicle architecture and remanufacturing, greening industry, represents the remaining 6 actions. These actions can be easily associated with indicators. Three of the indicators are twice on the list, since they are used to achieve two different objectives and therefore the indicators might be different depending on the pursued objective. Figure A1 provides an overview of the main actions that were identified.

Figure A1. Description of actions identified.

Source: Own elaboration.

Low-emission alternative energy for transport

Identified challenges and problems

Fifty-one challenges were identified in this roadmap. Half of them (25) are linked to road-related problems, whilst rail transport has 13 challenges (around 25% of the total). Aviation (7 challenges) and waterborne transport (6 challenges) close the list. The main challenges identified are:

— Methane leakage

— Fuel storage, handling and injection systems

— Production process scale, cost effectiveness and lack of infrastructure

— Better understanding of blend limits

In this roadmap barriers are classified according to transport mode and fuel type. In order to obtain the challenges, some interpretation from the authors of this report has been required, so refinements can be included in future versions of the research, particularly after experts' consultation and workshops updating the roadmap. The objectives were not clearly defined; therefore, they were obtained following an interpretation of the roadmap.

Roadmap objectives

The roadmap has 66 objectives, out of which 37 are attributed to road transport, 9 are associated with rail transport, 10 are linked to waterborne transport, while aviation comprises another 10 objectives. 30 objectives are linked to liquefied natural gas (LNG), 24 are associated with alcohols, ethers and esters, and the remaining 12 objectives are equally linked to synthetic paraffinic fuels (SPF) and liquefied petroleum gas (LPG), with 6 objectives each alternative fuel. The main objectives focus on:

— On-board storage improvements

— Dedicated fuel injection technology

— Thermal efficiency improvements

— Fuel flexible engines

— Mature technology

— Enlarge blend ratios

— Lower pollutants.

Definition of actions

The roadmap identifies R&I needs, linked to challenges and opportunities. No actions or indicators were identified. A number of actions (75) were extracted from the stated needs. The main actions include:

— Development / improvement of specific hardware

— After treatment control strategies

— Dedicated high pressure direct injection (HPDI) systems

— Combustion system designs

— Light weight fuel tanks

— Ignition improvers

— Catalyst system

— Further market development

— Develop high energy efficiency locomotive

— New engine designs

— Compatibility between technologies

Network and traffic management systems

Identified challenges and problems

The NTM roadmap identifies three main challenges towards developing an advanced multi-modal transport system:

— The lack of cooperation in planning and operating the NTM plans between the private and public sectors in any transport mode, which is the case at administrative, organisational and operative levels

— The quality of available data and the lack of regulations regarding the exchange of open data between the various stakeholders and actors from the different transport modes

— The risk of crime and terrorist attacks, as well as cyber-security threats to the transport systems, and the reliance on information and communication technologies, systems and services

These challenges led to defining a number of NTM roadmap objectives.

Roadmap objectives

The NTM roadmap introduces a strategic implementation plan in which objectives ("or milestones") and recommended actions are defined. Each objective is linked to an implementation target year in which the goals should be achieved:

— To identify and define the key indicators and the minimum data sources needed to assess NTM reliably and consistently throughout the EU (by 2020)

— Highly automated and modernised transport infrastructure, needed in the early stage to support first automated vehicles and to prepare the environment for a highly automated mobility (by 2025)

— Finalisation of the TEN-T core network (by 2030)

— Highly automated, coordinated and harmonised transport in the EU (by 2035)

— Fully intermodal and interconnected transport system (by 2050)

Each objective is paired with a set of actions.

Definition of actions

There are a total of 20 identified actions that define the scope in which steps need to be taken. In most cases, the actions could be further disaggregated. For instance, the action to 'Require sharing of basic operational data, in real time, between operators / actors in the mobility space' will require the introduction of industry agreements or legislative proposals. The NTM roadmap does not systematically define who is responsible for each individual action although a general division of responsibilities between stakeholders is described.

Smart mobility and services

Identified challenges and problems

According to the updated October 2019 version of the SMO roadmap, there are ten central challenges of integrating smart mobility systems and services, namely:

— Prioritise smart, sustainable and integrated mobility systems that provide public transport connectivity and individual public mobility in both urban and rural settings

— Identify and implement governance and regulatory frameworks that support active mobility and light travel modes, improving road safety for pedestrians, cyclists and micro-mobility users

— Facilitate smart urban, land-use and infrastructure design to allow for behavioural change and to prioritise active mobility, micro mobility, ride pooling, public transport and sustainable freight services

— Ensure smart and distributed zero-carbon primary transport energy supply, taking into account also energy demand from digital services and virtual mobility

— Provide for integrated energy and transport transformation and long-term sector coupling

— Establish ubiquitous and fair-access digital public infrastructure to ensure socially inclusive digital services, to enable equitable data-sharing and evidence-based public policy and to facilitate collaborative service innovation in private and public transport offerings

— Provide robust governance, regulatory and standardisation frameworks to enable scaling and effective integration of smart mobility services as a public good

— Identify and implement functional frameworks for both technical interoperability and shared operating models across current modes and purposes

— Support solutions for flexible physical infrastructure that can be functionally shared across type, time, mode and vector of transport for both passenger and freight services

— Validate and integrate sustainable automated, air and virtual mobility

Roadmap objectives

There are five targets highlighted in this SMO roadmap:

— Development of sustainable and integrated smart mobility systems connecting urban and rural mobility services and promoting modal shift, sustainable land use, sufficiency in travel demand and active and light travel modes

— Design of effective operating models for integrating smart mobility with public transport services and zero-carbon energy systems

— Fair-access public digital infrastructure and mobility data management solutions

— Implementation of intermodality, interoperability and sector coupling

— Validation and integration of automated, air and virtual mobility

Based on the above, specific innovation actions are proposed to support a pro-active integration of smart mobility services with existing public transport and utility systems.

Definition of actions

The innovation actions allocated per target are presented below.

Development of sustainable and integrated smart mobility systems connecting urban and rural mobility services and promoting modal shift, sustainable land use, sufficiency in travel demand and active and light travel modes:

— Smart mobility solutions sustainably interlinking urban and rural mobility systems

— Develop urban design and land use strategies that promote active, micro and public mobility and that facilitate the integration of passenger and freight services

— Defining new governance concepts, tools and technologies through large-scale systems implementation

— Frame transport policy to foster inclusion, public acceptance and respect for diversity through research on behavioural change and user needs

Design of effective operating models for integrating smart mobility with public transport services and zero-carbon energy systems:

— Design and development of effective operating models that sustainably integrate public and individual mobility service provision

— Development of integrated multimodal solutions providing a sustainable energy-transport nexus

Fair-access public digital infrastructure and mobility data management solutions:

— Collecting and collating systemic and dynamic mobility data to contribute to effective policymaking and implementation

— Fair-access digital infrastructure and mobility data management

Implementation of intermodality, interoperability and sector coupling:

— Design and development of efficient solutions for integrated infrastructure and mobility systems shared by passenger and freight services

— Expand and extend the role of active and light travel modes and use of micro-mobility solutions as part of integrated intermodal mobility systems

Validation and integration of automated, air and virtual mobility:

— Test and validate the potential contribution of automated mobility services to sustainable, zero-carbon and integrated public transport systems

— Test and validate real-world integration and governance of air mobility with urban and rural transport systems

— Validate and integrate virtual mobility

Transport infrastructure

Identified challenges and problems

The INF roadmap identifies five main challenges:

— Competitiveness – a level playing field in Europe and globally

— Safety and security as a priority for users' needs

— Digitalisation, big data and smart infrastructure to ensure global connectivity

— Environmental protection, including decarbonisation, reduction of emissions and protection of energy supplies

— Urban transport infrastructure to ensure efficient and safe urban mobility

In addition, mode specific challenges are identified (for road, rail, waterborne, air), as well as for multimodal and urban mobility.

Roadmap objectives

The INF roadmap aims to develop R&I in key areas, test new methodologies and prepare the ground for future transport infrastructure policies.

The objective of the 2019 revised version of the INF roadmap is to update and outline future transport R&I priorities to decarbonise the European transport sector and ensure competitiveness, safety and security.

Definition of actions

The roadmap includes an action plan for R&I initiatives in eight thematic areas. For each area, a package of actions under different topics has been proposed. A total of 100 actions has been identified, divided in "policy actions", "management actions" and "technological actions". A group of additional cross-cutting actions is also included. Most of the proposed actions are short term, meaning that the first steps should be taken between 2020 and 2025. Table A2 provides the list of thematic areas and topics identified in the roadmap.

Table A2. Thematic areas and topics identified in the INF roadmap.

THEMATIC AREAS	TOPICS
Governance	Planning; legal framework and regulations; procurement; standardisation.
Life cycle and asset management	Using new construction processes and materials; reutilisation and recycling – circular economy; maintenance and regeneration as a strategic policy; project delivery / implementation phase; asset management.
Financing, pricing and charging	Value for money; public-private partnership; pricing and charging strategies; public awareness.
Technology and digitalisation	Smart infrastructure; connected infrastructure; digitalisation, artificial intelligence and big data; automation/ robotisation / remote solutions.
Multimodality, interoperability and interconnectivity	Integrated operation across modes; integration of information; integration of multimodal nodes.
Safety and security	Reducing risks by integrating safety as a priority in the whole life-cycle of transport infrastructures; safety of vulnerable users; protecting infrastructures against attacks.
Sustainability, environment and resilience	Effective decarbonisation over the whole life-cycle; energy efficiency; adapting infrastructure to new energy resources; energy harvesting and storage; optimal operation of each mode; preservation of biodiversity and landscape; air quality, noise and vibration; vulnerability under natural and man-made hazards; climate safeguard of infrastructures.
Logistics	Innovations in logistics; last mile solutions.

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