European Commission

JRC SCIENCE FOR POLICY REPORT

Research and innovation in transport electrification in Europe

An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

Tsakalidis, A., van Balen, M., Gkoumas, K., Marques dos Santos, F., Grosso, M., Ortega Hortelano, A., and Pekár, F.

2020

Joint Research Centre

EUR 30387 EN

Contact information
Name: Ferenc Pekár
Address: European Commission, Joint Research Centre, Vie E. Fermi 2749, I-21027, Ispra (VA) — Italy
Email: ferenc.pekar@ec.europa.eu
Tel.: +39 0332 783925

EU Science Hub
https://ec.europa.eu/jrc

JRC120533

EUR 30387 EN

PDF	ISBN 978-92-76-22446-4	ISSN 1831-9424	doi:10.2760/00563
Print	ISBN 978-92-76-22445-7	ISSN 1018-5593	doi:10.2760/675535

Luxembourg: Publications Office of the European Union, 2020

How to cite this report: Tsakalidis, A., van Balen, M., Gkoumas, K., Marques dos Santos, F., Grosso, M., Ortega Hortelano, A., and Pekár, F., *Research and innovation in transport electrification in Europe: An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)*, EUR 30387 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-22446-4, doi:10.2760/00563, JRC120533.

Contents

Abstract

Electrification has a major role to play in decarbonising transport and in reducing its fossil fuel dependency. For transport electrification to be cost-efficient and ready for future needs, adequate research and innovation (R&I) in this field is necessary. This report provides a comprehensive analysis of R&I in transport electrification. The assessment follows the methodology developed by the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS). The report critically assesses research by thematic area and technologies, highlighting recent developments and future needs.

Acknowledgements

The European Commission's Joint Research Centre (JRC) is in charge of the development of the Transport Research and Innovation Monitoring and Information System (TRIMIS). The work has been carried out under the supervision of the European Commission's Directorate-General for Mobility and Transport (DG MOVE) and Directorate-General for Research and Innovation (DG RTD) which are co-leading the Strategic Transport Research and Innovation Agenda (STRIA). The authors would like to acknowledge the support of Harry Scammell and Gareth Horton of Ricardo-AEA Ltd. The views expressed here are those of the authors and may not, under any circumstances, be regarded as an official position of the European Commission.

Authors

Anastasios Tsakalidis, European Commission, Joint Research Centre

Mitchell van Balen, European Commission, Joint Research Centre

Konstantinos Gkoumas, European Commission, Joint Research Centre

Fabio Marques dos Santos, European Commission, Joint Research Centre

Monica Grosso, European Commission, Joint Research Centre

Alejandro Ortega Hortelano, European Commission, Joint Research Centre

Ferenc Pekár, European Commission, Joint Research Centre

Executive summary

The report presents a comprehensive analysis of research and innovation (R&I) in transport electrification (ELT) in Europe in the last years, focusing on European Union (EU) funded projects. It identifies progress in several thematic fields and technologies. It also highlights the relevant policy context and market developments both in Europe and outside.

Policy context

The 2011 EU White Paper on Transport sets a target to reduce transport GHG emissions by about 20% by 2030 (relative to 2008 levels) and by at least 60% by 2050 (relative to 1990 levels). Moreover, the European Green Deal indicates a 90% reduction in transport emissions across all modes by 2050 as a prerequisite to achieve climate neutrality. With its 2030 Climate Target Plan, based on a comprehensive impact assessment, the Commission has proposed to increase the EU's ambition on reducing GHG by at least 55% by 2030. Renewable energy in transport has to increase to around 24% (from 6% in 2015) through further development and deployment of electric vehicles (EVs), advanced biofuels and other renewable and low carbon fuels as part of a holistic and integrated approach. To this aim conventional cars will need to gradually be displaced by zero emissions vehicles, while sustainable collective transport services have to be further developed. In this frame, the impact assessment projects reduction levels in 2030 corresponding to an estimated 50% decrease (compared to 2021 targets) of the carbon dioxide (CO_2) emissions per km for passengers cars.

In May 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 key transport R&I areas and priorities for clean, connected and competitive mobility.

Transport electrification can contribute to breaking transport dependency on oil and decrease carbon dioxide emissions. The decarbonised electricity generation will provide cleaner energy to propel electric vehicles (EVs). EVs 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 charging points covering the whole EU road network is another key enabling condition for transport electrification.

The STRIA Roadmap for Transport Electrification[1] aims to bring forward the developments carried out in the framework of the European Green Vehicle Initiative and encourage multi-sectorial and multi-disciplinary research and innovation activities on new materials, advanced propulsion systems and information and communication technologies. The Transport Electrification roadmap covers hydrogen and thus it is included in this analysis, while other alternative fuels fall under a dedicated roadmap on Low-emission Alternative Energy for Transport[2].

Considering the above, the analyses included in this report are based on the targets and proposed actions set in the latest version of the roadmap and aim at supporting its further development by assessing research carried out in this specific area. The analysis identifies the current state of play and describes several developments that future R&I initiatives should consider. It is based on the European Commission's Transport Research and Innovation Monitoring and Information System (TRIMIS).

Key conclusions

Focusing on selected EU funded projects, this report presents a comprehensive analysis of R&I in transport electrification in Europe in the last years, while it identifies relevant researched technologies and their development phase.

Altogether, this report provides a comprehensive and up-to-date review of ELT R&I across Europe. Although with limitations (more notably, the lack of Member State (MS)-funded projects in the assessment), findings and insights into the current R&I status and future needs, help policy makers better define future R&I initiatives and provides valuable information to transport electrification stakeholders.

[1] https://trimis.ec.europa.eu/stria-roadmaps/transport-electrification
[2] https://trimis.ec.europa.eu/stria-roadmaps/low-emission-alternative-energy-transport

Main findings

Under the 7th Framework Programme for Research (FP7) and the Horizon 2020 Framework Programme for Research and Innovation (H2020) about €3.07 bn have been invested in ELT research projects. This includes €1.85 bn of EU funds and about €1.22 bn of own contributions by beneficiary organisations. The majority of these projects were funded within the 'Smart, Green and Integrated Transport' Challenge of H2020[3].

From the data it can be seen that funding has been increasing, particularly in the fields of multimodal and air transport, with road transport receiving most of the funding. Rail transport, which is already largely electrified, receives a relatively little amount of research funding. The daily funding for all transport modes culminated in the first quarter of 2018 above €600,000.

A total of 2,230 unique organisations participated in FP7 and/or H2020 projects on ELT. Some organisations focus exclusively on ELT research in one mode of transport, whereas others conduct research across modes. Of the top-15 beneficiaries, 15 are active in road, 10 in multimodal, 3 in air, 3 in waterborne and 1 in rail transport.

Among the top-20 technologies that were researched in Framework Programmes in terms of total budget, 15 are linked to the road transport mode. *Hydrogen storage system* is linked to multimodal transport, *aviation hybrid electric powertrain* is linked to aviation, while, *hydrogen production using an electrolyser system*, *electric ship concept* and *electric propulsion system for vessels* are linked to waterborne transport. The top-3 technologies in terms of funding are *public charging infrastructure* (€628 m), *hydrogen refuelling station using ionic compressor* (€270 m) and *fuel cell hybrid bus* (€196 m).

From a text analysis on scientific research from the Scopus database, the number of publications on ELT in general has an increasing trend from year to year, with the annual publication of documents related to the various aspects of transport electrification rising significantly from 2010 to 2019 and the majority of research being carried out within three fields: engineering, energy and environmental sciences.

Related and future JRC work

The TRIMIS team is consolidating and expanding the data repository to better assess R&I efforts of projects not funded by the EU or MSs. As part of this effort, information will be added on technologies, patents and publications, and various other topics of interest, including on transport electrification. TRIMIS will continue to provide support to STRIA and, on the basis of its research, provide recommendations to policymakers.

Quick guide

The report is structured in the following manner: Chapter 1 gives a brief introduction and background on transport electrification research. Chapter 2 provides the scope of the report together with a methodological background. Chapter 3 provides the state of play and Chapter 4 the policy context. Chapter 5 provides a quantitative assessment of transport electrification related research and innovation. Chapter 6 shows the R&I assessment, dividing transport electrification research in six sub-themes. Finally, Chapter 7 provides the conclusions.

[3] https://ec.europa.eu/programmes/horizon2020/en/h2020-section/smart-green-and-integrated-transport

1 Introduction

The transport sector is a main pillar of the European and global economy. Nevertheless, transport greenhouse gas (GHG) emissions account for approximately 27% of the total emissions economy-wide and have been increasing, despite a decline between 2008-2013 (EEA, 2018). Due to this, transport systems decarbonisation is a key element of European policy towards the mitigation of climate change effects. In this context, the 2011 EU White Paper on Transport sets a target to reduce transport GHG emissions by about 20% by 2030 (relative to 2008 levels) and by at least 60% by 2050 (relative to 1990 levels). Moreover, the European Green Deal indicates a 90% reduction in transport emissions across all modes by 2050 as a prerequisite to achieve climate neutrality (European Commission, 2011; 2019).

With its 2030 Climate Target Plan, based on a comprehensive impact assessment, the Commission has proposed to increase the EU's ambition on reducing GHG by at least 55% by 2030. Renewable energy in transport has to increase to around 24% (from 6% in 2015) through further development and deployment of electric vehicles (EVs), advanced biofuels and other renewable and low carbon fuels as part of a holistic and integrated approach. To this aim conventional cars will need to gradually be displaced by zero emissions vehicles, while sustainable collective transport services have to be further developed. In this frame, the impact assessment projects reduction levels in 2030 corresponding to an estimated 50% decrease (compared to 2021 targets) of the carbon dioxide (CO_2) emissions per km for passengers cars (European Commission, 2020a).

Transport electrification can contribute to breaking transport dependency on oil and decrease GHG emissions. The decarbonised electricity generation will provide cleaner energy to propel EVs. EVs will be able to provide storage services to the grid favouring further expansion of renewables. Decreasing battery costs while increasing their energy density and lifetime will speed up electrification of road transport. The development of energy storage technologies and devices remains the cornerstone of a fully electrified transport system integrated in a clean energy network. The deployment of a network of charging points covering the whole European Union (EU) road network is another key enabling condition for transport electrification. In this context, the market uptake of EVs needs to be nurtured by appropriate support measures for users, for technological advances related to the vehicle and its components, and for the necessary charging infrastructure deployment (Tsakalidis et al., 2019).

Despite the latest advances in the field of electrification, EVs have not yet achieved cost competitiveness with respect to incumbent technologies and further research and development efforts are necessary in order to further improve their performance and reduce their costs. Moreover, the adoption of appropriate policies that can have an impact on the users' consumer behaviour with reference to low-emission mobility, can play a major role supporting the transition towards a near zero emission mobility (Tsakalidis and Thiel, 2018).

In this context and in order to better address current socio-economic and environmental challenges arising within a transport sector that is changing with constantly added factors of complexity, new technological developments and innovative approaches are required. Furthermore, EVs still need support measures that will allow them to become a fully viable market proposition for prospective car buyers. Moreover, EVs in isolation may not be the next mobility 'killer app' that will lead to a radical mobility system transformation into a more sustainable, more affordable and more convenient one; potential synergies with other transport domains, technological solutions and new business models may also be required (Thiel et al., 2020).

Research and innovation (R&I) can provide the answer to many issues arising through this changing reality, providing novel solutions assisting the mobility of people and goods, but it has to be supported by the appropriate policy framework that will act as an enabler toward this direction (Tsakalidis et al., 2020a). To this aim, the European Commission (EC) adopted the Strategic Transport Research and Innovation Agenda (STRIA) in May 2017 as part of the 'Europe on the Move' package, which highlights main transport R&I areas and priorities for clean, connected and competitive mobility, covered by seven roadmaps focusing on seven thematic areas including smart mobility (European Commission, 2017a):

- 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).

However, new transport-related systems and services introduced need to be evaluated in terms of their contribution to the overall energy and transport system sustainability. Therefore, an effective monitoring and information mechanism is needed to support the implementation of STRIA. The EC Joint Research Centre (JRC) has developed the Transport Research and Innovation Monitoring and Information System (TRIMIS) in order to support the implementation of STRIA through a holistic assessment of technology trends and transport R&I capacities and to publish transport R&I information and data on the European transport system (Tsakalidis et al., 2018). TRIMIS received funding under the H2020 Work Programme 2016-2017 on Smart, Green and Integrated transport (European Commission, 2017c).

This report focuses on the STRIA Roadmap for Transport Electrification, which aims to bring forward the developments carried out in the framework of the European Green Vehicle Initiative and encourage multi-sectorial and multi-disciplinary R&I activities on new materials, advanced propulsion systems and information and communications technologies (ICT). In the context of the current roadmap, hydrogen is covered and thus it is included in this analysis, while other alternative fuels fall under a dedicated roadmap, on low-emission alternative energy for transport[4]. The current roadmap identifies several research needs for the years to come and 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;
  - R&I.

For each mode of transport, a package of relevant actions is proposed in order to achieve the aforementioned objectives.

The present report supports this process by assessing R&I in ELT, based on TRIMIS. It provides a comprehensive analysis of selected transport electrification research projects that are financed by the 7th

[4] https://trimis.ec.europa.eu/stria-roadmaps/low-emission-alternative-energy-transport

Framework Programme for Research (FP7) and the Horizon 2020 Framework Programme for Research and Innovation (H2020). A complete table of all projects considered, including the sub-themes that they are relevant to, is included in Annex 1.

The findings can help transport electrification stakeholders, including policymakers, regulators, transport service providers, and standardisation bodies. Furthermore, insights into the current status and future needs can help policy makers to better define R&I initiatives.

2 Methodological background

The main goal of this report is to thoroughly review EU funded projects related to transport electrification. To do so, three actions were necessary, namely:

1. The consolidation and further development of the TRIMIS project and programme database;
2. The development of a methodology for the identification and assessment of the technologies researched within Framework Programmes (FPs);
3. The conceptual framing for the project assessment.

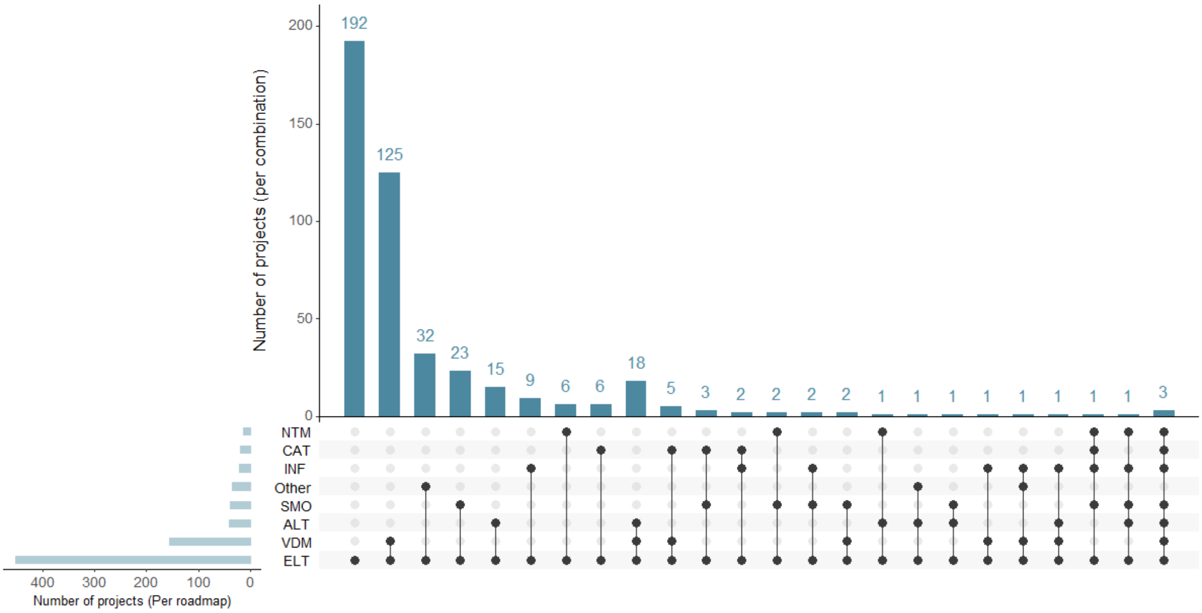
A brief description of these steps is provided in the following sections.

2.1 Database development and labelling

TRIMIS contains a continuously updated database of EU and Member State (MS) funded programmes and projects (currently over 7,000) on transport R&I. Projects funded by the European FPs are retrieved through an automated data link with the Community Research and Development Information Service (CORDIS), while projects funded by MSs are inserted manually by national contact points, but also by TRIMIS users on a voluntary basis. Project inputs are then evaluated and labelled according to a series of criteria linked to the STRIA roadmap classification and then added to the database and published on the TRIMIS web platform (van Balen et al., 2019).

An initial step is to identify those projects that fall within the ELT roadmap, matching the scope of the STRIA roadmap that was published in 2017. Transport experts related to the various aspects of the electrification of the transport sector, with a deep understanding of all STRIA roadmaps manually labelled the projects according to the STRIA roadmap classification. Considering that many projects cover various elements within the transport electrification domain, only those projects that cover a considerable transport electrification research component in the project description were assigned to the ELT roadmap. Alternatively, a project can also be assigned to multiple roadmaps if it covers aspects also falling within the domains of other roadmaps. An overview on the extent to which ELT projects overlap with other roadmaps is presented in Figure 1, based on 453 FP7 and H2020 projects that were assessed. It shows how often the keywords of each theme were detected (left horizontal bars) in the projects' objectives and how often a certain combination of keywords occurred (vertical bars). The experts also assessed several other aspects of the projects, including the mode of transport and geographical focus of each project. Through discussions and interrater reliability assessments, the quality of the labelling was assured.

Figure 1. Overlap between transport electrification projects with other STRIA roadmaps.

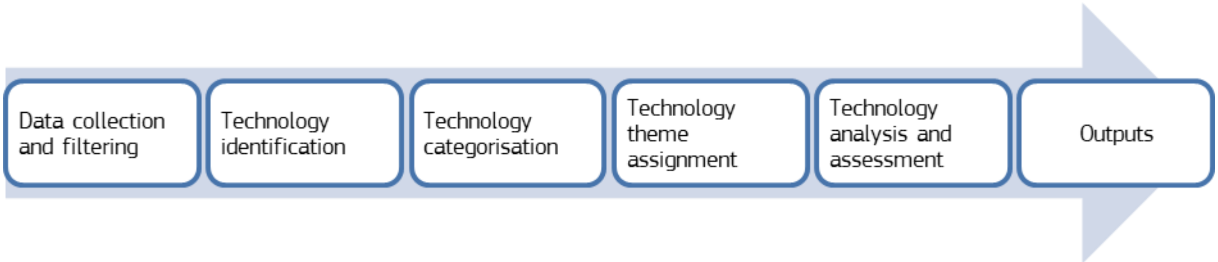


Source: Own elaboration based on TRIMIS.

2.2 Identification and assessment of the technologies researched within FPs

One of the sub-tasks of TRIMIS is the creation of an inventory and regular reporting on new and emerging technologies and trends (NETT) in the transport sector (Gkoumas et al., 2018, 2020). To this aim, a framework for the taxonomy, assessment and monitoring of NETT is proposed (Gkoumas and Tsakalidis, 2019), which supports innovation management at various levels, thus providing insights to the sector's stakeholders (e.g. researchers, business operators, national authorities and policymakers) while backing the current transport systems' transformation through technological advances. The TRIMIS NETT analysis currently focuses on technologies researched in European FPs, specifically FP7 and H2020 projects from the TRIMIS database. Figure 2 provides an overview of the methodology used for the technological assessment of the projects.

Figure 2. Technology assessment methodological steps.



Source: Gkoumas et al., 2019.

A total of 2,242 projects fall within the scope. Within these projects, 797 technologies were identified under 45 technology themes through a Grounded Theory approach (Glaser and Strauss, 1967). An iterative approach led to the development of a consistent taxonomy for transport technologies and technology themes.

First, the results of a study that identified technologies within European transport research projects (INTEND, 2017) were analysed by three researchers who have complementary experience in the field of transport innovation and who have individually assessed the technology list. Based on this review, the researchers came up with a standardised approach on what constituted a distinct technology and how to label them.

Following this approach, all 2,242 projects descriptions were read and flagged when a technology was mentioned. This filtering exercise was required because EU-funded projects also cover non-technology focused projects. Once a technology was flagged in the project description, another researcher would validate the flagging and record the technology name.

In a next step, the full list of technologies was evaluated, and the labelling of similar technologies was aligned. The labels were inspired by existing taxonomies, such as those under the Cooperative Patent Classification (CPC, 2019).

When the technology list was established, a number of overarching technology themes were defined. Themes enable a better understanding of how technologies cluster together and which fields of research receive relatively greater interest. An extensive list of themes was created and consequently reduced to the minimum number of themes under which all technologies could still be logically placed. This process led to a total of 45 themes.

Moreover, all projects were assessed on whether they focused on ELT. If so, the associated technologies and their themes were highlighted. The funds associated with each technology were determined by linking them with the total project budget. If multiple technologies were researched in the project, the budget allocated to the technology of interest was determined by dividing the project budget by the number of associated technologies. The limitations of this attribution approach are acknowledged but is considered to be transparent and appropriate in the absence of technology-budget reports.

Finally, a set of metrics was established to assess the 137 technologies identified within the ELT roadmap. These metrics are intended to indicate the potential for the technology to be taken forward to application through the level of support for its development.

2.3 Project assessment

Using data from the TRIMIS database, recent programmes that have funded research in topics related to transport electrification have been identified. All related projects within the last two Framework Programmes (FP7 and H2020) have been included.

The sub-themes of this roadmap were selected according to the roadmap's portfolio of proposed actions and are presented and analysed in detail in Chapter 6 under the report's research and innovation assessment. Research and innovation projects in the field of ELT are analysed under six key sub-themes, which cover the key areas of research being undertaken under this STRIA roadmap

By adopting this clustering, it is possible to assess R&I findings focusing on specific areas of interest, give ideas on which areas have been left out until now, and compare developments.

A complete table of all projects considered in this report, including the sub-themes that they are relevant to, is included in Annex 1.

2.4 Research scope

Each chapter of this report addresses ELT R&I from a complementary perspective, with a research scope and timeline that is adjusted accordingly. Table 1 highlights the approaches used in various parts of the report to facilitate understanding and interpreting the results.

Table 1. Research scope of each chapter and section.

Chapter (section)	Type of analysis	Scope
Chapter 3: State of play	Literature review	Review of trends and business initiatives
Chapter 4: Policy context	Literature review	Review of policy initiatives, focusing on the EU
Chapter 5, section 1 and 2: Quantitative project analysis	Statistical analysis	Covers FP7 and H2020 projects that commenced between 2007 and 2019
Chapter 5, section 3: Technology analysis	Statistical analysis	Covers FP7 and H2020 projects that developed a technology between 2007 and 2019
Chapter 5, section 4: Scientific output analysis	Bibliometric study	Covers publications within the Scopus database between 2010 and 2019
Chapter 6: Qualitative analysis	Project reviews	In-depth analysis of FP7, H2020 and other projects that commenced between 2012 and 2019

Source: Own elaboration based on TRIMIS.

3 State of play of transport electrification

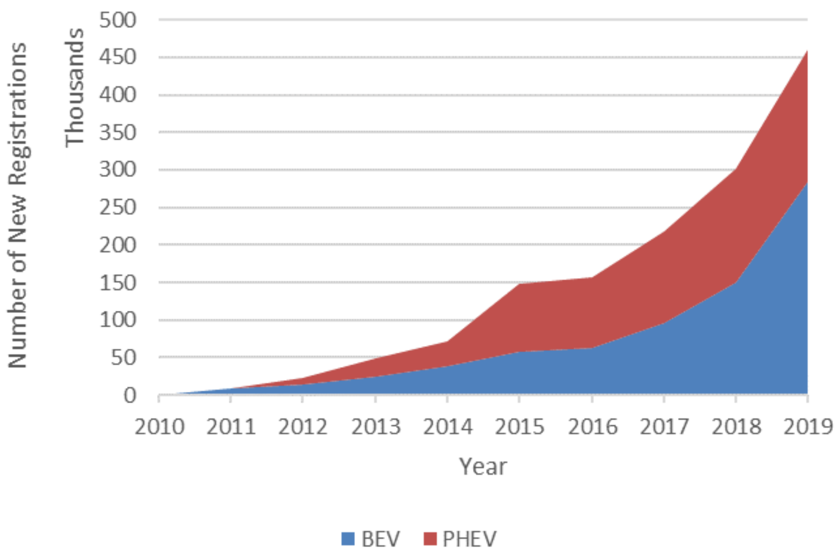
The market for EVs, particularly passenger cars, has grown rapidly in recent years, driven partly by tighter emissions regulations and partly by significant developments in battery technology. While electric vehicles were still a niche in 2010, most car brands nowadays offer EV models, while European consumers have the choice of a wide range of EV models that cover all car segments: the number of models offered, the size segment coverage, the number of EV registrations, their market share and the available charging infrastructure have increased significantly, but nevertheless still too small to be considered as full-scale commercialisation (Tsakalidis and Thiel, 2018).

Globally, over two million passenger EVs were sold in 2019, with an expectation that sales will continue to rise to 8.5 million by 2025, 26 million by 2030 and 54 million by 2040 (Bloomberg New Energy Finance, 2020). In its 2020 Global EV Outlook, the International Energy Agency projects an electric car fleet increase from 7.2 million in 2019 to between 140 million and 245 million in 2030, depending on the scenario (IEA, 2020). The future growth of sales of EVs will depend strongly on the policies and regulations that encourage sales of such vehicles (and restrict the use of conventionally-fuelled vehicles) and the future development of EV prices.

The majority of electric vehicles sold to date have been passenger cars; however, there are also developments in light commercial vehicles (eLCVs), driven largely by the demands for emission-free delivery services in cities to reduce air pollution (Green Car Congress, 2019; Petzinger, 2017; Szymkowski, 2017). The achievement of high penetration of eLCVs alone can lead to a reduction of total transport CO_2 emissions by more than 3% by 2030, while there is an equal or higher potential for other pollutants, such as NO_x and PM (Tsakalidis et al., 2020b).

At a European level, analyses of data from the European Alternative Fuels Observatory (EAFO) also show significant growth in new registrations of electric vehicles in the EU since 2010 (Figure 3).

Figure 3. New registrations of electric cars in the EU28[5].

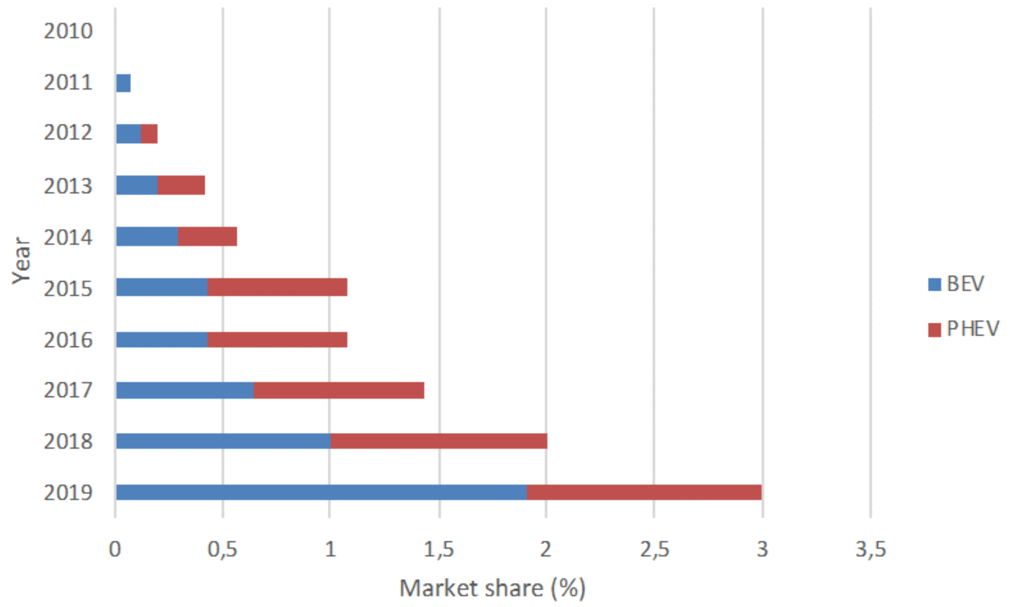


Source: European Alternative Fuels Observatory, 2020.

Figure 4 shows the growth in new registrations of electric cars when presented as a percentage of all new car registrations.

5 Group of 28 European Union Member States.

Figure 4. New registrations of electric cars in the EU28, presented as a percentage of total new car registrations.



Source: European Alternative Fuels Observatory, 2020.

Other reviews of the trends in sales of electric vehicles in Europe show similar results. The European Automobile Manufacturers Association (ACEA) reported that 1.5% of passenger cars sold in 2017 were 'electrically chargeable', a figure that rose to 2.0% (304,000 vehicles) in 2018 and to 3.0% in 2019 (ACEA, 2018; 2019, 2020a). These numbers continued to rise also in the first semester of 2020, regardless of the significant drop in overall sales (-38.1% first half of 2020), having reached 7.2% of total EU car sales, compared to a 2.4% share during the same period of the previous year (ACEA, 2020b, 2020c).

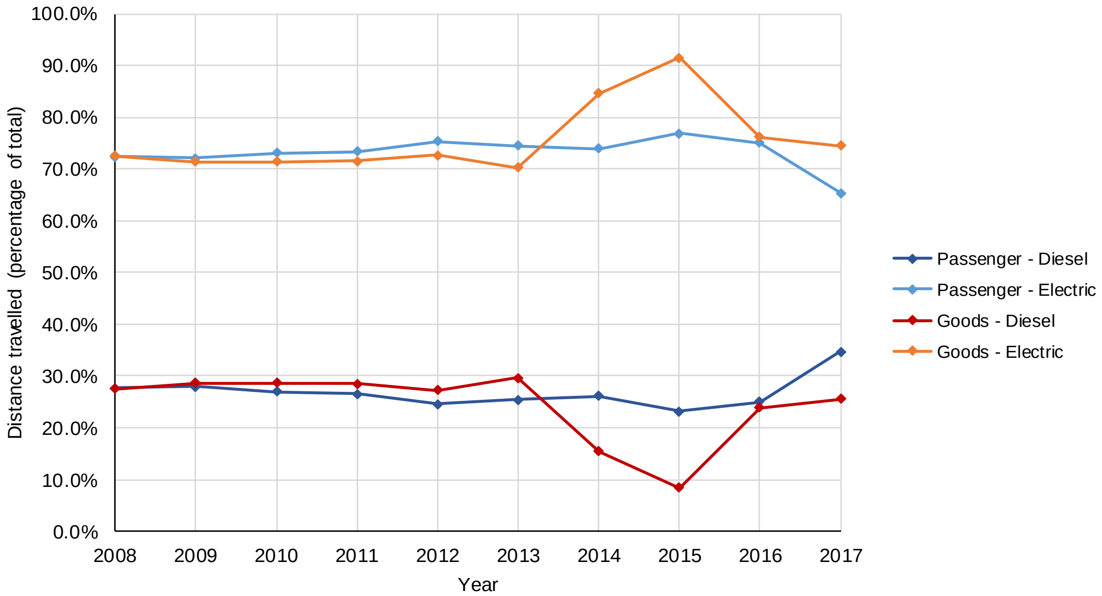
When considering the relevance of research to EV battery technology, it is important to note that much of the increased attractiveness of EVs has been due to the reduced costs and increased energy density of the batteries, which has largely resulted from developments in industry. For example, as discussed in Section 6.1, a project that started in 2015 investigated the development of what were, at the time, considered to be ambitious targets for cell energy density (up to 190 Wh/kg). However, current BEVs may already have cell energy densities of around 240 Wh/kg (Bower, 2019). Therefore, there is evidence that EV demand and competition between manufacturers is driving some technology developments in industry at a faster rate than the research community can provide. However, a key strength of the research community is its ability to develop more 'step-change' technologies that industry would consider too risky to invest in at an early stage.

Moreover, EAFO data show that fuel cell electric vehicle (FCEV) registrations to date have been extremely small. The first FCEV registrations in the EU were observed in 2013 and opposite to the model evolution of BEV and PHEV, numbers of available models and registered FCEVs have remained low compared to the other technologies, still comprising a very small fraction of the market and are targeted at mid-sized vehicles or sport utility vehicles (SUVs) (Tsakalidis and Thiel, 2018). EAFO[6] data indicate that in 2019 there were 296 H_2 powered LCVs in Europe, out of a total of 353,511 alternatively-fuelled LCVs (ca. 0.08% of alternatively-fuelled LCVs). Similarly, there were 848 H_2-fuelled passenger cars, out of a total of 10,616,774 alternative fuelled passenger cars (ca. 0.008%). Although the percentage of LCVs is greater than that of passenger cars, the numbers are still extremely small in comparison to other fuels. This comparison although factually correct does not take into consideration that BEVs and FCEVs had a different degree of technological maturity in the early 2000s. However, the fact that sales of FCEVs have remained low suggests that the issues are not just the technological maturity of the vehicles, but likely to be due to other factors (e.g. price, lack of refuelling stations, or, at least, lack of evidence of refuelling stations).

[6] https://www.eafo.eu/uploads/temp_chart_/data-export-130520.pdf?now=1589377422968

Apart from road transport, across much of Europe, a large part of the rail network is already electrified, using either overhead lines or third-rail systems. To illustrate this, data from Eurostat have been analysed to show the percentages of rail travel for passenger and freight use, split by diesel and electric power sources.

Figure 5. Percentage of rail travel in EU28 member States by energy source and purpose.

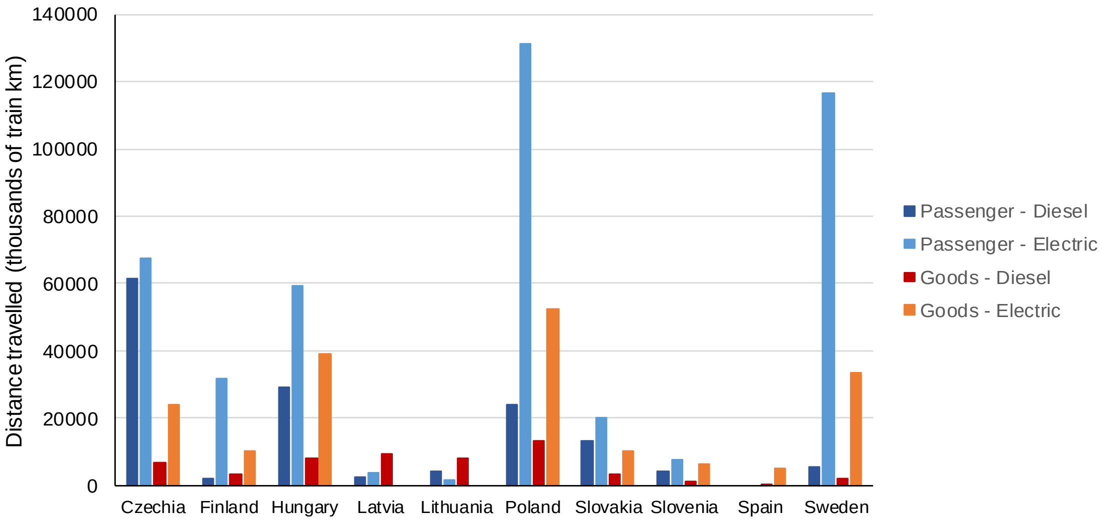


Source: Analysis of Eurostat data (Eurostat, 2019).

The provision of data from EU MSs on the split between diesel and electric power for rail travel is variable, with some MSs not separating the energy sources at all, and some not providing the data for all years. Therefore, to present a consistent view on the developments, Figure 5 includes only data from MSs that provided data split by energy source in all years. Although there have been some variations in recent years, overall the split of energy source for rail travel has been consistently at about 75%/25% electric/diesel since 2008.

Assessing the data for 2016 in greater detail (Figure 6, including only the MSs that provided data for that year) shows significant variations between MSs. Passenger travel in Czechia is almost 50:50 electric/diesel, while Finland and Sweden are almost entirely electric.

Figure 6. Rail travel by EU28 Member State in 2016 by purpose and energy source.



Source: Analysis of Eurostat data.

The International Energy Agency (IEA) report on the future of rail also notes that, globally, about 75% of rail travel uses electric power (IEA, 2019). In Europe, it identified that the percentage of passenger travel (expressed as passenger-km) on rail using electricity grew from about 73% in 1995 to 80% by 2016. For freight, the percentage of tonne-km using electric power rose from about 77% in 1995 to 80% in 2016.

In comparison with road vehicles, a much greater percentage of the rail transport market is already powered by electricity, with less use of other fuels (almost exclusively diesel). In addition to the third-rail and overhead line powered systems described above, there is also some interest in trains that can use battery power. These can either be purely electrically-powered or, more commonly, combine third-rail/overhead line with batteries to enable the same train to continue from a section of line with external power sources to one without. This can avoid, for example, the additional infrastructure costs of electrifying parts of lines through tunnels. Austrian Federal Railways have announced plans to acquire three such overhead line/battery trains, with deployment expected in 2019 (Railway Technology, 2017).

The use of hydrogen fuel cells to power trains is a relatively new technology, with first commercial operations being made in Germany in 2018 (Global Railway Review, 2018). Since then, further fuel cell powered trains have been ordered for use on German railways and their use is also being considered in the United Kingdom (UK) (Railway Gazette International, 2019; Wiseman, 2019). In September 2020, it was announced that, after successful testing in Germany between 2018 and 2020, Alstom's hydrogen train will enter regular passenger service in Austria by the end of November 2020 (Alstom, 2020).

In aviation, a number of manufacturers have been developing prototype electrically-powered aircraft, such as the Airbus E-Fan X[7], the Eviation Alice and the Lilium Jet; however, none are yet in production or in service (Airbus, 2018; Eviation, 2019; Lilium, 2019). In September 2020, Airbus revealed three new ZEROe zero-emission concept aircraft (in blended-wing body, turboprop and turbofan configuration), powered by hydrogen propulsion (hydrogen-hybrid) that could enter service by 2035 (Airbus, 2020).

[7] Cancelled in April 2020.

4 Policy context

4.1 Transport electrification in European transport policy

The 2011 EU White Paper on Transport, 'Roadmap to a Single European Transport Area – Towards a competitive and resource efficient transport system', identified the need to reduce GHG emissions by 60% relative to 1990 levels by 2050 (European Commission, 2011). It also recognised the potential for transport electrification to contribute to achieving the objective. However, it remained technologically neutral and did not set any specific targets for the level of electrification to be achieved.

In 2017, the Commission staff working document 'Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package' reviewed the status of electrification in all modes and provided direction for future research in this area as part of the development of the STRIA roadmaps (European Commission, 2017b). Furthermore, the European Battery Alliance (EBA) was launched in October 2017 as a cooperative platform that gathers the European Commission, interested EU countries, the European Investment Bank, key industrial stakeholders and innovation actors with the aim of creating a competitive manufacturing value chain in Europe with sustainable battery cells at its core. This will act as an enabler towards European technological independence and will capitalise on the job, growth and investment potential of batteries (European Commission 2020b).

In 2019, the European Parliament and Council adopted Regulation (EU) 2019/631 on CO_2 emissions from cars and vans post-2020 (European Parliament and Council of the European Union, 2019). This places targets on the emissions of newly registered cars and vans, but it does so at the manufacturer fleet level, leaving the individual manufacturers to determine the mix of vehicles that they wish to produce to meet the target. By setting challenging targets (for cars, a 15% reduction from 2025 and a 37.5% reduction from 2030, both relative to 2021; for vans the reductions are 15% and 31%, respectively), the regulation will encourage manufacturers to produce more EVs, as it will not be possible to meet the targets just through efficiency improvements to conventionally-powered vehicles. The regulation also includes specific incentives for zero and low-emission vehicles (ZLEVs), with a relaxation of the CO_2 emissions target if the ZLEV share of a manufacturer's production in a given year exceeds certain thresholds[8]. Moreover, along with the 2030 Climate Target Plan, the Commission proposed to raise the ambitions of reducing GHG emissions to at least 55% below 1990 levels by 2030 including reductions of an estimated 50% (compared to 2021 targets) of the CO_2 emissions per km for passengers cars on (European Commission, 2020a).

Starting from 1 January 2020, the Regulation (EU) 2019/631 sets CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (vans) in the EU. The Regulation also includes a mechanism to incentivise the uptake of zero- and low-emission vehicles, in a technology-neutral way.

A number of European states have implemented legislation to ban future sales of petrol and diesel engined cars and vans, effectively requiring a transition to electric (including hydrogen fuel cells) vehicles. The UK announced in 2017 that sales of new petrol and diesel cars and vans would be banned from 2040, although there is pressure on the government to bring the date forward (Harrabin, 2017). France also announced a similar ban on sales of petrol and diesel cars by 2040 at the same time (BBC News, 2017). Denmark, Ireland, the Netherlands and Sweden have all announced similar bans on petrol and diesel engined cars, but from 2030, while Norway plans to ban sales of such cars from 2025 (Burke-Kennedy, 2018; Gjerding Nielson, 2018; Hampel, 2019; Lambert, 2017; Staufenberg, 2016).

International aviation and maritime transport are both regulated by agencies of the United Nations (UN), the International Civil Aviation Organisation (ICAO) and the International Maritime Organisation (IMO) respectively. In 2017, the ICAO Council adopted a new aircraft CO_2 emissions standard that will apply to new designs from 2020, to aircraft type designs already in-production as of 2023 and to all newly manufactured aircraft from 2028 (ICAO, 2017b). The standard sets limits on the basis of a CO_2 metric system related to the aircraft cruise point fuel burn performance, size and weight. As such, it does not impose any requirement, nor provide any specific incentive, for the electrification of aircraft (ICAO, 2017a).

The IMO has also introduced a regulation of energy efficiency for new ships (IMO, 2019). The regulation is based on a requirement for a ship to achieve an energy efficiency design index (EEDI) with a minimum margin to a reference value. The required margin is set to increase from 0% in 2013 to 30% in 2025 for

8 For cars, the threshold is 15 % from 2025 and 35 % from 2030; for vans, the threshold is 15 % from 2025 and 30 % from 2030.

larger ships. The regulation provides some incentives for the development of hybrid propulsion systems as it exempts ships '*which have diesel-electric propulsion, turbine propulsion or hybrid propulsion systems*'.

According to the 2030 Climate Target Plan, both sectors will need to scale up efforts to improve the efficiency of aircraft, ships and their operations, while increasing the use of sustainably produced renewable and low-carbon fuels. This will be assessed in greater detail in the context of the ReFuelEU Aviation and FuelEU Maritime initiatives, which aim to increase the sustainable alternative fuels production and uptake for these sectors. The development and deployment of relevant technologies in necessary before 2030 to enable further rapid change (European Commission, 2020a).

4.2 Transport electrification in non-European countries' policies

Outside of Europe, several large countries have also implemented regulations requiring a transition of road transport to electric power, particularly cars and vans. In most cases, this is driven by a desire to reduce harmful air pollution, primarily in cities, rather than climate change considerations.

In 2015, China implemented a regulation requiring minimum percentages of buses to be electrified in its cities by 2019 (Sustainable Transport in China, 2015). For example, in Beijing, the target was that 80% of buses would be electric by 2019. The Government has also announced regulations requiring major manufacturers to produce or import minimum percentages of 'new energy vehicles', including BEVs, PHEVs and FCEVs (Bloomberg, 2018).

In 2017, India announced a regulation banning sales of petrol and diesel cars from 2030 as part of a move to reduce pollution in cities (Brodie, 2017).

The United States (US) does not have any federal regulations requiring a transition to EVs; however; a number of states have implemented their own regulations. California has implemented the Zero Emission Vehicle regulation, requiring manufacturers to produce a minimum percentage of zero emissions vehicles (including PHEVs), with credits being given depending on the electric driving range of the vehicle (California Air Resources Board, 2019). Further states that have adopted the same regulations include Connecticut, Maine, Maryland, Massachusetts, New York, New Jersey, Oregon, Rhode Island and Vermont.

5 Quantitative assessment of ELT research

This section presents an analysis of transport electrification research carried out under the EU research funding framework. The UK was still a member of the European Union in the period covered by the analyses, and therefore the UK results are included in the report. Furthermore, the UK continues to participate in programmes funded under the current 2014-2020 Multiannual Financial Framework (MFF) until their closure[9].

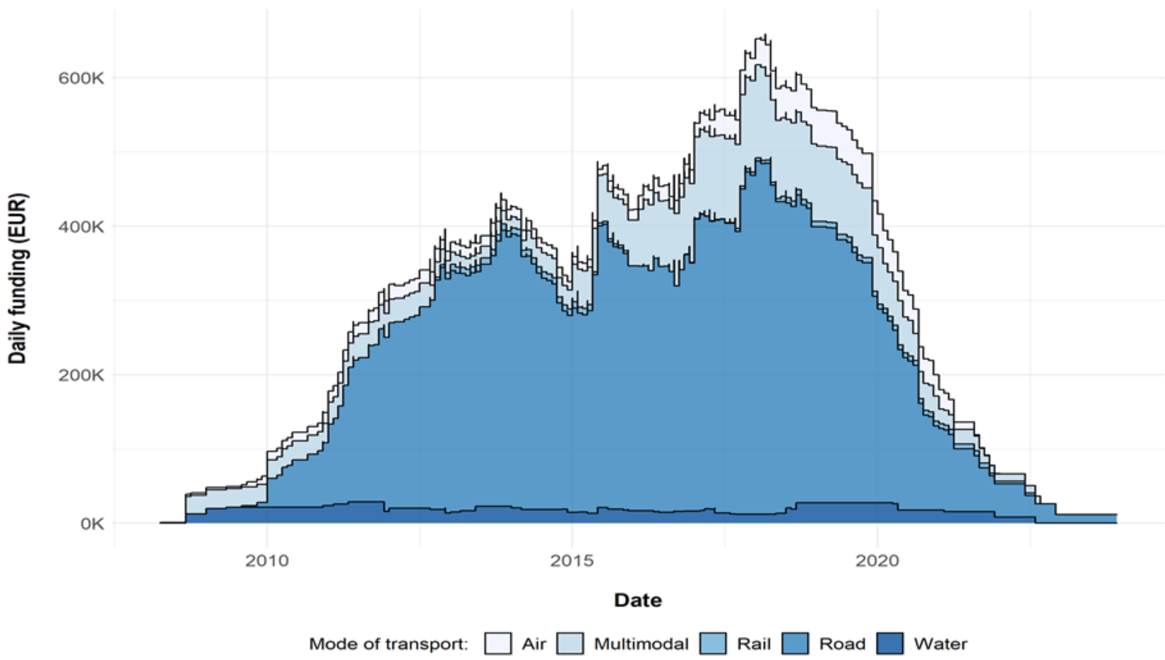
5.1 Framework Programmes analysis

Under FP7 and H2020, about €3.07 bn have been invested in ELT research projects. This includes €1.85 bn of EU funds and about €1.22 bn of own contributions by beneficiary organisations.[10]

Figure 7 shows the aggregated funding trend since 2008, assuming that funds are spread equally through the project's duration. The figure shows that funding increases, particularly in the fields of multimodal and air transport, with road transport receiving most of funding. Rail transport, which is already largely electrified, receives a relatively little amount of research funding.

The daily funding culminated in the first quarter of 2018 above €600,000. A funding forecast is also provided, which is based on those projects that were awarded by August 2019. As there are still upcoming H2020 calls, it is expected that the final funding will be higher.

Figure 7. Daily research funding by transport mode.



Source: Own elaboration based on TRIMIS.

5.2 Geographical and organisation analysis

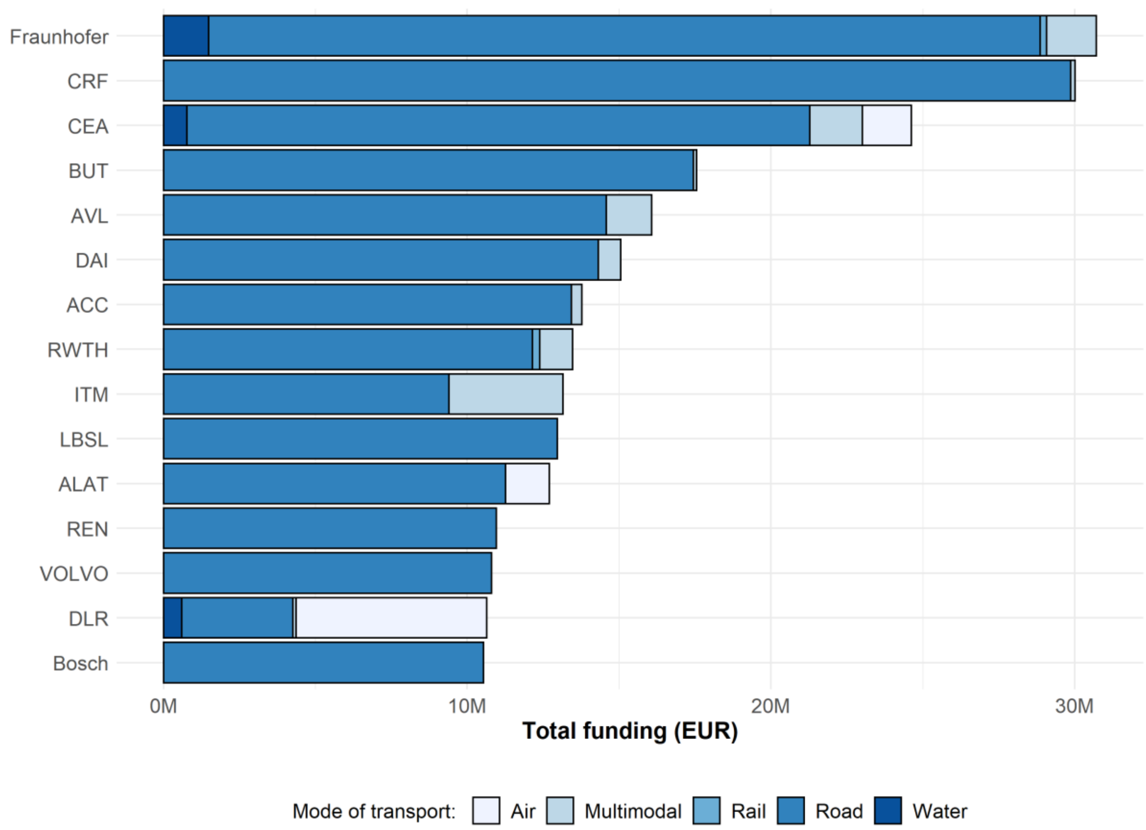
A total of 2,230 unique organisations participated in FP7 and/or H2020 projects on ELT. Figure 8 shows the top-15 beneficiaries with the total amount of funds received and their research focus in terms of transport mode.

9 https://www.gov.uk/government/publications/continued-uk-participation-in-eu-programmes/eu-funded-programmes-under-the-withdrawal-agreement

10 As indicated before projects can research multiple topics. No distinction could however be made regarding the share of funding that is directed towards each specific topic. Consequently, the identified budgets should be understood as the upper limit of funding in this specific field.

Some organisations focus exclusively on ELT research in one mode of transport, whereas others conduct research across modes. Of the top-15 beneficiaries, 15 are active in road, 10 in multimodal, 3 in air, 3 in waterborne and 1 in rail transport.

Figure 8. Top-15 ELT funding beneficiaries.



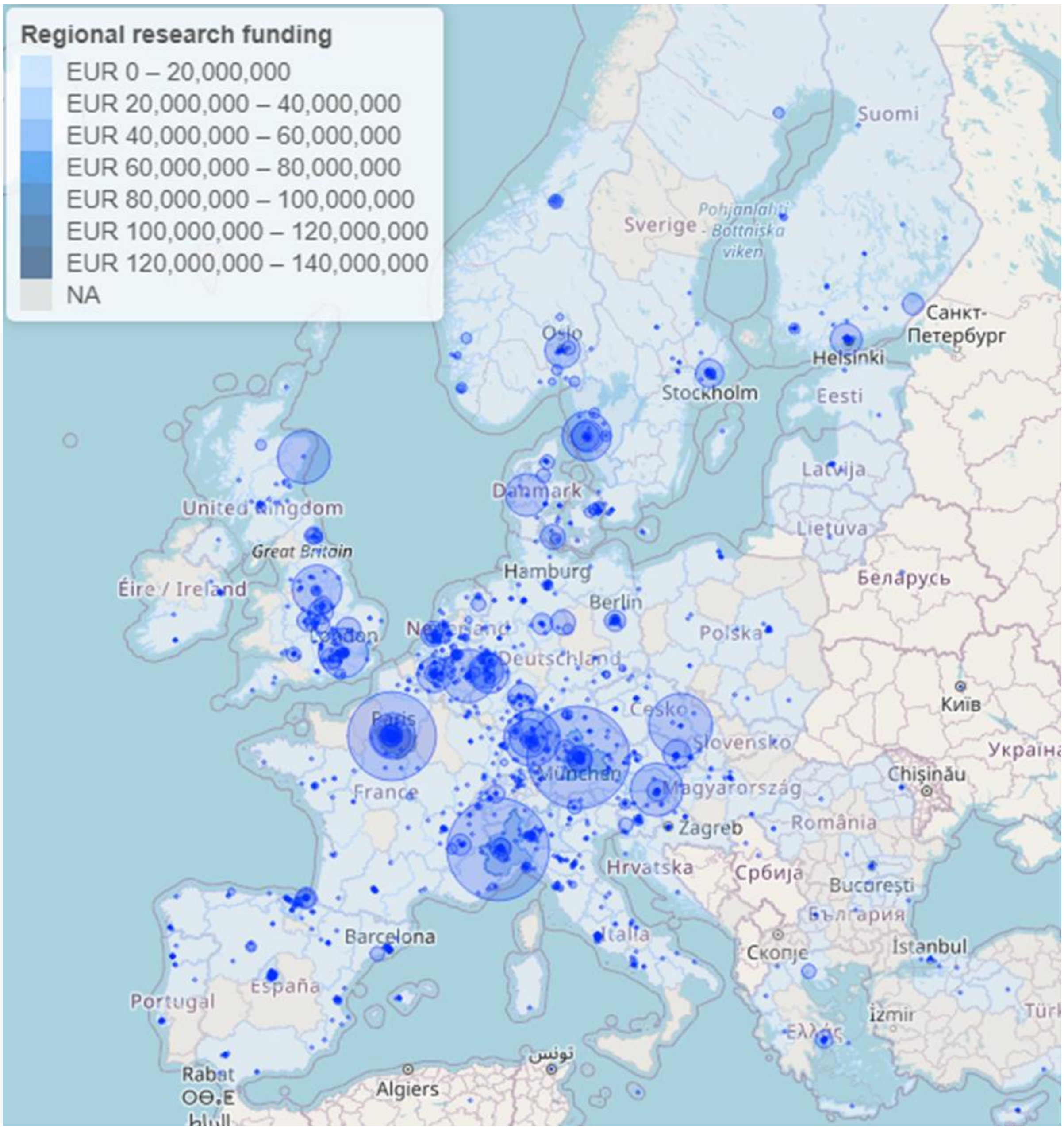
Source: Own elaboration based on TRIMIS.

The top-15 beneficiaries received approximately €243 m of funding, which is approximately 13% of the total EU ELT funding budget. The funds are therefore not very concentrated and bring benefits to a large number of organisations.

Figure 9 provides a deeper look onto the geographical spread of the funds. Several beneficiaries in Germany, France and Italy receive a large share of the funding, as indicated by the size of the circles. The main beneficiaries appear to be located in areas where car and aircraft manufacturers operate.

One footnote is that the spending of research funds may happen in a different location than where a beneficiary is registered. Such could happen when pilot studies occur at different sites. The map does however provide a reasonable approximation of where resources are allocated.

Figure 9. Location of ELT funding beneficiaries.



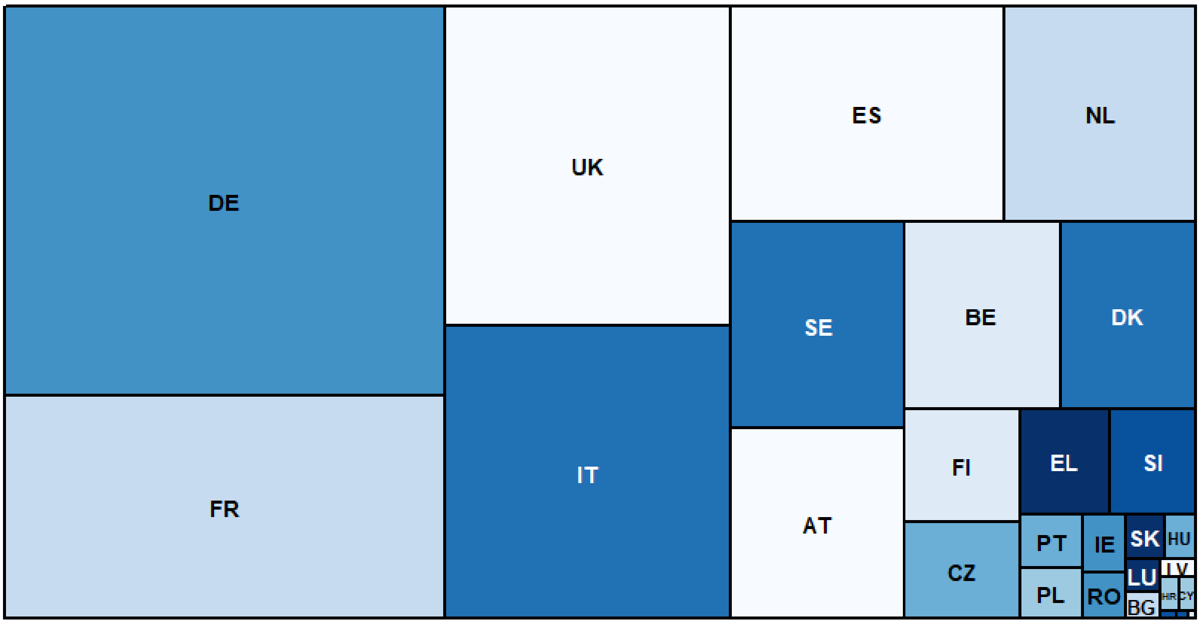
Source: Own elaboration based on TRIMIS.

5.3 Country analysis

An assessment of FP7 and H2020 ELT research in terms of funds received by country[11], based on the beneficiaries' addresses, shows that Germany is the largest beneficiary in absolute terms, followed by France (see Figure 10). In fact, those two countries along with the UK and Italy receive more than half of all funding in this field of research.

[11] EU28 country abbreviations: AT – Austria, BE – Belgium, BG – Bulgaria, CY – Cyprus, CZ – Czechia, DE – Germany, DK – Denmark, EE – Estonia, EL – Greece, ES – Spain, FI – Finland, FR – France, HR – Croatia, HU – Hungary, IE – Ireland, IT – Italy, LT – Lithuania, LU – Luxembourg, LV – Latvia, MT – Malta, NL – Netherlands, PL – Poland, PT – Portugal, RO – Romania, SE – Sweden, SI – Slovenia, SK – Slovakia, UK – United Kingdom. Other country abbreviations: CH – Switzerland.

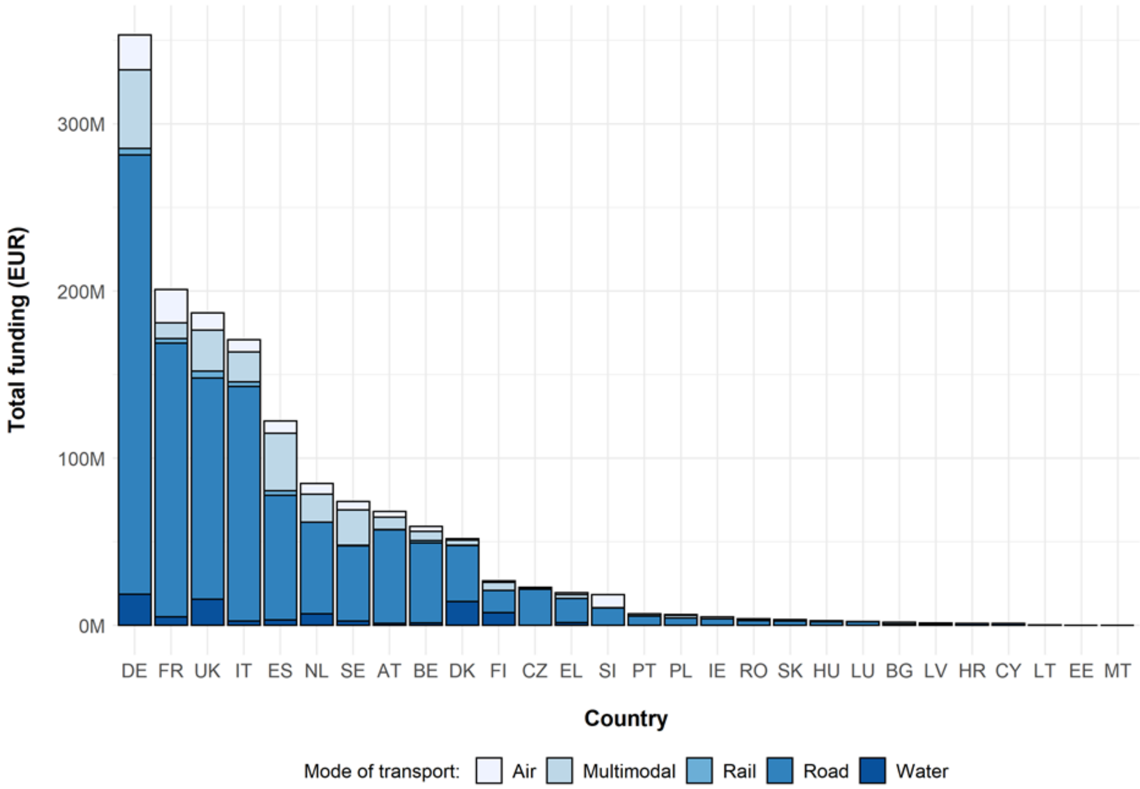
Figure 10. Shares of ELT funding by country.



Source: Own elaboration based on TRIMIS.

Figure 11 provides a more detailed overview on ELT research funding, showing the total amount of funding received per country split by mode of transport. The figure also highlights that there are few profound differences between countries when it comes to the mode of transport that is researched.

Figure 11. ELT funding by country, including division between transport modes.



Source: Own elaboration based on TRIMIS.

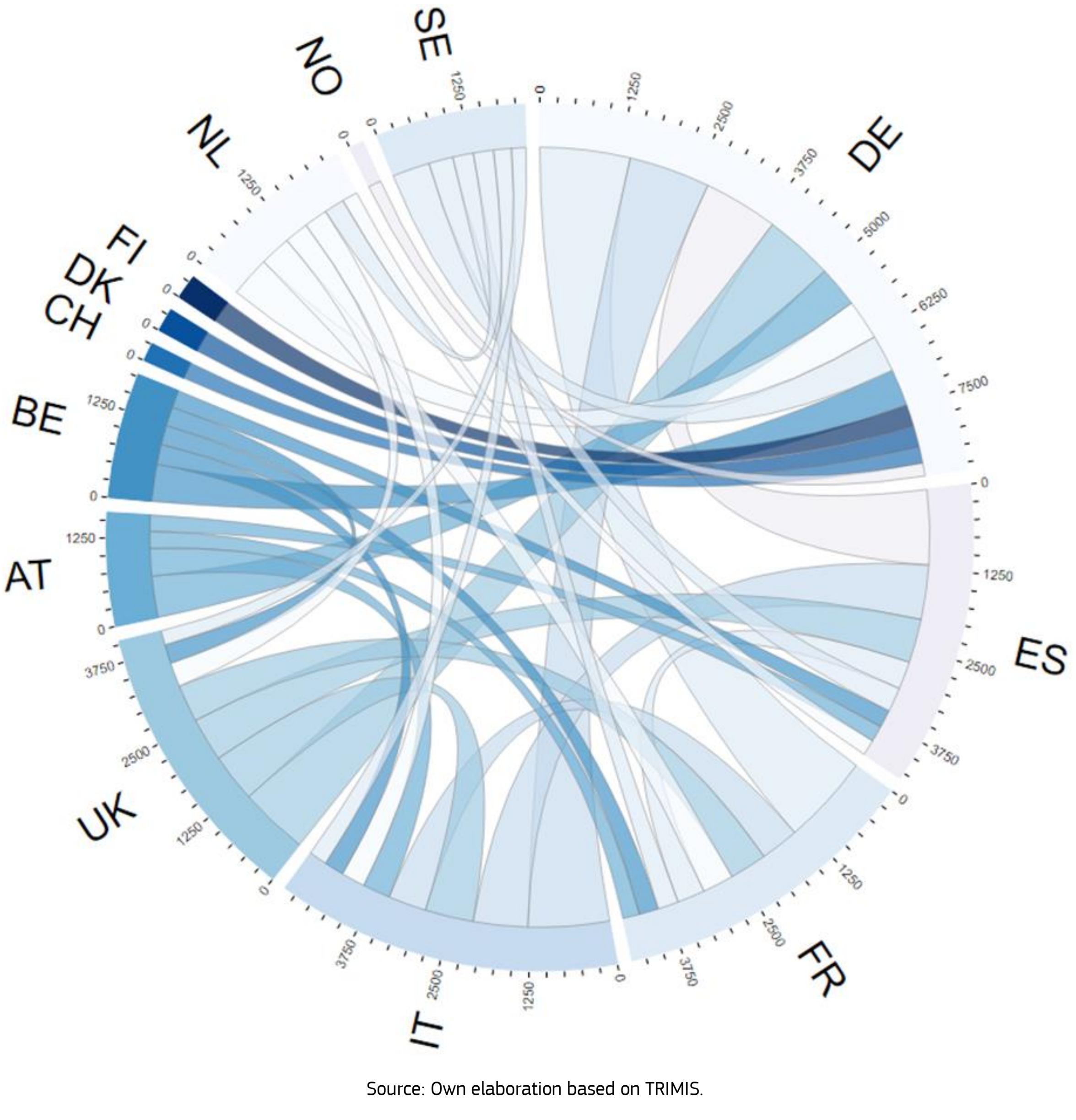
In many projects a large number of organisations from various countries participate. These collaborations can be aggregated at country level to show which countries work most often together in the field of ELT.

Figure 12 shows the most common links by highlighting those collaborations between organisations from European countries that occurred at least 200 times. This means for instance that if in a project one Spanish and two Austrian organisations collaborate, the link between Austria and Spain gains a strength of two. These counts are accumulated for all projects. The colours are indicative of the country, whereas the width of the cords is indicative of the number of collaborations.

Thirteen countries surpass the barrier of 200 organisational collaborations. Organisations from other countries also actively collaborate, but these ties are not visualised as they do not surpass the threshold. The analysis therefore focuses on absolute, rather than the normalised performance as was used in Figure 11.

A few observations can be shared. Unsurprisingly, the larger European countries are most visible in this chart. Additionally, the Netherlands, Sweden and Austria are notably present. Organisations from Belgium are also strongly present in the collaboration network, linking with many different countries. Such can be explained by the presence of many Brussels based associations in the field of transport and technology.

Figure 12. Chord diagram on collaborations in FP7 and H2020 ELT projects by country.

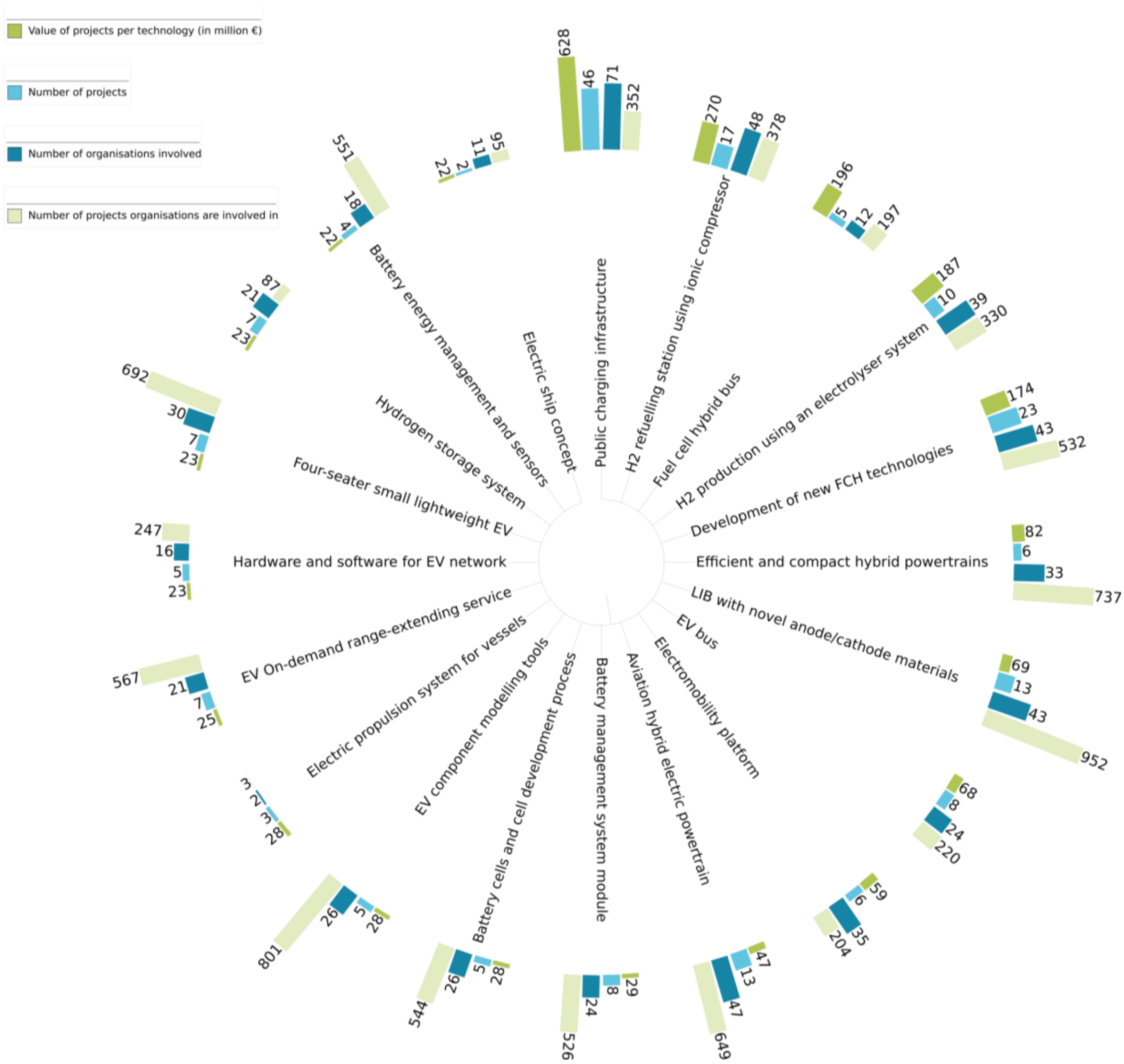


Source: Own elaboration based on TRIMIS.

5.4 Technologies identified in the ELT roadmap

The analyses presented focus on the overall 'top-20' technologies identified for the ELT roadmap. The radial structure of Figure 13 highlights the key metrics of the 'top-20' technologies in terms of total funding.

Figure 13. Top-20 ELT technologies in FPs.



Bars not in scale. Abbreviations: H2 – Hydrogen; FCH - Fuel Cells and Hydrogen; EV – Electric Vehicle; LIB - Lithium-ion batteriesSource: Own elaboration based on TRIMIS.

The metrics analysed in this case are:

- 'Value of projects': the total value of all projects that have researched the technology (i.e. the total investment, by both the EU and industry, in the development of the technology);
- 'Number of projects': the number of projects that have researched the technology;
- 'Number of organisations involved': the number of organisations that have been involved in projects that have researched the technology;
- 'Number of projects organisations are involved in': the total number of projects that the organisations (identified as having been involved in projects researching the particular technology) have been involved in.

The first two metrics highlight the combined effort that has been put into the technology, while the third and the fourth proxy the level of interest in the technology in industry and academia, indicating the available capabilities to bring the technology to market. Some highlights of this analysis is given below.

The top-3 technologies in terms of funding are public charging infrastructure (€628 m), hydrogen refuelling station using ionic compressor (€270 m) and fuel cell hybrid bus (€196 m).

Among the top-20 technologies, 15 are linked to the road transport mode. *Hydrogen storage system* is linked to multimodal transport, *aviation hybrid electric powertrain* is linked to aviation, while, *hydrogen production using an electrolyser system*, *electric ship concept* and *electric propulsion system for vessels* are linked to waterborne transport.

Although the approach taken here has its limitations, the exercise of linking several technology metrics with organisational data can be useful for identifying technology value chains and providing indications on overspending and inefficiencies. In the future, efforts will be made to have a better coverage of technologies researched within projects, indexed in higher aggregation levels.

In addition, the technology maturity was assessed for all technologies researched within the projects. The assessment is based on the technology readiness levels (TRLs), a method for estimating the maturity of technologies during the acquisition phase of a programme, developed by the US National Aeronautics and Space Administration (NASA) in the 1970s.

The EC advised that EU-funded R&I projects should adopt the TRL scale in 2010; TRLs were then implemented for the H2020 programme (Heder, 2017), although in practice TRLs are not assigned to all H2020 projects. TRLs are based on a scale from 1 to 9, with 9 being the most mature technology.

In TRIMIS, the nine TRLs have been consolidated into four development phases: research, validation, demonstration/prototyping/pilot production, and implementation. These are used to monitor and describe the maturing of each technology in a similar way to the original TRLs. Table 2 provides the description for each of the nine TRLs, as taken from Annex G of the H2020 work programme (2014-2015) and the corresponding development phases used in TRIMIS (European Commission, 2014).

Table 2. Technology readiness levels (TRLs) and corresponding TRIMIS development phases.

TRL	Description	TRIMIS development phase
TRL 1	Basic principles observed	Research
TRL 2	Technology concept formulated	
TRL 3	Experimental proof of concept	Validation
TRL 4	Technology validated in lab	
TRL 5	Technology validated in relevant environment	Demonstration/prototyping/pilot production
TRL 6	Technology demonstrated in relevant environment	
TRL 7	System prototype demonstration in operational environment	
TRL 8	System complete and qualified	Implementation
TRL 9	Actual system proven in operational environment	

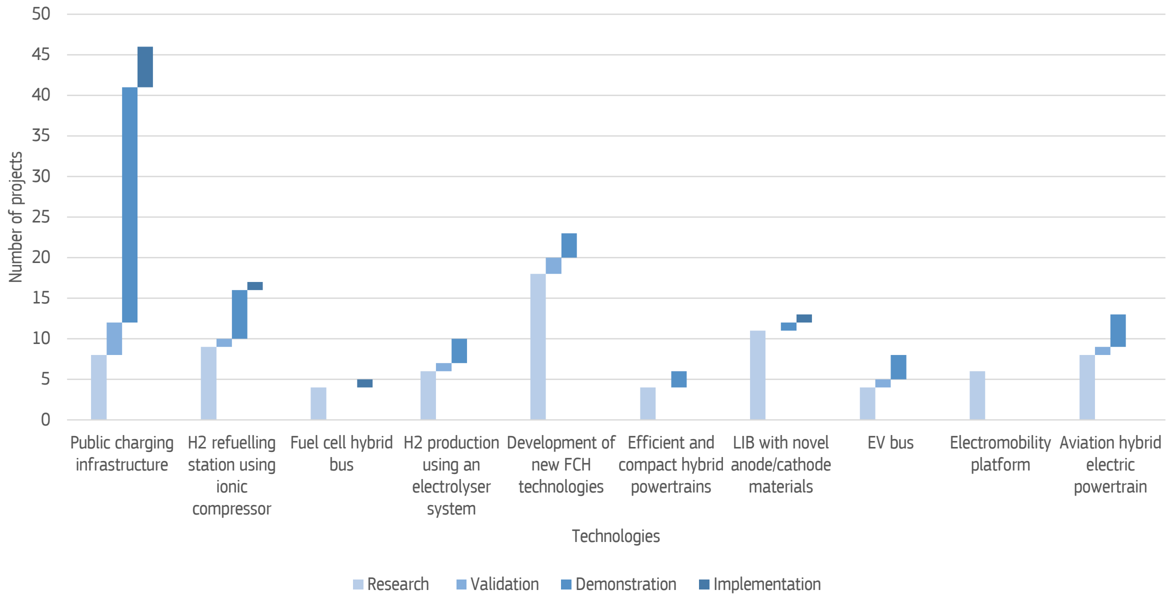
Source: Own elaboration. TRL scale based on (European Commission, 2014).

Figure 14 presents the development phases of the top-10 researched ELT technologies in FPs. *Public charging infrastructure* and *hydrogen refuelling station using ionic compressor* technologies have been researched over the entire development phase in FPs. Four of the top 10 technologies have been researched up to an implementation phase, which indicates a very good maturity.

Electromobility platform has been researched only at a (basic) research phase. Similarly, fuel cell hybrid bus, efficient and compact hybrid powertrains and lithium-ion batteries with novel anode/cathode materials appear to have an overall low maturity.

The technology maturity analysis is ongoing and will be extended in the future to include additional projects.

Figure 14. Development phases of the top-10 researched ELT technologies in FPs.



Abbreviations: H2 – Hydrogen; FCH - Fuel Cells and Hydrogen; EV – Electric Vehicle; LIB - Lithium-ion batteries

Source: Own elaboration based on TRIMIS.

5.5 Analysis on scientific research

The following exercise has as objective to mark the evolution of peer reviewed scientific publications in the area of transport electrification in the last years, providing also a perspective beyond Europe. For the exercise, the Scopus citation database for scientific research[12] has been used.

Considering the broadness of the topics addressed in the STRIA ELT roadmap, it was decided to focus on specific topics that can be linked directly to the ELT roadmap, instead of focusing on the evolution of the topics addressed within the six sub-themes in this report.

The complete list of regular expression (REGEX) used is reported in ANNEX 1, while Table 3 provides a coupling between the sub-themes defined in this report and some of the expressions used.

[12] www.scopus.com

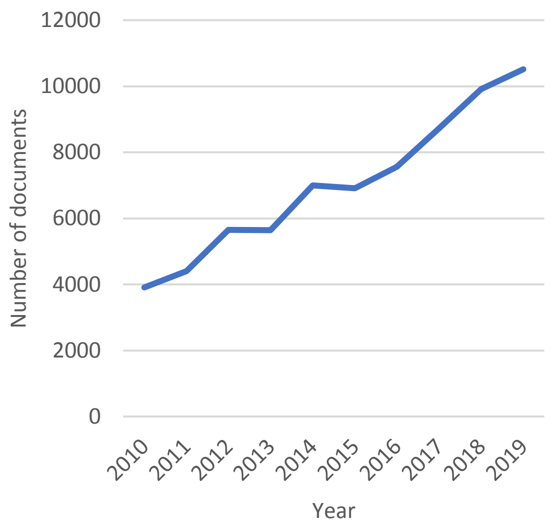
Table 3. STRIA ELT sub-themes and scientific research terms.

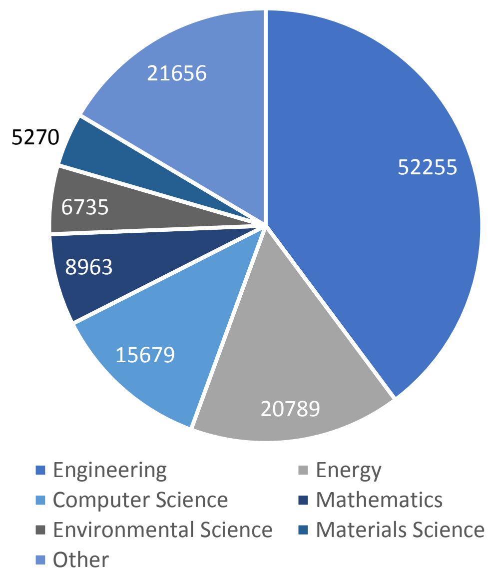
ELT sub-theme	Expressions
1. Battery and energy management systems	Battery capacity
2. Charging technology and infrastructure	Charging infrastructure
3. Power electronics, motors, and transmission systems for EVs	Electric propulsion
4. Hydrogen fuel cells and hydrogen refuelling	Plug-in hybrid; Fuel cell electric vehicle
5. Electromobility	Electric car; Electric bus
6. Electrification of other transport modes	Electric vessel

Source: Own elaboration based on TRIMIS.

An initial search focused on the use of the terms 'electric' and 'vehicle'. Terms such as 'transport' and 'electrification' gave very limited results (the term 'electrification' is not very common), while 'transport' and 'electr*' gave many additional results relevant to the transport of energy. In order to have a broad coverage of research, it was decided to extend the search including other sources (conference papers, book chapters etc.) and focus on the title, abstract and keywords. Figure 15 shows the number of documents published between 2010 and 2019 and the subject area. The total number obtained for the entire 10-year period is 70,219.

Figure 15. Overview of number of documents on transport electrification in the period 2010-2019 (left) and subject area (right).



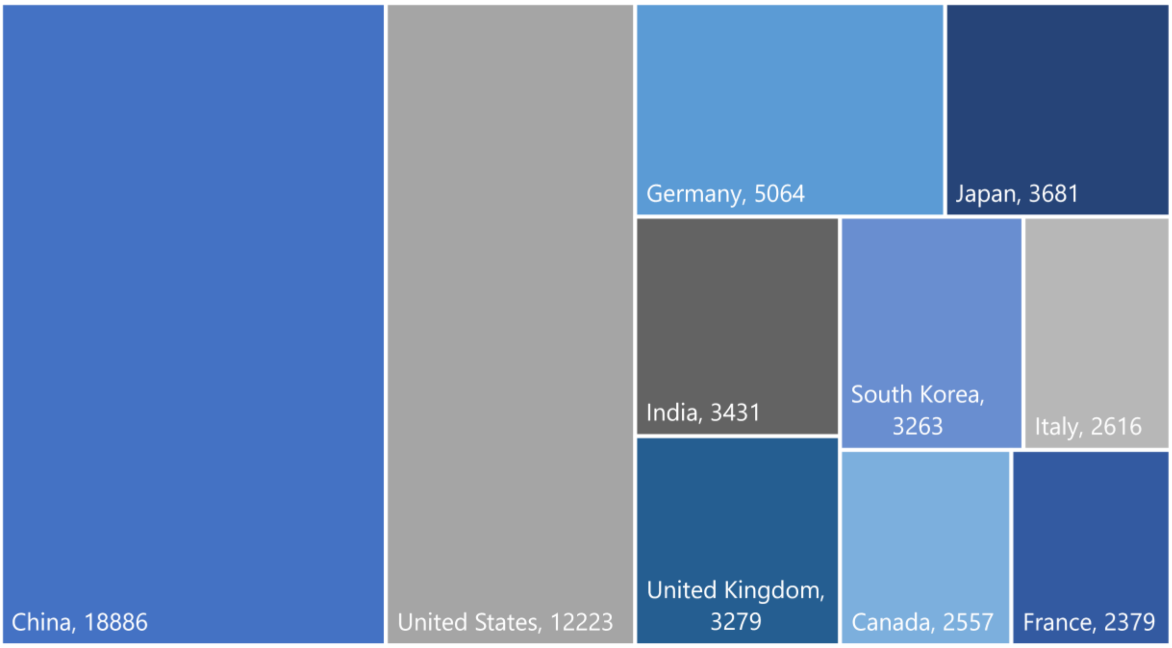


Source: TRIMIS elaborations based on Scopus.

As can be observed, the number of publications has increased significantly, from only 3,912 in 2010 to 9,910 and 10,518 in 2018 and 2019 respectively. The majority of research is carried out within three fields: engineering, energy and computer sciences.

Figure 16 provides the country breakdown (top-10 countries). It can be observed that the top-3 countries leading the research in terms of Scopus documents are China, the US and Germany.

Figure 16. Country breakdown for transport electrification research.

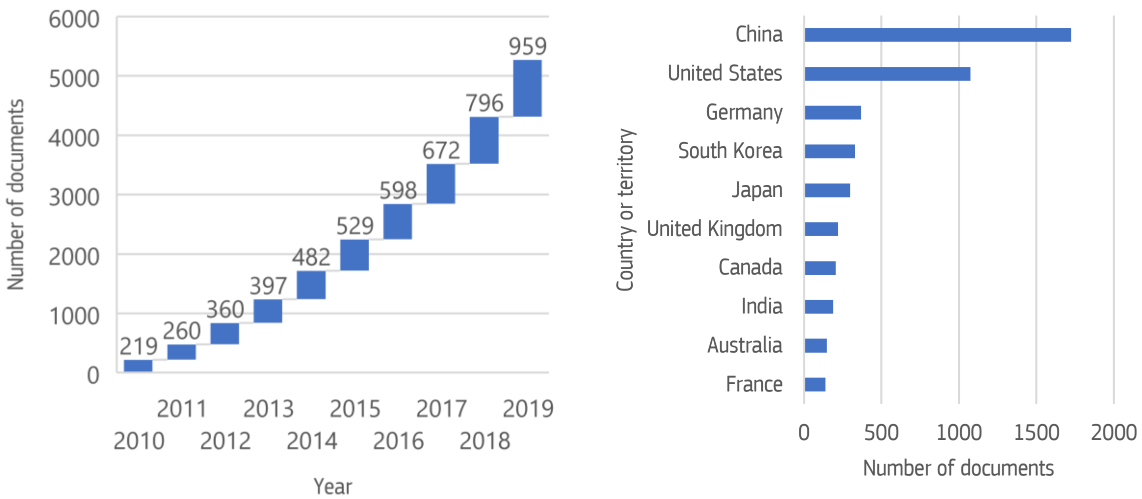


Source: TRIMIS elaborations based on Scopus.

Following these results, the rest of the analyses focus on regular expressions, representative[13]) of the sub-themes defined in the ELT roadmap.

As can be observed (Figure 17), on 'battery capacity', the trend has been positive, peaking in the last four years. China, the US and Germany are leading the research on this field.

Figure 17. Number of documents on battery capacity in the period 2010-2019 (left) and country of origin (right).

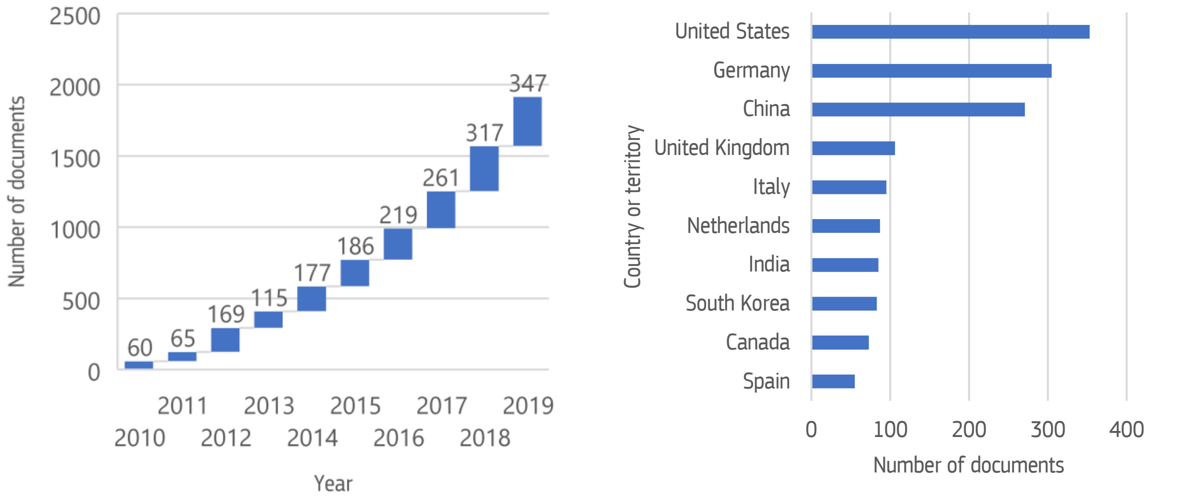


Source: TRIMIS elaborations based on Scopus.

As can be observed (Figure 18), on 'charging infrastructure', an area of research with clear influence on the diffusion of electromobility, the trend has been positive, peaking in the last four years. The US, Germany and China are leading the research on this field.

[13] Regular expressions are intended to be representative of each sub-theme but not necessarily exhaustive.

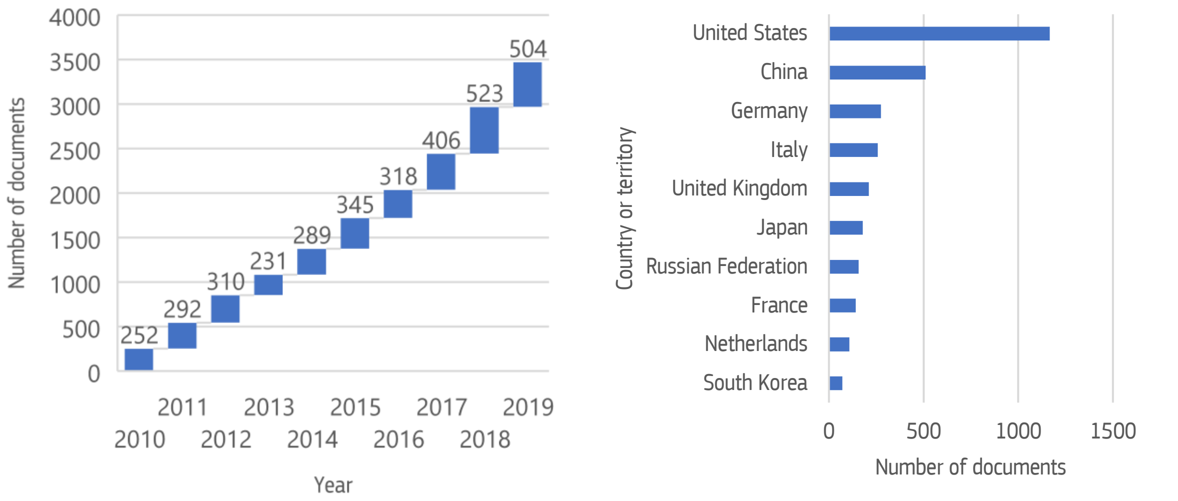
Figure 18. Number of documents on charging infrastructure in the period 2010-2019 (left) and country of origin (right).



Source: TRIMIS elaborations based on Scopus.

On ‘electric propulsion’, representative of the ‘power electronics, motors, and transmission systems for EVs’ sub-theme, Figure 19 shows an increasing trend in the last five years, peaking in 2018 with 523 documents. The US leads the research on this topic with 1,167 documents since 2010, followed by China with 511 and Germany with 274.

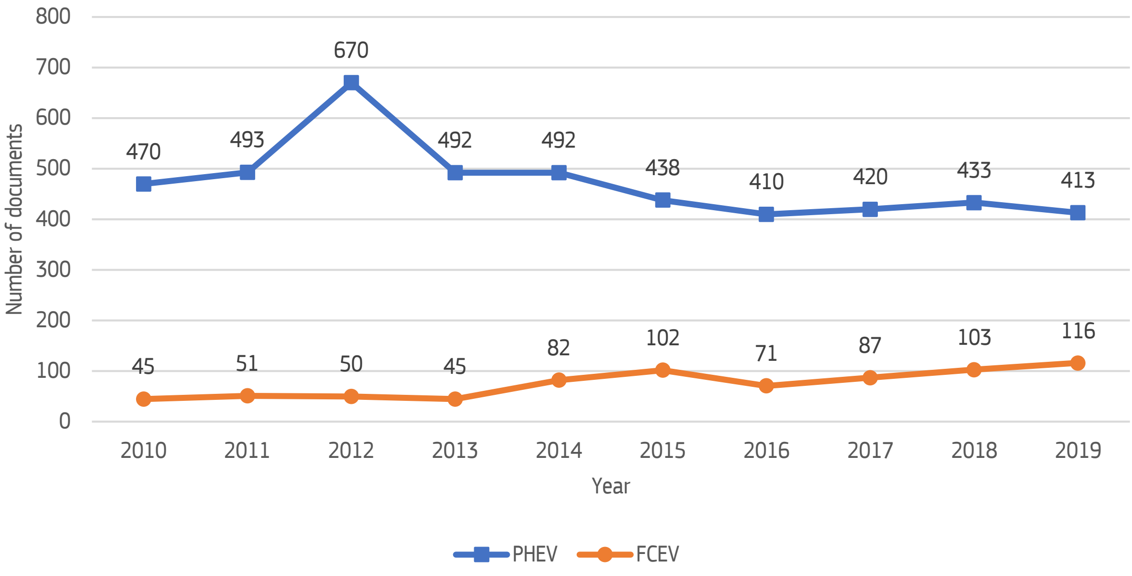
Figure 19. Number of documents on electric propulsion in the period 2010-2019 (left) and country of origin (right).



Source: TRIMIS elaborations based on Scopus.

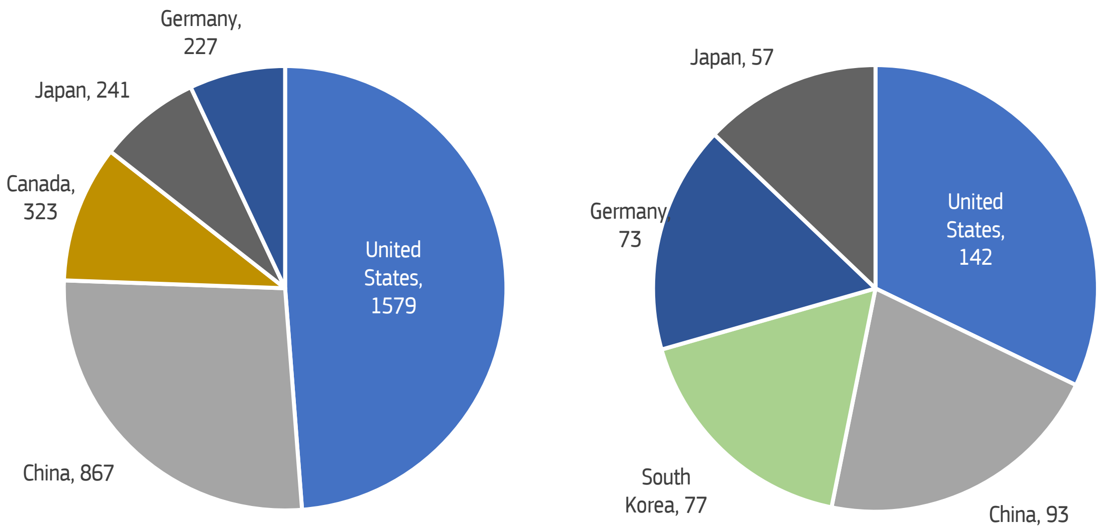
On the ‘hydrogen fuel cells and hydrogen refuelling’ sub-theme, it was decided to focus on the terms ‘plug-in hybrid’ and ‘fuel cell electric vehicle’. Figure 20 shows for PHEV a peak in publications in 2012 (670 documents) and a slightly decreasing trend in the last five years. A total of 4731 publications are found in the 10-year period. On FCEV, a total of 752 publications are found in the 10-year period, with an average of 55 publications per year between 2010 and 2014 and 92 publications per year between 2015 and 2019. Figure 21 provides the country breakdown for the four of the top-5 countries present in both PHEV and FCEV research. The US is leading the research in this field, followed by China, Japan and Germany.

Figure 20. Number of documents on PHEV and FCEV in the period 2010-2019.



Source: TRIMIS elaborations based on Scopus.

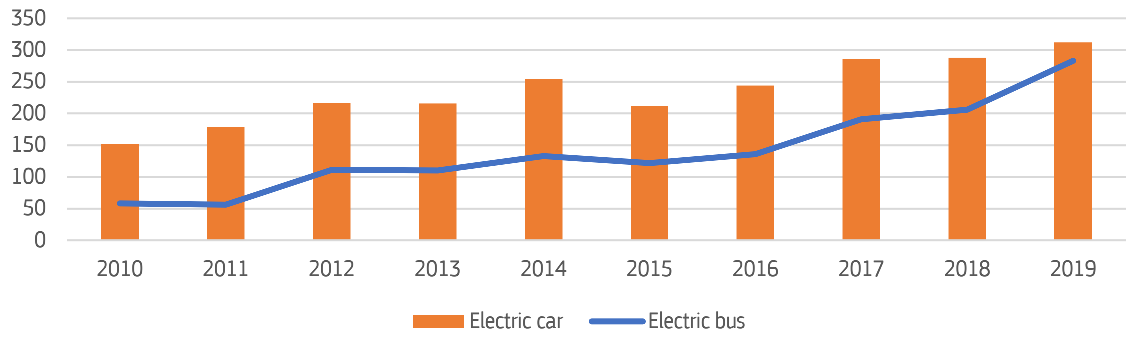
Figure 21. Country breakdown of PHEV (left) and FCEV (right) publications – top-5 countries.



Source: TRIMIS elaborations based on Scopus.

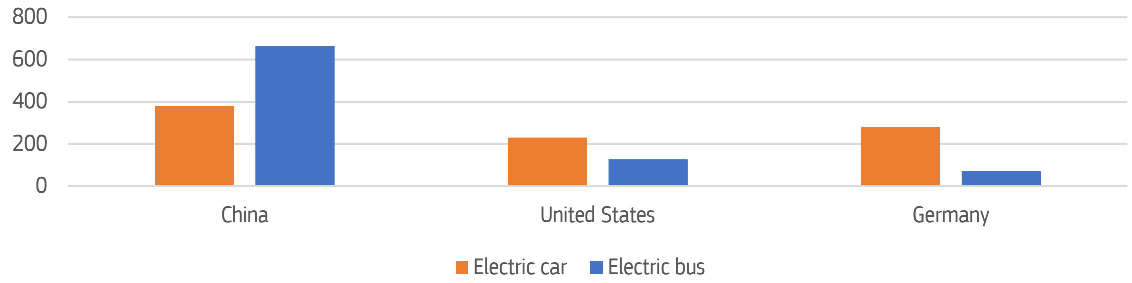
On ‘electromobility’, it was chosen to focus on representative terms of road and urban mobility, namely research on ‘electric car’ and ‘electric bus’. Figure 22 shows a very slightly increasing trend on electric car research, peaking in 2018 with 312 publications. Electric bus as a research topic has a steeper increasing trend, with publications in 2019 reaching the level of those of electric car research, while in 2010 publications were approximately one third of that. China, Germany and the US lead the research on this topic (Figure 23), with electric bus a leading research topic in China.

Figure 22. Number of documents on electric cars and electric buses in the period 2010-2019.



Source: TRIMIS elaborations based on Scopus.

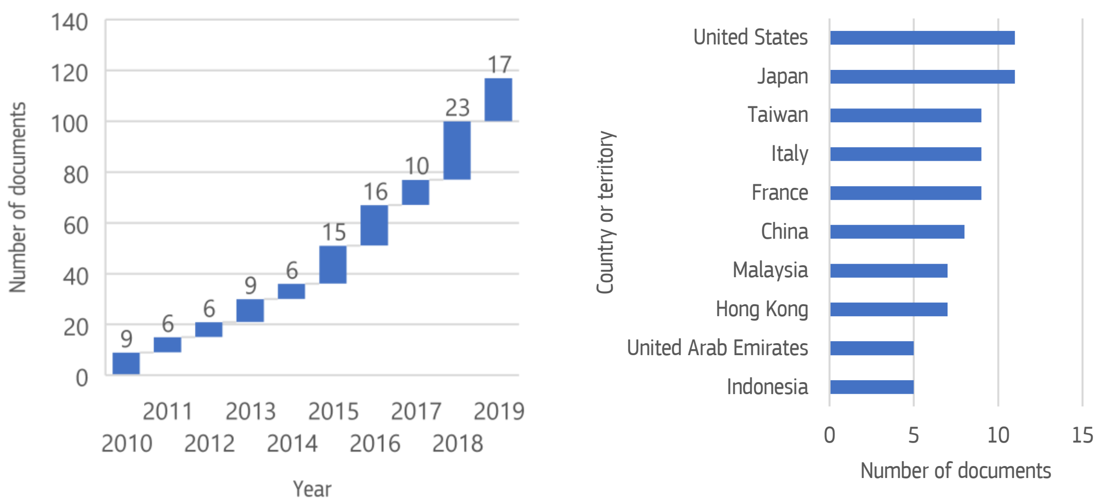
Figure 23. Top-3 countries on electric car and bus research.



Source: TRIMIS elaborations based on Scopus.

Finally, on the 'electrification of other transport modes', the Scopus database provides only a few meaningful data. Figure 24 shows the document in the last years that focus on 'vessel (boat) electrification' and the top-10 countries leading the research in this area.

Figure 24. Number of documents on electric boats (left) and countries/regions leading the research (right).



Source: TRIMIS elaborations based on Scopus.

The results provided in this section provide a meaningful analysis of research trends in transport electrification and can be a starting point for monitoring the ELT roadmap.

6 Research and Innovation assessment

This section analyses research and innovation projects in the field of ELT under six sub-themes, which cover the key areas of research being undertaken under this STRIA roadmap. The analysis provides an overview of the research being performed, its key results and the subsequent implications for future research and policy development. The sub-themes are:

1. Battery and energy management systems;

This sub-theme covers projects focusing on battery production, energy density and new materials. Projects within this sub-theme were aimed at increasing the range of current battery-electric vehicles by researching novel battery materials, as well as reducing the energy consumption of other vehicle features, such as cabin cooling and heating.

2. Charging technology and infrastructure;

This sub-theme covers projects focusing on novel charging technologies and electric vehicle charging infrastructure. Projects within this sub-theme were aimed at developing and implementing novel charging solutions, including dynamic and wireless charging, as well as grid management and vehicle-to-grid (V2G) technology.

3. Power electronics, motors, and transmission systems for EVs;

This sub-theme covers projects focusing on electric drivetrains for heavy-duty vehicles (HDVs), alternatives to 'rare-earth' metals, and lightweight materials for EVs. Projects within this sub-theme were aimed at reducing the reliance on rare-earth metals in EVs to avoid geopolitical issues, as well as improving the range for electric HDVs.

4. Hydrogen fuel cells and hydrogen refuelling;

This sub-theme covers projects focusing on implementing hydrogen fuel-cell vehicles and hydrogen refuelling infrastructure. Projects within this sub-theme were aimed at implementing hydrogen fuel cell buses in cities, as well as providing an efficient and safe hydrogen refuelling infrastructure.

5. Electromobility;

This sub-theme covers projects focusing on the development of small and lightweight electric vehicles for use in an urban environment. Projects within this sub-theme were aimed at designing and manufacturing novel electric vehicles, as well as using these lightweight vehicles for urban freight movement.

6. Electrification of other transport modes;

This sub-theme covers projects focusing on the electrification of other transport modes. Projects within this sub-theme have a focus on hybrid aircraft, electric waterborne transport and optimal use of electricity in overhead electric railway lines.

6.1 Sub-theme 1 – Battery and energy management systems

Batteries for electric vehicles is a research area currently attracting a number of projects with significant funding. Improving the driving range of EVs is a key research theme; this can be achieved by increasing energy density of batteries or managing the use of the battery energy efficiently throughout the EV. The total R&I funding and number of projects for this sub-theme are shown in Table 4 below.

The majority of the projects reviewed were funded through the H2020 programme, with FP7 projects making up the remainder of the research.

Table 4. Funding level per programme for battery and energy management systems.

Funding action	Number of projects	Total funding	EU contribution
FP7	26	€139 m	€128 m
H2020	48	€208 m	€184 m
Others	0	€0	€0

Source: Own elaboration based on TRIMIS.

The projects reviewed under this sub-theme address the following actions as outlined in the ELT roadmap document:

— Actions under road transport electrification:
  - Promote a +400 km range for electric passenger cars;
  - Certification of electric vehicles performance;
  - Support local production of batteries, components and electric vehicles; and
  - Develop electro-chemical systems for future high energy density electric batteries.

— Actions under aviation transport electrification:
  - Energy storage systems improvement.

— Actions under rail transport electrification:
  - Increase energy savings.

6.1.1 Overall direction of R&I

The overall direction of the research projects within the battery and energy management systems sub-theme is around improving battery energy density and reducing the cost per kilowatt-hour (kWh) of batteries. By improving the energy density of batteries, EVs can be manufactured with a longer range. The research into batteries for the purpose of transport electrification is mainly focused on the road transport sector. One of the major barriers for the widespread uptake of EVs is their shorter range (compared with internal combustion engine vehicles), which can cause ‘range anxiety’ in drivers. This is the term given to a concern that some EV drivers may experience that the vehicle range is not sufficient to complete their journey. Although the range of most EVs is now sufficient to avoid range anxiety, there are still practical limitations and implications of shorter range, such as more frequent recharging stops required on longer journeys and longer overall journey times due to charging time. The main idea behind increasing the energy density of the batteries is that the increased range would enable journeys to be undertaken without needing to stop specifically to recharge and thus remove the concerns over the vehicle range and hence contribute towards a wider uptake of EVs within Europe.

While improving the battery’s energy density is a method to increase the driving range of an EV, so are effective battery and on-board energy management systems. These can optimally control energy use and the energy flow in and out of the battery, including energy for other vehicle systems, such as heating or cooling for passenger comfort. There are a number of projects researching this area, with the specific goal to improve the energy management and hence improve the vehicle’s driving range.

6.1.2 R&I activities

There was funding and research towards the manufacture and mass-production of Li-ion batteries, with a particular focus on the development of new battery chemistries and materials. A selection of projects focusing on this area are presented below:

— The project ELIBAMA (2011-2014) had the objective to enhance and accelerate the creation of a European automotive battery industry, structured around industrial companies already committed to mass production of Li-ion cells and batteries for EVs. The project had an overall aim to reduce costs and environmental impacts across the value chain of battery production. Specifically, the project focused on the development of eco-friendly processes for electrode production, electrolyte manufacturing, fast and homogenous electrolyte filling processes, cell design and assembly.

— SPICY (2015-2018) was a collaborative research project consisting of five industrial partners and eight academic research centres focusing on the development of new generation Li-ion batteries. The aim was for the batteries to meet the expectations of EV end-users; including performance, safety, cost, recyclability and lifetime. Within the project, consideration was given to the development of new chemistry materials, cell architectures and packaging, supported by understanding and modelling activities. The whole value chain of the manufacturing process was addressed.

— The overall objective of eCAIMAN (2015-2018) was to bring European expertise together to develop a battery cell that can be produced in Europe and provide improvements on current battery technology. The specific aims of the project were to achieve an energy density of Li-ion batteries of around 270 Wh/kg and at a cost of €200 per kWh. This was to be achieved by industrialising various materials and high-voltage electrolytes, with the aim of producing TRL 6 large-scale automotive cells by using the industrialised technologies. Other goals of the project were to establish a complete battery value chain in Europe and bring European battery production to the level of global innovation leaders.

Improving the battery energy density is not the only way to improve the efficiency and range of an EV. The projects below address the issues around the energy consumption of other vehicle components, such as heating/cooling of the cabin.

— One of the main disadvantages of EVs has been the low distance range that the car could drive without stopping to recharge the battery. The JOSPEL (2015-2018) project was aimed at increasing the range of EVs by improving the efficiency of the battery and reducing the energy consumption. In extreme conditions the energy consumed on heating or cooling the vehicle cabin can be up to 40% of the total energy consumed in the vehicle.

— OPTEMUS (2015-2019) was a project focusing on overcoming the barriers towards large-scale adoption of electric and plug-in hybrid vehicles, with particular emphasis on addressing the current range limitation due to limited storage capacity of electric batteries. The project planned to develop a number of technologies:

  - an integrated thermal management system comprising the compact refrigeration unit and the compact heating, ventilation, and air conditioning (HVAC) unit;
  - battery housing and insulation as thermal and electrical energy storage;
  - a thermal energy management control unit.

— The main aim of the OpEneR (2011-2014) project was to create an overall energy management system for EVs that merges on-board and off-board information and data to run energy-optimal driving strategies. The data sources included battery packs and battery management systems, regenerative braking systems, and satellite navigation systems. By optimising the driving strategy based on the data, the project aimed to significantly increase driving ranges for EVs in a way that guaranteed safe driving.

6.1.3 Achievements

Due to the large amount of funding and attention received by improving battery technologies, the results from the research projects show significant achievements in terms of improving energy densities of batteries and improving energy management systems.

At the completion of the project ELIBAMA, most of the targets of the project were met. The expected cost reductions in the electrodes and cells' manufacturing have been made, as well as improving the quality of the components. The manufacturing of batteries currently has a large environmental impact; this was monitored during the ELIBAMA project by means of a life-cycle assessment (LCA) and found to be successfully reduced. For example, the global warming potential (GWP) of cathode manufacturing was reduced by 64% compared to the baseline by optimising the mixing and coating process[14]. Some of the results from the project have already been transferred to mass-production and others are ready to be scaled up. From the project OpEneR, two fully electric prototype vehicles were built to test the energy management system. Along with the prototype vehicles, a specific route calculation method was developed to calculate the most efficient route considering the individual characteristics of the EV. The effectiveness of this method was verified by test drives on public roads. On 20 different routes, average energy savings of almost 31% were achieved by using the energy efficient route compared to the fast route. However, travel time increased by 14% when using the most efficient route, which may not be desirable for all users.

Within the SPICY project four different battery energy densities were defined: 110 Wh/kg (‘reference gen’), 140 Wh/kg (‘Gen-1’), 165 Wh/kg (‘Gen-2’) and 190 Wh/kg (‘Gen-3’). The reference gen cells were developed and delivered to partners for evaluation. From the latest published project results, Gen-1 cells have not yet been assembled; however, the cell design based on components selection is still in line with the target as 139 Wh/kg has been expected. Regarding cost, the Gen-1 reduces cost by around 10% to 15% when compared to the reference Gen as well as being more environmentally sustainable. The Gen-2 and Gen-3 chemistries are still under development, but the project SPICY states that these new chemistries can see an improvement in energy density of 20% and a cost reduction of 20% when compared to current state-of-the-art battery chemistry.

A new cooling system for EVs was developed during the JOSPEL project. The benefits of the JOSPEL cooling system are the small size, high cooling performance and low electrical consumption. The current system requires power of less than 1 kW, achieving a 20% energy consumption reduction compared to current state-of-the-art cooling technology. The innovative heating system and improved battery efficiency objectives within JOSPEL are yet to be published.

During the OPTEMUS project, a thorough evaluation of the Fiat500e has been performed to refine the benchmarks around the design of different components and systems of an EV. An internal thermal management system for battery modules has been developed; combining battery protection, cooling and heating, as well as the possibility for heat storage. This system uses the available energy in the vehicle in the most efficient way by predicting the driver’s behaviour and providing a custom conditioning of the cabin according to the personal user temperature profiles which are saved on a smartphone application. The results from these novel systems are expected to provide a 30% energy reduction from the cooling of components, and 50% energy reduction for passenger comfort (heating and cooling of the cabin).

The project eCAIMAN offered significant steps towards improving battery technology. The project developed pilot scale cells using a new chemistry termed ‘LNMO’ ($LiNi_{0.5}\,Mn_{1.5}\,O_4$) and produced 100 units for use in a demonstrator module. Developments in terms of the electrolyte allowed for the assembly of a set of cells with commercial LNMO on the cathode side, paired with the graphite and electrolyte developed in the project. Based on the material development and testing (and in conjunction with the projects SPICY and FIVEVB funded under the same call), eCAIMAN has issued a whitepaper on the testing of the new generation high-energy/voltage cells. This project has produced the first working 5 V/10 Ah cobalt-free pouch cell with a LNMO cathode and graphite anode and assembled the first full coin cell with LNMO as cathode and SnO_2 as anode.

6.1.4 Implications for future research

From the project SPICY, high energy density cells were identified. Currently only the Gen-1 cell (140 Wh/kg) has been developed; which leaves the Gen-2 (165 Wh/kg) and Gen-3 (190 Wh/kg) technology still to be developed. Future research could be focused on raising the development phases of the higher energy density batteries, which would potentially allow for lighter batteries or improved vehicle driving range. The technologies could be tested in conjunction with the whitepaper developed from the eCAIMAN project, which outlines the testing for new generation high-energy batteries. These energy densities may have been a challenging target at the start of the SPICY project; however, the energy density of Li-ion batteries has greatly increased since 2015, with battery energy densities reaching over 200 Wh/kg in 2019 (Miao et al., 2019). It is difficult for European-funded projects to keep pace with the battery developments made by the

[14] https://elibama.files.wordpress.com/2014/10/vi-a-batteries-life-cycle-assessment-lca.pdf

manufacturers; therefore, there may be advantages in focusing future research also on other areas of battery development, such as reducing the environmental impact of the battery lifecycle.

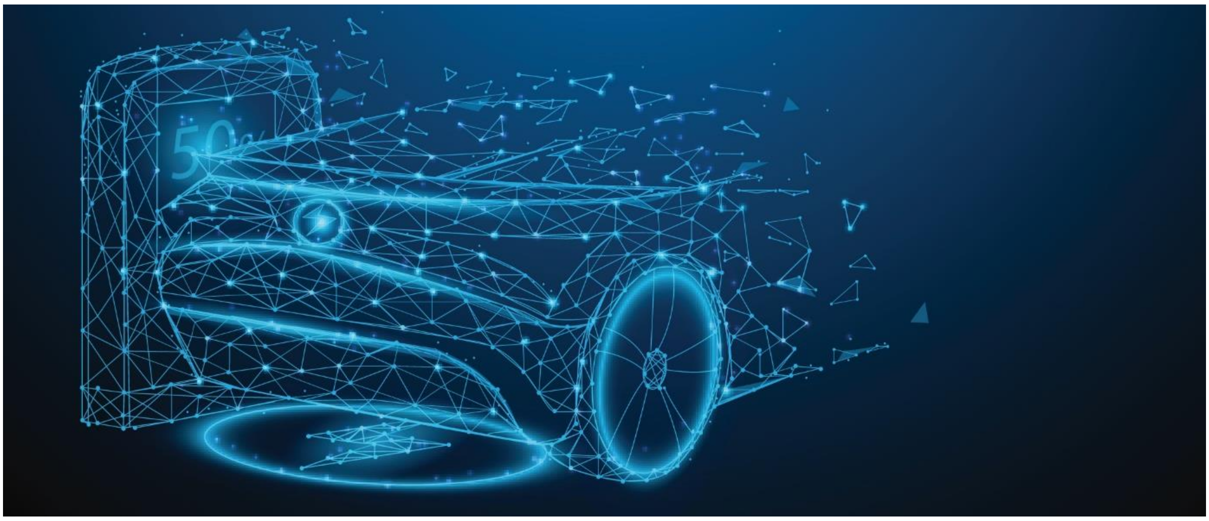
The ELIBAMA project successfully reduced the environmental impact of European battery manufacture processes. The project results state that some of the methods have been implemented into mass production, whilst others are ready to be scaled up. Future research could be focused on the scale-up of these methods, helping to further reduce the life-cycle environmental impact of batteries and electric vehicles.

6.1.5 Implications for future policy development

The core aim of the European Battery Alliance is to create a competitive manufacturing value chain in Europe with sustainable battery cells at its core (European Commission, 2020b). The results from the ELIBAMA project will help to deliver the strategic action of supporting the sustainability of EU battery cell manufacturing with the lowest environmental footprint possible. The results from the eCAIMAN project should support the scale-up of the European battery cell manufacturing sector, as new battery chemistries will help to advance the European battery market. It could be advantageous for research to focus on state-of-the-art battery chemistry and whole-pack engineering that can lead to substantially higher energy densities that are aiming for at least 300 Wh/kg and high-scale manufacturing.

There could perhaps be more projects addressing manufacturing for reuse, recycling and the sustainability of batteries over their entire lifecycle. Development of closed-loop recycling systems to recover material and feed back into the manufacturing process could be a research area to focus on. This would further reduce the overall environmental footprint of battery manufacture and help European industry to become a world leader in this sector.

6.2 Sub-theme 2 – Charging technology and infrastructure



A current disadvantage of EVs is the comparatively longer refuelling/charging times in relation to conventional internal combustion engines (ICEs). A solution to this problem would be for EVs – in addition to ultra-fast chargers and charging capabilities - to charge dynamically, which means that the vehicle would charge along the driving route with no stops required. This can be achieved through overhead electric wires along road corridors or wirelessly through innovative charging technology. Moreover, as transport electrification becomes more present in society, there will be a need to manage the electrical grid optimally to ensure a sufficient supply of electricity. A possible contribution to this grid management could be through novel V2G technology, where the EV batteries act as an energy storage system for the grid.

Total funding for this sub-theme is shown in Table 5. The majority of the research projects and funding fall under the H2020 programme, with FP7 and others making up the remainder.

Table 5. Funding level per programme for charging technology and infrastructure.

Funding action	Number of projects	Total funding	EU contribution
FP7	11	€48 m	€44 m
H2020	27	€181 m	€135 m
Others	2	€1 m	€1 m

Source: Own elaboration based on TRIMIS.

The projects reviewed under this sub-theme address the following actions as outlined in the Transport Electrification roadmap document:

- Actions under road transport electrification:
  - Progress and demonstration in urban bus electrification; and
  - Demonstration of electrified road systems for heavy-duty vehicles.
- Actions under rail transport electrification:
  - Increase the potential of utilisation of electric motorisation;
  - Increase energy savings; and
  - Minimise the losses of electric railway infrastructure.

6.2.1 Overall direction of R&I

Whilst standard plug-in charging methods are currently the norm, there is an increased focus on wireless charging. Wireless charging provides a more user-friendly and automated charging interface, and could allow EVs to charge while moving along the route, increasing the range of the vehicles and removing the need for a large and heavy battery. Whilst current high-power chargers (over 50 kW) can charge an EV up to 80% state of charge (SOC) in around 15 to 45 minutes (depending on the battery and its initial state of charge), dynamic wireless or conductive charging could remove the need to stop to recharge altogether. This could provide unrestricted range along equipped roads and help a more widespread EV take-up.

Projects are also researching the possibility of using the existing electrification infrastructure for vehicle charging. This involves using the existing public transport power networks (e.g. overhead tram lines) to charge other transport vehicles, such as battery electric buses. This type of charging will need careful management of the electrical grid, particularly in urban areas. Therefore, there are also projects investigating the best methods to manage the electrical supply given that transport electrification will only increase further in the coming years.

6.2.2 R&I activities

A major theme of the research under charging technology and infrastructure is wireless charging and dynamic power transfer. This allows EVs (not just limited to passenger vehicles) to charge along the route and to have smaller on-board battery packs, which reduces the weight, as well as the environmental footprint of the battery and thus, the vehicle.

- The project FABRIC (2014-2017) was focused on dynamic wireless charging, which has the potential to remove (or drastically reduce) the need for on-board battery packs in EVs. An aim of this project was to determine the end-user requirements and cost-effective solutions for the grid and road infrastructures. These solutions, with the objective of enabling full integration in the grid and road infrastructure within urban and extra-urban environments for a range of EVs, were implemented and tested on test tracks.
- Another project investigating wireless charging for EVs was UNPLUGGED (2012-2015). This project looked into the use of inductive charging of EVs in urban environments, and how this type of charging could help facilitate full EV integration in the urban road system. An aim of the project was to build two smart inductive charging systems, considering requirements from original equipment manufacturers (OEMs), energy utilities and end users. These charging systems were to go beyond current state-of-the-

art in terms of high-power transfer, allowing for smart communication between the vehicle and the grid, as well as being in line with the latest inductive standards and considering interoperability.

- The project FASTINCHARGE (2012-2015) was focused on developing an easier and more comfortable charging solution which will help with the widespread uptake of EVs and facilitate their implementation into the urban grid. The concept was aimed at creating a high-performing inductive charging solution which will enable a 40 kW power transfer to the vehicles both in stationary charging and on-route charging. The inductive technology was to be integrated into three EVs (of different types) and four charging stations (one stationary and three en-route).
- CONCEPT (2016-2018) is a project which had a particular goal to launch a conductive fast charging system for buses. The conductive fast charge system was designed for opportunity charging (e.g. at the end of a bus route), thereby extending the range of the electric bus.

There were also projects researching the integration of electric vehicles into the existing public transport grid. The idea behind these projects is that the electrical infrastructure (e.g. overhead tram lines) is already set up, so using it for passenger vehicle charging should not entail significant investment.

- ELIPTIC (2015-2018) is a project that has an overall aim to develop new concepts and business cases for the use of existing electric public transport systems as charging infrastructure in a multimodal mobility context. Existing electric public transport infrastructure, such as overhead electrified lines for trams, can be considered as a smart grid itself and as an enabler for further charging of electric vehicles. Specifically, ELIPTIC focuses on three thematic pillars: safe integration of electric buses into existing electric public transport infrastructure; upgrading electric public transport systems (with a focus on efficiency); and multi-purpose use of electric public transport infrastructure.
- eCo-FEV (2012-2015) had the objective to integrate fully-electric vehicles (FEVs) into the cooperative transport infrastructure. This was to be achieved by development of an integrated information technology electromobility platform that enables the connection and information exchange between multiple infrastructure systems that are relevant to FEVs, such as road information technology infrastructure, EV backend infrastructure and EV charging infrastructure. Over this platform, multiple advanced electric mobility services can be provided to FEV users to improve the energy management and the usability of the vehicle.

The increase in electrification of transport will require careful management of the electric grid, particularly in urban areas where there could be a high demand for electrified transport.

- The Me2 (2016-2018) project was aimed at developing and verifying an urban marketplace that combines electromobility-demand management technology with smart meter automation options within an innovative business model. The project included operational methods to encourage usage, resource optimisation, and to balance both the fluctuating renewable electricity generation and the urban local grid. A key aim was to modify the consumer demand for energy (i.e. to use less energy during peak hours in an urban community). The concepts were to be validated and optimised in two practical pilots and demonstrations in urban communities.

Research has also been performed into the use of V2G technology for BEVs:

- The project SMARTV2G (2011-2014) focused on connecting EVs to the electricity grid, monitoring the energy flows and their efficiency from a safety perspective. The idea was to create a system that allows for the vehicle to work as an energy storage system that can be used by the grid when the vehicle is not being used. This requires an advanced system of communication, automation and control of the information and the energy used.
- ELECTRIFIC (2016-2019) was also aimed at developing V2G technology, with a focus on developing new smart charging stations capable of dynamically controlling charging rate, maximising the use of renewables and making as 'grid-friendly' as possible. Another focus of the project was to manage the charged battery in such a way that it is not adversely affected by fluctuations in the power grid.

6.2.3 Achievements

The FABRIC project analysed the feasibility of dynamic wireless power transfer (DWPT) for EVs at typical driving speeds. Two charging solutions (electric-roads) were developed and demonstrated at the Susa test site in Italy. The two test sites consisted of a series of multi-winding coils and simple single turn coils, both embedded 6 cm to 7 cm deep and covered by asphalt. In these two sites, there were 81 tests performed; for the multi-windings solution the power efficiency was over 80% at 50 km/h, and for the single turn coil solution the power efficiency was over 62% at 30 km/h. The feasibility analysis showed that DWPT has a clear advantage where electricity is produced from renewable sources and where the battery size of a vehicle can be reduced to around 10% of a current battery-powered vehicle. However, the project also identified that the lower well-to-wheel (WTW) efficiency of DWPT compared to regular charging can counter any savings from the lower battery weight.

The main result achieved from the UNPLUGGED project was the development, production and implementation of two inductive chargers (3.7 kW and 50 kW). Both solutions contain a vehicle as well as grid implementation of the inductive charging system. As part of the project, a socio-economic impact study was also performed, taking into account aspects such as the environmental impacts and the user's willingness to move to a different method of charging. The results showed that there is an economic gain to society that can be made from switching a vehicle fleet to EVs and 'Unplugged' electric vehicles. Project partners from the FASTINCHARGE project developed and successfully validated a fast inductive charging technology for EV charging with no need to plug in. It enables a 30 kW power transfer to EVs in either stationary or on-route situations. The solution offers efficiency up to 92% through a 10 cm air gap between the primary coil located in the ground and the secondary coil inserted in the vehicle. The project also developed an energy management system that coordinates the charging network and offers several services to EV owners. In addition, a user interface was built that enables owners to communicate with the system.

The CONCEPT project states that the conductive fast charging can power an electric bus in just two to five minutes. The solution includes a fully automated contacting and fast charging system that enables opportunity charging during operation. With the recent commercialisation of batteries that do not need explicit overnight cell balancing, this means that a 24/7 electric bus service is now within reach. The technology will enable a substantial reduction in the weight of the on-board battery pack capacity, and therefore decrease the weight of the battery. This comes with cost savings, increased available space and reduced operational downtime.

ELIPTIC analysed 23 use cases within the three thematic pillars defined in the project. These use cases included studies in Warsaw and Leipzig which focused on the connection to the existing tram electric infrastructure and related legal, technological and organisational issues. The use case partner, Transport for London (TfL), analysed the potential of using power from the London Underground network to charge EVs with no adverse effects on underground train operations, and prepared a demonstration to show that power from the underground grid can support regular charging of EVs. The eCo-FEV project demonstrated the eCo-FEV technology under real conditions and in the public domain. During the driving demonstrations, which started at the 'Smart Park and Ride', the project demonstrated how the technology works and users gained experience on the cooperative electromobility platform. During the demonstration, two traffic events caused the electromobility systems to recalculate the route for the FEV. One of the traffic events was congestion; the electromobility platform suggested that the FEV be parked and recharged at the park-and-ride, and that the users travel by express bus to bypass the congestion. This showed that under real conditions the electromobility platform can adjust the routing and transport mode to give the user an optimal route for their journey.

A grid management system was tested and validated during the me2 project. Two pilot demonstrations were performed in two different settings; a city with a high degree of EV uptake (Amsterdam) and a city with a lower degree of EV uptake (Lisbon). From this project, the grid balancing algorithms resulted in a 10% smoothed load curve for the local electricity grid. This also resulted in a 10% reduction in household energy costs through smarter, more economical energy usage patterns. In addition, the project also developed policy recommendations and a viable business model for the grid management system.

EVs can be used as an energy management system for the grid, which requires careful management and planning to incorporate. The project SMARTV2G found that EVs could be used for storage for direct current charging, but only partially under alternating current charging due to standardisation limits. The systems allowed for users to sell the energy that they do not use back to the electricity grid. Another innovation from the project was a mobile phone application that allows users to receive information on vehicle battery conditions, and to locate the nearest charge point and reserve it for a specific time. The smart charging solution developed by the project ELECTRIFIC decentralises the control of the grid by inserting control intelligence at the charging station level. The charging station could then react to grid issues and help the grid to recover. If a vehicle is being charged during the grid problem, the battery of the vehicle will not be harmed by the possible fluctuation in power supply.

6.2.4 Implications for future research

The FABRIC project was focused on dynamic wireless charging. From the results of this project it was found that due to the low efficiency of the DWPT, any benefits of reducing the on-board battery was counteracted. Therefore, it would be beneficial for future research in DWPT to be focused on improving the efficiency of the wireless power transfer and on reducing the cost of the ground infrastructure. The UNPLUGGED project demonstrated the feasibility of highly-efficient wireless charging systems. This technology is now very close to being commercialised and the focus is now for major manufacturers to reduce the costs. Future research in this space could focus on the use of more efficient and lower cost high-power wireless charging systems, improving tolerances to misalignment and interoperability. Research could consider the application of such technology in other transport applications, such as rail or shipping.

From the project ELIPTIC it was found that power from the underground grid could support regular charging of EVs. Further research conducted into this area could aim at the identification of the scale of charging that the grid could support, making the best use of existing grid capacity and targeting future reinforcements. The projects showed that there could be potential to use existing infrastructure to charge EVs, which could provide substantial cost savings to local authorities if proven to be scalable. There could be research into the feasibility of using the public transport electrical infrastructure grids for other cities, as the power supply may not be sufficient to support the mass uptake of EVs in every European city.

Some developments for V2G technology have been made during the ELECTRIFIC project, although this is yet to be widely implemented. More research around smart charging, managed charging and V2G should be considered. The management of charging demand will need to be coordinated and ensure transport and energy system functionality is not detrimentally affected while minimising the cost of infrastructure investment. The complete integration of EVs into the electricity grid with bi-directional power flows and supporting business models should be explored.

6.2.5 Implications for future policy development

Based on the projects focusing on inductive charging, it would seem that there is potential for this charging method in the future. The pre-normative research in this field could lead to standards that would then be helpful to ensure a single market in the EU. Moreover, considering a scenario where smart charging and V2G technology is implemented across Europe, more field operational tests may be needed to also study different options for payment schemes that could support the development of a fair electricity trading platform between electricity suppliers and users.

6.3 Sub-theme 3 – Power electronics, motors, and transmission systems for EVs

Power electronics, motors, and transmission systems for EVs covers the design and manufacture of EV components and drivetrains. Currently, rare-earth metals are a key component for developing permanent magnet motors used in EVs. There is a need to move away from this dependency, as the sources for these metals tend to be in a few, isolated locations. Electric drivetrains for light passenger vehicles have previously had significant research attention; there is now a need for research into drivetrains for larger, HDVs if decarbonisation is to be achieved in the freight sector.

The total funding and number of projects for this sub-theme are shown in Table 6. The majority of the funding in this research area was provided through the FP7 programme; funding under the more recent H2020 programme has been significantly lower.

Table 6. Funding level per programme for power electronics, motors, and transmission systems for EVs.

Funding action	Number of projects	Total funding	EU contribution
FP7	41	€389 m	€259 m
H2020	53	€186 m	€165 m
Others	0	€0	€0

Source: Own elaboration based on TRIMIS.

The projects reviewed under this sub-theme address the following actions as outlined in the Transport Electrification roadmap document:

- Actions under road transport electrification:
  - Public and commercial procurement of electric vehicles;
  - Certification of electric vehicles performance; and
  - Support local production of batteries, components and electric vehicles.
- Actions under waterborne transport electrification:
- Actions under aviation transport electrification:
- Actions under rail transport electrification:

6.3.1 Overall direction of R&I

The research within the power electronics, motors, and transmission systems for EVs has several projects focusing on electrical drivetrains for HDVs. These projects are mainly focused on improving the efficiency of the drivetrain and overall range of the EV. HDVs are primarily used for the long-range delivery of goods, so improving the range of electric HDVs could help towards a shift from diesel to electric power.

Another potential barrier for the mass uptake of EVs is the dependency on rare-earth metals in permanent magnet motors. These rare-earth metals come with political issues, such as the centralisation of supply (Fishman et al., 2018; McLellan et al., 2014). These issues have led to several research projects focusing on how to limit or eliminate the use of rare-earth metals in EV motors.

6.3.2 R&I activities

With the recent focus into battery-powered and hybrid passenger cars, there is a need to develop electric or hybrid drivetrains for HDVs and buses. A selection of projects which focused on this research area are shown below:

- ECOCHAMPS (2015-2018) project had the objective to achieve efficient, compact, low-weight, robust and cost-effective hybrid powertrains for both passenger cars and commercial vehicles (including buses, and medium/heavy duty trucks). A major aim was to prove Euro 6 emission standards of the vehicles in real driving conditions. Five demonstrator vehicles (up to TRL 7) were to be developed to give an idea of cost versus performance comparison for light and heavy-duty vehicles. The project targeted a 20% improvement in powertrain efficiency and a 20% powertrain weight and volume reduction when compared to current state-of-the-art hybrid powertrains.

- The REBOOT (2016-2018) project focused on driving the growth for the FEV bus market. Objectives of the project included: development of a retrofit all-electric drive system, battery and charger pack for an 18-tonne bus that weighs less than 2.2 tonnes (the weight of a diesel drive) with the capacity to travel 160 km; development of a final system price of €166,000 that delivers a payback to the operator within 5 years; and a reduction of 80% in fuel operating cost for bus operators.
- The goal of the ELECTRIC_AXLE (2016-2018) project was to develop and test an 8.5-tonne electric axle and install it into vehicles. The project was also aimed at upscaling the company from a small company to a medium-sized, technology-oriented organisation which is active on the world market.
- The overall objectives of the ASTERICS (2012-2015) were to develop a systematic and comprehensive approach for the design, development and testing phases of electric drivetrains in FEVs. Other aims included the reduction of overall development time and testing efforts for EV and EV components by 50% (compared to current state-of-the-art) and to enable the improvement and optimisation of the overall efficiency and performance of EVs by at least 20%.
- The project ZeEUS (2013-2017) had a focus on the electrification of bus systems; with goals to develop large passenger capacity EVs (electric buses) and the creation of the infrastructure capable of providing sufficient energy for the daily bus operations. The project covered electric bus solutions with different types of electrical powertrain systems including full-electric battery-powered buses and well as plug-in or range-extender type power trains.

Current EV motors are dependent on rare-earth metals, the availability and price of which can be significantly affected by the geopolitical context. Several projects researched materials and components that reduce the reliance on rare-earth metals, including:

- SYRNEMO (2013-2016) proposed an innovative synchronous reluctance machine (SYRM) with higher power density and higher driving cycle efficiency at a lower cost than state-of-the-art permanent magnet synchronous machines (PMSM). The technology was aimed at improving the mass and volume specific power densities by around 5%, whilst removing the dependency on rare earth metals of current permanent magnet machines. Due to the proposed simple manufacturing process, the SYRM solution had a goal to reduce the manufacturing cost by 20% compared to PMSM. The final objective of the project was to improve the overall driving cycle efficiency by 5% to 15% compared to the current state-of-the-art.
- The VENUS (2013-2016) project set out to develop an electric drive system for EVs that does not contain scarce rare-earth materials, meets EV efficiency and power density performance, and is feasible for mass production.

New materials for EV components are also being researched, with the aim being to reduce the overall vehicle weight:

- The project ENLIGHT (2012-2016) was aimed at accelerating the technological development of innovative materials (thermoset, thermoplastic, bio-based and hybrid) which could offer a weight reduction and overall carbon footprint reduction for medium- to high-volume EVs. These materials were aimed at being implemented in EVs in the 2020 to 2025 timeframe. Five demonstrator modules using the materials were to be developed, with the goal to validate the performance of the materials in structurally demanding parts of the vehicle.

6.3.3 Achievements

The innovations from the ECOCHAMPS project have resulted in efficient, compact, low-weight and cost-effective hybrid powertrains for both passenger cars and commercial vehicles, which make European road vehicle manufacturers and their suppliers more competitive in hybrid vehicle technology. The project achievements include the development of six new hybrid electric components based on a modular system and standardisation framework, and five powertrains, which have been demonstrated in five vehicles at TRL 7. The results show that a significant CO_2 reduction is possible through a 20% increase in powertrain efficiency (for a class b passenger car)[15], whilst offering additional functionality to the end customer.

[15] https://ecochamps.eu/class-b-passenger-car-results-fiat-500x/

From the ENLIGHT project several manufacturing technologies were evaluated, such as fast resin transfer moulding and thermoforming. The validation of these processes on simple EV components and parts proved the cost efficiency of these methods for medium-volume production of EVs. Use of the new lightweight materials investigated within this project resulted in significant weight savings of up to 50% compared to commercial products.

In the ZeEUS project, full-electric buses were demonstrated in five locations (Barcelona, Bonn, Muenster, Plzen and Rome) and plug-in or range extender hybrid buses were demonstrated in three sites (London, Glasgow and Stockholm). Following this, an eBus report has been produced, which gives an overview of the European market for electric buses. The report describes the market in 90 cities, with over 20 million km having been driven by buses in electric mode.

The ASTERICS project had a number of technical developments for vehicle electrification. First, the researchers defined a set of real-world drive-cycle usage profiles based on real-world use of EVs, customer demands and fleet data. This helped to identify operating conditions, performance requirements and constraints for EV components. In a second phase, the team developed advanced test procedures that automatically populate component simulation models for the battery, inverter and electric motor. Capable of simulating the real-world of driveline components with the required accuracy and calculation speed, these models can be used in all phases of the development process in model, software and hardware in the loop as well as in other test environments. The developed technologies should enable a 50% reduction in overall development time and testing efforts for EVs and components.

A big challenge in current EV design is the dependency on rare earth metals in the permanent magnet motor. SYRNEMO overcame this issue by designing, prototyping and testing a rare earth-free permanent magnet assisted synchronous reluctance machine. In addition to the motor, the project also delivered the design for a full drive with integrated power electronics and an air-cooled housing. Based on the testing results, the final drive design provides a maximum torque performance of 133 Nm at 3600 rpm and a maximum power of 52.9 kW at 4300 rpm. The SYRNEMO design is evaluated based on its machine constant of mechanical power and torque density values – two relevant benchmark values for electric motors – bringing an improvement of 45% and 25% compared to the 2016 best benchmark. The SYRNEMO design was delivered at TRL 5.

The VENUS team manufactured various components for a rare-earth free motor. The full motor assembly was then tested and integrated into an electric van. The power density achieved by researchers was 10% better than benchmark motors without permanent magnets in low-powered vehicles and four-wheel vehicles. They also calculated that the inverter can provide the highest power per litre in the market (19 kW/l). To exploit the motor, a comprehensive industrialisation analysis was carried out, including cost evaluation, manufacturing processes and required investments. VENUS developed a motor that can provide similar performance at a competitive price and reduced size. The absence of rare earth magnets in the motor would significantly reduce the risks associated with supply shortages in key components during mass production.

From the REBOOT project two world-class cell manufacturers were secured and battery packs were designed and built to fit into two donor vehicles (one single and one double decker bus). Full installation designs and bills of materials were created for donor vehicles, along with full manufacturing procedures for the components and the installation into the vehicles. The project designed a super-high energy dense battery system, suitable for installation into buses. This would allow electric buses to operate for a full day without the need for fast charging along the route.

The project partners from the ELECTRIC_AXLE project achieved an up-scale in turnover, potentially reaching €6-8 m by the end of 2020. At the start of the project there were 12 employees; this number has grown significantly and will reach 50-70 by the end of 2020. The product increases European competitiveness, making vehicle manufacturers more competitive and hence increasing export to other non-European countries.

6.3.4 Implications for future research

The projects VENUS and SYRNEMO both researched the concept of a rare-earth metal-free synchronous motor for EVs. Significant advances were achieved, as VENUS proved that similar performance can be achieved to that of a motor containing the rare-earth metals. Future research on the upscaling of this technology could be beneficial, as this will help to move away from the dependence on rare-earth metals in EV manufacturing. The SYRNEMO technology has been raised to TRL 5 (demonstration); more research projects will be needed to raise the development phase of this technology to implementation with a specific focus on making it economically viable.

The ENLIGHT project investigated several novel manufacturing processes, and the cost effectiveness of the methods were proven up to medium-volume production of EVs. As these methods have shown promise, future research could be based on proving the cost effectiveness for large-scale EV manufacturing. Once this has been completed the development phase could be raised from validation to demonstration and implementation and applied to real-world manufacturing processes.

ENLIGHT also focused on the development of new materials; a very important area for weight reduction, cost and environmental impacts of manufacturing. More research is likely to be necessary in this area to improve on current state-of-the-art as reduced vehicle weight can improve the performance. Further projects investigating the weight aspect to some extent were ECOCHAMPS and REBOOT. The lightweight drivetrains designed in the ECOCHAMPS project were demonstrated in actual vehicles up to TRL 7 (demonstration). Further research could be focused on bring this technology to implementation by assessing the economic viability of the technology.

6.3.5 Implications for future policy development

The research projects have shown that it is possible to manufacture a motor for EVs without the use of rare-earth metals and relevant research could be useful since as the uptake of electric vehicles increases, these rare-earth metals will become increasingly in demand.

New materials were developed in the ENLIGHT project, a very important area for weight reduction, cost and environmental impacts of manufacturing. More research is likely to be needed in this area to improve on current state-of-the-art as reduced vehicle weight can improve the performance, while the life-cycle implications of these materials will need to be assessed.

6.4 Sub-theme 4 – Hydrogen fuel cells and hydrogen refuelling

Hydrogen fuel cells for transport are also being considered as the tailpipe emissions of CO_2 are zero, and there is the potential to use renewable, carbon-neutral hydrogen (depending on how the hydrogen is sourced). In principle, the hydrogen fuel cell functions like a battery, producing electricity which can run an electric motor. Although the concept of hydrogen fuel cell vehicles has existed for many years, progress in developing affordable vehicles has been slow and research has continued to attempt to overcome some of the problems. There have been more research projects focusing on the use of hydrogen in larger vehicles, such as buses, than for passenger cars. There is also a need for more efficient and safer hydrogen refuelling if a mass take-up of hydrogen vehicles is to be achieved.

The total funding and number of projects for this sub-theme are shown in Table 7. The funding split between the FP7 and H2020 programmes is fairly even, with approximately 45% having been provided by FP7 and 55% by H2020.

Table 7. Funding level per programme for hydrogen fuel cells and hydrogen refuelling.

Funding action	Number of projects	Total funding	EU contribution
FP7	41	€451 m	€222 m
H2020	38	€550 m	€369 m
Others	0	€0	€0

Source: Own elaboration based on TRIMIS.

The projects reviewed under this sub-theme address the following actions as outlined in the Transport Electrification roadmap document:

— Actions under road transport electrification:

  - Promote a +400 km range for electric passenger cars; and
  - Progress and demonstration in urban bus electrification.

6.4.1 Overall direction of R&I

The majority of research projects on hydrogen fuel cells in vehicles have focused on larger vehicles, such as buses or heavy-goods vehicles; the developments for passenger cars have a stronger focus on battery energy storage. Hydrogen fuel cells have the ability to offer longer driving ranges as well as shorter refuelling times than BEVs (Gröger et al., 2015); these factors could be advantageous for long distance heavy-goods driving. However, some challenges remain in the areas of fuel cell costs, reliability and longevity.

Research has also been conducted into the feasibility of refuelling a large number of vehicles from one hydrogen refuelling station. If hydrogen fuel cells are to become commonplace within the European transport system, then the refuelling stations must be able to provide safe, fast and efficient hydrogen refuelling.

6.4.2 R&I activities

There are projects researching the use of hydrogen fuel cells in buses, with some projects aimed at implementation of the technology:

— CHIC (2010-2016) was a large project that was focused on commercialisation of hydrogen powered fuel cell buses. CHIC was aimed at reducing the time to market for the technology and supporting the market development. Specific goals of the projects included: testing of the hydrogen technology by operating a minimum of 26 hydrogen fuel cell buses in medium-sized fleets in normal city bus operations, and substantially enlarging hydrogen infrastructure in five European regions; conduction of a life-cycle assessment (based on sustainability) of the use of hydrogen fuel cell buses in public transport; and identify the advantage and potential for improvements of such buses as compared to conventional and alternative technologies.

— The project GIANTLEAP (2016-2019) investigated using hydrogen fuel cells in buses. Specifically, the project had a goal to improve the availability and reliability of fuel-cell systems for buses by developing diagnostic and prognostic systems for automotive fuel cells and their supplementary components. Issues arise when the fuel cells malfunction en-route and require an alternative propulsion method to arrive back at the depot for maintenance. GIANTLEAP therefore proposed to build a range extender and test it in real-world scenarios.

Research has also been conducted into the use of a solid-oxide fuel cell (SOFC) as an auxiliary power unit (APU) to combat the emissions generated from the idling of HDVs:

— The idling of heavy-duty trucks is cause for concern given the resulting power consumption, pollution, noise and financial issues. The project DESTA (2012-2015) was aimed at developing and demonstrating the first European SOFC truck APU, which would address the issues around the idling of engines. Prior to the project starting there were two SOFC APU systems available at laboratory prototype level. The main objective of the project was to test and optimise these systems so that a final 'DESTRA' SOFC APU could be developed.

Hydrogen itself is a challenging element to store due to its volatile nature and low density. Therefore, projects have focused on the storage and refuelling aspects of using hydrogen in vehicles:

- H2REF (2015-2018) aimed to address the compression and buffering function for the refuelling of 70 MPa passenger vehicles and encompasses all of the necessary activities for advancing a novel hydraulics-based compression and buffering system from TRL 3 to TRL 6. The specific targets of the projects included: increasing the throughput capacity from 6 to 15 vehicles per hour with a 75 kW power supply; and improve the energy efficiency to 50% below the energy consumption of current systems.
- Hydrogenlogistics (2017-2019) recognised that due to the low density of hydrogen gas, storage and transportation of hydrogen using current technologies is technically challenging, inefficient and expensive. The solution developed offers safe and cost-efficient high-density hydrogen storage in an easy-to-handle oil, which eliminates the need for pressurised tanks for hydrogen storage. The goals of this project were: to develop a dynamic, automated hydrogen release system; to reduce price, complexity and delivery time; and to prepare commercial roll-out in key EU countries.
- The NewBusFuel (2015-2017) project set out to understand whether it is possible to refuel very large numbers of fuel cell buses at large hydrogen depots of the future. The project was conceived to address concerns that costs, practicalities or regulatory barriers may prove problematic in achieving the vision of a 100% hydrogen fuelled public transport system. The overall objective of the project was to assess the feasibility of a hydrogen station capable of providing fuel to a fleet of around 75 to 260 hydrogen fuel cell buses.
- Project partners within the COPERNIC (2013-2016) project aimed to improve the performance and reduce the cost of 70 MPa composite vessels for use in the automotive sector. A full scale demonstration was planned on a pilot manufacturing line, with the target of providing technical and economic assessment of materials, components, processes and designs.

The large-scale rollout of FCEVs will help to reduce the overall costs of these vehicles, which are still high in comparison to other powertrains due to small production scale.

- The ZEFER (2017-2022) partners will oversee the deployment of 180 FCEVs in Paris, Brussels and London, with the overall aim to demonstrate the readiness of hydrogen technology. ZEFER will complement these ambitious deployments with robust data collection, analysis of the business cases and technical performance of the deployments. A targeted dissemination campaign will aim to replicate the business cases across Europe.
- Similar project targets were observed within the HyFIVE (2014-2018) project, which planned to deploy up to 185 FCEVs from five global automotive companies leading the commercialisation of FCEVs. There was also an aim to develop a hydrogen refuelling network, with 6 new stations to be deployed linking to 12 already existing stations. The overall aim of the project partners was to demonstrate that the vehicles met and exceeded the technical and environmental expectations of FCEVs.

6.4.3 Achievements

The results from the project CHIC included eight million km travelled by the hydrogen fuel cell buses, which resulted in a saving of over four million litres of diesel fuel. These hydrogen buses were also demonstrated to have a range similar to the diesel buses (around 400 km); and an improvement of over 25% in the fuel efficiency as compared to diesel buses. The emissions savings from these buses depended on the primary energy source used for the hydrogen, which achieved between 10% to 100% savings in CO_2 compared to fossil-fuel counterparts. This resulted in emission savings of over 6,000 tonnes of CO_2 throughout the project.

During the DESTRA project, six APU systems were built and rigorously tested. The SOFC stacks were also tested for thermal cycle ability, sulphur tolerance and long-term operation. Project partners identified and integrated the most promising approaches from the SOFC systems into the final SOFC APU system. They devised a new system architecture, developed a control system and designed a vehicle interface. In addition, various optimisation tasks were performed to improve system performance, lifetime and reliability. The main achievement of this project was the first European SOFC APU successfully demonstrated on-board a heavy-duty truck. The solution has fuel savings potential, resulting in lower costs and CO_2 emissions.

During the first half of the GIANTLEAP project, fuel cells in a variety of sizes were produced for testing. Stack durability has been tested up to 8,000 hours and will continue to the final target of 12,000 hours. An innovative, passive hydrogen pump (ejector) has been developed and integrated into the stack-module, reducing the number of moving parts and inherently improving reliability.

With the support of EU funding, the Hydrogenlogistics project engineered, constructed and tested a modular liquid organic hydrogen carrier (LOHC) dehydrogenation system (ReleaseBOX) at an industrial scale for supply to hydrogen refuelling stations – one of the key markets for the technology. Hydrogenlogistics's systems have been in field operation with a US-based industrial hydrogen supplier since 2018. The team are currently constructing two units for an EU-funded project (HySTOC), with a field test planned for 2019.

In the locations assessed by the NewBusFuel project, it was possible to produce a design for a hydrogen refuelling station which met the local specification for refuelling capacity, refuelling speeds, reliability and did so within the local regulatory conditions. This result helps to prove the technical viability of the hydrogen option as a low-carbon fuel source for transport. The project found that hydrogen prices are likely to be site specific and dependent on the local electricity price. Four stations showed prices of €6 per kg of hydrogen, which was the target to achieve similar prices with diesel buses.

The project partners from H2REF aimed to address the compression and buffering function for the refuelling of 70 MPa passenger vehicles. The project results included a first of its kind full-scale prototype high-pressure bladder accumulator in composite material, which is operational up to 90 MPa. This is above the initial 70 MPa target, and the average energy consumption of the technology is halved compared to conventional storage methods. The initial targets from the COPERNIC project have all been reached, with the target cost reduction to €600 per kg hydrogen of the composite tank achieved (down from around €3000 per kg hydrogen). Internal volume of the storage tank was also raised from 37 litres to 61 litres, and the annual production was increased by around 70%.

The progress within the ZEFER project to date has shown the deployment of 81 (out of the 180 planned) FCEVs in Paris and London. These vehicles have been highly utilised and have amassed over two million vehicle kilometres since first deployment. The performance of the FCEVs has been noted as being similar operationally to conventional diesel vehicles. A result of the HyFIVE project was the deployment of 154 FCEVs (against an initial target of 185), with a total vehicle mileage of over two million miles (3.2 million vehicle kilometres). A key takeaway from this project was that over four years of monitoring, there were no hydrogen or fuel-cell related safety incidents with the vehicles or the infrastructure.

6.4.4 Implications for future research

When considering the requirements for a hydrogen-fuelled vehicle, including range, performance (speed and acceleration), weight and luggage space (to equal that of a conventional passenger car), there is a challenge regarding having sufficient on-board hydrogen storage. Recent research has focused on high-pressure (700 bar) gaseous hydrogen storage systems, which can offer large storage capacity on board passenger vehicles. On-board hydrogen storage tanks remain a critical component and further reduction of prices by employing new materials, novel architectures, better manufacturing, and creation of a European value chain is needed for composite overwrapped pressure vessel (COPV) type IV, as found in the FCH 2 Joint Undertaking Work Plan[16]. Additional fundamental research is also required on COPV Type V vessels, beyond the achievements of recently finished COPERNIC project.

The cost and efficiency of hydrogen dispensing will be a factor in the widespread uptake of hydrogen vehicles. The project H2REF was focused on improving the efficiency of hydrogen dispensing, allowing for 15 vehicles per hour to be refuelled. NewBusFuel also produced a design for a refuelling station which met local specifications for refuelling speeds. Potential short refuelling times for hydrogen vehicles would give an advantage over BEVs in this aspect; further research is needed to validate the high level of throughput (15 vehicles per hour) to ensure that this short refuelling time can be achieved in real-world scenarios.

A field test for the Hydrogenlogistics storage system was planned for 2019. This could offer an improved solution to current hydrogen transportation and storage, which is often seen as a limitation for hydrogen-fuelled vehicles. Upon completion of the field test, further research will be necessary to assess the commercial viability of this product, and whether it is suitable for scale-up and implementation in the real world.

[16] ttps://www.fch.europa.eu/sites/default/files/MAWP%20final%20version_endorsed%20GB%2015062018%20%28ID%203712421%29.pdf

6.4.5 Implications for future policy development

Innovative storage systems could offer an improved solution to current hydrogen transportation and storage, which is often seen as a limitation for hydrogen fuelled vehicles. Upon completion of relevant field testing, further research should be conducted to assess the commercial viability of this product for passenger cars against BEVs, and whether it is suitable for scale-up and implementation in the real world for the entire passenger car market. Future research should ensure that hydrogen used in transport has a low carbon footprint to avoid negligible CO_2 reductions or even worse performance than fossil fuels. If innovative hydrogen storage systems currently being tested are found to be successful in the field tests, then policy will be needed to ensure the safe delivery and storage of hydrogen across Europe.

The large-scale deployment of hydrogen fuel cell vehicles would benefit from publicly viable business cases, which are not currently widely available. A total cost of ownership (TCO) analysis was performed by a UK company[17] after deploying 25 vehicles, with a further 25 vehicles deployed after the positive results from the TCO analysis. A target within the ZEFER project is to implement a business model based on the assumption that a sufficient and stable hydrogen demand will decrease the cost of the end-use hydrogen dispenser. This project also has a targeted dissemination campaign, with the aim to make the business case results available and hence replicable to interested parties. A standardised approach to calculating hydrogen fuel cell vehicles TCO (for both vehicles and refuelling infrastructure) would help to provide decision makers with accurate information on the total cost of switching to hydrogen fuel cell technologies. The approach set up by HyFIVE is a good reference, which should be updated and refined by other projects when relevant.

Hydrogen refuelling infrastructure has been successfully developed such that time to refuel a hydrogen vehicle is similar to conventional petrol or diesel refuelling. However, further developments are required for compressors, metering and quality assurance. The targeted refuelling time (3 to 4 minutes) has been reached by pre-cooling the fuel and applying infra-red communication between the vehicle and the filling station, in compliance with the SAE J2601 standard[18]. Further development of hydrogen refuelling stations could include the integration of other transport modes (such as heavy-goods vehicles, buses, trains etc.) with the overall aim of creating a hydrogen refuelling ecosystem. With the increase in hydrogen fuel use for these other transport modes, there will also be a need for refuelling protocols for vehicles aside from passenger cars and light-duty vehicles.

6.5 Sub-theme 5 – Electromobility

Electromobility covers the design and manufacture of novel lightweight EVs for use in an urban environment. Many of the innovations are focused on developing a vehicle that is smaller than a conventional passenger car, but larger than a motorbike. These vehicles can have benefits in terms of air quality and congestion within urban areas, as well as having applications for urban freight movement.

17 https://www.greentomatocars.com/

18 https://www.fch.europa.eu/sites/default/files/MAWP%20final%20version_endorsed%20GB%2015062018%20%28ID%203712421%29.pdf

The total level of funding and number of projects are shown in Table 8. The majority of the funding comes from the H2020 programme, with a significant input from FP7 and a smaller level of funding from other programmes.

Table 8. Funding level per programme for electromobility.

Funding action	Number of projects	Total funding	EU contribution
FP7	16	€142 m	€102 m
H2020	31	€276 m	€217 m
Others	5	€20 m	€9 m

Source: Own elaboration based on TRIMIS.

The projects reviewed under this sub-theme address the following actions as outlined in the Transport Electrification roadmap document:

— Actions under road transport electrification:
  - Progress and demonstration in urban bus electrification;
  - Developments of small and light smart electric vehicles; and
  - Further development of small and light smart electric vehicles.

6.5.1 Overall direction of R&I

Electric vehicles in the urban environment have many applications. One of which is the use of 'micro' EVs for both passenger and freight delivery. There have been several projects researching this area, with the aim of delivering lightweight and safe vehicles using composite materials for use in the urban environment. As these vehicles are much smaller than the average passenger car currently on the market, there was a real focus within the research on the safety and crash-testing of the vehicles.

Urban freight is estimated to be responsible for 25% of all urban transport related CO_2 emissions, and 30% to 50% of other transport-related pollutants (PM, NO_x) (ALICE / ERTRAC Urban mobility WG, 2015). For this reason, there have been several projects addressing the need to incorporate electromobility into the urban freight system, as this will drastically reduce NO_x and PM tailpipe emissions whilst also offering a route to decarbonisation.

6.5.2 R&I activities

Within the Electromobility sub-theme there has been a considerable focus on the design and manufacture of a new category of EVs, which are smaller than the ultra-compact car:

— The WEEVIL (2015-2019) project was aimed at developing a new 3-wheel vehicle that is quiet, clean, energy efficient and safe, as well as attractive to the public so that barriers for adopting it are minimised. The focus of the project was on the light weight and safety of the vehicle, with a strong use of composite materials through new and affordable processing methods. A new drivetrain with improved energy efficiency was to be incorporated, as well as new solutions on system integration such as modular battery packs.

— FREE-MOBY (2013-2016) was a project focused on the implementation of easy to deploy micro FEVs (450 kg to 650 kg and speeds of up to 90 km/hr) and city EVs (650 kg to 1,000 kg). Specific objectives of the project included:
  - development of prototypes of the premium micro EVs for both passenger and freight delivery by applying large-scale manufacturing concepts;
  - full convergence between renewable energy and electromobility with common technology developments;
  - development of universal battery-monitoring systems, with a focus on simplified battery management systems based on pure monitoring of cell status.

— EPSILON (2013-2017) was aimed at conceptualising, developing and prototyping a new category of vehicle between the ultra-compact (urban) car and present-day moped category, small covered vehicles or semi-covered scooters. A specific goal of the project was to develop a driveable prototype along with two crash-tested body structures.

— The project BEHICLE (2013-2017) had the objective to deliver a safe, lightweight, performance enhanced and updated version of an existing urban EV, the IH QBEAK car. The overall goal was to fulfil the safety requirements as defined by European New Car Assessment Programme (Euro NCAP) assessment. Four BEHICLE prototypes were to be manufactured and tested according to Euro NCAP requirements, and crash compatibility cases were also to be assessed by virtual means.

Urban freight is also a key area for transport electrification, and there have been projects researching the promotion of electric urban freight:

— SmartFUSION (2012-2015) had the objectives to build upon existing urban freight development strategies of three demonstrator regions and to demonstrate smart urban freight solutions and cooperative and sustainable city distribution in urban and interurban supply chains. The primary ideas were to introduce the concept of the European Green Car Initiative into last-mile operations and to introduce innovative technology developments in the field of urban freight planning, vehicle technology and urban/inter-urban shipments.

— The overall goal of the project BuyZET (2016-2019) was to promote zero emission urban delivery of goods and services through the strategic and innovative use of public procurement approaches. Specific objectives of the project included the development of plans for innovative zero emission procurement activities for high-priority areas in cooperation with key market players and other stakeholders, and the development of a series of recommendations for both public authorities and national/European policymakers in support of zero emission deliveries of goods and services.

Projects have also investigated the possibility of a European-wide standard for electromobility, and how to support the growth of electromobility throughout Europe:

— The main objective of the FREEWAY (2015-2017) business innovation project was the transfer of a new innovative and competitive solution (a small three-wheeled electric scooter) to meet European sector opportunities with the view of providing profitability and growth. The specific objectives were to provide the technological and economic viability of the FREEWAY electromobility concept to develop a market strategy ensuring Europe-wide market uptake, support growth and self-sufficiency at mid-term and participate in the leadership of the European bike industry.

— The Green eMotion (2011-2015) project was part of the European Green Cars Initiative (EGCI) that was launched within the context of the European Recovery Plan. The primary goal of the project was to define Europe-wide standards for electromobility. Practical research was to be conducted in different demonstration regions across Europe with the aim of developing and demonstrating a commonly accepted and user-friendly framework that combined interoperable and scalable technical solutions with a sustainable business platform.

6.5.3 Achievements

The project SmartFUSION rationalised urban goods distribution services, reducing pollution and traffic, and developing/evidencing the role of electrical and hybrid vehicles for clean urban logistics. SmartFUSION built upon the existing urban freight development strategies of three demonstration city-regions: Newcastle, Berlin and the Lombardy region. At each demonstration site, SmartFUSION developed technological solutions addressing specific problems: intelligent, hybrid electric propulsion systems for different environments; deployment of battery drive metering systems; and intelligent routing and planning systems for freight deliveries.

The EPSILON project successfully developed an innovative EV prototype specifically designed for urban environments. EPSILON's new vehicle is considerably lighter, more energy efficient and requires less road space than today's sub-compact cars, while offering the same level of safety. To ensure safe and efficient usage of the drivetrain, partners developed a thermal management system. Moreover, a vehicle control strategy was implemented. EPSILON placed special focus on the control of regenerative braking to achieve high values of recuperation and to provide a comfortable one-pedal driving feeling. The project's new car prototype weighed around 600 kg and could accelerate to 100 km/h within 10 seconds. It provided over 150 km of total electric range and had an energy efficiency of around 8 kWh per 100 km.

Project partners within the BEHICLE project used a mix of different materials to develop a lightweight body structure for a micro EV. BEHICLE combined both ergonomic concepts and advanced automotive technologies that were considered clean, energy-efficient and safe. The project's new car prototype weighed 550 kg and could accelerate to 100 km/h within 10 seconds. It had an adequate 150 km of total electric range, with average energy consumption of around 7 kWh per 100 km.

The first phase of the project BuyZET saw the development of a transport CO_2 footprinting methodology for procurement activities, and its successful application in the three cities of Copenhagen, Oslo and Rotterdam. Each city has now selected two priority procurement areas to be focused on for the market engagement and procurement planning phase of the project. The footprinting methodology has been documented and made available for other cities to use. Further work will be carried out to refine, present and disseminate this tool.

The conclusions from the Green eMotion project were that the business case for public charging as a standalone business can only be profitable if the charging station is very highly utilised. This means that the charging stations must be located at points of interest, so that people are willing to pay to use it. The charge time must also be short enough to allow for several charging events per day. The project found that a good option to improve the business case of public charging points is the combination of different businesses; for example, use charging to attract customers for other services such as shopping or restaurants.

Project partners within the WEEVIL project utilised a composite material called glass fibre reinforced polymer to reduce the chassis weight by 70%. This material can also dissipate five times more impact energy than metals, contributing to road safety and energy efficiency of the vehicle. The project FREEWAY resulted in a standard prototype of a small three-wheeled electric scooter, which offers good dynamic balance which is essential for turning. Simulations of six drivetrain architectures were performed within the FREE-MOBY project. It was found that traditional single-speed transmission has energy consumption 10% to 15% higher than some variable transmissions.

6.5.4 Implications for future research

Although the dynamics and stability targets for the prototype in FREEWAY were achieved, adjustments must still be made as the standard prototype does not meet its weight objective of about 15 kg. Further research is needed to address the weight issues around the prototype, which would help to significantly reduce the weight of the current electric bike. There have been several 'micro' mobility electric prototypes produced (e.g. EPSILON, BEHICLE) which have shown improvements in energy efficiency and safety. The next step is to bring these from the prototype development phase and into implementation. Future research could focus on bringing these technologies to market, with assessment into potential demand for the vehicles. Future research could also consider the most efficient way of introducing these vehicles into the transport system to avoid potential unintended negative impacts of increasing overall energy consumption and emissions through use of more but smaller vehicles, and a potential increase in congestion.

6.5.5 Implications for future policy development

There have been achievements in terms of bringing electrification to the urban freight sector. Future policy development should reflect the need for a reduction in urban freight emissions, and the results from the electromobility projects have shown that this is possible with transport electrification.

With the rise of new category EVs (such as EPSILON[19]) in urban areas, policy will need to be implemented to ensure the integration of these vehicles into the wider transport system. Whole life-cycle emissions will need to be evaluated for each vehicle type to give an indication of the overall benefits. Last mile deliveries are to an increasing extent being carried out by electric cargo bikes which permit to take on heavier loads.

There may be a need for urban transport policy to reflect not only the need to curb emissions (covering both climate and air quality impacts), but also the need to avoid increased congestion on the road resulting from a wide use of small, clean vehicles in place of public transport options. There will also need to be guidelines on where a vehicle can or cannot be parked within the urban environment.

[19] http://www.epsilon-project.eu/

6.6 Sub-theme 6 – Electrification of other transport modes

The previous sub-themes have had a large focus on electrification of road transport; which is where the majority of funding for the ELT roadmap has been provided. The electrification of other transport modes (air, water and rail transport) is still being researched. This sub-theme covers R&I around the electrification of these other transport modes. On air transport, the research is largely focused on hybrid-electric powertrains for aircraft, as pure battery electric aircraft would require very large and heavy batteries. There are applications for the maritime sector to use batteries as an energy source, with the large surface area of ships allowing for on-board battery applications.

The total level of funding and number of projects for this sub-theme are shown in Table 9. The majority of the funding is under the H2020 programme, with the remainder of the funding coming under the FP7 programme.

Table 9. Funding level per programme for electrification of other transport modes.

Funding action	Number of projects	Total funding	EU contribution
FP7	13	€65 m	€31 m
H2020	32	€109 m	€103 m
Others	0	€0	€0

Source: Own elaboration based on TRIMIS.

The projects reviewed under this sub-theme address the following actions as outlined in the Transport Electrification roadmap document:

- Actions under waterborne transport electrification:
  - Deploy new materials and technologies.
- Actions under aviation transport electrification:
  - Achieve maturing in high temperature superconductors.
- Actions under rail transport electrification:
  - Increase the potential of utilisation of electric motorisation; and
  - Development of new motorisation.

6.6.1 Overall direction of R&I

With the majority of transport electrification research being aimed at road transport, the other transport modes have not received the same levels of research. However, there are definitely applications for transport electrification in the waterborne sector due to the vessels large surface area and ability to carry weight. These projects are mostly focused on small to medium-sized vessels and the charging infrastructure associated with these.

Applications are also present for aircraft, with the development of a prototype light-sport aircraft (LSA) being a project aim. There are also projects researching hybrid-electric propulsion for future large civil aircraft.

6.6.2 R&I activities

A large amount of the research into electrification of other transport modes is focused on the electrification of waterborne transport:

- E-ferry (2015-2019) was a research project focused on the demonstration of a 100% electrically powered medium-sized ferry for passengers and cars. The vessel was to be based on newly developed, energy efficient design concept and demonstrated in full-scale operation on longer distances than previously seen for electric drivetrain ferries (i.e. greater than five nautical miles). The ferry aimed at having a high charging power capability of up to 4 MW, allowing for short port stays. In addition, the project had goals to reduce the weight of the electric ferry by implementing carbon composite materials with the aim of reducing weight by up to 60% for certain components.
- The project HYBRID_BOATS (2015-2016) was focused on developing and launching a hybrid propulsion and generation system for yachts, which can be retrofitted to existing boat engines. The aim of the technology was to reduce fuel consumption by 25% compared to current state-of-the-art, and also reduce CO_2, NO_x, sulphur oxides (SO_x) and particulate emissions by 25%. The core aim of the project was to validate the business model to allow for installation of the hybrid propulsion kits on existing boats.
- There are approximately 1.5 million boats with small and medium-sized diesel engines. The project MarketStudy-OV (2016-2017) has a solution that can replace the engines with electric propulsion technology that is free of tailpipe GHG emissions, lightweight, reliable and with reduced maintenance. The main aim of the project was to find two or three suitable markets that have significant growth potential, and which could be addressed directly with existing products or with minor modifications. The outcome was to include a specific go-to-market plan, legal and regulatory landscape, and freedom-to-operate analysis.

There are also research projects aimed at incorporating electrification into air transport, with a focus on developing prototypes of the technology:

- The WATTsUP (2015-2017) project was focused on industrialising and commercialising a prototype electric LSA. The end product from this project was aimed at being a production-ready electrically powered LSA, which is both fully functional and cost-effective. The final product was to be accompanied by full documentation and a training information system (interactive training system and flight school management).
- ASuMED (2017-2020) is an on-going project that was aimed at building the first fully superconducting motor prototype, with the aim of achieving the power densities and efficiencies needed for hybrid-electric distributed propulsion of future large civil aircraft. The technologies were to be tested and demonstrated in a prototype with approximately 1 MW power at 10,000 rpm and a thermal loss of less than 0.1%, showing scalability to higher power values. After the assembly of the final motor, final tests were to be conducted to evaluate the technology's benefits and allow integration into future aircraft design.

Electrification of the railway system is not a new technology; however, with the rise of electric transport across Europe, electrification of the railway system will need to be carefully managed and optimised to ensure sufficient electrical demand for operation:

- The project MERLIN (2012-1015) was aimed at investigating and demonstrating the viability of an integrated management system to achieve a more sustainable and optimised energy use in European electric mainline railway systems. Specific targets include, but are not limited to:
    - improved design of railway distribution networks and electrical systems and their interfaces;

- better understanding of the influence of railway operations and procedures on energy demand;
- identification of technologies to optimise the use of energy.

6.6.3 Achievements

The E-ferry project has seen some major developments in electric ferry design and demonstration. Weight reduction has been achieved by an innovative electric propulsion and drivetrain system, which is based on Direct Current/ Direct Current (DC/DC) converter technology so that heavy Alternating Current/ Direct Current (AC/DC) converters can be placed on shore instead of on-board the vessel.

The WATTsUP consortium developed a prototype training vehicle, of the light sport aircraft class, into a mature product. The project is the first to achieve a production line dedicated to such aircraft. Thrust comes from a lightweight 60 kW electric motor attached to an energy-recuperating forward-mounted propeller. The vehicle's motor and power controller were specifically developed for aviation propulsion and include a cooling system that optimally circulates liquid around the motor and air around batteries. Either of the two 10.5 kWh batteries alone can power the aircraft if the other fails. The battery management system optimises charging and discharge during all flight phases. Since the project concluded in 2017, almost 30 aircraft have been delivered to customers.

The HYBRID_BOATS project assembled the electrical system for hybrid diesel-electric boats. Tests have demonstrated the benefits of the system on land and water. An intelligent control system has been developed for the integration of the generation system and propulsive energy. This has been installed on a real boat for the first tests in an operational setting. Tests using the new diesel-electric propulsion system have shown that the fuel consumption and resulting carbon footprint, as well as noise and vibrations, have been considerably reduced, thus increasing the comfort on-board, at sea and at anchor.

Based on the results from the MarketStudy-OV project, a very promising new market for the technology is in commercial workboats and small ferries, with a total market size of €4 bn by 2024. The technology gap from the current product is relatively small, and suitable products can be developed and launched quickly. The project did find that successful market entry would require wider commercialisation activities, such as cooperation and piloting with boat manufacturers, ship operators, regulators and electrical charging infrastructure providers.

The characterisation of the main subsystems of the main railway networks was carried out in the project MERLIN. The standardisation and calibration of energy meters and data communication, from on-board energy meters to smart grid components, were analysed and assessed due to the lack of standards. Energy consumption maps of four different representative networks were also developed by the project. These energy consumption maps comprehensively represent the energy flows in the whole railway power supply system. The four different networks assessed through the energy consumption maps were the network of the French Rail Network (RFF), the Swedish network of Trafikverket, the Spanish network of the Administrator of Railway Infrastructures (ADIF), and the British network of Network Rail.

6.6.4 Implications for future research

The results from the E-ferry project show that more research is needed to bring the electric ferry design to demonstration, with the minor parts holding up the construction of the overall vessel. Similarly, the HYBRID_Boats project has yet to be demonstrated in a full operational test. Electric waterborne transport is a new area of technology and will require significantly more research and funding before electric vessels are developed sufficiently to be commercialised.

From the project MarketStudy-OV a very promising area for waterborne electrification was small ferries. Future research could be focused on closing the relatively small technology gap between the current product and suitable products for small ferries. This could help the technology to break into this market and improve the electrification within waterborne transport.

The possibility of hybrid systems in future large civil aircraft is being explored in the ASuMED project. As air transport is typically hard to decarbonise, it would be beneficial for future research to be focused on the hybrid aircraft concept. This would require efficient and lightweight motors being developed, as well as lightweight batteries. Further research could focus on the further development of lightweight electric components for aircraft, as well as the safety implications of large on-board battery packs.

6.6.5 Implications for future policy development

Policy would be needed to ensure a consistent and fair approach, as consideration would be needed for the location of charging points' interoperability issues. Lessons learned from the road transport electrification could be applied in this case, as interoperability between charge points is key for a successful electric transport network.

Consideration will need to be given towards future funding of electric waterborne and aviation projects, such as E-ferry, HYBRID_Boats and ASuMED. This is because the electrification of these modes still requires considerable research, with HYBRID_Boats yet to demonstrate their technology and the aircraft being explored in ASuMED still requiring improvements to certain components. Other alternative fuels, such as natural gas (and biogas in future) for shipping and advanced biofuels for aviation, may prove to be more promising routes to decarbonising waterborne and aviation transport given that there is still major research required in the electrification of these modes.

7 Conclusions

Focusing on selected EU-funded projects, this report presents a comprehensive analysis of R&I in transport electrification in Europe in the last years. The report identifies relevant researched technologies and their development phase and highlights the relevant policy context and the market activities both in Europe and outside. From the assessment carried out, key conclusions are:

Overview on European ELT research funding

— Under FP7 and H2020 about €3.07 bn has been invested in ELT research projects. This includes €1.85 bn of EU funds and about €1.22 bn of own contributions by beneficiary organisations. The large majority of these projects were funded through the 'Smart, Green and Integrated Transport' programme.

— From the data it can be seen that funding have been increasing, particularly in the fields of road and air transport. Rail transport, which is already largely electrified, receives a relatively little amount of research funding. The daily funding culminated in the first quarter of 2018 above €600,000.

— A total of 2,230 unique organisations participated in FP7 and/or H2020 projects on ELT. Some organisations focus exclusively on ELT research in one mode of transport, whereas others conduct research across modes. Of the top-15 beneficiaries, 15 are active in road, 10 in multimodal, 3 in air, 3 in waterborne and 1 in rail transport.

— From a text analysis on scientific research from the Scopus database, the number of publications on ELT in general has an increasing trend from year to year, with the annual publication of documents related to the various aspects of transport electrification rising significantly from 2010 to 2019 and the majority of research being carried out within three fields: engineering, energy and environmental sciences.

— Among the top-20 technologies that were researched in FP programmes in terms of total budget, 15 are linked to the road transport mode. *Hydrogen storage system* is linked to multimodal transport, *aviation hybrid electric powertrain* is linked to aviation, while, *hydrogen production using an electrolyser system*, *electric ship concept* and *electric propulsion system for vessels* are linked to waterborne transport. The top-3 technologies in terms of funding are *public charging infrastructure* (€628 m), *hydrogen refuelling station using ionic compressor* (€270 m) and *fuel cell hybrid bus* (€196 m).

Project related findings by sub-theme

More specific findings focus on the R&I of the six sub-themes. On the Battery and energy management systems sub-theme:

— Due to the large amount of funding and attention received by improving battery technologies, the results from the research projects show significant achievements in terms of improving energy densities of batteries and improving energy management systems.

— Future research could be focused on raising the development phases of the higher energy density batteries, which would potentially allow for lighter batteries or improved vehicle driving range. Focusing also on post Li-Ion battery solutions could be a key for the EU to gain ground in this domain. On the other hand, since it is difficult for European funded projects to keep pace with the battery developments made by the manufacturers, there may be advantages in focussing future research on other areas of battery development, such as reducing the environmental impact of the battery lifecycle. In this context, research could be focused on the scale-up of methods, helping to further reduce the life-cycle environmental impact of batteries and electric vehicles, helping the European industry to become a world leader in this sector.

On the Charging technology and infrastructure sub-theme:

— Most of the research is focused on dynamic wireless charging, grid management and vehicle to grid technologies. More research around smart charging, managed charging and V2G should be considered. The management of charging demand will need to be coordinated and ensure that transport and energy system functionality is not detrimentally affected while minimising the cost of infrastructure investment. The complete integration of electric vehicles into the electricity grid with bi-directional power flows and supporting business models should be explored.

— Based on the projects focusing on inductive charging, it would seem that there is potential for this charging method in the future. The pre-normative research in this field could lead to standards that would then be helpful to ensure a single market in the EU.

- Moreover, considering a scenario where smart charging and V2G technology is implemented across Europe, more field operational tests may be needed to also study different options for payment schemes that could support the development of a fair electricity trading platform between electricity suppliers and users.

On the Power electronics, motors, and transmission systems for EVs sub-theme:

- Research has shown that it is possible to manufacture a motor for EVs without the use of rare-earth metals and relevant research could be useful since as the uptake of electric vehicles increases, these rare-earth metals will become increasingly in demand.
- Several novel manufacturing processes were investigated, and the cost effectiveness of the methods were proven up to medium-volume production of EVs. As these methods have shown promise, future research could be based on proving the cost effectiveness for large-scale EV manufacturing. Once this has been completed the development phase could be raised from validation to demonstration and implementation and applied to real-world manufacturing processes.
- New materials were developed, a very important area for weight reduction, cost and environmental impacts of manufacturing. More research is likely to be needed in this area to improve on current state-of-the-art as reduced vehicle weight can improve the performance, while the life-cycle implications of these materials will need to be assessed.

On the Hydrogen fuel cells and hydrogen refuelling sub-theme:

- The cost and efficiency of hydrogen dispensing will be a factor in the widespread uptake of hydrogen vehicles. Short refuelling times for hydrogen vehicles give an advantage over BEVs in this aspect; further research is needed to validate the high level of throughput to ensure that the short refuelling time that was achieved through research can be achieved in real-world scenarios.
- Innovative storage systems could offer an improved solution to current hydrogen transportation and storage, which is often seen as a limitation for hydrogen fuelled vehicles. Upon completion of relevant field testing, further research should be conducted to assess the commercial viability of this product, and whether it is suitable for scale-up and wider implementation.
- Future research should ensure that hydrogen used in transport has a low carbon footprint to avoid negligible CO_2 reductions or even worse performance than fossil fuels.
- If innovative hydrogen storage systems currently being tested are found to be successful in the field tests, then policy will be needed to ensure the safe delivery and storage of hydrogen across Europe.

On the Electromobility sub-theme:

- There have been several 'micro' mobility electric prototypes produced which have shown improvements in energy efficiency and safety. The next step is to bring these from the prototype development phase and into implementation. Future research could focus on bringing these technologies to market, with assessment into potential demand for the vehicles. Future research could also consider the most efficient way of introducing these vehicles into the transport and energy system to avoid potential unintended negative impacts of increasing overall energy consumption and emissions through use of more but smaller vehicles, and a potential increase in congestion.
- There have been achievements in terms of bringing electrification to the urban freight sector. Future policy development should reflect the need for a reduction in urban freight emissions, and the results from the electromobility projects shown that this is possible with transport electrification.

On the Electrification of other transport modes sub-theme:

- Electric waterborne transport is a new area of technology and will require significantly more research and funding before electric vessels are developed sufficiently to be commercialised.
- A very promising area for waterborne electrification was small ferries. Future research could be focused on closing the relatively small technology gap between the current product and suitable products for small ferries. This could help the technology to break into this market and improve the electrification within waterborne transport.
- As air transport is typically hard to decarbonise, it would be beneficial for future research to be focused on the hybrid aircraft concept. This would require efficient and lightweight motors being developed, as

well as lightweight batteries. Further research could focus on the further development of lightweight electric components for aircraft, as well as the safety implications of large on-board battery packs.

- Incorporating electrification into waterborne transport would require cooperation between manufacturers, operators and charging infrastructure providers. Policy would be needed to ensure a consistent and fair approach, as consideration would be needed for the location of charging points' interoperability issues. Lessons learned from the road transport electrification could be applied in this case, as interoperability between charge points is key for a successful electric transport network.

Altogether, this report provides a comprehensive and up-to-date review of ELT R&I across Europe. Although with limitations (more notably, the lack of MS projects in the assessment), findings and insights into the current R&I status and future needs, help the STRIA WG to better identify R&I activities and provides valuable information to connected and automated transport stakeholders.

References

ACEA, *Trends in fuel type of new cars between 2016 and 2017, by country*, 2018; available at: https://www.acea.be/statistics/article/trends-in-fuel-type-of-new-cars-between-2016-and-2017-by-country (last accessed 7 April 2020).

ACEA, *Key Figures*, 2019; available at: ps://www.acea.be/statistics/tag/category/key-figures (last accessed 7 April 2020).

ACEA, *Fuel types of new cars: petrol +11.9%, diesel -3.7%, electric +80.5% in fourth quarter of 2019*, 2020a; available at: https://www.acea.be/press-releases/article/fuel-types-of-new-cars-petrol-11.9-diesel-3.7-electric-81.3-in-fourth-quart (last accessed 16 October 2020).

ACEA, *Passenger car registrations: -38.1% first half of 2020; -22.3% in June*, 2020b; available at: https://www.acea.be/press-releases/article/passenger-car-registrations-38.1-first-half-of-2020-22.3-in-june (lat accessed 16 October 2020).

ACEA, *Fuel types of new cars: petrol 51.9%, diesel 29.4%, electric 7.2% market share second quarter 2020,* 2020c; available at: https://www.acea.be/press-releases/article/fuel-types-of-new-cars-petrol-51.9-diesel-29.4-electric-7.2-market-share-se (last accessed 16 October 2020).

Airbus, *The future is electric*, 2018; available at: https://www.airbus.com/newsroom/news/en/2018/07/the-future-is-electric.html (last accessed 7 April 2020).

Airbus, *Airbus reveals new zero-emission concept aircraft*, 2020; https://www.airbus.com/newsroom/press-releases/en/2020/09/airbus-reveals-new-zeroemission-concept-aircraft.html (last accessed 16 October 2020).

ALICE / ERTRAC Urban mobility WG, *Urban freight research roadmap*, ERTRAC, Brussels, 2015.

Alstom, *Alstom's hydrogen train enters regular passenger service in Austria*, 2020; available at: https://www.alstom.com/press-releases-news/2020/9/alstoms-hydrogen-train-enters-regular-passenger-service-austria (last accessed 16 October 2020).

BBC News, *France set to ban sale of petrol and diesel vehicles by 2040*, 2017; available at: https://www.bbc.com/news/world-europe-40518293 (last accessed 9 April 2020).

Bloomberg, *China Is Leading the World to an Electric Car Future*, 2018; available at: https://www.bloomberg.com/news/articles/2018-11-14/china-is-leading-the-world-to-an-electric-car-future (last accessed 9 April 2020).

Bloomberg New Energy Finance, *Electric Vehicle Outlook 2020*, 2020; available at: https://about.bnef.com/electric-vehicle-outlook/#toc-download (last accessed 7 August 2020).

Bower, G., *Tesla Model 3 2170 Energy Density Compared To Bolt, Model S P100D*, 2019; available at: https://insideevs.com/news/342679/tesla-model-3-2170-energy-density-compared-to-bolt-model-s-p100d/ (last accessed 7 April 2020).

Brodie, C., *India will sell only electric cars within the next 13 years*, 2017; available at: https://www.weforum.org/agenda/2017/05/india-electric-car-sales-only-2030/ (last accessed 9 April 2020).

Burke-Kennedy, E., *Ireland 2040: €22bn to turn State into low-carbon economy*, 2018; available at: https://www.irishtimes.com/business/energy-and-resources/ireland-2040-22bn-to-turn-state-into-low-carbon-economy-1.3394805 (last accessed 9 April 2020).

California Air Resources Board, *Zero-Emission Vehicle Program*, 2019; available at: https://ww2.arb.ca.gov/our-work/programs/zero-emission-vehicle-program/about (last accessed 20 November 2019).

CPC, *Cooperative Patent Classification*, 2019; available at: https://www.cooperativepatentclassification.org (last accessed 26 February 2019).

EEA, *Greenhouse gas emissions from transport in Europe*, 2018; available at: https://www.eea.europa.eu/data-and-maps/indicators/transport-emissions-of-greenhouse-gases/transport-emissions-of-greenhouse-gases-11 (last accessed 15 December 2019).

European Alternative Fuels Observatory, *European Alternative Fuels Observatory*, 2020; available at: http://www.eafo.eu (last accessed 30 January 2020).

European Commission, *WHITE PAPER Roadmap To A Single European Transport Area – Towards A Competitive And Resource Efficient Transport System,* COM/2011/0144 final, 2011.

European Commission, *Commission Decision C(2014)4995, Horizon 2020 – Work Programme 2014-2015, Annex G: Technology readiness levels (TRL),* 2014; available at: https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf (last accessed 7 April 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, *Towards clean, competitive and connected mobility: the contribution of Transport Research and Innovation to the Mobility package,* Commission Staff Working Document, SWD/2017/0223 final, 2017b.

European Commission, *TRIMIS Transport and Research and Innovation Monitoring and Information System*, 2017c; available at: https://trimis.ec.europa.eu/ (last accessed 17 November 2019).

European Commission, *The European Green Deal,* Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, COM/2019/640 final, 2019.

European Commission, *Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people*, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM/2020/562 final, 2020a.

European Commission, *European Battery Alliance,* 2020b; available at: https://ec.europa.eu/growth/industry/policy/european-battery-alliance_en (last accessed 16 October 2020).

European Parliament and Council of the European Union, 'Regulation (EU) 2019/631 of the European Parliament and of the Council of 17 April 2019 setting CO2 emission performance standards for new passenger cars and for new light commercial vehicles, and repealing Regulations (EC) No 443/2009 and (EU) No 510/201', *Official Journal of the European Union*, Vol. L No. 111, pp. 13–53, 2019.

Eurostat, *Transport - Data - Database*, 2019; available at: https://ec.europa.eu/eurostat/web/transport/data/database (last accessed 29 September 2019).

Eviation, *Alice*, 2019; available at: https://www.eviation.co/alice/ (last accessed 7 April 2020).

Fishman, T., Myers, R. J., Rios, O. and Graedel, T. E., 'Implications of emerging vehicle technologies on rare earth supply and demand in the United States', *Resources*, Vol. 7, No. 1, pp. 1–15, 2018. https://doi.org/10.3390/resources7010009.

Gjerding Nielson, E., *Denmark embraces electric car revolution with petrol and diesel ban plan*, 2018; available at: https://www.reuters.com/article/us-denmark-autos/denmark-embraces-electric-car-revolution-with-petrol-and-diesel-ban-plan-idUSKCN1MC121 (last accessed 9 April 2020).

Gkoumas, K., Tsakalidis, A., van Balen, M., Grosso, M., Haq, G., Ortega Hortelano, A. and Pekar, F., *Inventory, Modelling and Assessment of New and Emerging Technologies and Trends (NETT) in the transport sector: A methodology for the Transport Research and Innovation Monitoring and Information System (TRIMIS)*, Publications Office of the European Union, Luxembourg, 2018. https://doi.org/10.2760/552646.

Gkoumas, K., van Balen, M., Ortega Hortelano, A., Tsakalidis, A., Grosso, M., Haq, G. and Pekar, F., *Research and innovation in transport infrastructure in Europe: 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/10.2760/065365.

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, pp. 455–466. 2019. https://doi.org/10.3846/transport.2019.9318.

Gkoumas, K., Marques dos Santos, F., Tsakalidis, A., Van Balen, M., Ortega Hortelano, A., Grosso, M. and Pekar, F., *New and Emerging Transport Technologies and Trends in European Research and Innovation Projects-An assessment based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)*, Publications Office of the European Union, Luxembourg, 2020. https://doi.org/10.2760/977404, JRC121318.

Glaser, B. G. and Strauss, A. L., *The Discovery of Grounded Theory: Strategies for Qualitative Research*, Aldine Transaction, New Brunswick, 1967.

Global Railway Review, *First hydrogen fuel cell passenger train approved for service in Germany*, 2018; available at: https://www.globalrailwayreview.com/news/71394/hydrogen-fuel-cell-germany/ last accessed 7 April 2020).

Green Car Congress, *Swiss Post, Austrian Post to move to fully electric fleets by 2030*, 2019; available at: https://www.greencarcongress.com/2019/03/20190305-ev100.html (last accessed 7 April 2020).

Gröger, O., Gasteiger, H. A. and Suchsland, J.-P., 'Review—Electromobility: Batteries or Fuel Cells?', *Journal of The Electrochemical Society*, Vol. 162, No. 14, pp. A2605–A2622, 2015. https://doi.org/10.1149/2.0211514jes.

Hampel, C., *Sweden to ban sales of fossil-fuel powered cars by 2030*, 2019; available at: https://www.electrive.com/2019/01/22/sweden-joins-nations-dropping-combustion-engines-target-2030/ (last accessed 9 April 2020).

Harrabin, R., *New diesel and petrol vehicles to be banned from 2040 in UK*, 2017; available at: https://www.bbc.com/news/uk-40723581 (last accessed 9 April 2020).

ICAO, *Aircraft CO2 Emissions Standard Metric System*, 2017a; available at: https://www.icao.int/environmental-protection/Documents/CO2 Metric System - Information Sheet.pdf (last accessed 9 April 2020).

ICAO, *ICAO Council adopts new CO2 emissions standard for aircraft*, 2017b available at: https://www.icao.int/newsroom/pages/icao-council-adopts-new-co2-emissions-standard-for-aircraft.aspx (last accessed 9 April 2020).

IEA, *Global EV Outlook 2020*, IEA, Paris, 2020.

IEA, *The Future of Rail - Opportunities for energy and the environment*, 2019; available at: https://www.iea.org/futureofrail/ (last accessed 7 April 2020).

IMO, *Low carbon shipping and air pollution control*, 2019; available at: http://www.imo.org/en/MediaCentre/HotTopics/GHG/Pages/default.aspx (last accessed 20 November 2019.

INTEND, *Home - Intend Project*, 2017; available at: https://intend-project.eu (last accessed 26 February 2019).

Lambert, F., *The Dutch government confirms plan to ban new petrol and diesel cars by 2030*, 2017; available at: https://electrek.co/2017/10/10/netherlands-dutch-ban-petrol-diesel-cars-2030-electric-cars/ (last accessed 9 April 2020).

Lilium, *The Jet*, 2019; available at: https://lilium.com/the-jet (last accessed 7 April 2020).

McLellan, B. C., Corder, G. D., Golev, A. and Ali, S. H., 'Sustainability of the Rare Earths Industry', *Procedia Environmental Sciences*, vol. 20, pp. 280–287, 2014. https://doi.org/10.1016/j.proenv.2014.03.035.

Miao, Y., Hynan, P., Von Jouanne, A. and Yokochi, A., 'Current li-ion battery technologies in electric vehicles and opportunities for advancements', *Energies*, Vol. 12, No. 6, pp. 1–20, 2019. https://doi.org/10.3390/en12061074.

Petzinger, J., *Tired of waiting on the auto industry, the German postal service built its own e-trucks*, 2017; available at: https://qz.com/1158107/the-german-postal-service-has-built-its-own-electric-trucks/ (last accessed 7 April 2020).

Railway Gazette International, *'World's largest fleet of fuel cell trains' ordered*, 2019; available at: https://www.railwaygazette.com/news/traction-rolling-stock/single-view/view/worlds-largest-fleet-of-fuel-cell-trains-ordered.html (last accessed 7 April 2020).

Railway Technology, *Powering the trains of tomorrow*, 2017; available at: https://www.railway-technology.com/features/featurepowering-the-trains-of-tomorrow-5723499/ (last accessed 7 April

2020).

Staufenberg, J., *Norway to 'completely ban petrol powered cars by 2025'*, 2016; available at: https://www.independent.co.uk/environment/climate-change/norway-to-ban-the-sale-of-all-fossil-fuel-based-cars-by-2025-and-replace-with-electric-vehicles-a7065616.html (last accessed 9 April 2020).

Sustainable Transport in China, *New Policy on Electric Buses Published in China*, 2015; available at: http://www.sustainabletransport.org/archives/3607 (last accessed 9 April 2020).

Szymkowski, S., *UK Royal Mail electric vans now entering service*, 2017; available at: https://www.greencarreports.com/news/1112324_uk-royal-mail-electric-vans-now-entering-service (last accessed 7 April 2020).

Thiel, C., Tsakalidis, A. and Jäger-Waldau, A., 'Will Electric Vehicles Be Killed (again) or Are They the Next Mobility Killer App?', *Energies*, Vol. 13, No. 7, pp. 1828, 2020. https://doi.org/10.3390/en13071828.

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.

Tsakalidis, A., Julea, A. and Thiel, C., 'The Role of Infrastructure for Electric Passenger Car Uptake in Europe', *Energies*, Vol. 12, No. 22, pp. 4348, 2019. https://doi.org/10.3390/en12224348.

Tsakalidis, A. and Thiel, C., *Electric vehicles in Europe from 2010 to 2017: is full-scale commercialisation beginning?*, Publications Office of the European Union, Luxembourg, 2018. https://doi.org/10.2760/8053.

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, pp. 3171, 2020a. https://doi.org/10.3390/su12083171.

Tsakalidis, A., Krause, J., Julea, A., Peduzzi, E., Pisoni, E. and Thiel, C., 'Electric light commercial vehicles: Are they the sleeping giant of electromobility?', *Transportation Research Part D: Transport and Environment*, Vol. 86, 102421, 2020b. https://doi.org/10.1016/j.trd.2020.102421.

van Balen, M., Ortega Hortelano, A., Grosso, M., Tsakalidis, A., Gkoumas, K., Haq, G. and Pekar, F., *EU Transport Research & Innovation status assessment report: An overview based on the Transport Research and Innovation Monitoring and Information System (TRIMIS) database*, Publications Office of the European Union, Luxembourg, 2019. https://doi.org/10.2760/6954.

Wiseman, E., *Hydrogen fuel cell trains to run on British railways from 2022*, 2019; available at: https://www.telegraph.co.uk/cars/news/hydrogen-fuel-cell-trains-run-british-railways-2022/ (last accessed 7 April 2020].

List of abbreviations and definitions

AC	Alternating Current
ACEA	European Automobile Manufacturers Association
ADIF	Administrator of Railway Infrastructures
ALT	Low-Emission Alternative Energy for Transport
APU	Auxiliary Power Unit
AT	Austria
BE	Belgium
BEV	Battery Electric Vehicle
BG	Bulgaria
CAT	Cooperative, Connected and Automated Transport
CEF	Connecting Europe Facility
CH	Switzerland
CO_2	Carbon Dioxide
CORDIS	Community Research and Development Information Service
CY	Cyprus
CZ	Czechia
DC	Direct Current
DE	Germany
DG MOVE	Directorate-General for Mobility and Transport
DG RTD	Directorate-General for Research and Innovation
DK	Denmark
DWPT	Dynamic Wireless Power Transfer
EAFO	European Alternative Fuels Observatory
EBA	European Battery Alliance
EC	European Commission
EE	Estonia
EEDI	Energy Efficiency Design Index
EGCI	European Green Cars Initiative
EL	Greece
eLCV	Electric Light Commercial Vehicle
ELT	Transport electrification
ES	Spain
EU	European Union
EU28	Group of 28 EU countries
Euro NCAP	European New Car Assessment Programme
EV	Electric Vehicle
FCH	Fuel Cells and Hydrogen
FEV	Fully-Electric Vehicle

FI	Finland
FR	France
FP	Framework Programme
FP4	4th Framework Programme of European Community Activities in the Field of Research and Technological Development and Demonstration
FP7	7th Framework Programme for Research
GHG	Greenhouse Gas
GWP	Global Warming Potential
H_2	Hydrogen
H2020	Horizon 2020 Framework Programme for Research and Innovation
HDV	Heavy Duty Vehicle
HR	Croatia
HU	Hungary
HVAC	Heating, Ventilation and Air Conditioning
ICAO	International Civil Aviation Organisation
ICE	Internal Combustion Engine
ICT	Information and Communication Technologies
IE	Ireland
IEA	International Energy Agency
IMO	International Maritime Organisation
INF	Transport Infrastructure
IT	Italy
JIVE	Joint Initiative for Hydrogen Vehicles Across Europe
JRC	Joint Research Centre
LCA	Life-Cycle Assessment
Li-ion	Lithium-ion
LIB	Lithium-ion Batteries
LOHC	Liquid Organic Hydrogen Carrier
LSA	Light-Sport Aircraft
LT	Lithuania
LU	Luxembourg
LV	Latvia
MFF	Multiannual Financial Framework
MS	Member State
MT	Malta
NASA	National Aeronautics and Space Administration
NETT	New and Emerging Technologies and Trends
NL	Netherlands
NO_x	Nitrogen Oxide

NTM	Network and Traffic Management Systems
OEM	Original Equipment Manufacturer
PHEV	Plug-In Hybrid Electric Vehicle
PL	Poland
PM	Particulate Matter
PMSM	Permanent Magnet Synchronous Machine
PT	Portugal
R&I	Research and Innovation
REGEX	Regular expressions
RFF	French Rail Network
RO	Romania
SE	Sweden
SI	Slovenia
SK	Slovakia
SME	Small and Medium Enterprise
SMO	Smart Mobility and Services
SOC	State of Charge
SOFC	Solid Oxide Fuel Cell
SO_x	Sulphur Oxides
STRIA	Strategic Transport Research and Innovation Agenda
SUV	Sport Utility Vehicle
SYRM	Synchronous Reluctance Machine
TfL	Transport for London
TRIMIS	Transport Research and Innovation Monitoring and Information System
TRL	Technology Readiness Level
UK	United Kingdom
UN	United Nations
US	United States
V2G	Vehicle-to-Grid
VDM	Vehicle Design and Manufacturing
WG	Working Group
WTW	Well-to-Wheel
ZLEV	Zero and Low-Emission Vehicle

List of figures

List of tables

Annexes

Annex 1. Project tables

The following table shows all projects that were considered during the development of this report and the sub-theme(s) under which they were considered.

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
1000kmPLUS	Scalable European Powertrain Technology Platform for Cost-Efficient Electric Vehicles to Connect Europe	2019-2022	H2020-EU.3.4			Y			
2021 GRIP	Crouzet Next Grip Generation	2019-2021	H2020-EU.3.4			Y			
3EMOTION	Environmentally Friendly, Efficient Electric Motion	2015-2019	FP7-JTI				Y		
ACCURATE	Aerospace Composite Components - Ultrasonic Robot Assisted Testing (ACCURATE)	2017-2021	H2020-EU.3.4.						Y
ACEP	Airlander Civil Exploitation Project	2015-2017	H2020-EU.3.4.						Y
ACHILES	Advanced Architectures Chassis/Traction concept for Future Electric vehicles	2018-2022	H2020-EU.3.4			Y			
Adaptcontrol	A modular and compact controller design for light electric vehicles	2015-2019	H2020-EU.3.4.					Y	
ADVICE	ADvancing user acceptance of general purpose hybridized Vehicles by Improved Cost and Efficiency	2017-2020	H2020-EU.3.4			Y			
AHEAD	Advanced Hybrid Engines for Aircraft Development	2011-2014	FP7-TRANSPORT						Y
ALISE	Advanced Lithium Sulphur battery for xEV	2015-2019	H2020-EU.2.1.	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
ALIVE	Advanced High Volume Affordable Lightweighting for Future Electric Vehicles	2012-2016	FP7-TRANSPORT	Y					
AMBER-ULV	Automotive Mechatronic Baseline for Electric Resilient Ultra Light Vehicle	2013-2016	FP7-TRANSPORT					Y	
AMELIE	Advanced Fluorinated Materials for High Safety, Energy and Calendar Life Lithium Ion Batteries	2011-2013	FP7-TRANSPORT			Y			
AMPS	Aircraft Modular Power Converter Solutions	2018-2020	H2020-EU.3.4.						Y
APU-OFF	Auxiliary Power Unit SubstitutiOn Service For AircraFt	2017-2017	H2020-EU.3.4.						Y
AQUASONIC DIESEL	FUEL EFFICIENCY AND EMISSIONS REDUCTION SYSTEM FOR THE MARITIME AND ROADTRANSPORT INDUSTRIES	2018-2020	H2020-EU.2.1.			Y			Y
ARMEVA	Advanced Reluctance Motors for Electric Vehicle Applications	2013-2016	FP7-TRANSPORT			Y			
ARTEMIS	Automotive pemfc Range extender with high TEMperature Improved meas and Stacks	2012-2015	FP7-JTI				Y		
ASSURED	fASt and Smart charging solutions for full size URban hEavy Duty applications	2017-2021	H2020-EU.3.4		Y				
ASTERICS	Ageing and efficiency Simulation & TEsting under Real world conditions for Innovative electric vehicle Components and Systems	2012-2015	FP7-TRANSPORT			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
ASuMED	Advanced Superconducting Motor Experimental Demonstrator	2017-2020	H2020-EU.3.4.						Y
AURORA	Advanced User-centric efficiency metRics for air traffic perfORmance Analytics	2016-2018	H2020-EU.3.4.	Y					
AUTOMICS	Pragmatic solution for parasitic-immune design of electronics ICs for automotive	2012-2015	FP7-ICT			Y			
AUTO-STACK	Automotive Fuel Cell Stack Cluster Initiative for Europe	2010-2011	FP7-JTI				Y		
AUTO-STACK CORE	Automotive Fuel Cell Stack Cluster Initiative for Europe II	2013-2017	FP7-JTI				Y		
AUTOSUPERCA P	Development of High Energy/High Power Density Supercapacitors for Automotive Applications	2011-2014	FP7-NMP			Y			
Auxilia	Hybrid Drive for Commercial Ships and Yachts	2017-2017	H2020-EU.3.4			Y			
AVENUE	Autonomous Vehicles to Evolve to a New Urban Experience	2018-2022	H2020-EU.3.4.					Y	
AVTR	Optimal Electrical Powertrain via Adaptable Voltage and Transmission Ratio	2012-2015	FP7-ICT			Y			
BASIC	Battery Modular System Integrated with Conversion	2014-2016	FP7-JTI	Y					
BATMAN	Feasibility study of a high energy BATtery with novel Metallic lithium ANode	2015-2016	H2020-EU.3.4.	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
BATTERIES2020	BATTERIES2020: TOWARDS REALISTIC EUROPEAN COMPETITIVE AUTOMOTIVE BATTERIES	2013-2016	FP7-NMP	Y					
BATTERY PLUS	High performing batteries for accelerated uptake of hybrid and electric vehicles	2018-2018	H2020-EU.3.4.	Y					
BEHICLE	BEst in class veHICLE: Safe urban mobility in a sustainable transport value-chain (BEHICLE)	2013-2017	FP7-TRANSPORT					Y	
BITRIDE BIKE SHARING	The solution for flexible bike sharing initiatives without fixed stations	2017-2018	H2020-EU.3.4.					Y	
BuyZET	BuyZET - Procurement of innovative solutions for zero emission urban delivery of goods and services	2016-2019	H2020-EU.3.4.					Y	
C2C-NewCap	Towards a safe, reliable and cost competitive transport sector in Europe	2017-2017	H2020-EU.3.4.	Y					
CAPOWER	Advanced material for cost effective and high density ultracapacitors for the transport sector	2016-2018	H2020-EU.3.4.	Y					
Carr-e	CARR•e: Lightweight and versatile electric vehicle applied to urban logistics	2017-2017	H2020-EU.3.4.					Y	
CASTOR	Car multi propulsion integrated power train	2010-2013	FP7-ICT			Y			
CATAPULT	novel CATAlyst structures employing Pt at Ultra Low and zero loadings for auTomotive MEAs	2013-2016	FP7-JTI				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
CATHCAT	Novel catalyst materials for the cathode side of MEAs suitable for transportation applications	2013-2015	FP7-JTI				Y		
CEVOLVER	Connected Electric Vehicle Optimized for Life, Value, Efficiency and Range	2018-2022	H2020-EU.3.4.	Y					
CEWET	Cost Effective Wireless Electrical Transportation	2015-2016	H2020-EU.3.4		Y				
ChargeAtHome	CHARGE@HOME: A Software That Enables Fast Charging Services For Electric Vehicles at Home	2017-2018	H2020-EU.3.4		Y				
CHATT	Cryogenic Hypersonic Advanced Tank Technologies	2012-2015	FP7-TRANSPORT				Y		
CHIC	Clean Hydrogen in European Cities	2010-2016	FP7-JTI				Y		
CITY MOVE	City multi-Role Optimised Vehicle	2010-2012	FP7-TRANSPORT					Y	
CityBike	CityBike: A comfortable, safe, and adaptable electric-bike for everyone	2017-2017	H2020-EU.3.4.					Y	
CIVITAS CAPITAL	CIVITAS CAPITAL – making the best of CIVITAS!	2013-2016	FP7-TRANSPORT		Y				
CIVITAS CITYLAB	City Logistics in Living Laboratories	2015-2018	H2020-EU.3.4.					Y	
CIVITAS ECCENTRIC	Innovative solutions for sustainable mobility of people in suburban city districts and emission free freight logistics in urban centres.	2016-2020	H2020-EU.3.4.					Y	

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
COBRA	COatings for BipolaR plAtes	2014-2017	FP7-JTI				Y		
COMPASS	Competitive Auxiliary Power Units for vehicles based on metal supported stack technology	2016-2019	H2020-EU.3.4			Y			
CONCEPT	CONductive fast Charge system for Electric buses in Public Transport	2014-2015	H2020-EU.3.4		Y				
CONCEPT 2	CONductive fast Charge system for Electric buses in Public Transport (2)	2016-2018	H2020-EU.3.4		Y				
CONVENIENT	Complete Vehicle Energy-saving Technologies for Heavy-Trucks	2012-2015	FP7-TRANSPORT			Y			
COPERNIC	COst & PERformaNces Improvement for Cgh2 composite tanks	2013-2016	FP7-JTI				Y		
CORE	CO2 REduction for long distance transport	2012-2015	FP7-TRANSPORT			Y			
COSIVU	Compact, Smart and Reliable Drive Unit for Fully Electric Vehicles	2012-2015	FP7-ICT			Y			
COSMHYC	COmbined hybrid Solution of Metal HYdride and mechanical Compressors for decentralised energy storage and refueling stations	2017-2020	H2020-EU.3.4.				Y		
COSMHYC XL	COmbined hybrid Solution of Metal HYdride and mechanical Compressors for eXtra Large scale hydrogen refuelling stations	2019-2021	H2020-EU.3.4.				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
CREEV	Novel Compound Rotary Engine Range Extender for Electric Vehicles	2016-2018	H2020-EU.3.4.	Y		Y			
CROP	Cycloidal Rotor Optimized for Propulsion	2013-2014	FP7-TRANSPORT						Y
CS2-WP714-DE	Advanced Design of Very High Power Density Piston Engine and Thermal Management Challenges for Aircraft Application	2016-2019	H2020-EU.3.4.						Y
DELIVER	Design of Electric LIght Vans for Environment-impact Reduction	2011-2015	FP7-TRANSPORT			Y			
DEMOBASE	DEsign and MOdelling for improved BAttery Safety and Efficiency	2017-2020	H2020-EU.3.4.	Y					
DESTA	Demonstration of 1st European SOFC Truck APU	2012-2015	FP7-JTI				Y		
DIGIMAN	DIGItal MAterials CharacterisatioN proof-of-process auto assembly	2017-2020	H2020-EU.3.4.				Y		
DISPURSAL	Distributed Propulsion and Ultra-high By-pass Rotor Study at Aircraft Level	2013-2015	FP7-TRANSPORT						Y
DOMUS	Design OptiMisation for efficient electric vehicles based on a USer-centric approach	2017-2021	H2020-EU.3.4			Y			
DRIVEMODE	Integrated Modular Distributed Drivetrain for Electric/Hybrid Vehicles	2017-2020	H2020-EU.3.4			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
E4-Share	Models for ecological, economical, efficient, electric car sharing	2014-2017	JPI UE					Y	
EAGLE	Efficient Additivated Gasoline Lean Engine	2016-2020	H2020-EU.3.4.				Y		
EASYBAT	Models and generic interfaces for easy and safe Battery insertion and removal in electric vehicles	2011-2013	FP7-TRANSPORT	Y					
eCAIMAN	Electrolyte, Cathode and Anode Improvements for Market-near Next-generation Lithium Ion Batteries	2015-2018	H2020-EU.3.4.	Y					
ECOCHAMPS	European COmpetitiveness in Commercial Hybrid and AutoMotive PowertrainS	2015-2018	H2020-EU.3.4			Y			
ECO-FEV	Efficient Cooperative infrastructure for Fully Electric Vehicles	2012-2015	FP7-ICT		Y				
ECOSHELL	Development of new light high-performance environmentally benign composites made of bio-materials and bio-resins for electric car application	2011-2013	FP7-TRANSPORT			Y			
EDAS	Holistic Energy Management for third and fourth generation of EVs	2013-2016	FP7-ICT	Y					
E-DASH	Electricity Demand and Supply Harmonizing for EVs.	2011-2014	FP7-ICT		Y				
EE-VERT	Energy Efficient Vehicles for Road Transport	2009-2012	FP7-TRANSPORT			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
E-ferry	Prototype and full-scale demonstration of next generation 100% electrically powered ferry for passengers and vehicles	2015-2020	Horizon2020						Y
EFUTURE	Safe and Efficient Electrical Vehicle	2010-2013	FP7-ICT			Y			
ELECTRIC_AXLE	Electric axle for hybrid / electric commercial vehicles	2015-2015	H2020-EU.3.4			Y			
ELECTRIC_AXLE 2	Electric axle for commercial vehicles	2016-2018	H2020-EU.3.4			Y			
ELECTRIFIC	Enabling seamless electromobility through smart vehicle-grid integration	2016-2019	H2020-EU.3.4		Y				
ELECTROMOBILITY+	ERA-NET Plus on Electromobility	2010-2015	FP7-TRANSPORT					Y	
ELIBAMA	European Li-Ion Battery Advanced Manufacturing for Electric Vehicles	2011-2014	FP7-TRANSPORT	Y					
E-LIGHT	Advanced Structural Light-Weight Architectures for Electric Vehicles	2011-2013	FP7-TRANSPORT			Y			
ELINKKER	Solutions for TCO optimized electrification of city bus systems	2014-2015	H2020-EU.3.4.					Y	
ELIPTIC	Electrification of Public Transport in Cities	2015-2018	H2020-EU.3.4		Y				

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
E-LOBSTER	Electric LOsses Balancing through integrated STorage and power Electronics towards increased synergy between Railways and electricity distribution networks	2018-2021	H2020-EU.3.3		Y				
ELSA	Energy Local Storage Advanced system	2015-2018	H2020-EU.3.3.	Y					
ELVA	Advanced Electric Vehicle Architectures	2010-2013	FP7-TRANSPORT			Y			
ELVITEN	Electrified L-category Vehicles Integrated into Transport and Electricity Networks	2017-2020	H2020-EU.3.4.					Y	
EMA4FLIGHT	Development of Electromechanical Actuators and Electronic control Units for Flight Control Systems	2017-2021	H2020-EU.3.4.						Y
EMERALD	Energy ManagEment and RechArging for efficient eLectric car Driving	2012-2015	FP7-ICT		Y				
EMEurope	ERA-NET Cofund Electric Mobility Europe	2016-2021	H2020-EU.3.4.					Y	
ENABLEH2	Enabling cryogenic hydrogen based CO2 free air transport (ENABLEH2)	2018-2021	H2020-EU.3.4.				Y		
ENDURUNS	Development and demonstration of a long-endurance sea surveying autonomous unmanned vehicle with gliding capability powered by hydrogen fuel cell	2018-2022	H2020-EU.3.4.				Y		
ENERGIZE	Efficient Energy Management for Greener Aviation	2017-2022	H2020-EU.3.4.	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
EnergyKeeper	Keep the Energy at the right place!	2017-2019	H2020-EU.3.3.	Y					
ENIGMA	Supervisor Control for ENhanced electrIcal enerGy MAnagement	2018-2021	H2020-EU.3.4.	Y					
ENLIGHT	Enhanced Lightweight Design	2012-2016	FP7-TRANSPORT			Y			
EP TENDER	An innovative range extending service for Electric Vehicles (EV), based on a modular range extender, available for on demand rental, and attached occasionally to the EV for long distance trips	2015-2017	H2020-EU.3.4.	Y					
EPICEA	Electromagnetic Platform for lightweight Integration/Installation of electrical systems in Composite Electrical Aircraft	2016-2019	H2020-EU.3.4.						Y
EPSILON	small Electric Passenger vehicle with maximized Safety and Integrating a Lightweight Oriented Novel body architecture	2013-2017	FP7-TRANSPORT					Y	
ESPRIT	Easily diStributed Personal RapId Transit	2015-2018	H2020-EU.3.4.					Y	
ESTEEM	Advanced Energy STorage and Regeneration System for Enhanced Energy Management	2017-2021	H2020-EU.3.4.	Y					
ESTOLAS	A novel concept of an extremely short take off and landing all-surface (ESTOLAS) hybrid aircraft: from a light passenger aircraft to a very high payload cargo/passenger version	2012-2014	FP7-TRANSPORT						Y

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
ESTRELIA	Energy Storage with lowered cost and improved Safety and Reliability for electrical vehicles	2011-2014	FP7-ICT	Y					
E-TSIN	Modular, scalable, multi-funtional, high power density power controller for electrical taxi	2016-2021	H2020-EU.3.4.						Y
EU-elabus4.0	reduce - recycle - reuseeMobility - retrofitting-kits for buses	2015-2015	H2020-EU.3.4			Y			
EU-LIVE	Efficient Urban LIght VEhicles	2015-2018	H2020-EU.3.4			Y			
EUNICE	Eco-design and Validation of In-Wheel Concept for Electric Vehicles	2012-2015	FP7-NMP			Y			
EUROLIION	High energy density Li-ion cells for traction	2011-2015	FP7-TRANSPORT	Y					
EUROLIS	Advanced European lithium sulphur cells for automotive applications	2012-2016	FP7-NMP	Y					
EVADER	eVADER: Electric Vehicle Alert for Detection and Emergency Response	2011-2014	FP7-TRANSPORT					Y	
EVC1000	Electric Vehicle Components for 1000km daily trips (EVC1000).	2019-2021	H2020-EU.3.4			Y			
EVERLASTING	Electric Vehicle Enhanced Range, Lifetime And Safety Through INGenious battery management	2016-2020	H2020-EU.3.4.	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
EVOLUTION	The Electric Vehicle revOLUTION enabled by advanced materials highly hybridized into lightweight components for easy integration and dismantling providing a reduced life cycle cost logic	2012-2016	FP7-NMP					Y	
FABRIC	FeAsiBility analysis and development of on-Road chargIng solutions for future electric vehiCles	2014-2017	FP7-TRANSPORT		Y				
FASTINCHARGE	innovative FAST INductive CHARGing solution for Electric vehicles	2012-2015	FP7-SST		Y				
FCGEN	Fuel Cell Based Power Generation	2011-2015	FP7-JTI			Y			
Fit-4-AMandA	Future European Fuel Cell Technology: Fit for Automatic Manufacturing and Assembly	2017-2020	H2020-EU.3.4.				Y		
FITGEN	Functionally Integrated E-axle Ready for Mass Market Third GENeration Electric Vehicles	2019-2021	H2020-EU.3.4			Y			
FIVEVB	Five Volt Lithium Ion Batteries with Silicon Anodes produced for Next Generation Electric Vehicles	2015-2018	H2020-EU.3.4.	Y					
FLAGSHIPS	Clean waterborne transport in Europe	2019-2022	H2020-EU.3.4.				Y		Y
FlexiFuel-SOFC	Development of a new and highly efficient micro-scale CHP system based on fuel-flexible gasification and a SOFC	2015-2019	H2020-EU.3.3			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
FlexiHyLift	A flexible hybrid forklift that utilises advanced power technology and electronics to offer high performance and efficiency in both indoor and outdoor applications for the logistics industry	2015-2015	H2020-EU.3.4			Y			
FLHYSAFE	Fuel CelL HYdrogen System for AircraFt Emergency operation	2018-2020	H2020-EU.3.4.				Y		
FlyNano	FLYNANO - ELECTRIC AIRCRAFT FEASIBILITY VERIFICATION	2018-2018	H2020-EU.2.1.						Y
FORCE	Future Outboards Run Conventionally and Electrically	2014-2015	H2020-EU.3.4			Y			
FREE-MOBY	People Centric easy to implement e-mobility	2013-2016	FP7-ICT					Y	
FREEWAY	FREEWAY: safely and effortless commute in an urban environment	2015-2017	H2020-EU.3.4.					Y	
FUEREX	Multi-fuel Range Extender with High Efficiency and ultra low Emissions	2011-2012	FP7-TRANSPORT			Y			
FURBOT	Freight Urban RoBOTic vehicle	2011-2015	FP7-TRANSPORT			Y			
GASTONE	New powertrain concept based on the integration of energy recovery, storage and re-use system with engine system and control strategies	2013-2017	FP7-TRANSPORT			Y			
GEM E-drive	In-wheel electric drive for E-commercial vehicles	2015-2015	H2020-EU.3.4.					Y	

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
GFF	Green Fast Ferry - the world's first 30 knots battery powered Air Supported commuter ferry	2016-2018	H2020-EU.3.4.						Y
GHOST	InteGrated and PHysically Optimised Battery System for Plug-in Vehicles Technologies	2017-2021	H2020-EU.3.4.	Y					
Giantleap	Giantleap Improves Automation of Non-polluting Transportation with Lifetime Extension of Automotive PEM fuel cells	2016-2019	H2020-EU.3.4.				Y		
GOFLEX	Generalized Operational FLEXibility for Integrating Renewables in the Distribution Grid	2016-2020	H2020-EU.3.3		Y				
GREEN EMOTION	Green eMotion	2011-2015	FP7-TRANSPORT					Y	
GreenCharge	GreenCharge	2018-2021	H2020-EU.3.4		Y				
GrowSmarter	GrowSmarter	2015-2019	H2020-EU.3.3.					Y	
GSOP-SC	Feasibility assessment on the GreenFlux Service Operations Platform for Smart Charging (GSOP-SC)	2015-2016	H2020-EU.3.4		Y				
H2ME	Hydrogen Mobility Europe	2015-2020	H2020-EU.3.4.				Y		
H2ME 2	Hydrogen Mobility Europe 2	2016-2022	H2020-EU.3.4.				Y		
H2MOVE	Hydrogen generator for higher fuel efficiency and lower carbon emissions in maritime transport	2017-2017	H2020-EU.3.4.				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
H2MOVES SCANDINAVIA	H2moves.eu Scandinavia	2010-2012	FP7-JTI				Y		
H2OCEAN	Development of a wind-wave power open-sea platform equipped for hydrogen generation with support for multiple users of energy	2012-2014	FP7-TRANSPORT				Y		
H2Ports	Implementing Fuel Cells and Hydrogen Technologies in Ports	2019-2022	H2020-EU.3.3.				Y		
H2REF	Development of a Cost Effective and Reliable Hydrogen Fuel Cell Vehicle Refuelling System	2015-2019	H2020-EU.3.4.				Y		
H3PS	H3PS - High Power High Scalability Aircraft Hybrid Powertrain	2018-2021	H2020-EU.3.4.						Y
HARMONY	Title: Holistic Approach for Providing Spatial & Transport Planning Tools and Evidence to Metropolitan and Regional Authorities to Lead a Sustainable Transition to a New Mobility Era	2019-2022	H2020-EU.3.4		Y				
HARVEST	Hierarchical multifunctional composites with thermoelectrically powered autonomous structural health monitoring for the aviation industry	2018-2021	H2020-EU.3.4.						Y
HASTECS	Hybrid Aircraft; academic reSearch on Thermal and Electrical Components and Systems	2016-2021	H2020-EU.3.4			Y			
HAWL	Large scale demonstration of substitution of battery electric forklifts by hydrogen fuel cell forklifts in logistics warehouses	2013-2017	FP7-JTI				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
HCV	Hybrid Commercial Vehicle	2010-2013	FP7-TRANSPORT			Y			
HDBAT	High Density Batteries for e-Mobility and Industrial Automated Guided Vehicles.	2017-2018	H2020-EU.3.4.	Y					
HEAVEN	High powEr density FC System for Aerial Passenger VEhicle fueled by liquid HydrogeN	2019-2022	H2020-EU.3.4.				Y		
HELIS	High energy lithium sulphur cells and batteries	2015-2019	H2020-EU.2.1.	Y					
HEMIS	Electrical powertrain HEalth Monitoring for Increased Safety of FEVs	2012-2014	FP7-ICT			Y			
HEPODIS	HVDC Electrical Power cOnversion and DIstribution System	2016-2020	H2020-EU.3.4		Y				
HiFi-ELEMENTS	High Fidelity Electric Modelling and Testing	2017-2020	H2020-EU.3.4			Y			
HIGH V.LO-CITY	Cities speeding up the integration of hydrogen buses in public fleets	2012-2019	FP7-JTI				Y		
HiPower	Development of a commercial manufacturing process for a low cost, small footprint, high efficiency fully electric compressor and power controls to fulfil a market need for use in heavy goods vehicles	2016-2016	H2020-EU.3.4.					Y	
HIVACS	High Voltage Aerospace Cable System	2019-2021	H2020-EU.3.4.						Y

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
HI-WI	Materials and drives for High & Wide efficiency electric powertrains	2010-2014	FP7-TRANSPORT			Y			
HoxyTronic	Fuel savings and emissions reduction technology	2017-2017	H2020-EU.3.4.				Y		
HPCForEVs	High Power Charger For Electric Vehicles	2017-2019	H2020-EU.3.4.	Y					
HPC-rotors	Disrupting the global e-mobility sector by production of application-specific rotors for the automotive industry with an innovative and unique vertical laminar squeeze-casting process	2018-2020	H2020-EU.2.1			Y			
HyAC	HyAC – high measurement accuracy of hydrogen refueling	2013-2014	FP7-JTI				Y		
HYBPRO	HYBRID PROPULSION FOR AVIATION	2017-2017	H2020-EU.3.4			Y			
HYBRID_BOATS	An innovative hybrid propulsion and generation system for yachts	2015-2016	H2020-EU.3.4.						Y
HYCARUS	HYdrogen cells for AiRborne Usage	2013-2018	FP7-JTI				Y		
Hydrogenlogistics	Enabling the Hydrogen Economy	2017-2019	H2020-EU.3.4.				Y		
HYDRUS	high-pressure HYdrogen booster for DistRibUted small-medium refuelling Stations	2017-2017	H2020-EU.3.4.				Y		
HYFIVE	Hydrogen For Innovative Vehicles	2014-2018	FP7-JTI				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
HYLIFT-DEMO	European demonstration of hydrogen powered fuel cell materials handling vehicles	2011-2014	FP7-JTI				Y		
HYLIFT-EUROPE	HyLIFT-EUROPE - Large scale demonstration of fuel cell powered material handling vehicles	2013-2018	FP7-JTI				Y		
HYMAR	High Efficiency Hybrid Drive Trains for Small and Medium Sized Marine Craft	2009-2012	FP7-TRANSPORT						Y
HYPER	Integrated hydrogen power packs for portable and other autonomous applications	2012-2015	FP7-JTI				Y		
HyPoGA	Feasibility study of a superefficient hybrid power train as a replacement unit for existing engines - Hybrid Power for General Aviation (HyPoGA)	2015-2015	H2020-EU.3.4.						Y
HYPSTAIR	Development and validation of hybrid propulsion system components and sub-systems for electrical aircraft	2013-2016	FP7-TRANSPORT			Y			
HYQ	Hydrogen fuel Quality requirements for transportation and other energy applications	2011-2014	FP7-JTI				Y		
HySeas III	Realising the world's first sea-going hydrogen-powered RoPax ferry and a business model for European islands	2018-2021	H2020-EU.3.4.				Y		
HySolarKit	Converting conventional cars into hybrid and solar vehicles	2015-2015	H2020-EU.3.4			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
HySTOC	Hydrogen Supply and Transportation using liquid Organic Hydrogen Carriers	2018-2020	H2020-EU.3.3.				Y		
HyTEC	Hydrogen Transport in European Cities	2011-2015	FP7-JTI				Y		
HYTECHCYCLIN G	New technologies and strategies for fuel cells and hydrogen technologies in the phase of recycling and dismantling	2016-2019	H2020-EU.3.4.				Y		
HYTRANSIT	European Hydrogen Transit Buses in Scotland	2013-2018	FP7-JTI				Y		
HyTunnel-CS	PNR for safety of hydrogen driven vehicles and transport through tunnels and similar confined spaces	2019-2022	H2020-EU.3.4.				Y		
I3PS	Integration of Innovative Ice Protection Systems	2018-2020	H2020-EU.3.4.						Y
ICE	MagnetoCaloric Refrigeration for Efficient Electric Air Conditioning	2010-2014	FP7-TRANSPORT	Y					
ICOMPOSE	Integrated Control of Multiple-Motor and Multiple-Storage Fully Electric Vehicles	2013-2016	FP7-ICT	Y					
ICT4EVEU	ICT services for Electric Vehicle Enhancing the User experience	2012-2014	CIP					Y	
ID4EV	Intelligent Dynamics for fully electric vehicles	2010-2012	FP7-ICT			Y			
IDEALHY	Integrated Design for Efficient Advanced Liquefaction of Hydrogen	2011-2013	FP7-JTI				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
IDEN	Innovative Distributed Electrical Network	2018-2020	H2020-EU.3.4.	Y					
i-HeCoBatt	Intelligent Heating and Cooling solution for enhanced range EV Battery packs	2019-2021	H2020-EU.3.4.	Y					
IMAGE	Innovative Manufacturing Routes for Next Generation Batteries in Europe	2017-2021	H2020-EU.3.4.	Y					
IMMEDIATE	Innovative autoMotive MEa Development – implementation of Iphe-genie Achievements Targeted at Excellence	2013-2016	FP7-JTI				Y		
iModBatt	Industrial Modular Battery Pack Concept Addressing High Energy Density, Environmental Friendliness, Flexibility and Cost Efficiency for Automotive Applications	2017-2020	H2020-EU.3.4.	Y					
IMPACT	Improved Lifetime of Automotive Application Fuel Cells with ultra low Pt-loading	2012-2016	FP7-JTI				Y		
IMPALA	IMprove PEMFC with Advanced water management and gas diffusion Layers for Automotive application	2012-2015	FP7-JTI				Y		
IMPROVE	Integration and Management of Performance and Road Efficiency of Electric Vehicle Electronics	2013-2016	FP7-ICT	Y					
INCOBAT	INnovative COst efficient management system for next generation high voltage BATteries	2013-2016	FP7-ICT	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
INLINE	Design of a flexible, scalable, high quality production line for PEMFC manufacturing	2017-2020	H2020-EU.3.4.				Y		
INN-BALANCE	INNovative Cost Improvements for BALANCE of Plant Components of Automotive PEMFC Systems	2017-2021	H2020-EU.3.4.				Y		
INOMANS²HIP	INOvative Energy MANagement System for Cargo SHIP	2011-2015	FP7-TRANSPORT	Y					
inteGRIDy	integrated Smart GRID Cross-Functional Solutions for Optimized Synergetic Energy Distribution, Utilization Storage Technologies	2017-2020	H2020-LCE		Y				
InterFlex	Interactions between automated energy systems and Flexibilities brought by energy market players	2017-2019	H2020-EU.3.4		Y				
INVADE	Smart system of renewable energy storage based on INtegrated EVs and bAtteries to empower mobile, Distributed and centralised Energy storage in the distribution grid	2017-2019	H2020-EU.3.3		Y				
iPHEV	Advanced Plug-in Hybrid Electric Drive System for Commercial Fleet Trucks	2015-2016	H2020-EU.3.4			Y			
IRIS	Integrated and Replicable Solutions for Co-Creation in Sustainable Cities	2017-2022	H2020-EU.3.3.	Y					
ISAR	The world's first purpose-built professional all-terrain passenger vehicle	2017-2017	H2020-EU.3.4			Y			
ISG	Induction Starter Generator	2016-2019	H2020-EU.3.4			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
JIVE	Joint Initiative for hydrogen Vehicles across Europe	2017-2022	H2020-EU.3.4.				Y		
JIVE 2	Joint Initiative for hydrogen Vehicles across Europe 2	2018-2023	H2020-EU.3.4.				Y		
JOSPEL	Low energy passenger comfort systems based on the joule and peltier effects.	2015-2018	H2020-EU.3.4.	Y					
JOULES	Joint Operation for Ultra Low Emission Shipping	2013-2017	FP7-TRANSPORT						Y
KITVES	Airfoil-based Solution for Vessel On-board Energy Production Destined to Traction and Auxiliary Services	2008-2012	FP7-TRANSPORT						Y
KTX-20	Mass production platform for L-EVs	2017-2018	H2020-EU.3.4.					Y	
LABOR	Lean robotized AssemBly and cOntrol of composite aeRostructures	2018-2021	H2020-EU.3.4.						Y
LeydenJar	Boosting Battery Energy Density in Electric Vehicles	2017-2017	H2020-EU.3.4.	Y					
LiBAT	Development of a High Voltage Lithium BATtery	2018-2020	H2020-EU.3.4.	Y					
LIFE-BATTERY	Long lifespan battery for hybrid vehicles	2015-2015	H2020-EU.3.4.	Y					
lif-E-Buoy	Compact hydro generator for electric vehicles charging stations (to serve as an energy lifebuoy)	2018-2018	H2020-EU.2.1		Y				

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
LiionFire	Automated e-buses Lithium Ion Battery Early Warning and Fire Suppression System	2018-2019	H2020-EU.3.4.	Y					
Li-IonFire	An Automated HEV and EV Vehicle Fire Early Warning and Suppression System	2015-2016	H2020-EU.3.4.	Y					
LISSEN	Lithium Sulfur Superbattery Exploitating Nanotechnology	2012-2015	FP7-NMP	Y					
LivingRAIL	Living in a sustainable world focused on electrified rail	2012-2015	FP7-TRANSPORT						Y
MAG-DRIVE	New permanent magnets for electric-vehicle drive applications	2013-2016	FP7-TRANSPORT			Y			
MAHEPA	Modular Approach to Hybrid Electric Propulsion Architecture	2017-2021	H2020-EU.3.4.						Y
MARANDA	Marine application of a new fuel cell powertrain validated in demanding arctic conditions	2017-2021	H2020-EU.3.4.				Y		
MarketStudy-OV	Market Research for Oceanvolt zero-carbon emission marine electric propulsion system	2016-2017	H2020-EU.3.4.						Y
MARS-EV	Materials for Ageing Resistant Li-ion High Energy Storage for the Electric Vehicle	2013-2017	FP7-NMP	Y					
MAXITHERM 2	Innovative textile-based heating system for technical applications with a special focus on Electric Vehicles (2)	2016-2018	H2020-EU.3.4			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
MDD	Denis Ferranti JTI-CS2-2017-CfP07-LPA-01-40	2018-2020	H2020-EU.3.4			Y			
me2	Integrated smart city mobility and energy platform	2016-2018	JPI UE		Y				
MEISTER	Mobility Environmentally-friendly, Integrated and economically Sustainable Through innovative Electromobility Recharging infrastructure and new business models	2018-2021	H2020-EU.3.4		Y				
MEM-DG	Modular Electric Motor technology with integrated Digital Gears for increased driving performance	2017-2017	H2020-EU.3.4			Y			
MERLIN	Sustainable and intelligent management of energy for smarter railway systems in Europe: an integrated optimisation approach	2012-2015	FP7-SST	Y					
MISSION	Multifunctional aIrcraft power network with Solid-State electrIcal pOwer SwitchiNg	2019-2021	H2020-EU.3.4.						Y
Mobi	The Mobi Charger, a novel mobile Electric Vehicle charging station that requires no installation costs, offers easy scalability and utility bill savings for users.	2016-2016	H2020-EU.3.4		Y				
MOBIEUROPE	Integrated and Interoperable ICT Applications for Electro-Mobility in Europe	2012-2014	CIP					Y	
MOBILITY2.0	Co-operative ITS Systems for Enhanced Electric Vehicle Mobility	2012-2015	FP7-ICT					Y	
MOBINCITY	SMART MOBILITY IN SMART CITY	2012-2015	FP7-ICT		Y				

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
MOBYPOST	Mobility with Hydrogen for Postal Delivery	2011-2015	FP7-JTI				Y		
ModulED	Modular Electric Drivetrains	2017-2020	H2020-EU.3.4			Y			
MOEWA	MOdular Eco WAterbus ABLE TO BE DIVIDED INTO TWO IDENTICAL INDIPENDENTHYBRID UNITS ALLOWING OPERATING FLEXIBILITY IN TRANSPORTATION	2015-2016	H2020-EU.3.4.						Y
MOLECULES	Mobility based on eLectric Connected vehicles in Urban and interurban smart, cLean, EnvironmentS	2012-2014	CIP					Y	
MOTORBRAIN	Nanoelectronics for electric vehicle intelligent failsafe powertrain	2011-2014	FP7-TRANSPORT			Y			
MultiCharge	Feasibility Study for the Development of a PFC Harmonic Filter Missing Link for Creation of Simultaneous Multi-Point Fast Charging Stations for Electric Vehicles	2015-2015	H2020-EU.3.4		Y				
MVDC-ERS	Flexible medium voltage DC electric railway systems	2018-2021	Shift2Rail		Y				
mySMARTLife	Smart Transition of EU cities towards a new concept of smart Life and Economy	2016-2021	H2020-EU.3.3.					Y	
NANO-CAT	Development of advanced catalysts for PEMFC automotive applications	2013-2017	FP7-JTI				Y		
NEC14	New Electric Vehicle Chassis-Cab 10-14 for urban logistic	2015-2017	H2020-EU.3.4.					Y	

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
NedraEV	A lightweight, fast charging, EV platform to be utilised on Car Share and Urban Mobility Systems	2016-2016	H2020-EU.3.4			Y			
NEMESIS2+	New Method for Superior Integrated Hydrogen Generation System 2+	2012-2015	FP7-JTI				Y		
NeMo	NeMo : Hyper-Network for electroMobility	2016-2019	H2020-EU.3.4.					Y	
NETFFICIENT	Energy and economic efficiency for today's smart communities through integrated multi storage technologies	2015-2018	H2020-EU.3.3.	Y					
NewBusFuel	New Bus ReFuelling for European Hydrogen Bus Depots	2015-2017	H2020-EU.3.4.				Y		
NEWIR	NEW WIRING for VEHICLES	2016-2016	H2020-EU.3.4			Y			
NEWS	Development of a Next generation European Inland Waterway Ship and logistics system	2013-2015	FP7-TRANSPORT						Y
NEXTHYLIGHTS	Supporting action to prepare large-scale hydrogen vehicle demonstration in Europe	2010-2010	FP7-JTI				Y		
OBELICS	Optimization of scalaBle rEaltime modeLs and functIonal testing for e-drive ConceptS	2017-2020	H2020-EU.3.4.	Y					
ODIN	Optimized electric Drivetrain by INtegration	2012-2015	FP7-ICT			Y			
OPENER	Optimal Energy Consumption and Recovery based on system network	2011-2014	FP7-ICT	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
OPEUS	Modelling and strategies for the assessment and OPtimisation of Energy USage aspects of rail innovation	2016-2019	H2020-EU.3.4.						Y
OPTEMUS	Optimised Energy Management and Use	2015-2019	H2020-EU.3.4	Y					
OPTIBODY	Optimized Structural components and add-ons to improve passive safety in new Electric Light Trucks and Vans (ELTVs)	2011-2014	FP7-TRANSPORT			Y			
OPTIMORE	Optimised Modular Range Extender for every day Customer Usage	2012-2014	FP7-TRANSPORT			Y			
ORCA	Optimised Real-world Cost-Competitive Modular Hybrid Architecture for Heavy Duty Vehicles	2016-2020	H2020-EU.3.4			Y			
OSEM-EV	Optimised and Systematic Energy Management in Electric Vehicles	2015-2018	H2020-EU.3.4.	Y					
OSTLER	Optimised storage integration for the electric car	2011-2014	FP7-TRANSPORT	Y					
PACS	Pantograph Active Control System for e-Highways	2017-2017	H2020-EU.3.4		Y				
PANDA	Powerfull Advanced N-Level Digitalization Architecture for models of electrified vehicles and their components	2018-2021	H2020-EU.3.4			Y			
PANORAMIX	PANORAMIX: Platform for the operAtion aNd Optimization in ReAl-time of MIXed autonomous fleets	2018-2018	H2020-EU.3.4.					Y	

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
PEMICAN	PEM with Innovative low cost Core for Automotive applicatioN	2011-2014	FP7-JTI				Y		
PerMarDrive	Integrated PERmanent Magnet Motor-Clutch Drive for Parallel Hybrid Power MARINE Propulsion Systems	2015-2016	H2020-EU.3.4			Y			
PHiVe	Power Electronics High Voltage Technologies	2018-2020	H2020-EU.3.4			Y			
PHP2	Pulsating Heat Pipes for Hybrid Propulsion systems	2018-2022	H2020-EU.3.4.	Y					
PICAV	Personal Intelligent City Accessible Vehicle System	2009-2012	FP7-TRANSPORT					Y	
PLUS-MOBY	Premium Low weight Urban Sustainable e-MOBilitY	2013-2016	FP7-TRANSPORT			Y			
P-MOB	Integrated Enabling Technologies for Efficient Electrical Personal Mobility	2010-2013	FP7-ICT	Y					
POCOL	Power Conversion Units for LifeRCraft demonstrator	2015-2019	H2020-EU.3.4			Y			
POSE²IDON	Power Optimised Ship for Environment with Electric Innovative Designs on Board	2009-2012	FP7-TRANSPORT						Y
POSSUM	POsition-based ServiceS for Utilities Maintenance teams	2012-2014	FP7-TRANSPORT					Y	
POWERSWAP	Fully robotic system for swapping electric car batteries within 3 minutes.	2018-2018	H2020-EU.2.1.	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
POWERUP	Specification, Implementation, Field Trial, and Standardisation of the Vehicle-2-Grid Interface	2011-2013	FP7-ICT		Y				
PRODRIVE	Production-Ready Oriented Development of Radically Innovative Vehicle Electric drive	2016-2018	H2020-EU.3.4			Y			
Project Buffer	Project Buffer - a new solution to fast charging electrical vehicles "on the road".	2015-2016	H2020-EU.3.4		Y				
PUMA MIND	Physical bottom Up Multiscale Modelling for Automotive PEMFC Innovative performance and Durability optimization	2012-2015	FP7-JTI				Y		
PURE	Development of Auxiliary Power Unit for Recreational yachts	2013-2016	FP7-JTI				Y		
QUIET	QUalifying and Implementing a user-centric designed and EfficienT electric vehicle	2017-2020	H2020-EU.3.4.	Y					
REBOOT	Retrofit all-Electric Bus for reduced Operator Operating costs in urban Transport (REBOOT)	2016-2018	H2020-EU.3.4			Y			
REFITT	Rare Earth Free Innovative Truck Traction	2018-2018	H2020-EU.2.1			Y			
ReFreeDrive	Rare Earth Free e-Drives featuring low cost manufacturing	2017-2020	H2020-EU.3.4			Y			
REMOURBAN	REgeneration MOdel for accelerating the smart URBAN transformation	2015-2019	H2020-EU.3.3		Y				

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
REPLICATE	REnaissance of Places with Innovative Citizenship and TEchnolgy	2016-2021	H2020-EU.3.3.					Y	
RESOLVE	Range of Electric SOlutions for L-category VEhicles	2015-2018	H2020-EU.3.4.					Y	
REVIVE	Refuse Vehicle Innovation and Validation in Europe	2018-2021	H2020-EU.3.4.				Y		
Ruggedised	Rotterdam, Umea and Glasgow: Generating Exemplar Districts In Sustainable Energy Deployment	2016-2021	H2020-EU.3.3.					Y	
SAFARI	Sofc Apu For Auxiliary Road-truck Installations	2014-2016	FP7-JTI				Y		
Safe Hydrogen Fuel	Safe Hydrogen-On-Demand Fuel for E-Vehicles	2016-2016	H2020-EU.3.4.				Y		
SAFEADAPT	Safe Adaptive Software for Fully Electric Vehicles	2013-2016	FP7-ICT			Y			
SafeEV	Safe Small Electric Vehicles through Advanced Simulation Methodologies	2012-2015	FP7-SST					Y	
SCALAiR	Scaled Test Aircraft Preparation and Qualification	2016-2021	H2020-EU.3.4			Y			
SeaBubble	Fast-Forwarding to the Future of On-Demand Urban Water Transportation	2017-2017	H2020-EU.3.4.						Y
SELFIE	SELF-sustained and Smart Battery Thermal Management SolutIon for Battery Electric Vehicles	2018-2022	H2020-EU.3.4.	Y					
SHAR-Q	Storage capacity sharing over virtual neighbourhoods of energy ecosystems	2016-2019	H2020-EU.3.3.	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
SHEL	Sustainable Hydrogen Evaluation in Logistics	2011-2014	FP7-JTI				Y		
SHOTL	A shared mobility On-Demand Service	2016-2017	H2020-EU.3.4		Y				
SIBACK	Smart Inceptor BACKup electronics	2018-2020	H2020-EU.3.4			Y			
Silver Stream	Social innovation and light electric vehicle revolution on streets and ambient	2015-2018	H2020-EU.3.4.					Y	
SIRENA	Novel electric stair climber to break barriers in transport of disabled people and goods through a safe, quick and comfortable movement	2018-2020	H2020-EU.2.1.					Y	
SMARTBATT	Smart and Safe Integration of Batteries in Electric Vehicles	2011-2012	FP7-TRANSPORT	Y					
SMARTCAT	Systematic, Material-oriented Approach using Rational design to develop break-Through Catalysts for commercial automotive PEMFC stacks	2013-2017	FP7-JTI				Y		
SmartCEM	Smart Connected Electro Mobility	2012-2014	CIP					Y	
SmartCharge	SmartCharge: Smart integrated circuits for advanced battery management	2018-2018	H2020-EU.2.1	Y					
SMARTFUSION	Smart Urban Freight Solutions	2012-2015	FP7-TRANSPORT					Y	

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
SMART-LIC	Smart and Compact Battery Management System Module for Integration into Lithium-Ion Cell for Fully Electric Vehicles	2011-2014	FP7-ICT	Y					
SMARTOP	Self powered vehicle roof for on-board comfort and energy saving	2010-2013	FP7-TRANSPORT			Y			
SMARTV2G	Smart Vehicle to Grid Interface	2011-2014	FP7-ICT		Y				
SMILE	SMart IsLand Energy systems	2017-2021	H2020-EU.3.3.						Y
SOFTCAR	The cleanest and lowest cost car ever!	2018-2018	H2020-EU.2.1			Y			
SOPHIA	Solar integrated pressurized high temperature electrolysis	2014-2017	FP7-JTI				Y		
SORCERER	Structural pOweR CompositEs foR futurE civil aiRcraft	2017-2020	H2020-EU.3.4.						Y
SPICY	Silicon and polyanionic chemistries and architectures of Li-ion cell for high energy battery	2015-2018	H2020-EU.3.4.	Y					
SPIDER PLUS	Sustainable Plan for Integrated Development through the European Rail Network Projecting Logistics & Mobility for Urban Spatial Design Evolution	2012-2015	FP7-TRANSPORT						Y
STABLE	STable high-capacity lithium-Air Batteries with Long cycle life for Electric cars	2012-2015	FP7-TRANSPORT	Y					

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
STEVE	Smart-Taylored L-category Electric Vehicle demonstration in hEtherogeneous urbanuse-cases	2017-2020	H2020-EU.3.4.					Y	
Storage4Grid	Storage4Grid	2016-2020	H2020-EU.3.3.	Y					
STOREandGO	Innovative large-scale energy STOragE technologies AND Power-to-Gas concepts after Optimisation	2016-2020	H2020-EU.3.3		Y				
STYLUS	Sustainable urban mobiliTY: ELectric double decker bUS	2017-2017	H2020-EU.3.4.					Y	
SUAV	Microtubular Solid Oxide Fuel Cell Power System developement and integration into a Mini-UAV	2011-2015	FP7-JTI				Y		
SUNSET	Storage energy UNit for Smart and Efficient operation on Tarmac	2018-2021	H2020-EU.3.4.	Y					
SUPERLIB	Smart Battery Control System based on a Charge-equalization Circuit for an advanced Dual-Cell Battery for Electric Vehicles	2011-2014	FP7-ICT	Y					
SWARM	Demonstration of Small 4-Wheel fuel cell passenger vehicle Applications in Regional and Municipal transport	2012-2016	FP7-JTI				Y		
SYRNEMO	Synchronous Reluctance Next Generation Efficient Motors for Electric Vehicles	2013-2016	FP7-TRANSPORT			Y			

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
SYS2WHEEL	Integrated components, systems and architectures for efficient adaption and conversion of commercial vehicle platforms to 3rd generation battery electric vehicles for future CO2-free city logistics	2019-2021	H2020-EU.3.4			Y			
TAHYA	TAnk HYdrogen Automotive	2018-2020	H2020-EU.3.4.				Y		
TARGETS	Targeted Advanced Research for Global Efficiency of Transportation Shipping	2010-2014	FP7-TRANSPORT						Y
TAUPE	Transmissions in Aircraft on Unique Path Wires	2008-2012	FP7-TRANSPORT						Y
TEFLES	Technologies and Scenarios For Low Emissions Shipping	2011-2014	FP7-TRANSPORT	Y					
TELL	Towards a fast-uptake of mEdium/Low-voltage eLectric power trains	2018-2021	H2020-EU.3.4			Y			
THEMOTION	TheMotion: Revolution in Motion	2015-2015	H2020-EU.3.4			Y			
THOMSON	Mild Hybrid cOst effective solutions for a fast Market penetratiON	2016-2020	H2020-EU.3.4			Y			
THOR	Thermoplastic Hydrogen tanks Optimised and Recyclable	2019-2021	H2020-EU.3.4.				Y		
TRADE	Turbo electRic Aircraft Design Environment (TRADE)	2017-2020	H2020-EU.3.4.						Y

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
TrAM	Transport: Advanced and Modular	2018-2022	H2020-EU.3.4.						Y
Triangulum	Triangulum: The Three Point Project / Demonstrate. Disseminate. Replicate.	2015-2020	H2020-EU.3.3.					Y	
Turbo-FuelCell	Compact, light, efficient and reliable turbo compressor for fuel cell vehicles	2017-2018	H2020-EU.2.1.				Y		
TVP-eNext	Torque Vectoring Platform for Next Generation of Electric Driven Vehicles	2016-2016	H2020-EU.3.4			Y			
UNPLUGGED	Wireless charging for Electric Vehicles	2012-2015	FP7-TRANSPORT		Y				
UPSCALE	Upscaling Product development Simulation Capabilities exploiting Artificial inteLligence for Electrified vehicles	2018-2022	H2020-EU.3.4			Y			
URBAN-EV	Super Light Architectures for Safe and Affordable Urban Electric Vehicles	2013-2016	FP7-TRANSPORT					Y	
VENUS	Switched/Synchronous Reluctance Magnet-free Motors for Electric Vehicles	2013-2016	FP7-TRANSPORT			Y			
V-FEATHER	InnoVative Flexible Electric Transport	2012-2015	FP7-TRANSPORT			Y			
VOLT	Innovative high VOLTage network battery concept	2016-2021	H2020-EU.3.4.	Y					
VOLUMETRIQ	Volume Manufacturing of PEM FC Stacks for Transportation and In-line Quality Assurance	2015-2019	H2020-EU.3.4.				Y		

Project acronym	Project name	Project duration	Source of funding	Sub theme 1	Sub theme 2	Sub theme 3	Sub theme 4	Sub theme 5	Sub theme 6
WATTsUP	WATTsUP Electric flight to future	2015-2017	H2020-EU.3.4.						Y
WEEVIL	Ultralight and ultrasafe adaptable 3-wheeler	2015-2019	H2020-EU.3.4.					Y	
WIDE-MOB	Building blocks concepts for efficient and safe multiuse urban electrical vehicles	2010-2014	FP7-TRANSPORT			Y			
WiseGRID	Wide scale demonstration of Integrated Solutions and business models for European smartGRID	2016-2020	H2020-EU.3.3		Y				
XERIC	Innovative Climate-Control System to Extend Range of Electric Vehicles and Improve Comfort	2015-2018	H2020-EU.3.4.	Y					
XILforEV	Connected and Shared X-in-the-loop Environment for Electric Vehicles Development	2019-2021	H2020-EU.3.4.					Y	
ZAP	ZAPINAMO - Affordable, future-proof rapid charging infrastructure for electric vehicles from stored (clean and economical) energy	2017-2018	H2020-EU.3.4		Y				
ZeEUS	Zero Emission Urban Bus Systems	2013-2017	FP7-TRANSPORT			Y		Y	
ZEFER	Zero Emission Fleet vehicles For European Roll-out	2017-2022	H2020-EU.3.4.				Y		
	Methanol: A Future Transport Fuel based on Hydrogen and Carbon Dioxide?	2015-2020	H2020-EU.3.3.				Y		

Source: TRIMIS.

Annex 2. Scopus database regular expression analysis keywords

REGEX keywords (documents retrieved on April 2020):

Transport electrification

TITLE-ABS-KEY (“electric” and “vehicle”) AND PUBYEAR > 2009 AND PUBYEAR < 2020

Battery capacity

TITLE-ABS-KEY ("battery" and "capacity" and "vehicle") AND PUBYEAR > 2009 AND PUBYEAR < 2020

Charging technology and infrastructure

TITLE-ABS-KEY ("charging infrastructure" or "charging point") AND PUBYEAR > 2009 AND PUBYEAR < 2020

Power electronics, motors, and transmission systems for EVs

TITLE-ABS-KEY ("electric propulsion") AND PUBYEAR > 2009 AND PUBYEAR < 2020

Hydrogen fuel cells and hydrogen refuelling

TITLE-ABS-KEY ("plug-in hybrid" or “PHEV”) AND PUBYEAR > 2009 AND PUBYEAR < 2020

TITLE-ABS-KEY ("fuel cell electric vehicle" or “FCEV”) AND PUBYEAR > 2009 AND PUBYEAR < 2020

Electromobility

TITLE-ABS-KEY ("electric car") AND PUBYEAR > 2009 AND PUBYEAR < 2020

TITLE-ABS-KEY ("electric bus") AND PUBYEAR > 2009 AND PUBYEAR < 2020

Electrification of other transport modes

TITLE-ABS-KEY ("electric vessel" or "electric boat") AND PUBYEAR > 2009 AND PUBYEAR < 2020

GETTING IN TOUCH WITH THE EU

In person

All over the European Union there are hundreds of Europe Direct information centres. You can find the address of the centre nearest you at: https://europa.eu/european-union/contact_en

On the phone or by email

Europe Direct is a service that answers your questions about the European Union. You can contact this service:

- by freephone: 00 800 6 7 8 9 10 11 (certain operators may charge for these calls),

- at the following standard number: +32 22999696, or

- by electronic mail via: https://europa.eu/european-union/contact_en

FINDING INFORMATION ABOUT THE EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website at: https://europa.eu/european-union/index_en

EU publications

You can download or order free and priced EU publications from EU Bookshop at: https://publications.europa.eu/en/publications. Multiple copies of free publications may be obtained by contacting Europe Direct or your local information centre (see https://europa.eu/european-union/contact_en).

KJ-NA-30387-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub

EU Science Hub - Joint Research Centre

EU Science, Research and Innovation

EU Science Hub

Publications Office
of the European Union

doi:10.2760/00563

ISBN 978-92-76-22446-4