ANNEX 5 - CLUSTER 5: CLIMATE, ENERGY AND MOBILITY

1. Global Challenges and Their Drivers

The main objectives of this cluster are to foster climate action, improve the competitiveness of the energy and transport industry as well as the quality of the services that these sectors bring to society. This requires to better understand climate change's causes, evolution, risks, impacts and opportunities, and to make the energy and mobility systems climate- and environment-friendly, smarter, safer, more resilient, inclusive, competitive and efficient (minimising any possible environmental, social or economic rebound effects). The overarching driver is the ambition to achieve climate neutrality in Europe by 2050, entailing decarbonisation of the energy, transport and other sectors by 2050 at the latest, while, at the same time, ensuring the security of energy supply and boosting the sectors' competitiveness. This is crucial as both sectors represent an important share of the GDP and jobs in Europe, the transformation of these sectors offers tremendous business opportunities on a global scale and the energy and transport services represent major cost factors for businesses and households alike and are indispensable for the well-being and quality of life of citizens and the competitiveness of the European economy as a whole. To these ends, Europe follows the "energy-efficiency-first" principle. Actions will support the implementation of the Paris Agreement, the European Green Deal to reach Climate Neutrality by 2050 (and a greater level of ambition by 2030) and EU policy priorities in the areas of climate, energy, and mobility, and contribute to creating more and better jobs, accelerating industrial transformation and generating innovation-based and inclusive growth.

Energy and transport sectors are vital for the European economy, for the mobility of people and goods and for affordable and sustainable energy supply for European citizens. Both sectors are the lifeblood of an integrated European single market, territorial cohesion and an open and inclusive society. At the same time, energy- and transport related activities cause the largest part of greenhouse gas emissions in the EU – the energy sector representing 54 %, the transport sector 24 % of EU greenhouse gas emissions in 2016[116], so decoupling their environmental impacts from economic growth and achieving deep decarbonisation of these sectors is crucial. As foreseen by the European Commission's strategic vision "A Clean Planet for All"[117], digitalisation and decarbonisation will transform both sectors in the coming decades, and they will be increasingly intertwined. At the same time, becoming a leading actor on fast expanding global markets for sustainable technologies and services is imperative for the European economy and the energy and transport sectors in particular.

2. EU Policy Objectives

The EU has been at the forefront when addressing the causes and challenges of climate change and strengthening a concerted global response in the framework of the Paris Agreement. In this context, the European Commission presented in November 2018 its strategic vision[118] for achieving net-zero greenhouse gas emissions by 2050. The long-term strategic vision outlines a vision of the technological, economic and societal transformations required to achieve climate neutrality, and ensuring a socially fair transition that does not leave any EU citizens or regions behind. Commission President von der Leyen emphasised the commitment of the EU by announcing the ambition for the EU to become the world's first climate-neutral region by 2050.

Research and Innovation will heavily influence the speed at which this transition can take place, directly affecting the associated costs, impacts and co-benefits, such as better air quality, increased employment, social inclusion, sustainable resource management (including biodiversity), and reduced dependency on fossil fuels. Beyond the inevitable social transitions and lifestyle changes, a key contribution to success is the development of a wide portfolio of – from a life-cycle

[116] https://ec.europa.eu/eurostat/statistics-explained/pdfscache/1180.pdf
[117] COM(2018) 773 final, A Clean Planet for all
[118] COM(2018) 773 final, A Clean Planet for all

perspective – cost-effective carbon-free alternatives for each GHG-emitting activity, based on often in combination with enhanced sector coupling, digitalisation and system integration. The rate at which European research and innovation actions succeed in developing, upscaling, implementing, and commercialising such innovative solutions will steer EU's future competitiveness of its existing and newly emerging industries.

In the medium term, EU legislation under the Energy Union Strategy provides the regulatory framework for achieving the EU's 2030 greenhouse gas emission reduction target – a decrease by 40% compared to 1990 levels[119] – in a cost-efficient way, including the EU Emission Trading Scheme and national targets. Sectoral EU legislation, such as the Clean Energy for All package and the Clean Mobility packages, imply major market transformation by 2030 in the energy and transport sectors. Horizon Europe can make a major contribution to bring more low and zero carbon technologies and solutions to market readiness and feed the innovation cycle with discoveries that may lead to disruptive solutions (including shift in user behaviour) in the longer term.

Coordination of EU instruments with private sector engagements and funding programmes within Member States is essential to accelerate transformation and maximise impact. In the energy area, the Strategic Energy Technology Plan (SET-Plan) helps align research and innovation between the private sector, the Commission and Member States. Similar guidance for the transport sector is provided by the Strategic Transport research and innovation Agenda (STRIA). As regards climate knowledge, JPI Climate provides a platform to align national research priorities according to a jointly agreed Strategic Research and Innovation Agenda (SRIA).

Activities in this cluster will contribute to multiple SDGs, with the most direct impact on SDG 7 (Affordable and clean energy), SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). In addition, SDG 3 (Good health and well-being), SDG 6 (Clean Water and Sanitation), SDG 8 (Decent work and economic growth), and SDG 12 (Responsible production and consumption) will be positively impacted.

3. Targeted impacts

The long term targeted impact of this cluster corresponds directly to the main objectives of fostering climate action while at the same time improving the sustainability, security and competitiveness of the energy and transport industry as well as the quality of the services that these sectors bring to citizens and society at large. Actions will aim to provide the basis for systemic change as well as shaping the necessary technological, industrial economic and societal transformations to achieve climate neutrality in an inclusive and socially fair way, and to contribute to creating more and better jobs thus helping people to embrace the systemic transformation.

The strategic plan focuses on targeted impacts across the various parts of the cluster. These include:

- Achieving an advanced knowledge base in climate science that can guide the development of required policy measures and low-and zero-carbon technologies essential to catalyse the transition to a climate-neutral emissions economy and society and for adaptation to the unavoidable climate change impacts.
- New cross-sectoral energy/transport solutions enabling both the clean and sustainable energy transition and the decarbonisation of transport.
- Achieve cleaner, more efficient, more secure and competitive energy supply, notably by boosting cost performance and reliability of renewable energy solutions and by making the energy grid more flexible and secure.

[119] Additional targets are set for energy efficiency – an improvement of 32.5% by 2030 – and for renewable energy which should provide for at least 32% of the final EU energy consumption by 2030.

- Support cleaner, safer, affordable and sustainable energy demand side solutions for all users, ensuring a just transition towards fully decarbonised, more energy efficient and renewable energy system reducing any negative impacts, and European dependency on energy import.
- Significantly contribute to net-zero greenhouse gas emissions and reduced air pollutants in and across all transport modes protecting human health and achieving at the same time strengthened global competitiveness of the European transport sector, through the development and usage of new technological solutions in all transport modes.
- New, affordable smart, inclusive and sustainable mobility services which will result in significant safety, environmental, health, economic and social benefits such as reduced accidents, decreased congestion, reduced energy consumption and emissions of vehicles, increased efficiency and productivity of transport operations, improved working conditions and the creation of new jobs.
- Help people to embrace the systemic transformation

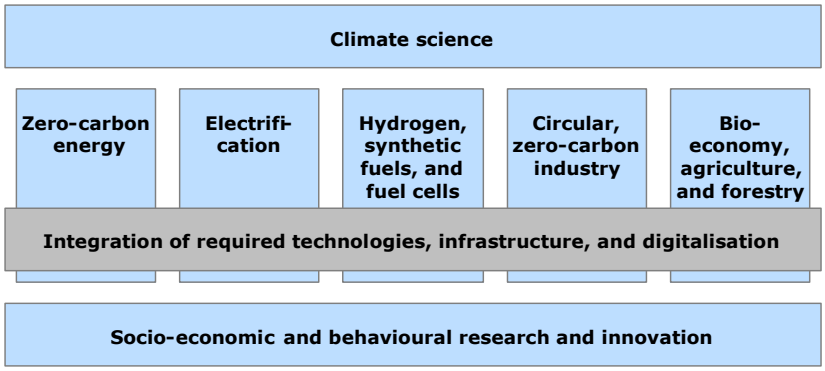
The desired impacts are further specified in the following section in relation to each priority.

4. Key Research and Innovation Orientations

The energy and mobility sectors are closely interlinked and face many common challenges. An integrated, systemic approach is needed to maximise synergies and cross-fertilisation across these and any other relevant sectors. For example, research and innovation actions aiming at reducing cost for hydrogen generation and at increasing battery capacity – thereby fostering competitive European value chains – would bring pivotal change benefiting the clean energy transition and the decarbonisation of transport and industry. Similarly, an integrated approach, is essential to make urban ecosystems more efficient and clean, thus improving the quality of life and health of citizens in cities and communities. Cross-fertilisation between different industries and programs (such as EU navigation and earth observation programs, e.g. EGNOS, Galileo) can also lead to the emergence of new solutions to support the efficient transition to a net-zero greenhouse gas emissions economy.

Figure 3 illustrates the need to not only develop a wide range of advanced low and zero carbon technologies, but to organise research and innovation activities from a system perspective, by working on solutions (e.g. electrification, energy efficiency, capture of renewable energy and storage, zero carbon fuels, carbon neutral communities and cities) across sectors such as energy, transport, infrastructure, and buildings. Infrastructure, network development, digitalisation and skill development of the workforce are key enabling factors for decarbonisation, as well as to enhance security, safety and efficiency of the energy system in all its demand side domains, especially the transport system and the built environment. In addition, climate resilience and climate proofing of infrastructure, as well as a full value chain circularity approach, help the EU with climate change adaptation while protecting the planet resources as a whole. Moreover, there is a need to optimise research and innovation activities from a value chain perspective, to support the circular economy and to reduce environmental footprint and pollution arising from different stages.

Relevant research and innovation areas for decarbonisation



To address the research and innovation challenges in the context of decarbonising the EU's economy and go for a full circular economy, the Horizon Europe proposal [2018/0225 (COD)] identifies a number of research and innovation priorities within the fields of climate, energy and mobility as follows:

4.1 Advance climate science and solutions for a climate neutral and resilient society

Challenge: The efficient transition to a net-zero greenhouse gas emissions economy resilient to the impacts of climate change requires profound knowledge in various fields of research. Advancing climate science and creating a knowledge base to inform societal and social transition and to guide the development of policy measures, low-, zero-, and carbon negative technologies, as well as other solutions. It will also look at their application by people, businesses and policymakers at all levels. It is essential that research into solutions contributes to actual deployment of actions and policies (in both mitigation and adaptation). Interactions with other parts of Horizon Europe, and other programmes, are therefore essential.

Europe has been at the forefront of climate science and has to continue to deliver the knowledge to enable efficient decarbonisation pathways.

Targeted impact: Impact will be generated along three main research and innovation objectives. The first objective is to accelerate climate action (both mitigation and adaptation) uptake globally in line with the Paris Agreement and the SDGs, by improving knowledge of the climate-earth system and knowledge of technological and nature-based solutions for short-to-medium and long-term adaptation and mitigation. The second objective is to contribute substantially to key international assessments such as the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES). The third objective is to strengthen the European research area on climate change.

Potential research challenges and topics[120]:

- Produce state of the art science on climate change and on its impacts, how to adapt to it and how to mitigate climate change;
- Build a user-driven knowledge base that comprehensively informs human response to global change;
- Design cost-effective resilient net-zero greenhouse gas emission pathways compatible with a sustainable long-term transition and the Paris Agreement goals;
- Spearhead the development of climate services and decision-support tools and methodologies at local, regional, national and global levels, and evaluate adaptive capacities and limits;
- Further study the interactions, between climate change and biodiversity;
- Incorporate and further advance research in social science and humanities, behavioural science methodologies, integrated assessment modelling, expertise to assess impacts, distributional and spatial effects and a just transition.

Implementation:

Potential research challenges and topics will be addressed through collaborative research and innovation actions, with international cooperation wherever needed.

Since climate action is mainstreamed across Horizon Europe, actions specifically related to climate science and solutions should target challenges that cannot be addressed adequately elsewhere. Therefore, there should be synergies within Horizon Europe and with other programmes to ensure the knowledge generated by climate science research are tested and implemented across sectors (including activities in Pillar I, and other cluster activities in Pillar II, as well as Missions), at all levels of the innovation chain including facilitating market uptake (namely activities in Pillar III).

Links to other parts of Horizon Europe dealing with Industry, Copernicus and Earth Observation (Clusters 4 and 6); Biodiversity, Oceans, Agriculture, forestry, Water and food systems (Cluster 6

[120] For all research and innovation areas, the planned activities should not be considered as comprehensive nor limitative

and Mission areas on Soils and Oceans); cities (including Mission area on Cities), health (Cluster 1) and just transition (cluster 2) need to be systematically taken into account. In the context of Digital Europe, European High Performance Computing infrastructure (EuroHPC), cloud computing, artificial intelligence techniques and the combination of increasingly varied data sets, can be enablers for developing the next generation of climate models (see Advanced Computing and Big Data) and precise and holistic digital simulations of Planet Earth.

4.2 Cross-sectoral solutions for decarbonisation

The energy sector and the two main sectors of energy use in cities and communities (housing and mobility) are closely interlinked and face many common challenges. Citizens' support and involvement is central for achieving the transformation to a decarbonised sustainable and inclusive society. Furthermore we need an integrated approach to maximise synergies and cross-fertilisation across all sectors. Such approach is essential for making urban transport and energy systems more efficient and clean thus improving the quality of life in cities and communities. Cross-fertilisation between different industries can also lead to the emergence of new solutions to support the efficient transition to a net-zero greenhouse gas emissions economy.

4.2.1 Establish a competitive and sustainable European battery value chain

Challenge: Electrification is one key technological pathway to decarbonise substantial parts of demand side sectors. In a world that is increasingly electrified, batteries will become a key technological component. In the road transport sector, affordable, durable, fast-charging batteries with high capacities are an indispensable enabler for large-scale deployment of electric vehicles. In short-distance waterborne transport, a switch to battery and hybrid propulsion would enable decarbonisation and a reduction in harmful emissions. We also need to assess the potential for long-term solutions for maritime transport and aviation. In the power sector batteries can enable very high shares of intermittent renewable energy technologies. More widely in the industry, batteries can deliver various energy services.

Targeted impact: There is an urgent need for the EU to invest in the development of future battery technologies that are essential to sustain a competitive and sustainable EU battery value chain. To support the development of a world-class European research and innovation eco-system on batteries, by advancing the state of the art of battery technology in terms of material availability and circularity, cost, performance, energy density, safety, user convenience, speed charging and environmental footprint along the value chain and according to sectorial needs, with a view towards establishing a competitive, circular, and sustainable European battery manufacturing value chain.

Potential research challenges: The entire value chain should be covered from materials, electrochemistry, cells design (with a view to full sustainability including re-use, scarcity of materials and recycling), cell manufacturing and cover for mobile, stationary and possibly other sectorial applications. Research topics such as innovative materials, discovery and engineering of new battery chemistries, smart batteries with sensing and self-healing functionalities, advanced cell manufacturing, circular economy and recycling (cluster 4), batteries, battery management systems, safety and standardisation through pre-normative research should be integrated in this work stream. In terms of TRL levels, both enhancement of close-to-market Li-ion technologies, as well as new promising and longer-term break-through technological solutions[121] should be included. Research should integrate the full potential contribution of digital technologies.

Implementation: In order to develop a coherent, cross-cluster and strategic battery research programme, and enhance leverage and industrialisation of research results, it is proposed that this strategic research and innovation area is developed through a co-programmed partnership with industrial players and the research community. Strong coordination/cooperation with other relevant partnerships will be essential. International cooperation is key to improving the worldwide sustainability of the entire batteries value chain.

[121] Preparatory actions on future battery technologies supported under the FET Flagships part of Horizon 2020 will feed the Strategic Planning process under Horizon Europe and inform the work on e.g. the proposed partnership Batteries: Towards a competitive European industrial battery value chain (see Annex 7).

4.2.2 Strengthen the European value chain for near-zero carbon hydrogen and fuel cells

Challenge: Near-zero carbon hydrogen and fuel cell technologies offer a major decarbonisation pathway for energy, transport and industry. Hydrogen offers significant potential for large-scale, long-term storage of renewable energy. There is a growing interest to use hydrogen in energy- and carbon-intensive industry, in particular the steel industry, for the direct reduction of iron ore in steelmaking, and in the chemicals sector as an important chemical feedstock. Hydrogen has started to be used as an energy carrier in the transport sector, in logistics and in the heating sector. In order to achieve large-scale deployment, major advances are needed to be achieved in terms of cost, performance and convenience for the supply, infrastructure and demand side technologies.

Targeted impact: Advancing the state of the art in terms of efficiency, cost, performance, safety and environmental footprint will allow to the global leadership role of European industry along a competitive near-zero carbon hydrogen supply chain.

Potential research challenges:

- Near-zero carbon hydrogen production pathways, particularly renewable based, and including energy system integration aspects.
- Development of infrastructure for safe, cost- and energy-efficient transport, storage and provision of hydrogen and hydrogen-rich energy carriers, incl. long–term, large-scale storage of hydrogen as energy buffer.
- Demand side technologies to produce power and/or heat for mobile and stationary applications. In the transport sector, focus on long range, heavy-duty road freight, rail, and waterborne[122].
- Life-cycle analysis for the design of low-emission, energy- and resource-efficient hydrogen supply chains.

Implementation: Building on the existing Joint Undertaking, it is proposed that this strategic research and innovation area is implemented through a European Partnership (possible institutionalised Partnership based on Article 187 TFEU), with strengthened industrial participation combining public and private financial resources across the value chain, to develop a coordinated pan-European approach. International cooperation will be established in particular through the Mission Innovation Challenge on Renewable and Clean Hydrogen, and supported by bi-lateral international cooperation where appropriate. Synergies will be sought with the cluster 'Digital, Industry and Space' and cluster 'Food and Natural Resources'

4.2.3 Develop sustainable infrastructure, services and systems for smart and sustainable communities and cities

Challenge: With more than 80% of the EU's population living in urban areas it is essential to adopt new system approaches to (re)design our spaces/cities, incorporating regenerative paradigms with a focus on new energy & mobility systems, sustainable and carbon-free built environment , supported through user-friendly and secure digital services, able to adapt to climate change and to increase quality of living. Co-design and co-creation approaches with- and for society can help ensure uptake and deployment of solutions.

Targeted impact: Increase the overall energy and resource efficiency as well as the climate-resilience of Europe's cities and communities and their attractiveness to businesses and citizens in a holistic fashion (including business and operating models, financing issues, public sector innovation, incentive structures and social innovation) Improve air and water quality, resilience of energy supply, intelligent mobility services and logistics, liveability and accessibility of cities, public health, comfortable, affordable zero emissions housing as well as the exploitation of relevant European technologies and knowledge.

Potential research challenges:

[122] Hydrogen applications in aviation will be addressed separately in research and innovation related to aviation

- City/district management systems for energy, mobility, water and waste systems towards the EU-wide deployment of low-carbon, Positive Energy Districts, Energy Communities and zero-emission mobility and logistics by 2050;
- Quality of life for the citizens through demand-based, zero carbon accessible, inclusive and safe mobility, services and logistics, sustainable and carbon-free housing, built environment, and their impact on energy consumption and resources, urban social innovation, cities' and communities circular and regenerative capacity,
- New governing and financial models to support historic/existing districts regeneration through adaptive reuse of buildings and infrastructures,
- Reducing life-cycle environmental footprint and pollution in cities through nature-based solutions and circular material and equipment,
- Urban land use and integrated planning, including governance and public sector innovation, urban policies, decision-making tools, new models for citizen participation;
- Next generation scalable interoperable digital infrastructure and software solutions for innovative services across different urban sectors (energy, mobility, buildings, water and sewage, urban planning, etc.), fuelled by latest information and communication (ICT) (like Artificial Intelligence, Internet of Things, new computing paradigms, etc.) and (open) data governance models (including new business models). Robust and effective financing solutions and business models to increase investors' confidence.

Implementation: Potential research challenges and topics will be addressed through collaborative research and innovation actions, and/or as part of other Clusters and cross-cluster Horizon Europe Mission research and innovation in the area of 'Climate-Neutral and Smart Cities' and/or in relevant partnerships. Additional synergies will be examined with other EC-funded projects with large stakeholder platforms and co-programmed partnerships. International cooperation can be pursued with third countries and regions with an expanding market for sustainable technologies.

4.2.4 Empowering citizens to engage in the transformation to a decarbonised society

Challenge: Societal transformation is embedded in broader societal needs and hence depends crucially on the buy-in of citizens, beyond technological aspects. Finding new and better ways to involve Europe's citizens in the low-carbon transition and in the sustainable economy, in the design / implementation of the policy measures, and for creating win-win situations for consumers and producers, network providers and investors is therefore of critical importance.

Targeted impact: Reduced energy consumption and related emissions in all stages of the energy, housing and transport sector. More involved citizens will help devise novel and original business models and facilitate sustainable finance. Socio-economic research can provide analysis and recommendations for effectively engaging and empowering citizens to participate in the clean energy transition, from planning to decision-making and implementation. Research results can also inform transition strategies of regions. This will facilitate the transformation to a decarbonised society, in line with the EU's 2050 climate targets.

Potential research challenges:

- Develop technologies, services and business models for enhancing decision-making in home life and working life. This includes increasing awareness about the impacts of our consumption habits, lifestyles towards decisions and the adoption of sustainable practices at domestic levels;
- Develop and demonstrate technologies, tools and business models based on multiple (also non-energy) user benefits, for optimising the energy production and use, as well as resource flows.
- Develop and enhance methods of citizen's engagement in long-term energy, and transport investment planning and transition policies. Develop new participatory models to engage citizens in investments.
- Socio-economic and interdisciplinary research on re-qualification of workers currently in carbon-intensive sectors and building new employment opportunities targeted towards the needs of the transition to a decarbonised society.

- Further elaborate Contribute to the Initiative of Coal Regions in Transition from a research and innovation perspective, enabling regions to identify and respond to their unique contexts and opportunities[123].

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation, including citizen-science/user-led innovation approaches. A close cooperation with materials for energy, built environment and city related research and innovation initiatives across different parts of Horizon Europe will ensure complementarity. Actions will be closely coordinated with the Clean Energy Transition part of the LIFE programme (2021-2027) which focusses on policy support and market uptake action. International cooperation can be pursued with third countries and regions where advanced EU approaches can support implementing climate mitigation objectives.

4.2.5 Foster emerging breakthrough technologies and climate solutions

Challenge: Although the contribution of a wide range of technologies to decarbonisation is already foreseeable, EU research and innovation programming should also leave room for unanticipated emerging and break-through technologies with a high potential for decarbonisation. Research and innovation in this area may be technological in nature but needs to be accompanied with assessment of environmental impact, social and economic impacts, measures to mitigate them and, and possible regulatory needs. Examples of such cases may be in the areas of: direct conversion of solar energy to synthetize fuels and artificial photosynthesis; solar-driven chemistry, direct air CO_2 capture and storage (DACCS) and re-use; methane capture / cracking for blue hydrogen; sustainable production of ~~various~~ synthetic fuels from renewable energy; disruptive transport technologies, etc.

Targeted impact: The emergence of unanticipated and/or the sufficient development of emerging zero-greenhouse gas and negative emission technologies, including, in parallel, the assessment of their technological and economic potential, as well as their environmental impact, social acceptance and possible regulatory needs.

Implementation: This research and innovation priority will be implemented through a mix of non-prescriptive and open approaches, in order not to exclude relevant future frontier technologies and keep flexibility and more targeted support to highly promising emerging technologies at an early stage of development. Topics in this area should preferably be implemented through strong international collaboration, for instance Mission Innovation.

4.3 Develop cost-efficient, net zero-greenhouse gas emissions energy system centred on renewables

The transition of the energy system will rely on reducing the overall energy demand and decarbonising the energy supply side. Research and innovation actions will contribute to making the energy supply side cleaner, more secure and competitive, notably by boosting cost performance and reliability of a broad portfolio of renewable energy solutions and by making the energy grid more flexible so it can accommodate higher shares of renewable energy in a secure and flexible way. Innovative energy storage solutions should be further investigated. To reduce CO_2 emissions from the power and energy-intensive industry sector, environmentally sound solutions for capturing, utilisation and storage of CO_2 (CCUS) will be matured. To accelerate technological progress along the value chain and maximise EU added value, EU support should be developed and implemented in synergy with national initiatives, leveraging actions in support of the priorities and targets set by the EU's Strategic Energy Technologies Plan (SET-Plan) for its 10 Key Actions[124].

4.3.1 Achieve global leadership in renewable energy

Challenge: The EU long-term climate strategy highlights the pivotal role of renewable energies in the future energy system and the achievement of the zero-emission target. Renewables provide also major opportunities for the decarbonisation of other sectors such as heating/cooling, transportation and industry and their large scale and decentralised deployment will also improve security of energy supply and boost domestic jobs. While efficiency improvements for the more established renewables, such as wind energy, photovoltaics or bioenergy, are envisaged, a further diversification of the technological portfolio is also needed to support the clean energy transition.

[123] This does not entail activities aimed at the continuation of fossil fuel based energy

[124] https://setis.ec.europa.eu/actions-towards-implementing-integrated-set-plan/implementation-plans

Renewable fuels, including synthetic and biofuels, provide long-term solutions for the transport and energy-intensive industry sectors, in particular for applications where fuels with high energy density or very large fuel quantities are required to reduce the carbon footprint of these sectors.

Targeted impact: To foster European global leadership in affordable, secure and sustainable renewable energy technologies and services by improving their competitiveness in global value chains and their position in growth markets, notably through the diversification of the renewable services and technology portfolio. To provide sustainable solutions for specific transport needs in aviation, shipping, or heavy duty road transport, for the heating/cooling sector, and in the heavy industry, within an overall circular economy concept in synergy with the bioeconomy.

Potential research challenges:

- Develop disruptive renewable energy and fuel technologies, and systems, including the use of new materials, for existing and new applications and breakthrough solutions;
- Improve efficiency, competitiveness, sustainability of renewable energy and fuel technologies and their value chains ~~and life-cycle costs~~ (from cradle to cradle) to allow their scaling up in market and market penetration, thus securing energy independence;
- Develop flexible renewable-based solutions and fuels allowing high penetration in the energy system;
- Significantly expand renewable solutions and fuels in sectors other than power generation, including transport and energy-intensive industries;
- Develop solutions to integrate renewables efficiently within the existing energy system infrastructure;
- Create synergies of bioenergy with bio-economy and other industrial sectors, in particular for new sustainable feedstock and through the development of integrated bio-refineries.

Implementation: Potential research challenges and topics will be addressed through collaborative research and innovation actions. Actions on biofuels will need to be coordinated cross-cluster with activities of cluster 'Food and Natural Resources'. International cooperation with other technology leaders will be pursued where relevant (in particular through the Mission Innovation initiative and bi-lateral cooperation with strategic partner countries).

4.3.2 Develop flexible, zero greenhouse gas emission and citizen-centred energy systems and grids

Challenge: Decarbonisation, cost-effectiveness and affordability, security and stability of supply and other objectives of the clean energy transformation depend on an efficient and effective network management and optimisation, leading to increased demand response and the ability to integrate higher shares of variable renewable energy and to appropriately monitor their availability (at all voltage levels). Exploiting synergies between different electricity, heating and cooling networks, gas networks, transport infrastructure and digital infrastructure will be crucial for enabling the smart, integrated, flexible and green operation of the relevant infrastructures.

Targeted impact: New approaches to manage smart and cyber-secure energy grids and related investments to enable more interaction and optimisation between producers, consumers, networks, infrastructures and vectors ensuring the cost-effective uninterrupted and affordable supply of energy to households and industries in a scenario of high penetration of variable renewables and other new low carbon energy supply.

Potential research challenges:

- Technologies and tools, including the use of Internet of Things and Artificial Intelligence, for electricity networks to integrate renewables and new loads, including flexibility solutions for managing electricity grids and Pan-European energy network management approaches, including improved cross-border cooperation in the transmission grid;
- New approaches and tools to empower market players, consumers and local energy communities (beyond smart meters);
- Solutions for the integration of energy systems and coupling of different energy vectors, networks and infrastructures, in the context of a digitalised, green and cyber-secure energy system, relying also on EU-specific technologies ;

- Develop/demonstrate solutions to adapt the gas infrastructure to transport low-carbon gases, including hydrogen;
- Integrated local energy systems, microgrids and modular solutions;
- Innovative grid services through demand response, storage and small-scale production of energy from renewable sources.

Implementation: Potential research challenges and topics will be addressed through collaborative research and innovation actions. Leveraging more investments and a better coordination with national funding programmes may require a partnership approach. International cooperation will be pursued where relevant, both with other technology leaders (in particular through the Mission Innovation initiative) and with countries/regions with expanding markets for advanced sustainable energy system technologies.

4.3.3 Develop carbon capture, utilisation and storage (CCUS) solutions for the power sector and energy-intensive industries

Challenge: Carbon Capture, Utilisation and Storage is a CO_2 emission abatement option that holds great potential for the power sector and especially for industries with high process emissions. It is also an important technology that allows the production of large volumes of near-zero carbon ('blue') hydrogen and other synthetic fuels from natural gas until sufficient renewable ('green') hydrogen and synthetic fuels becomes available.

Targeted impact: To accelerate the development of CCUS as a CO_2 emission mitigation option in electricity generation and industry applications. This includes CCS in combination with sustainable bioenergy (BECCS) which, combined with appropriate land use, can result in 'negative' CO_2 emissions. It can also address the conversion of CO_2 to products either to replace the use of fossil fuel feedstock (i.e. production of synthetic fuels) or to store it for a climate-relevant time horizon (e.g. mineralisation), in collaboration with cluster 'Digital, Industry and Space'.

Potential research challenges:

- Development and demonstration of novel energy efficient, cost-effective and environmentally friendly capture technologies, including using new materials
- Development of new storage sites (including operational best practices and public engagement);
- Strategies and feasibility studies for the development of CCUS hubs and clusters, including strategies for CO2-transport and CO2-infrastructures, addressing both technology and regulation aspects;
- Improving the CO_2 balance and energy performance of CO_2 conversion to value-added products;

Implementation: Potential research challenges and topics will be addressed through collaborative research and innovation actions, in particular with cluster 'Digital, Industry and Space' which includes industrial CCUS applications in the co-programmed partnership 'zero-carbon and circular industries'. International cooperation will be pursued both with other technology leaders (in particular through the Mission Innovation Carbon Capture Challenge) and with carbon-intensive technology followers to enhance the EU energy and climate diplomacy.

4.3.4 Develop flexible and efficient energy storage solutions

Challenge: Capturing excess electricity and heat to use it at a later point in time is an essential requirement for the cost-effective and secure transition of the energy system. Chemical, mechanical, electrical and thermal storage solutions will increase the flexibility of the energy system and complement the research and innovation areas of batteries (area 2.2.1) and hydrogen (area 2.2.2).[125] More than 50% of our energy use is thermal energy. Therefore, thermal energy

storage enables a higher utilization of variable renewable sources (direct solar or geothermal heat) in the heating and cooling sector.

Targeted impact: Advancing the technological readiness of centralised and decentralised energy storage for industrial-scale and domestic applications.

Potential research challenges: For energy storage, the research priority is to work on new, low-cost solutions (including the use of new materials) enabling to widen the scope and scale of application of storage technology. There is a particular need to:

- Develop more compact thermal energy storage for domestic applications of storage periods typically up to 4 weeks long;
- Re-design large-scale thermal energy storage for district heating and cooling in order to match the seasonal supply and demand of a large number of renewable sources on a district level;
- Develop more efficient electrical storage solutions (such as supercapacitors and superconducting magnetic energy storage);
- Develop novel alternative storage technologies;
- Demonstrate the integration of different energy storage technologies in specific hybrid solutions and their integration in the grid;

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation. Actions will be developed in complementarity with other areas addressed in this cluster. International cooperation will be pursued where relevant, both with other technology leaders and with countries/regions with expanding markets for advanced energy storage systems and technologies.

4.3.5 Leverage more public and private investments in clean energy systems

Challenge: All pathways to reach the clean energy transition require a better leveraging of public and private investments. Over the last decade, Strategic Energy Technology Plan (SET Plan) built platforms to align research and innovation agendas in dedicated areas stimulating Member States to coordinate national programmes and to pool funding across borders. Given the scale of the research and innovation investments needed, this leverage effect on public and private funding towards joint research and innovation activities in support of the clean energy transition should be intensified. The proposed co-funded partnership would deepen the trans-national integration in thematic areas of joint interest.

Targeted impact: Leverage public and private funding towards joint research and innovation activities and necessary accompanying measures in support of the clean energy transition, and coordinate national and regional research programmes with the aim to create trans-national integration in thematic areas of joint interest within the European Research Area.

Implementation: The proposed co-funded partnership would build on the work already carried out in the SET-Plan – i.e. definition of common targets and creation of Implementation Plans endorsed by Member States – and leverage public and private funding towards joint research and innovation activities. The proposed co-funded partnership would integrate the existing support into a larger, more efficient and more ambitious system.

4.4 Develop demand side solutions to decarbonise the energy system

Research and innovation actions aiming at fostering demand side solutions and improving energy efficiency are among the most cost effective ways to support decarbonisation, to create inclusive growth and employment in Europe, to bring down costs for consumers, to reduce our import dependency and redirect investments towards smart and sustainable infrastructure. The transition to a decentralised and decarbonised energy system will greatly benefit from the use of digital technologies which will enable buildings and industrial facilities to become inter-active elements in the energy system by optimising energy consumption, distributed generation and storage and vis-à-vis the energy system. They will also trigger new business opportunities and revenue streams for up-graded, innovative energy services which valorise energy savings and flexible consumption.

4.4.1 Achieving a highly energy-efficient and decarbonised EU building stock

Challenge: Buildings are pivotal to the energy transition and the achievement of a climate neutral economy. Energy consumption of buildings (in the operation phase) represents approximately 40% of energy consumption and 36% of CO_2 emissions in the EU[126]. Enabling cost-effective energy renovation of buildings, including built heritage, is a top research and innovation objective for the EU which can lead to significant energy savings and better life-cycle resource efficiency, including whole life carbon. This, together with enhanced interactions of buildings with the energy system and between buildings, opens up a significant decarbonisation and employment potential.

Targeted impact: Delivering the technology and socio-economic breakthroughs necessary to achieve the full decarbonisation of the building stock by 2050 through energy efficiency, renewables, digitalisation and smart operation of buildings, bearing in mind user needs and the need to move towards climate neutrality in the longer term as well as to limit whole life carbon as well as other life-cycle environmental impacts of buildings.

Potential research challenges:

This intervention area will primarily focus on the decarbonisation of buildings and on the contribution of the buildings sector to the clean energy transition, including life-cycle perspective and circularity:

- Cost-effective renovation, including design and construction processes, and modernisation of existing buildings towards nearly zero-energy performance level, also taking into account environmental life-cycle performance
- Digital tools for design, monitoring and optimisation of energy performance of buildings and technical equipment, taking into account life-cycle environmental performance, health, accessibility and comfort criteria, ensuring synergies with relevant policy initiatives (e.g. smart readiness indicator under the Energy Performance of Buildings Directive)
- Cost-effective integration of renewables at building - and neighbourhood - level, energy demand flexibility, integrated heat and electricity storage (including EV charging) and energy symbiosis (e.g. electricity and heat exchanges) with industrial zonings;
- Socio-economic aspects of innovation (e.g. business and financing models, costs & affordability, safety, accessibility, user needs, behaviour and acceptance);
- Life cycle approaches integrating resource efficiency, circular economy and environmental impacts (e.g. biodiversity, natural resource depletion, materials, carbon footprint).

Implementation: Potential research challenges and topics will be addressed through collaborative research and innovation actions. Synergies will be sought in particular with cluster 'Digital, Industry and Space' on activities relating to construction, construction materials and circular economy. Furthermore, cooperation with other cluster on life cycle approaches, optimisation of accessibility, safety, comfort, well-being and health in buildings will be essential and addressed in a co-programmed partnership on 'Built environment and construction'.

4.4.2 Support industrial facilities in the energy transition

Challenge: Industry has a key role in the clean energy transition, and also needs to become climate-neutral by 2050 while remaining competitive at global level. This needs to go hand-in-hand with an industrial transformation towards a circular industry. The efficient use of energy and resources will be optimised at all levels: at plant, industrial hub and energy system level. This priority, which focuses on the interfaces of the industrial plants and hubs with the wider energy system, will therefore be implemented jointly with Cluster 'Digital, industry and space' (cluster 4). Industry will switch to renewable and low-carbon energy sources, either produced locally or procured via grids. Through flexibility and demand response, industry will also contribute to the stability of energy grids supplied with a growing share of variable renewable sources.

[126] Looking at the full life cycle of buildings, the energy consumption is about 50%, as is the share of EU CO2 emissions.

Targeted impact: Enable competitiveness and carbon-neutrality of industry through the integration of renewable and low-carbon energy sources and the optimisation of energy flows across integrated industrial installations and the wider energy system.

Potential research challenges:

- Develop and demonstrate technologies, planning and modelling tools and infrastructure for optimising the energy flows (e.g. electricity, heat, Hydrogen) between industrial plants/hubs including ports and the energy grids, so as to enable contribution to the integration of RES, energy efficiency and stability of energy grids;
- Develop and improve technologies to use industrial waste energy (heat, cold …), including its conversion to other energy vectors, so that it can be re-commercialised in the energy system;

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation. To ensure complementarity across different parts of Horizon Europe, these will be addressed through, or in close cooperation with, industry-related research and innovation initiatives, notably with 'Climate neutral and circular industries' in Cluster 'Digital, industry and space'.

4.5 Develop low-carbon and competitive transport solutions across all modes

Europe is world leader in transport design and manufacturing in all transport modes. The automotive, rail, aeronautics and shipbuilding sectors have a turnover of above EUR 350 billion and employ more than 3.6 million highly-qualified staff[127]. At the same time, transport is a major producer of harmful emissions that contribute to climate change and affect air quality, particularly in urban areas. The transport sector is responsible for 23% of CO_2 emissions and remains dependent on oil for 92% of its energy demand. Furthermore, despite significant technological progress over past decades, current and projected GHG emissions from transport are not in line with the objectives of the Paris Agreement due to the expected sharp increase in transport demand. Intensified research and innovation activities are therefore needed, across all transport sectors, in order for the EU to reach its policy goals towards a net-zero greenhouse gas emissions by 2050 and to significantly reduce air pollutants. New technological solutions that will emerge from these efforts will not only contribute to the EU policy goals regarding fighting climate change, but will also enhance the global competitiveness of the European transport sector in all modes. These research and innovation activities are briefly described below.

4.5.1 Achieve zero-emission road transport

Challenge: The Clean Mobility package and in particular legislation on vehicle emissions implies that low and zero-emission vehicles will gain substantial market shares by 2030. In addition, improving air quality remains a key challenge in many cities and regions throughout Europe. To preserve and enhance Europe's competitiveness in the automotive sector in this effort, in the face of increasing international competition, and to respond to societal challenges related to mobility, air quality and health, substantial research and innovation efforts are required focussing on the development of the next generations of zero- and low emission vehicles, including clean road vehicles technologies and technologies of a more systemic nature, which will address the integration of clean vehicles and new and affordable system services into the transport system .

Targeted impact: The transformation of road transport to zero-emission mobility through a world-class European research and innovation and industrial system, ensuring that Europe remains world leader in innovation, production and services in relation to road transport.

Potential research challenges and topics: This priority will address both 1) clean road vehicles technologies (lightweight materials, drive trains, brakes, tyres, emissions after-treatment systems, power electronics, vehicle management systems and advanced and digital manufacturing technologies) and their infrastructure, including their interfaces, and 2) technologies of a more systemic nature, which will address the integration of clean vehicles and new affordable system services into the transport system. All types of road transport vehicles are included (e.g. two-wheeler, passenger cars, vans, trucks and buses), as well as system integration with infrastructures and services.

[127] "Towards clean, competitive and connected mobility: the contribution of transport research and Innovation to the Mobility Package" SWD (2017) 223 final

Implementation: In order to develop a coherent and strategic research and innovation programme, and enhance leverage and industrialisation, it is proposed that this strategic research and innovation area is developed through a co-programmed partnership with industrial players and the research community, building on the existing European Green Vehicle Initiative.

4.5.2 Enhance the competitiveness of rail as a low-carbon mode of transport

Challenge: Pave the way for a major transformation of the railway system: focussing on decarbonisation, automation and digitalization. Moreover, address major issues at EU level, such as congestion, security of energy supply and retain the EU leadership role in producing innovative rail transport solutions.

Targeted impact: Achieve the Single European Railway Area as the backbone of an integrated and sustainable mobility in Europe and towards a globally competitive transport system, generating growth and jobs in Europe. Strengthen the EU leadership role in producing innovative rail transport solutions, and their integration into digital service chains, leveraging EU satellite navigation / positioning technologies.

Implementation: Building on the successful operation of the existing Joint Undertaking, potential research challenges and topics will be addressed via a possible institutionalised Partnership based on Article 187 TFEU and /collaborative research.

4.5.3 Make aviation cleaner and more competitive

Challenge: The European Union is one of the leading exporters of aeronautics products in the world. Aviation is also a growing means of transport and a strong contributor to the European Union economy. Despite technological progress, in fuel efficiency per passenger-km GHG emissions from aviation are rapidly increasing, both in the EU and globally, making it one of the industry sectors with the highest need for new technological solutions to contribute to meeting the goals of the Paris Agreement. Beyond CO2 emissions, aviation is responsible for the creation of contrails and non-CO2 emissions, which also exhibit radiative forcing. In addition, air pollution and noise levels need to be addressed. Research and innovation is necessary to advance technologies as well as operational procedures of aviation to minimise the adverse environmental effects and maintain the EU's leadership position.

Addressing Aviation's Environmental Credentials

Targeted impact: To pave the way towards a transformative clean aviation. To strengthen European aero-industry collaboration and maintain a global leadership position. To develop innovative, cutting edge research and innovation projects accelerating the reduction of all aviation impacts and emissions (CO_2 and non-CO_2, including manufacturing and end-of-life, noise). To develop enabling and integrated aircraft technologies for deep decarbonisation transformation, as well as enable and promote the use of sustainable aviation fuels.

The research and innovation activities will be based on a transformative decarbonisation roadmap that encompasses impactful solutions for different platforms at appropriate time frames in line with the transition to a climate neutral economy by 2050. It is envisaged that new technologies will provide for a substantial fuel efficiency improvement for next generation aircraft technology, a substantial decrease in aviation non-CO_2 emissions and major progress towards cost-competitive sustainable alternative fuels[128].

Potential research challenges:

- Research new aircraft configurations and new propulsion systems towards substantially enhanced GHG performance and fuel efficiency for the next generation of commercial aircraft technology. Accelerate the electrification of aviation;
- Develop and demonstrate solutions that reduce the impact of non-CO_2 emissions on climate and environment, while considering the interdependencies with CO2 emissions;
- Develop solutions to accelerate the introduction of sustainable low carbon fuels (including synthetic fuels, hydrogen);
- Deliver ecological and cost-efficient manufacturing, and end-of-life procedures;

[128] Measurable key performance indicators to be defined.

- Promote strategic research activities in non-traditional aviation areas (e.g. electrification, digitalisation, autonomy, data-driven sciences, circular economy);

Implementation: Planned research challenges and topics can be best addressed though a dedicated European Partnership, possibly as institutionalised Partnership based on Article 187 TFEU, in order to maximise impact and the exploitation of synergies with a more efficient and transparent setup, stronger financial and nonfinancial commitments, potentially complemented through collaborative research projects. At least half of the budget will be allocated to technological solutions aiming at deep decarbonisation.

Air Traffic Management

Targeted impact: To overcome current shortcomings of the Air Traffic Management (ATM) systems, while addressing future challenges of digitalised and sustainable aviation. Continuing to develop the Single European Sky - tripling the capacity of the current ATM system, reducing its costs by 50%, increasing safety by a factor of 10, and reducing the environmental impact for each flight by 10%, from a 2004 baseline.

Potential research challenges:

- Develop solutions that address the capacity challenge and deliver safer, greener and more affordable aviation (Modernise and harmonise ATM systems in Europe);
- Address new priorities of the aviation ecosystem (e.g. cybersecurity, urban air-transport, U-space drone traffic management system), leveraging EU satellite navigation / positioning technologies.
- Increased automation of ATM and aircraft, integration of the different systems (aircraft/ATM/airports).

Implementation: Building on the successful operation of the existing Joint Undertaking, planned research challenges and topics can be addressed via a possible institutionalised Partnership based on Article 187 TFEU.

4.5.4 Enable low-carbon, smart, clean and competitive waterborne transport

Challenge: In 2018, a global agreement was reached to cut total GHG emissions from shipping by at least 50% by 2050 compared to 2008, with the ambition of achieving zero emissions[129]. Shipping also contributes significantly to air and water pollution. Automation and information technology is revolutionizing the operations of inland and marine shipping, enabling new business models, increasing efficiency, improving security, developing new markets and supporting competitiveness.

Targeted impact: Accelerate the development and prepare the deployment of low-carbon and clean solution in the shipping sector, improve its system efficiency, enhancing digital and EU satellite-navigation solutions and contribute to the competitiveness of the European waterborne sector. Reduce environmental impact (on biodiversity, noise, pollution and waste management).

Potential research challenges:

- Increase the performance of hybrid/ full battery electric, fuel cell applications, propulsion systems with low-carbon fuels, on-board renewable energy and improved efficiency through changes in vessel design, and/or operations
- Automation and digitalisation in maritime;
- Research and innovation in Ports: alternate fuel and electricity supplies and uses, floating ports, capacity management and sustainability in context of mega ships, logistic chains, port-city opportunities and integration of water freight and passenger solutions in spatial planning;

[129] Initial IMO Strategy on Reduction of GHG Emissions From Ships http://www.imo.org/en/MediaCentre/PressBriefings/Pages/06GHGinitialstrategy.aspx

- Flexible manufacturing, increasing the competitiveness of production in shipyards, improving attractiveness of inland waterway transport and short sea shipping within integrated supply chains.

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation and / or a partnership.

4.5.5 Reduce the impact of transport on the environment and human health

Challenge: Transport emissions are one of the main contributors to air quality problems, particularly in urban areas. At the same time, noise also negatively affects health. Electrification promises to address most of these issues, but as some transport modes are more difficult to electrify in the near future, there is need for research and innovation activities to develop appropriate solutions. Furthermore, possible new health-related challenges need to be monitored and investigated.

Targeted impact: Improved scientific knowledge on the impacts of existing and new transport emissions, while at the same time devising ways of reducing emissions and their impacts, by technological or regulatory means, both at the source and once these emissions are in the environment.

Potential research challenges:

- Deeper understanding of the impact of air polluting transport emissions and noise emissions on health and ecosystems;
- Develop/demonstrate solutions for the mitigation of these negative effects adapted to each specific aspect; quality of life and wellbeing of passengers and citizens;
- Methods to influence environmentally virtuous vehicle end user behaviours and discouraging negative ones (aggressive driving, tampering etc.), taking into account user needs and mobility changing requirements stemming from new forms/future of work; methods and tools to incentivise a change in citizen behaviour.

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation, in collaboration with cluster 'Health'.

4.6 Develop seamless, smart, safe, accessible and inclusive mobility systems

Europe needs to maintain the competitiveness of its transport industry and manage the transformation of supply-based transport to demand-driven, safe and sustainable mobility services. Suitable research and innovation initiatives will help to prepare such transformation. Emerging digital technologies, such as Big Data, Internet of Things (IoT), artificial intelligence, and advanced satellite navigation services (Galileo/EGNOS) provide a great potential for developing connected and automated transport and managing traffic across the whole transport network. It can enable significant safety, environmental, economic and social benefits by reducing accidents caused by human error, decreasing traffic congestion, reducing energy consumption and emissions of vehicles, increasing efficiency and productivity of transport operations, improving working conditions, creating new jobs and contributing to social cohesion. To succeed in this transformation, Europe's ageing (and not always sustainable) transport infrastructure needs to be prepared for enabling cleaner and smarter operations. Research and innovation results will set the basis for future standards, creating European and global markets and adapting and modernising the overall regulatory framework. To maximise societal, environmental and economic benefits, in addition to technological solutions, it is essential to address human and social aspects such as: analysis of mobility factors and patterns, representations of different social groups and inclusiveness of new solutions, capacity building and public acceptance, etc.

4.6.1 Make automated and connected road transport safe and competitive

Challenge: Implement the goals for cooperative, connected and automated mobility on roads at EU and national levels as described in the Communication "On the road to automated mobility: An EU

strategy for mobility of the future"[130] and support the development and deployment of connected and automated, fully accessible mobility technologies, services and infrastructure.

Targeted impact: The objective is to bring societal benefits, strengthen the competitiveness of European industry and to manage properly the long transition phase towards a highly connected and automated transport system in a safe and secure way, favouring social inclusion, low emissions and overall efficiency (allowing for personal mobility while reducing overall environmental impact).

Potential research challenges:

- Interaction of automated vehicles with the surrounding environment, physical and digital infrastructure, interfaces with other transport modes;
- Technical enablers and Non-technical enablers: smart sensors, 3D HD maps, advanced EU satellite navigation/ positioning technologies, data-processing, artificial intelligence and connectivity, ethics, privacy, safety, security and cybersecurity accessibility liability, user and public acceptance, governance and international cooperation;
- Societal and environmental impacts of the automated road transport system (economic, environmental, social, training, qualifications, employment).
- Large-scale, cross-border demonstrations to get insights in the abilities of automated driving systems and their limitations and to enable deployment

Implementation: Planned research challenges and topics could be addressed through a European Partnership (possibly institutionalised Partnership based on Article 187 TFEU), in order to maximise impact and the exploitation of synergies with a more efficient and transparent setup, stronger financial and nonfinancial commitments, in collaboration with cluster 'Digital, Industry and Space'.

4.6.2 Develop efficient and innovative transport infrastructure

Challenge: Infrastructure innovation will be vital for implementing the TEN-T network and, more generally, in implementing the technological transition and efficiently limiting GHG emissions. Thus, there is a need to cater for the need for new solutions to ensure that despite increasing budgetary constraints, EU transport infrastructure can be maintained, upgraded and expanded to ensure competitiveness of the transport system while reducing unwanted impacts. Anticipating climate change is crucial for developing new types of innovative transport infrastructure for 2050, with an increasing challenge on its resilience and its environmental impact. Moreover, focusing on new transport modes and usages is a key to improve inter-modality and therefore improve the competitiveness and the quality of the services.

Targeted impact: Develop and validate new solutions to increase efficiency, inter-modality, resistance, safety and security of the transport system, for passengers and freight. At the same time, reduce greenhouse gas emissions from transport operations and improve the environmental performance of transport maintenance and modernisation works, over the entire lifecycle of the infrastructure. The infrastructure will have to withstand more frequent severe weather events by adapting to the climate change.

Potential research challenges:

- Develop and test new methods of transport infrastructure maintenance and upgrade, with a view to improving safety, climate resilience and environmental impact (incl. habitat and biodiversity) and develop new solutions to accommodate connected mobility;
- Support the development of transport infrastructure which will accommodate new and evolving transport modes and improved integration (national, regional) of transport infrastructure and energy systems through deployment of relevant infrastructure;
- Integration of physical and secure digital infrastructure including aspects of cybersecurity;
- Develop tools for information and data collection and management to monitor the performance of the infrastructure (asset utilisation rate) and the efficient management of mixed vehicle fleets on road networks;

[130] COM (2018) 283

- Develop and test governance, regulatory, and public procurement models and new contractual performance indicators and incentives to maintain and upgrade infrastructure.

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation.

4.6.3 Develop the future transport network and integrated traffic management

Challenge: Lack of timely information, reliability, multimodal coordination, safety/security, passenger comfort and accessibility of collective mobility, exacerbated by inefficient freight traffic all lead to an increased use of individual transport by road. Overcoming system-wide capacity constraints will allow for better management of traffic streams for passengers and freight, enabling seamless door-to-door mobility and transport, resulting in an optimal traffic mix and circumventing temporary capacity limitations.

Targeted impact: Develop and prepare for deployment of an advanced multi-modal network and integrated traffic management system, in order to enable seamless door-to-door mobility, increase safety, reduce congestion and transport related emissions.

Potential research challenges:

- Architecture and concept of operations for an efficient, resilient and adaptable multi-modal network and traffic management (NTM) system, using advanced digital technological solutions and EU satellite navigation services
- Integration of service chains with cooperative and connected vehicles for improved traffic management and overall higher information percentage rate of mobile travellers.
- Validation of next-generation multi-modal NTM systems (including intra-modal optimisation and development of interfaces)
- Data sharing issues: exchange models and data use by different public / private stakeholders, need for common approaches, and/or rules and regulations;
- Traffic optimisation of conventional, (semi-) automated and unmanned vehicles within a multi-modal NTM system.
- Enabling EU-wide co-modal freight transport services connected to global supply chains within a well synchronised, smart and seamless network.
- Inclusion of provisions for soft / active mobility (bikes + walking).

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation.

4.6.4 Enable multimodal freight logistics and passenger mobility services

Challenge: New mobility services are needed to improve opportunities for greater equity and accessibility for people who currently have few options. Public and private transport operators are evolving their service models – blurring traditional demarcations between public transport and private mobility and across modes.

Targeted impact: Ensure European competitiveness in logistics and mobility services, while decreasing climate and environmental impact in line with the Paris Agreement. Develop and validate new, low-carbon approaches for the freight transport system and logistics operations over the entire lifecycle. Develop and validate people-centred, smart public transport and sustainable mobility services in all modes in rural and urban areas.

Potential research challenges and topics:

- New digital infrastructures and their interconnectivity and interoperability also with EU satellite navigation, to improve the efficiency of logistics chains;
- In the supply chain, the network capacity usage and management as well as synchro-modal services;
- Assess emerging business and operating models, their employment and social effects (e.g. need for upskilling and reskilling of the labour force), considering new digital and space technologies, vehicles (e.g. drones), new mobility patterns, and new global trends;

- Assess the impact and opportunities of cooperative, connected and automated mobility on multimodal freight logistics based on digital technologies and EU satellite navigation services, open platforms and standards/ data formats;
- Developing and defining new governance models for accessible, smart mobility services for all;
- Emerging demands through future interoperability of physical, digital, technical, social (health, education, etc.), and spatial systems;
- Adapting the data/IoT eco-system to integrate new technologies from different sources (including non-transport) and to integrate new mobility demand (patterns).

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation, in collaboration with cluster 'Digital, Industry and Space' and with Cluster 'Food, Bioeconomy, Natural Resources, Agriculture and Environment'.

4.6.5 Increase transport safety – per mode and across modes

Challenge: Safety is of primary concern for any transport system and the EU set ambitious targets in its 2011 Transport White Paper. Research and innovation will underpin the three pillars affecting safety - technologies, regulations and human factors (individual and organisational aspects, including interaction with automation). The approach will be risk-based and systemic, including transport means/vehicles, infrastructure (e.g. train stations, airports, and ports), the physical environment (e.g. weather) and the various actors (e.g. manufacturers, regulators, operators, users) as well as all their interfaces. Specific issues per transport mode and synergies across modes will be addressed, in particular for safety culture, data-exploitation and safety/cyber-security interaction. Specific consideration will be given to high consequence low frequency events (such as passenger ship accidents) and emergency issues requiring fast-track research to accelerate safety assurance. Synergies will be exploited across research at national, EU and international level together with national authorities, EU agencies and international organisations to improve rulemaking, safety promotion and oversight.

Targeted impact: Contribute to drastically reduce accidents and incidents, fatalities, injuries and environmental damage and ensure that the EU is a world leader in safety in all modes of transport by furthering knowledge and awareness, and by developing technologies, products, services, and solutions that reconcile safety with efficiency and user-friendliness.

Potential research challenges and topics:

- Building, analysing and sharing safety data and safety intelligence;
- Understanding and predictive assessment of safety risks for design, operations and system effectiveness;
- Human factors, including societal behaviours, new mobility patterns, perception of information, situational awareness and interaction with automation;
- Smooth interaction between all users, their vehicles, infrastructure and physical environment in a safe system approach;
- New technologies and safety solutions, considering emerging risks and enablers (e.g. artificial intelligence);
- Improved preparation, validation, monitoring and enforcement of safety regulations, rules, standards, safety management systems and training, exploring potential of EU space technologies;
- Accident management and rapid response;

Implementation: Potential research challenges and topics will be addressed via collaborative research and innovation.

Overview of links between intervention areas (HE SP) and strategic research and innovation areas of the Strategic Plan document
X – strong link, **o** – link (less strong as for '**X'**)

Intervention areas as in Horizon Europe legal base / Strategic research and Innovation areas	Climate Science and Solutions	Energy Supply	Energy Systems and Grids	Buildings and Industrial Facilities in Energy Transition	Communities and Cities	Industrial Competitiveness in Transport	Clean Transport and Mobility	Smart Mobility	Energy Storage
Develop knowledge and more efficient climate action									
Climate science and solutions	X		o		o		o		
Develop cross-sectoral solutions to decarbonise the energy and mobility sectors									
Batteries		X	X	X	o	o	X		X
Hydrogen		X	o	o		o	X		X
Communities and cities	o	o	X	X	X		X	X	o
Emerging breakthrough technologies and climate solutions	o	X	X	X	X	o	X	o	X
Develop cost-efficient, zero-carbon energy systems									
Renewable energy		X	X	o	X		o		o
Energy Systems and grids		X	X	o	X		X		X
CC(U)S		X		X					
Energy storage		X	X	X	X		o	o	X
Leveraging public and private investments in the Clean Energy Transition		X	X		X				
Develop demand side solutions to decarbonise the energy system									
Empowering citizens		o	X	X	X		o	o	o
Decarbonising building stock		o	X	X	X		o		X
Industrial facilities in energy transition		o	X	X					o
Develop low-carbon and competitive transport solutions across all modes									
Towards zero-emission road transport (2ZERO)			o	o	o	X	X		
Rail			o		o	X		X	
Cleaner and competitive aviation						X	X		
Waterborne transport		o	o		o	X	X	X	
Impact on human health and environment	0				o		X		

Develop seamless, smart, and safe mobility systems									
Mobility and Safety for Automated Road Transport					o	X		X	
Competitive and innovative transport infrastructure			o	X		X		X	
Future transport network and integrated traffic management		o	o		o	X		X	
Multimodal freight logistics and passenger mobility services			o		o	X		X	
Transport safety across modes						X	X	X	o

5. International cooperation

International cooperation is crucial to ensure access to talent, knowledge, know-how, facilities and markets worldwide, to effectively tackle global challenges, to implement global commitments and to ensure global standards, inter-operability and a level playing field. Cooperation with third countries and international organisations/initiatives will be based on common interest, mutual benefit and global commitments to implement the Paris Agreement and the SDGs. This will strengthen the EU's research and innovation excellence, attractiveness and economic and industrial competitiveness, contribute to tackle global challenges, and to support the Union's external policies.

The EU intends to play an increasingly leading role in global/multilateral initiatives and/or organisations (e.g. Mission Innovation, Clean Energy Ministerial, IEA, IRENA, IPCC, GEO, United Nations' agencies as the International Civil Aviation Organisation, International Maritime Organisation) and maintain technological leadership in critical technology areas. The EU plans to develop its bilateral/multilateral and bi-regional/multi-regional research and innovation cooperation with strategic partners who can positively contribute to the EU's excellence in research and innovation or that represent promising markets for advanced European technologies. Particular attention will be paid to international research and innovation cooperation which will support countries to implement effective climate mitigation strategies in line with their commitments under the Paris Agreement, as well as adaptation strategies, in particular in developing countries. The EU will cooperate with international partners on innovative solutions for resource efficient personal and freight transport that respects the environment. This includes integrated, safe and inclusive mobility solutions for cities that will accelerate the transition to climate neutrality. The EU plans to further develop the African Union-European Union Research and Innovation Partnership on Climate Change and Sustainable Energy (CCSE), to continue research and innovation cooperation with its neighbourhood countries and with strategic and like-minded partners in the Americas and Asia, in the frame of its energy, transport and research and innovation dialogues, and Connectivity partnerships.

6. European Partnerships

A partnership approach is used in case it will more effectively achieve objectives and targeted impacts than regular calls for proposals of Horizon Europe. Thus, European Partnerships shall be established for addressing European or global challenges only in cases where they will more effectively achieve objectives of Horizon Europe than the Union alone and when compared to other forms of support of the Framework programme.

The following possible areas for future partnerships with a lead under this cluster have been identified:

- **Transforming Europe's rail system**: The proposed partnership would build upon the results achieved by Shift to Rail (S2R) Joint Undertaking (JU) under Horizon 2020, and has the objective of strengthening the role of rail in the transport system (by increasing the

capacity, cost-efficiency and reliability of EU rail services) and reinforcing the global technological leadership of the European rail industry. A Partnership approach is needed in this area because of the high degree of fragmentation of the railway ecosystems, the rail subsystems and the rail innovation life cycle. The proposed Partnership will focus its scope on a limited number of priorities to address emerging challenges, such as automation, digitalisation, decarbonisation and the need to increase the attractiveness of rail freight and its integration into digital multimodal mobility and logistics chains.

- **Integrated Air Traffic Management**: The proposed Partnership has the objective of developing an interoperable and harmonised EU air traffic management (ATM) system based on interoperable technological and operational solutions that foster sustainable air transport and connectivity within Europe and globally. A Partnership approach is warranted because EU intervention to modernise the ATM infrastructure at network level has, so far, been economically more effective and efficient compared to fragmented, local initiatives. The proposed Partnership will build on the Single European Sky Air Traffic Management Research (SESAR) Joint Undertaking (SESAR JU) under Horizon 2020.
- **Clean Aviation**: The primary objective is to contribute to deep decarbonisation of aviation, contributing to the EU's climate and energy goals in-line with the Paris Agreement. It also aims to support industrial policy objectives, by creating sustainable jobs in the EU, while also ensuring safety, security, and EU aviation global leadership, where EU support leads to additionality. A Partnership approach is needed because aviation research needs a coherent and holistic ecosystem approach, with a clear EU leadership, encompassing aircraft technologies, but also new business models, maintenance, operations and services. Furthermore, no single country or private company in Europe has the financial, technological, and human resources to take the technological and financial risk for an ambitious and transformative deep decarbonisation aviation research and innovation path on its own. The Partnership will help to manage the technological and financial risks and will seek synergies with other European Partnerships (e.g. key digital technologies, batteries, clean hydrogen and air-traffic management).
- **Clean Hydrogen:** The overall objective of the initiative is to create a strong, innovative and competitive European Clean Hydrogen sector, fully capable of underpinning the European energy transition by accelerating the market entry of nearly-zero carbon hydrogen-based technologies and delivering a wide range of socio-economic benefits to the European society. A Partnership approach is needed because the hydrogen and fuel cell stakeholder landscape is still extremely fragmented while massive investments are needed which exceed the capabilities of any single actor and requires a credible long-term commitment. The proposed Partnership will build on the existing Fuel Cells and Hydrogen 2 Joint Undertaking (FCH 2 JU), but would significantly revise its scope and expand partners (involve more energy companies, waterborne and rail transport, as well as industry, and civil society).
- **People-centric sustainable built environment**: The objective of this Partnership is to generate the necessary technology and socio-economic breakthroughs for an improved built environment supporting the socio-economic transition towards sustainability and the achievement of EU 2050 decarbonisation goals. The partnership goes beyond buildings, taking forward and broadening the activities of the 'Energy-efficient Buildings' PPP under Horizon 2020. The scope of the partnership extends to the whole life-cycle of the built environment (buildings, transport infrastructures, etc.). It will bring together the entire sector, from both the supply side and the demand side, in order to consider aspects such as energy performance, environmental impact, material and resource efficiency, as well as societal innovation towards sustainability and decarbonisation, all this driven by the user-centric approach.. These complex challenges call for a partnership approach which is driven by innovation and pulled by citizen demand for clean, safer, affordable, smarter, decarbonised and sustainable living.
- **Towards zero-emission road transport (2ZERO)**: **Towards zero-emission road transport (2ZERO)**: The Partnership aims to accelerate the transformation of the road transport system to a new fuel and powertrain base. Making an essential contribution to mitigating climate change while improving air quality, it will target further development of

highly efficient battery-electric vehicles, their infrastructure (including interfaces) and innovative use services, leading to innovation at system scale. 2ZERO has a clear objective: Europe remains the world leader in innovation, production and services in the field of zero-emission mobility. It will build on and widen the current European Green Vehicle Initiative (EGVI cPPP) The Partnership approach is essential for building consensus among the diverse road transport stakeholders on research and innovation roadmaps/priorities and for allowing the needed synergies to support innovative solutions across the entire value chain, also acting as a catalyst for supporting commitments from the private side.

- **Mobility and Safety for Automated Road Transport (MOSART)**: This initiative will contribute to significantly improve road safety and traffic efficiency (thus reducing system-wide fuel consumption and emissions) by addressing problems hindering the uptake of automated mobility systems and services on roads in the EU. It includes notably the lack of systemic and interoperable solutions at EU level, and the slow market update of research and innovation results and aims at maintaining EU industry leadership in this field. A Partnership is needed to bring together a broader spectrum of stakeholders to better align research and innovation efforts at European and Member State levels and to coordinate public and private investments.
- **Batteries: Towards a competitive European industrial battery value chain**: This partnership will support the development of a world-class European research and innovation ecosystem on batteries, with a view to build an European industrial leadership in the design and production of batteries for both stationary and mobile applications. It will support technological leadership in the field of current and particularly the development of future battery technologies beyond 2030. A Partnership approach will allow establishing close collaboration of all relevant actors along the complete batteries value chain, entailing clear commitment of partners to provide additional resources and investments. It will establish synergies with other European Partnerships depending on innovative batteries (e.g. 2ZERO, Clean Aviation).
- **Clean Energy Transition**: This Partnership will contribute to the 'Green Deal', put forward by the President of the European Commission, and to the objective of a fully decarbonised energy system by 2050. The complexity and scale of this challenge calls for a Partnership approach enabling the coordination of relevant EU instruments, private sector engagements and funding programmes in and among Member States. The proposed partnership will address the clean energy transition in a cross-thematic context, allowing a just transition for all citizens, regions and Member states and enabling the decarbonisation of all economic sectors - including energy-intensive industry - in a circular economy.
- **Sustainable, Smart and Inclusive Cities and Communities**: This partnership will support European cities in designing and implementing the required transformation for transition to sustainable urbanisation and climate neutrality in line with relevant EU and international policy frameworks such as SDGs, the EU Green Deal, Paris Agreement, Urban Agenda of the EU and the Habitat III New Urban Agenda. It will focus on innovation, in particular in the public sector (e.g capacity building, smart specialisation). It will have an ecosystem approach, addressing also peri-urban areas. It will align EU, national, regional and municipal research and innovation agendas and the rolling out of joint calls and activities to promote EU-wide collaboration, engagement and mobilisation of all relevant resources.
- **Zero-emission waterborne transport**: The partnership will create a foundation for shipping that underpins a climate neutral future, with the demonstration of deployable zero-emission solutions, suitable for all main ship types and services by 2030. It will also contribute to maintaining and further reinforcing Europe's global leadership in green shipping technologies. The partnership is expected to mobilise a critical mass of public and private actors in waterborne transport, which are committed to the urgent development of the necessary knowledge, technology and operational solutions, while ensuring and accelerating their deployment.

Activities within the Cluster "Climate, Energy and Mobility" will also be closely related and collaborate with relevant EIT KICs, in particular the EIT InnoEnergy, EIT Climate KIC and EIT

Urban mobility. In addition, a candidate European Partnership on a Geological Service for Europe would contribute to this cluster by providing expertise and data services in areas of energy storage and carbon capture storage.

7. Missions

Depending on the scope of future specific Missions, activities within the Cluster Climate, Energy and Mobility are expected to be particularly relevant to the Mission(s) identified within the "Climate-Neutral and Smart Cities" and the "Climate Adaptation including Societal Transformation" mission areas, as well as other mission areas.