TRIMIS: Modular Development of an Integrated Policy-Support Tool for Forward-Oriented Transport Research and Innovation Analysis

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Abstract: The European Commission’s Strategic Transport Research and Innovation Agenda (STRIA) outlines future transport research and innovation (R&I) priorities towards the decarbonization of European transport. Seven STRIA roadmaps focus on crosscutting research areas. In order to support and monitor their implementation, the Transport Research and Innovation Monitoring and Information System (TRIMIS) was developed. It is an integrated transport policy-support tool with a modular design, serving as a knowledge management system that offers open-access information, as well as an inventory of transport technologies and innovations. TRIMIS provides a holistic assessment of current and emerging technologies and trends and R&I capacities in the European transport sector incorporating foresight capabilities based on transport R&I data collection, innovation capacity mapping, technological status assessment, horizon scanning, and identification of new and emerging technologies and trends. This paper presents an overview of TRIMIS and its benefits as an integrated analytical tool that provides support to sustainable transport governance and decision-making. Moreover, it provides insights on current technology trends in the road transport domain with a focus on smart innovation and identifies emerging trends with a potential future impact through a dedicated case study, combining a techno-economic assessment with findings of a horizon scanning exercise.

Keywords: transport research; transport innovation; transport technologies; horizon scanning; innovation capacity; capacity mapping; technology taxonomy

1. Introduction

Sustainable transport is paramount for sustainable development, as identified within the United Nations (UN) Sustainable Development Goals (SDGs) [1]. Sustainable transport systems play an important role in sustainable development, as they ensure the movement of people and goods, achieving less negative environmental effects and fostering economic development, while supporting a balanced development of cities [2].

In Europe, the transport sector plays a key role in the economy, being responsible for an estimated EUR 599 billion in gross value added (GVA) in the European Union (EU), which is almost 5% of total EU GVA (2018) [3]. Apart from its economic impact, transport represents 33% of final energy consumption [4] and 19.5% of total greenhouse gas (GHG) emissions [5] and is the only sector that did not see a decrease in GHG emissions between 1990 and 2015 [6]. Transport affects public health by being a major contributor to urban air pollution; in the EU, premature deaths attributed to population exposure to particulate matter (PM$_{2.5}$) are estimated at 436,000, those to nitrogen dioxide (NO$_{2}$) at 68,000...
and those to ozone (O$_3$) at 16,000 [7]. Moreover, the cost of road traffic congestion has been estimated to be EUR 100 billion, equal to one percent of EU gross domestic product (GDP) [8]. Transport remains one of the main pillars of development, having socio-economic benefits, but it is also responsible for a series of externalities that negatively affect society. The existing transport policy framework and advances in transport technology have affected both the evolution of the transport sector and how it has integrated with economy and society. However, an updated legislative framework and the adoption of energy efficient and sustainable innovative transport technologies are needed if transport externalities are to be addressed.

The EU Transport White Paper of 2011 aimed at a 20% reduction in transport-related GHG emissions by 2030 (compared to 2008 levels) and at least 60% by 2050 (relative to 1990 levels) [9]. The recent European Green Deal indicates a 90% reduction in transport emissions across all modes by 2050 as a prerequisite to achieve climate neutrality [10], while with its 2030 Climate Target Plan, based on a comprehensive impact assessment, the European Commission (EC) has proposed to increase the EU’s ambition on reducing GHG by at least 55% by 2030. In this frame, renewable energy in transport must increase to around 24% (compared to 6% in 2015), which will require conventional cars to be gradually replaced by zero-emissions vehicles, whereas sustainable collective transport services must be further developed, aiming at an estimated 50% decrease in the carbon dioxide (CO$_2$) emissions per km for passenger cars in 2030 compared to 2021 targets [11].

In this context, the EC published in 2016 a European strategy for low-emission mobility along with a series of relevant Communications to promote clean energy innovation in Europe. The EC outlined a new approach to transport research and innovation (R&I) aimed at tackling current and future socio-economic and environmental challenges, as expressed in the European Commission’s Communications for the Energy Union Package [12], the European Strategy for Low-Emission Mobility [13], and the Accelerating Clean Energy Innovation [14]. In order to address socio-economic challenges arising from an ever-changing complex and competitive environment, technological advancement is required. To this aim, targeted transport R&I can act as an enabler to improve transport and mobility and underpin European competitiveness. In 2017, with its Europe on the Move package, the EC adopted the Strategic Transport Research and Innovation Agenda (STRIA) [15], highlighting key transport R&I areas for clean, connected, and competitive mobility, complementing the 2015 Strategic Energy Technology Plan (SET Plan), which focuses on the energy sector [16]. The transport R&I priority areas are covered in seven roadmaps, namely [15]:

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

An effective monitoring and information mechanism that provides transport R&I insights for all relevant stakeholders is paramount for the implementation and further development of STRIA. To meet this need, the EC Joint Research Centre (JRC), with the authors as main co-developers, developed the Transport Research and Innovation Monitoring and Information System (TRIMIS). TRIMIS provides a holistic assessment of technology trends and transport R&I technical and socio-economic capacities, and publishes data and analyses that cover the whole European transport system [17].

This paper analyzes the features, functionalities, and benefits of TRIMIS as the European platform and analytical policy-support tool, modularly designed to support transport governance and policymaking through an integrated approach to transport R&I monitoring and information. Moreover, it provides insights on current technology trends in the road transport domain with a focus on smart innovation and identifies emerging trends with a potential future impact.
2. Background and Motivation

The transport sector covers a range of activities with related physical and non-physical elements (e.g., infrastructure, vehicles, information and communications technology (ICT) solutions) that are inherently complex and dynamic in nature. The development of a policy-support tool therefore requires a series of technical and technological analyses that cover financial and socio-economic aspects of transport R&I in order to provide useful insights for policymakers (see Figure 1).

![Figure 1. Transport policy support through research and innovation analyses.](image)

Innovation and new technologies have a principal role in the future of sustainable transportation. Several trends and technologies have been identified as having the potential to improve or disrupt transportation in the urban context. This is the case of Mobility as a Service (MaaS), a recently emerged trend among commuters, or cooperative, connected and automated mobility (CCAM) that can support safer and more inclusive urban mobility [18]. Still on urban transport innovation, Goyal and Howlett [19] suggest that different stakeholders foster technological innovation by either (a) promoting the technology as an answer to societal need, thus facilitating the development and diffusion of new technologies, or (b), by supporting the development and diffusion of specific policy instruments. These two means may overlap or come as a consequence of one or the other, but in any case, the role of policy tools is important. In addition, when assessing policy measures necessary to stimulate innovation, these need to be planned in terms of various criteria (functional, social, economic, environmental) through an optimization process that identifies those policies that best address the adopted criteria, and thus those that could contribute the most to sustainable transport innovation [20].

Identifying and assessing new emerging transport technologies and trends and the relative benefits and challenges is of strategic importance to academics, policymakers, and analysts in order to face the transport-related challenges of a transportation system that is based on interconnecting elements [21]. Under this perspective, the taxonomic representation of mobility services and technologies provides a common language for mapping and sharing information about smart mobility initiatives [22]. This representation should be extended beyond technologies in the “strict” sense, since often, non-technological innovations appear as more promising for sustainable transport [23]. Focusing on innovative technologies and new transportation concepts, a holistic approach is necessary to assess their effective implementation within a network, accounting for different aspects such as the infrastructure costs, transport costs for the transported goods, the effectiveness for each transport mode, and regional development [24]. Furthermore, technology acceptance and knowledge regarding interest by consumers is of vital importance to policymakers, as highlighted in recent studies focusing on technology diffusion and consumer interest for ride-sharing services [25], electric vehicles [26], delivery drones [27], autonomous cars [28], autonomous buses [29], and urban air mobility [30].
Assessing research and development (R&D) investments and examining the factors influencing the level of innovation of transport services, manufacturers of transport equipment, and construction companies involved in transport infrastructure leads to a better identification of areas where public intervention is necessary [31]. Within this, limitations and bottlenecks to innovation need to be identified. For example, while investing in R&D is important, still, a lack of funds often makes companies reluctant to do so. Uncertainty about the outcome of an investment usually has a negative impact on the decision to invest. However, this can also be inverted for large companies with substantial innovation capacity (measured by the number of patents owned by a company) [32].

Furthermore, a systemic, long-term foresight is required in order to address major challenges in the transport sector, with the anticipation and consideration of potential socio-technical transitions in strategic transport planning [21]. Foresight can support policymaking at three levels: through informing, counseling, and providing guidance on the process [33]. The European Commission adopted its first annual Strategic Foresight Report in September 2020, highlighting its strategy to integrate strategic foresight into EU policymaking. In this regard, horizon scanning as a foresight technique is highlighted as a means with a central role providing insights underpinning strategic political choices, which can serve as a forward-oriented information sharing forum and an early warning system [34]. Specifically, horizon scanning is a systematic approach for collectively exploring change [35] that has the potential to provide insights covering a series of potential futures, as described through the futures cone by Voros [36]. Its application entails a search process, reaching and possibly crossing the margins of the currently known environment [37], while its outputs and its function as an early warning or alerting mechanism enable policymakers to anticipate opportunities and threats through the identification of emerging trends with future potential [38].

Considering the above, a policy-support tool involves identifying potentially interlaced activities and functionalities that, when arranged in a comprehensive manner, produce an effective instrument for policymaking. Although several tools have been used at the national and international level to facilitate the development and implementation of transport policies, they vary in their features, functionalities, complexity, coverage, and target audience. The main R&I platforms and database tools, along with an analysis of their available characteristics, are reported in Figure 2 (adapted from [39]).

![Figure 2. Main R&I platforms and databases (adapted from [39]).](image-url)
The main European tools include the Economics of Industrial Research and Innovation action (IRI) [40], the Research and Innovation Observatory (RIO) [41], the Tool for Innovation Monitoring (TIM) [42], the EU Innovation Scoreboard [43], the EU Transport Scoreboard [44], the Strategic Energy Technologies Information System (SETIS) [45] and mode-specific platforms such as the Advisory Council for Aviation Research and Innovation in Europe (ACARE), the Alliance for Logistics Innovation through Collaboration in Europe (ALICE), the European Rail Research Advisory Council (ERRAC), the European Road Transport Research Advisory Council (ERTRAC), and Waterborne [46]. At the global level, the two main platforms are the Transport Research International Documentation (TRID-TRB) [47] and the Organization for Economic Co-operation and Development (OECD) Science, Technology and Innovation Outlook [48].

It is evident that the available platforms and tools provide varying outputs to their end users, highlighting the need for an integrated tool that can provide a holistic monitoring and analysis of R&I in the transport sector. TRIMIS was developed as a comprehensive platform and policy-support tool to cover effectively every aspect of transport R&I, facilitating all types of transport stakeholders while aiming at policymaking and governance. Figure 3 presents the potential benefits of TRIMIS allocated per potential user target group.

![Benefits of TRIMIS per target group](image)

**Figure 3.** Benefits of TRIMIS per target group [49].

3. TRIMIS Structure and Methods

TRIMIS is an integrated transport policy-support tool with a modular design serving as a knowledge management system that offers open-access information, as well as an inventory of transport technologies and innovations. It monitors and assesses the implementation status of STRIA and at the same time supports transport governance, policymaking, and research by identifying innovations with the greatest future potential, thus assisting policymakers to focus on those areas where public intervention can provide the maximum benefits [49]. In addition, the TRIMIS online platform serves as the end-user interface, offering outputs by monitoring the effectiveness of EU/Member State-level funded research and assessing the level of contribution of transport research initiatives to a clean, connected, and competitive European transport system. The development of TRIMIS follows a modular approach that allows the collection and analysis of transport R&I data as well as technology horizon scanning. It also provides a taxonomy of transport technologies, mapping and analyzing new and emerging technologies and trends (NETT) and technological and socio-economic innovation capacities against selected performance indicators. Figure 4 provides an overview of the main TRIMIS features and functionalities. These include, inter alia, mapping technologies and capacities in the EU transport sector, horizon scanning, identification and inventory of NETT, dissemination of information, and development of toolboxes.
TRIMIS follows a modular approach (Figure 5) that allows R&I status assessment by monitoring and assessing the transport sector’s innovation performance and foresight activity, a forward-oriented approach to supporting transport governance.

TRIMIS covers a series of priority areas as identified by STRIA, where policy intervention can address transport challenges and support EU energy and transport strategy. The development of TRIMIS follows a modular approach (Figure 5) that allows R&I status assessment by monitoring and assessing the transport sector’s innovation performance and foresight activity, a forward-oriented approach to supporting transport governance.

<table>
<thead>
<tr>
<th><strong>Innovation capacity assessment</strong></th>
<th><strong>Transport technologies inventory and assessment</strong></th>
<th><strong>Patent and scientific research analysis</strong></th>
<th><strong>Horizon Scanning</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gathering insights from private and public transport stakeholders on research trends, drivers and enablers, challenges, etc.</td>
<td>Identifying new technologies and opportunities through an inventory based on a transport technology taxonomy</td>
<td>Monitoring technology developments from industry and research interests from Academia</td>
<td>Use of foresight techniques for identifying of potential NETT and support a forward-oriented culture</td>
</tr>
</tbody>
</table>

**R&I Status assessment**
Monitoring and assessing transport sector innovation performance

**Foresight**
Forward-oriented support to transport governance

**Figure 4.** TRIMIS main features and functionalities [39].

**Figure 5.** TRIMIS modular development.
A comprehensive database is a fundamental element of TRIMIS. The database includes a wide collection of data and indicators on transport technologies and innovations. This repository also provides an input for the development and use of transport R&I key performance indicators (KPIs). Moreover, it enables communication between TRIMIS and transport stakeholders, allowing manual inputs to the database. It also supports additions and amendments with an automated link to existing data repositories.

The present and future analytical capabilities of TRIMIS are founded on the database structure that incorporates information on several transport R&I dimensions [50]. The structure of the TRIMIS database can be seen in Figure 6. It is structured by four distinctive fields (A, B, C, D), with each field containing one or more different tables. The core part (field A) includes the project table, program table, technology table, and organization table. Field B includes a labor statistics table and an economic statistics table. Field C includes the patent table (which interacts with field A). Finally, field D incorporates the horizon scanning table.

**Figure 6.** Structure of the TRIMIS database, (A) project table, program table, technology table, and organization table; (B) labor statistics table and economic statistics table; (C) patent table; (D) horizon scanning table [50].

### 3.1. Innovation Capacity Assessment

TRIMIS maps transport innovation capacity in Europe by providing a list of R&D indicators, by analyzing European performance at the country level, and by informing about transport stakeholders' views on R&I [51]. The innovation capacity assessment delivers a high-level overview of European transport R&I status, acting as a reference point for the assessment of the individual STRIA roadmaps and providing the baseline to understand where transport innovation stands and its possible future development.

Following a twofold approach, the analysis includes indicators of R&D funding, human resources engaged in R&D, and patenting activities. The list of indicators used is presented in Table 1. Additionally, the innovation engagement of the business sector is captured in a list of additional indicators collected every two years within the European Community Innovation Survey [31].
projects from the TRIMIS database. A grounded theory approach [53] was implemented to identify the robust taxonomy [54]. Figure 7 provides an overview of the methodology used for the technological assessment of the projects. Following this step, the technology readiness levels (TRLs), a classification of the technology readiness, was calculated on the basis of the data obtained from the TRIMIS survey. The technology development maturity was estimated for each technology considered. The technology assessment methodological steps [55] were used to define the technology readiness levels. Furthermore, transport stakeholders’ opinions were captured by the TRIMIS survey in “Innovation Capacity of the European Transport Sector” [52]. The survey investigated the role of R&I within the transport sector, looking at the main enablers as well as the obstacles that support or prevent its development and major R&I trends. The impacts of policy measures were also considered.

The questionnaire was distributed to European private and public transport experts with R&I experience and knowledge, between November 2019 and March 2020. Representatives from all transport modes operating in European countries were selected, capturing a variety of perspectives from across the spectrum of the European transport sector.

### 3.2. Technologies Inventory

TRIMIS identifies new technologies and emerging trends with an impact on the transport sector. Based on an inventory of scientific developments of new and emerging transport technologies, it flags those that are more mature and thus closer to a possible market introduction. The TRIMIS technology analysis currently focuses on technologies researched in European Framework Programs for Research and Innovation, specifically the 7th Framework Program (FP7) and Horizon 2020 (H2020) projects from the TRIMIS database. A grounded theory approach [53] was implemented to identify technologies and overarching technology themes within projects, leading, after several iterations, to a robust taxonomy [54]. Figure 7 provides an overview of the methodology used for the technological assessment of the projects.

<table>
<thead>
<tr>
<th>Area of Indicator</th>
<th>Indicator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Funding</td>
<td>Business expenditure on R&amp;D (BERD)</td>
<td>BERD represents the component of gross domestic expenditure on R&amp;D (GERD) incurred by units belonging to the business enterprise sector. It is the measure of intramural R&amp;D expenditures within the business enterprise sector during a specific reference period.</td>
</tr>
<tr>
<td>Funding</td>
<td>Business R&amp;D Intensity</td>
<td>Total business R&amp;D spending as percentage of gross domestic product (GDP)</td>
</tr>
<tr>
<td>Funding</td>
<td>Total Government Budget Appropriations or Outlays for Research and Development (GBAORD)</td>
<td>The GBAORD measures the government support for research and development activities. GBAORD includes all appropriations given to R&amp;D in central government budgets.</td>
</tr>
<tr>
<td>Funding</td>
<td>Total GBAORD as a % of total general government expenditure</td>
<td>Percentage of government expenditure</td>
</tr>
<tr>
<td>Human resources</td>
<td>Total R&amp;D personnel in business enterprise</td>
<td>Total number of persons employed in research in a specific sector</td>
</tr>
<tr>
<td>Human resources</td>
<td>Total R&amp;D researchers in business enterprise</td>
<td>Total number of researchers employed in a specific sector</td>
</tr>
<tr>
<td>Innovation engagement</td>
<td>Patent applications to the European Patent Office (EPO)</td>
<td>Patent applications filed directly under the European Patent Convention or applications filed under the Patent Co-operation Treaty and designated for the EPO</td>
</tr>
</tbody>
</table>

Furthermore, transport stakeholders’ opinions were captured by the TRIMIS survey in “Innovation Capacity of the European Transport Sector” [52]. The survey investigated the role of R&I within the transport sector, looking at the main enablers as well as the obstacles that support or prevent its development and major R&I trends. The impacts of policy measures were also considered.
As a first step, the results of a previous study were reviewed [56]. On this basis, a standardized approach was adopted for the definition on what can be considered a distinct technology and how it can be labeled. In the next step, all project descriptions were assessed to see whether technological developments were mentioned. In the next step, existing taxonomies, for example those under the Cooperative Patent Classification (CPC) [57], were used as a basis for the labeling the full listing of technologies. Following that, overarching technology themes were defined for the technologies. Finally, the funding for each technology was calculated from the total project budget through the division of the project budget by the number of associated technologies (if more than one).

Several indicators were established for assessing the technologies, including an indication of technology maturity during the acquisition phase of a program based on the technology readiness levels (TRLs), a metric that was established by the United States National Aeronautics and Space Administration (NASA). This metric includes a scale between 1 and 9, ranging from the lowest to the highest technology maturity levels, and their implementation was recommended for H2020 projects [58]. Within the TRIMIS process, four development phases were allocated to the nine TRLs, clustering them into a research, validation, demonstration/prototyping/pilot production, and implementation phase. The development phases used in TRIMIS, based on the nine TRLs defined by the European Commission in [59], are provided in Table 2 [55].

<table>
<thead>
<tr>
<th>TRL</th>
<th>Description</th>
<th>TRIMIS Development Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Basic principles observed</td>
<td>Research</td>
</tr>
<tr>
<td>2</td>
<td>Technology concept formulated</td>
<td>Validation</td>
</tr>
<tr>
<td>3</td>
<td>Experimental proof of concept</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Technology validated in lab</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Technology validated in relevant environment</td>
<td>Demonstration/prototyping/pilot production</td>
</tr>
<tr>
<td>6</td>
<td>Technology demonstrated in relevant environment</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>System prototype demonstration in operational environment</td>
<td>Implementation</td>
</tr>
<tr>
<td>8</td>
<td>System complete and qualified</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Actual system proven in operational environment</td>
<td></td>
</tr>
</tbody>
</table>

As of today, the TRIMIS technology database includes 814 technologies under 46 overarching technology themes researched in 3203 projects. It should be noted that most technologies (approximately 45%) are assigned to the VDM roadmap.

3.3. Patent and Scientific Research Analysis

TRIMIS currently focuses on publicly funded research projects but aims to provide additional insights into private investments and research outputs. For this, patent data provide a solid and well-established source of information. Moreover, patent data are highly standardized and can be retrieved from different countries. As such, they enable comparative analyses on how Europe performs versus other regions in terms of transport R&I.

The JRC team working for TRIMIS collaborates with the JRC researchers behind SETIS to gather information on transport patents. The SETIS team has extensive experience with patent-based innovation analysis [60] and the collaboration makes it so that TRIMIS can rely on robust patent data and analyses. The goal is to link patent data to existing information on projects, organizations, and technologies, with the aim of mapping technology value chains.
Currently, the 2019 autumn EPO Worldwide Patent Statistical Database (PATSTAT) dataset has been incorporated into TRIMIS. The dataset was created by identifying CPC codes that are relevant to TRIMIS. The TRIMIS dataset includes granted patents and has the following relevant attributes: patent application number, CPC code, patent title, and patent abstract.

The methodology developed allows queries to be built focusing on specific technologies by:

a. Attributing a CPC code directly (if the technology directly fits within a single category);
b. Assigning a set of keywords to each technology to carry out a keyword search on titles and abstracts; and
c. Setting a year for the earliest filing date (2013 is the earliest available starting year from the patent database).

A final quality check is carried out manually to ensure that the patents retrieved are related to each technology. Patents under the same family (e.g., the same or similar patent submitted to different offices worldwide) are counted only once.

Likewise, academic publications provide a rich source of information that shows where academic transport R&I occurs and what its direction is. The data can provide a complementary perspective compared to project- and patent-based analysis. Bibliometric analyses, based on the Scopus dataset, are used for the analysis of the identified technologies. The Scopus database allows for advanced temporal, geographical, and content filtering. Regular expressions (REGEX) deriving from corroborated keywords and their synonyms are used as the query.

Similar to patent data, publications allow for the comparison of various countries and regions across the globe. By linking project, patent, and publication data, greater insights into transport R&I can be provided from research until implementation.

3.4. Horizon Scanning

Foresight techniques are used to identify promising technologies that could affect the further development of European transport. Such techniques foster a forward-oriented culture in transport policymaking. However, for many years, the insights from a sporadic assessment of the status of various related fields, combined with the intuition of decision-makers, have been the basis for strategically oriented policy formulation. This is a paradigm that is proving insufficient for the increasingly dynamic and complex field of transport innovation [61].

One of the main goals of TRIMIS is to provide forward-oriented support to transport R&I governance by using foresight in its technological and socioeconomic assessment. Horizon scanning is a structured, forward-oriented process that allows organizations to develop an anticipatory framework of conduct and be prepared for changes that could involve significant opportunities or threats [62]. It can therefore contribute to the TRIMIS forward-oriented R&I monitoring, assessment, and information approach. Within the transport policymaking framework, horizon scanning has a twofold role: supporting the information of policymakers about emerging trends and developments by scanning their external environment; and supporting policymaking through the promotion of network creation, enabling a common overview of desired futures that have the potential to contribute to new and innovative policies.

The TRIMIS Horizon Scanning module takes advantage of the existing Horizon Scanning at the JRC mechanism and the Megatrends Hub, creating a bidirectional data feed between TRIMIS and other schemes in order to produce policy insights and promote the transport sector along with the existing megatrends. Figure 8 presents the characteristics of the TRIMIS Horizon Scanning mechanism.
Figure 8. TRIMIS Horizon Scanning module and interconnections [63].
Horizon scanning within the TRIMIS context is part of a framework of systematic collaborative work that creates and builds upon synergies and takes advantage of a wide spectrum of expertise. Thus, it aims to establish a new transport R&I framework, introducing an anticipatory and adaptive culture and providing insights to the TRIMIS users while contributing to a higher-level strategic framework. TRIMIS supports a forward-oriented culture in transport policymaking through the systematic examination of different signals (e.g., potential threats, opportunities, and early signs of future developments) from various sources, e.g., media, science literature, and social media. A complete analysis of the role of TRIMIS as a transport horizon scanning tool in the context of a European horizon scanning frame can be found in [63].

4. Case Study

Focusing on the modular structure of TRIMIS described in Section 3. TRIMIS Structure and Methods, this section intends to provide an example of the outcomes aiming to support transport policymaking. This is done through a dedicated case study, combining a techno-economic assessment related to the STRIA roadmap on smart mobility and services and on road transport with findings of a horizon scanning exercise. With reference to Figure 9 and considering the modular development of TRIMIS outlined in Figure 5, TRIMIS analysis outputs are presented according to the type of information provided. Considering transport R&I status outputs as an overarching activity covering the entire area, the horizontal axis focuses on the level of information provided, from quantitative to qualitative.

Quantitative analyses focus on figures related to R&I activity (e.g., number of projects, funding of projects, duration, funding bodies). Qualitative analyses provide further descriptive information (e.g., description of researched technologies). The vertical axis focuses on the aggregation of information. Aggregated information indicates grouping of similar findings (e.g., technologies belonging to a broader theme), while disaggregated information focus on specific findings (e.g., a specific technology). The next two paragraphs provide some examples.

![Figure 9. TRIMIS modules and output analysis.](image)

4.1. Technologies in European Framework Programs for Research and Innovation

The tree-like diagram in Figure 10 reports the technologies identified in the TRIMIS database following the methodology in Section 3.2. Technologies Inventory. The analyses focus on the SMO roadmap and on the “road” transport mode. The figure presents several metrics. These include two that highlight the total effort that has been put into the development of a single technology: the value of projects per technology, i.e., the total investment by both the EU and industry, and the number of...
projects per technology, i.e., the number of projects that have developed the technology. Two additional metrics highlight the level of interest in the technologies, also indicating the organization capable of bringing them to market: the number of organizations involved, i.e., the number of organizations that have been involved in projects researching the technology, and the number of projects organizations are involved in, i.e., the total number of projects that the organizations have been involved in.

As seen in Figure 10, 16 technologies are identified, grouped under eight overarching themes. The themes are omitted from the graph to save space, but also because their relevance is marginal when such filtering occurs. The graph provides quick information about the status of technology. Even though it is difficult to compare technologies to each other due to the way the technology database was developed, it is straightforward to see that major efforts were dedicated to road safety and intelligent mobility communication technologies.

In addition to these analyses, the maturity phase of the top three technologies in terms of projects that research them are identified (Figure 11). Figure 11 also gives some quick indications. For example, most projects investigating intelligent mobility communication and evidence-based road safety technologies do so at an early stage of research. This is not the case for parking management systems that have reached a higher research maturity.

Identifying metrics to assess technologies and technology maturity data can contribute to the improvement of funding programs and help develop focused measures to support sustainable transport innovation.

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![Figure 10](image_url)

**Figure 10.** Technologies under the STRIA roadmap on smart mobility and services roadmap and road transport. Abbreviations: IoT—Internet of Things; EV—electric vehicle; App—application.
Figure 11. Top three technologies in terms of projects researching them and corresponding development phases.

4.2. TRIMIS Horizon Scanning Outputs

Within the TRIMIS horizon scanning activities, the first TRIMIS Horizon Scanning Session on 26 September, 2019, aimed at collecting insights from transport experts with various scientific and professional backgrounds and making sense of transport-related horizon scanning items (I) that were previously selected through a JRC horizon scanning scheme based on their potential impact on the future of transport. Horizon scanning items correspond to factual information that is collected from various sources that can provide indications on relevant trends, new drivers of change, discontinuities, weak signals, sudden unexpected events, etc. (e.g., text mining systems, scientific publications repositories, trade and business publications, social media). This process enabled the collection of relevant technical insights regarding emerging trends and the evaluation of the potential of technologies that can affect the transport sector. The results of this activity will be used to highlight trends in transport innovation and by extension to support policymaking within the transport domain [64].

The horizon scanning exercise built upon 98 horizon scanning items identified as being of high relevance to the transport sector. They were first collated in clusters (CL) and a selection process based on the experience of the various experts led to the creation of a series of meta-clusters (MC) on the basis of items covering themes with a potential future value for the transport domain. Finally, the meta-clusters were ranked according to their perceived priority and potential by the participants, while the top prioritized ones were further processed and analyzed by ad-hoc participant expert groups according to their respective scientific/professional backgrounds. A realistic and an extreme scenario were developed for each meta-cluster and potential consequences were identified for each future scenario. Table 3 presents the list of meta-clusters, clusters and observations (OBS), their timeframes, and relevance to each STRIA roadmap. The four prioritized meta-clusters cover the following domains:

- Radical solutions to replace cars in urban environments;
- Fleet modernization through retrofitting;
- Electrification and escalation of power demand; and
- Automation to maintain the current system with fewer externalities.
Table 3. Mapping of meta-clusters according to STRIA roadmap and time horizon [64].

<table>
<thead>
<tr>
<th>Time Horizon</th>
<th>STRIA Roadmaps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CAT</td>
</tr>
<tr>
<td>Long Term</td>
<td></td>
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<tr>
<td>&gt;10 years</td>
<td></td>
</tr>
<tr>
<td>Medium Term</td>
<td>CL_L</td>
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<tr>
<td>5–10 years</td>
<td></td>
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<tr>
<td>Short Term</td>
<td>CL_M</td>
</tr>
<tr>
<td>&lt;5 years</td>
<td></td>
</tr>
</tbody>
</table>

List of meta-clusters (MC), clusters (CL) and observations (OBS) (prioritized in bold): MC_1 Insurance as enabler for new technologies; CL_A Extreme weather events to impact mobility; MC_3 Individualization, diversification, and interconnection of transport modes for minimizing efforts and time; CL_B Widening the scope of aviation—moving closer to urban mobility; CL_C Hope or hype?; CL_D Opening of markets to new passengers and users; MC_7 Artificial intelligence leading to optimization at system level; MC_8 Safety, security, and use of drones, small-scale use/niches calling for regulations; MC_9 Radical solutions to replace cars in urban environments; OBS_E User-based valuation of transport services; CL_F Connectivity and automation to reduce individual freedom of mobility; CL_G Vehicle design for new usage, ownership, and business model; MC_13 Integrated design innovations for vehicles and their ancillary systems; CL_H Competitiveness losses of leading EU rail manufacturers; MC_15 Fleet modernization through retrofiting; CL_J Alternative propulsion for aircraft; MC_17 Electrification and escalation of power demand; MC_18 Reduction of maritime pollution; MC_19 Renewables (solar/wind) for direct propulsion instead of fuel; CL_L Waste, by-products, and natural elements for fuels; OBS_K Social differentiation/disparities; CL_M Autonomous ships; MC_23 Automation to maintain current system with fewer externalities; CL_N Unorthodox modelling and testing for autonomous vehicles.
5. Discussion and Conclusions

Transport R&I plays a major role in the decarbonization of the European transport sector. STRIA has outlined R&I priorities in order to achieve clean, connected, and competitive mobility in seven roadmaps. TRIMIS was developed as an integrated policy-support tool monitoring the implementation and further development of STRIA and providing insights to relevant transport stakeholders. In this context, it monitors the progress of the STRIA and provides insights that will assist the further development and updating of the STRIA roadmaps in different steps, including through the STRIA governance process. It will provide an up-to-date “technology map” covering the technological status, existing barriers, and future potential according to the STRIA structure alongside a capacity mapping.

Research projects relevant to the STRIA roadmaps, both EU and Member State funded, are being assessed against defined KPIs and scoreboards to determine progress in meeting the STRIA objectives. Moreover, by assessing socio-economic developments and how they influence transport technology and innovation, the effective functioning of an extensive network of industry stakeholders is facilitated.

TRIMIS support for the above is twofold. First, the methodology adopted for the assessment of technologies in European R&I projects can support the optimization of funding allocation through R&I funding programs and through the selection of the appropriate measures that can further promote sustainable transport innovation. This is exemplified in this paper in the case of smart mobility systems and services in the road sector, which have been developed on a large scale in the last decade due to developments in ICT-enabled web, mobile, and big data applications, and can contribute to the decarbonization of the European transport sector. Second, foresight is used for the identification of potential future technologies with an impact on the transport sector because TRIMIS has developed specific approaches to horizon scanning and assessment of emerging and new transport technologies.

Technology analysis allows for the identification of clusters that are in European research projects at various development phases. Development phase metrics provide solid indications on technology maturity and are now integral to the TRIMIS assessment methodology. Findings based on the technology assessment indicate that road safety, intelligent mobility communication, and eco-drive applications have been among the top of priorities in European R&I. These technologies focus on improvement using new methods or techniques of consolidated applications. On the other hand, the Horizon Scanning exercise identified further technologies related to the transport sector that can be both complimentary to existing applications, but also have a disruptive effect in the transport sector. Apart from incremental changes, radical solutions to replace cars in the urban environment may be one potential approach, while electrification and automation of transport may be among the future disruptors that will change mobility, mostly at the urban level.

The above should be considered within the transition from a legacy unidimensional planning and governance approach to a multi-dimensional one, where the different disruptors and their respective domains (e.g., automation, connectivity, electrification) are interlaced. Furthermore, the developments in transport are increasingly connected to advances in other sectors such as energy and ICT and need to be seen in the context of the policy objective of achieving climate neutrality by 2050. This has already been reflected in the definition of the next EU research and innovation program Horizon Europe [65], in which a specific cluster will cover climate, energy, and mobility. TRIMIS’ future development will take this into account and will increasingly integrate R&I and technology developments in these fields into its assessment work. In this sense, compared to other transport policy tools, TRIMIS and its modular and multifaceted structure distinguishes itself by its coverage of all transport modes and its aim to support the needs of a wide range of transport stakeholders. Its current functionalities and future developments therefore make it a useful hub for researchers, practitioners, and policymakers to assess and understand developments in European transport R&I.

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Conflicts of Interest: The authors declare no conflict of interest.

Glossary

ACARE Advisory Council for Aviation Research and Innovation in Europe
ALT Low-emission Alternative Energy for Transport
BERD Business expenditure on Research and Development
CAT Connected and Automated Transport
CCAM Cooperative, Connected and Automated Mobility
CL Horizon Scanning Cluster
CO₂ Carbon dioxide
CORDIS Community Research and Development Information Service
CPC Cooperative Patent Classification
DG MOVE European Commission Directorate-General for Mobility and Transport
DG RTD European Commission Directorate-General for Research and Innovation
EC European Commission
ELT Transport electrification
EPO European Patent Office
ERRAC European Rail Research Advisory Council
ERTRAC European Road Transport Research Advisory Council
EU European Union
EUR Euro
EV Electric vehicle
GBAORD Government Budget Appropriations or Outlays for Research and Development
GDP Gross domestic product
GHG Greenhouse gases
GVA Gross value added
H Horizon Scanning Item
ICT Information and Communications Technology
JRC Joint Research Centre
INF Transport infrastructure
IOT Internet of Things
IRI Industrial Research and Innovation
KPI Key performance indicator
Maas Mobility as a Service
MC Horizon Scanning meta-cluster
NASA National Aeronautics and Space Administration
NETT New and emerging technologies and trends
NO₂ Nitrogen dioxide
NTM Network and traffic management systems
O₃ Ozone
OBS Horizon Scanning observation
OECD Organization for Economic Co-operation and Development
PATSTAT EPO Worldwide Patent Statistical Database
PCT Patent Cooperation Treaty
PM₂.₅ Particulate matter
REGEX Regular expressions
R & D Research and Development
R & I Research and Innovation
RIO Research and Innovation Observatory
SDG Sustainable Development Goal
SET Strategic Energy Technology
SETIS Strategic Energy Technologies Information System
SMO Smart mobility and services
STRIA Strategic Transport Research and Innovation Agenda
TIM Tools for innovation monitoring
TRB Transportation Research Board
TRID Transport Research International Documentation
TRIMIS Transport Research and Innovation Monitoring and Information System
TRL Technology readiness level
UN United Nations
VDM Vehicle design and manufacturing
WIPO World Intellectual Property Office
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