Research & Innovation Agenda

D4.3 DEEDS Research & Innovation Agenda

DEEDS

Dialogue on European Decarbonisation Pathways

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Executive Summary

The main objectives of the DEEDS-project are to deliver state-of the art knowledge on decarbonisation pathways and to facilitate knowledge co-creation on decarbonisation pathways with policy and business representatives, scientists, NGO's and other stakeholders.

In this DEEDS Research & Innovation Agenda recommendations on Research and Innovation (R&I) aimed at decarbonisation of the European economy and society are compiled to inform the next Research and Innovation framework programme Horizon Europe. Horizon Europe, in synergy with other EU programmes, will play a pivotal role in leveraging national public and private investments in the frame of the EU Green Deal. The following R&I recommendations are aligned with the topics and objectives of the EU Green Deal. They are derived from the work and products that DEEDS delivered, more specifically from the final report of the High-Level Panel of the European Decarbonisation Pathways Initiative, the workshops that DEEDS organised and the Policy Briefs and Business Guide that DEEDS published. Below we present the titles of the R&I recommendations per research area relevant for the EU Green Deal. Each chapter of this Research Agenda is dedicated to a relevant research area and describes the main knowledge gaps that should be addressed by R&I, and highlights the challenges and desired impact of the R&I recommendations.

The cross-cutting character of the European Green Deal

- *R&I priority 1:* New modes of governance for system integration
- *R&I priority 2:* Better (integrated) policies and law for systems integration
- *R&I priority 3:* Develop tools and methodologies that foster effective interdisciplinary and transdisciplinary knowledge production
- *R&I priority 4:* Develop dedicated ICT and ICT-applications to advance and implement intelligent and flexible energy systems and further integration with other systems
- *R&I priority 5:* Develop ICT-applications for accelerated and enhanced service innovation to support climate neutrality in the built environment (cities), mobility, food, industry and business sector
- *R&I priority 6:* Counter adverse impacts of ICT for the decarbonisation of the European economy
- *R&I priority 7:* Facilitate dedicated "learning programmes" to increase the capacity of involved actors to navigate towards climate neutrality
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- *R&I priority 2:* Prospective development of integrated and consistent sets of energy policies
- *R&I priority 3:* New market designs
- *R&I priority 4:* Flexible electrification in buildings, industry, and transport
- *R&I priority 5:* System-level strategies for VRE integration
- *R&I priority 6:* E-fuel technology development

- *R&I priority 7:* System-level strategies for E-fuels
- *R&I priority 8:* System-level Strategies & Roadmaps for Smart & Clean Infrastructures
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- *R&I priority 2:* Cost reduction, improving performance and reliability of close-to-market decarbonisation technologies in order to scale up their deployment
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- *R&I priority 6:* Create (local) capacity to mitigate possible negative impacts of the energy transition and create new jobs

1 Introduction

Tackling climate and environmental-related challenges is the defining task of our generation. **We cannot solve tomorrow's problems with today's thinking**; hence a bold policy response is required. The current political framework brings forward climate change as a priority. **The European (EU) Green Deal [1] sets an ambitious climate goal: to be the first climate-neutral continent by 2050**. The transition towards climate neutrality by 2050 will require transformational change. Research & Innovation (R&I) should provide the necessary support in delivering the zero-carbon solutions needed, while promoting industrial competitiveness in the EU economy.

1.1 The DialoguE on European Decarbonisation Strategies (DEEDS)

DEEDS[1] is a H2020-project that delivers state-of the art knowledge on decarbonisation pathways and facilitates knowledge co-creation with policy and business representatives, scientists, NGO's and other stakeholders. Moreover, it delivers knowledge and products that are relevant for the EU Green Deal. In 2018, **the project supported the High-Level Panel of the European Decarbonisation Pathways Initiative** (EDPI) in writing its final report [2] that contained recommendations for R&I relevant for the EU Green Deal, on four sectors and three horizontal topics: Energy, Transport and mobility, Industries, Agriculture, Cities, Social Innovation, and Economic implications (finance). A schematic summary of the R&I recommendations of the High-Level Panel (HLP) is presented below (Figure 1).

To expand on the R&I recommendations and actions of the Final Report of the HLP, and to understand the ways in which they can be applied in the various sectors, **the DEEDS project facilitated a dialogue between relevant representatives from policy making, science, business, scientists, industry and civil society**. For this purpose, DEEDS hosted a number of workshops in 2019 under each policy area, bringing together experts to discuss the challenges they face with regards to the introduction of decarbonisation practices and to bring forward further policy recommendations. These workshops and the HLP-report resulted in *Policy Briefs* and *Business Guide* that support policy makers (on different levels), industry and their stakeholders to make decisions on investment in R&I, as well as choices for technology trajectories based on various scenarios.

These briefings and other relevant material can be found on the DEEDS website (www.deeds.eu). One of these DEEDS products is the present DEEDS Research Agenda that provides input to the new Research and Innovation Programme of the European Commission, Horizon Europe.

[1] The project has received funding from the European Union's Horizon 2020 Programme of the EU under grant agreement 642242, https://deeds.eu/

Figure 1 Graphic representation of the HLP recommendations

1.2 The European Green Deal

The EU Green Deal was presented by the European Commission in December 2019 and it sets the steps for achieving the most ambitious goal for the EU: to become climate-neutral by 2050. Such an ambitious transformation must ensure that the economy remains competitive, while the society and the environment are protected. Thus, the transition must be just and inclusive for all. "The European Green Deal is a new growth strategy that aims to transform the EU into a fair and prosperous society, with a modern, resource-efficient and competitive economy where there are no net emissions of greenhouse gases in 2050 and where economic growth is decoupled from resource use. It also aims to protect, conserve and enhance the EU's natural capital, and protect the health and well-being of citizens from environment-related risks and impacts. At the same time, this transition must be just and

inclusive" [1]. The EU Green Deal will require special attention to be paid to the citizens, regions, industries and workers who will face the greatest challenges in transitioning to a carbon neutral economy. All EU actions and policies will have to contribute to the EU Green Deal objectives.

"**New technologies, sustainable solutions and disruptive innovation are critical to achieving the objectives of the European Green Deal**" [1]. R&I, thus, plays an important role in supporting the actions within the framework of the EU Green Deal. It will define the speed at which decarbonisation will take place, at which costs and with which co-benefits or trade-offs. The challenges are complex, interlinked and overlapping and new measures on their own will not be enough. This will require technological innovations, social innovation and behavioural change, as well as new policies and regulations that can support the implementation of these innovations. The development and implementation of these innovations in the socio-technical system requires a careful interplay between policy, industry, research and stakeholders, while crossing disciplines, sectors and policy domains, which makes it a formidable challenge. "Horizon Europe, in synergy with other EU programmes, will play a pivotal role in leveraging national public and private investments. At least 35% of the budget of Horizon Europe will fund new solutions for climate, which are relevant for implementing the Green Deal." [1]

1.3 A green recovery from the COVID-19 Pandemic

The COVID-19 Pandemic of spring 2020 has revealed several vulnerabilities in our modern society, such as in mobility and supply chains, but also in the deepening of divides, between societal groups, between city and rural areas, or between "the haves and the have not's". Many vulnerabilities are pointing at the unsustainability of processes and routines in society. Recovery from the pandemic will require high investments, which gives the opportunity to couple these to the objectives of the EU Green Deal. **The R&I recommendations presented in this Research Agenda are relevant not only to the EU Green Deal but also for the recovery from COVID-19** and the way in which we can use this as an opportunity to design a green recovery and achieve carbon neutrality in 2050.

1.4 The Research & Innovation Agenda

The following chapters with Research and Innovation recommendations are based on the work of DEEDS, i.e. the final report of the High-Level Panel, the workshop reports, the policy briefs, and the special session on "Transformation to a climate-neutral society – The role of beyond GDP indicators" held in the Beyond Growth Conference on 28th October 2019 in Helsinki. The report is structured along the lines of the EU Green Deal. It starts with a chapter on the cross-cutting character of the innovations that are needed for the EU Green Deal. The Research Agenda continues to present relevant R&I recommendations for the Green Deal for: clean, affordable, and secure energy, a clean and circular industry, promoting climate-neutral

and smart cities, accelerating the shift to sustainable and smart transport systems, a fair, healthy and environmental-friendly food system, green finance and investments, and a fair and inclusive energy transition. In each chapter the introduction gives a short overview of the context and the main knowledge gaps followed by specific R&I recommendations and expected impacts.

2 The cross-cutting character of the European Green Deal

2.1 Introduction

To realise the goals of the EU Green Deal a transformational change is needed that will require new approaches across sectors, disciplines and policies. The associated changes are of systemic nature, which means that problems will not stay within set "boundaries" (physical, governmental, or social) and that solutions can easily introduce new interconnected problems or unwanted interdependencies. This "cross-cutting" character of the transformational change is recognised in the EU Green Deal [1]: "[...] there is a need to rethink policies for clean energy supply across the economy, industry, production and consumption, large-scale infrastructure, transport, food and agriculture, construction, taxation and social benefits." […] "While all of these areas for action are strongly interlinked and mutually reinforcing, careful attention will have to be paid when there are potential trade-offs between economic, environmental and social objectives." (p.4). […] "Conventional approaches will not be sufficient. Emphasising experimentation, and working across sectors and disciplines, the EU's Research and Innovation agenda will take the systemic approach needed to achieve the aims of the Green Deal." (p. 18)

The transition to a climate neutral energy system will lead to a technical **integration within energy systems and further integration with other systems in different sectors**, such as mobility, industry or built environment. This will introduce new challenges as separate governance systems that will also need to be integrated. Integration of systems will also lead to new challenges for research, as **scientific knowledge from all branches of scientific disciplines** (technical and social) need to contribute to a better evidence base for policies and strategies. **Digitalisation** will support system integration and its management and will also support tailored solutions by increasing their "smartness". The transformation to a climate neutral society and economy is a unique process that is without precedent. It requires **adaptability, reflection and learning**, as no recipe is available.

In this chapter we will highlight R&I topics for the above mentioned themes: system integration and new modes of governance, fostering interdisciplinary and transdisciplinary science, digitalisation, and adapting and learning to transform. Specific attention will be given to R&I with respect to "Transition Super-Labs" that is an elaboration of this last category, and was already mentioned by the High-Level Panel [2] in its final report. All R&I topics are addressing existing knowledge gaps. These are cross-cutting by nature and are all relevant for the chapters to follow.

The main knowledge gaps on system integration and governance are:

- New modes of governance for system integration [3][4][5][6][7][8];
- Better (integrated) policies and law for systems integration [9][10][11].

For interdisciplinary and transdisciplinary science the gaps are:

- Develop tools and methodologies that foster effective interdisciplinary and transdisciplinary knowledge production [12][13][14][15].

For digitalisation to support decarbonisation the knowledge gaps are:

- Develop dedicated ICT and ICT-applications to advance and implement intelligent and flexible energy systems and further integration with other systems [16][17];
- Develop ICT-applications for accelerated and enhanced service innovation to support climate neutrality in the built environment (cities), mobility, food, industry and business sector [18][19];
- Counter adverse impacts of ICT for the decarbonisation of the European economy [20].

For "adapting and learning to transform" the gap is:

- Facilitate dedicated "learning programmes" for involved actors [21][22][23].

2.2 System integration and new modes of governance

Challenge
The transition to climate neutrality will require technological systems integration, within the energy system, but also with systems in other sectors (built environment, industry, mobility and transport). These system integration measures, elaborated further in the following chapters of this report, need to go hand in hand with new modes of governance in order to be able to capitalise on the technological changes and to achieve carbon neutrality in 2050.

R&I priority 2.1: New modes of governance for system integration
New modes of governance need to accompany the technological changes that are being introduced for system integration within the energy system or with other systems. Higher levels of electrification coupled with increased levels of variable renewables and the introduction of new fuels and energy vectors will require new governance measures. Traditionally, the governance has focused on individual energy carriers (electricity, gas, liquids hydrocarbons) but greater systems integrations requires new governance measures and structures that are able to address the system level. These should be developed in cooperation with the actors from the involved sectors or systems and should contain rules for joint management, procedures for knowledge sharing, joint data management, accounting rules, new standards, or communication principles. For instance, electrification of industrial processes could deliver flexibility to the energy system, when industrial processes are able to (better) follow the production profile of electricity. This will require cooperation between the industrial and electricity producer and an agreement about when (and when not) industry can take up excessive electricity, accounting procedures, remuneration, monitoring, etc. Generic research on this topic will not lead to the desired impact. Each sector has separate governance systems and structures with their own "language" and routines. As these former

separate approaches will not work for integrated systems, R&I should develop governance systems and structures that can bridge the divides.

R&I priority 2.2: Better (integrated) policies and law for systems integration
At a policy making level, increased integration of systems poses a challenge to develop, or to better integrate policies that support the objective of climate neutrality. EU Member States must establish integrated National Energy and Climate Plans (NECP) for the period from 2021 to 2030. Greater systems integration will pose challenges in terms of complexity, reporting and coherence and R&I should focus on developing a solid analytical framework to facilitate Member States to explore and illustrate the impacts of proposed targets policies and measures. Existing rules, regulations and laws can obstruct the integration of the systems and R&I can help to identify those. R&I should produce the state-of-the-art, deliver input to new supportive policies and help to develop supportive European policy frameworks.

Expected impact
A timely and smoothly implementation of integrated systems supported by specifically developed modes of governance and supportive policies (or policy frameworks) to reach the targets of the EU Green Deal. These new modes of governance and supportive policies should enable actors from different sectors to develop new ways of cooperation and should support new agreements for effective joint actions that are supported with timely and accurate data and information.

2.3 Fostering inter- and transdisciplinary science

Challenge
Transformation of systems will require deep integrated knowledge to investigate and support required system changes. Knowledge integration is furthermore needed for assessing, developing, and monitoring systems integration and new modes of governance. R&I for decarbonised systems will require that scientists from a wide range of disciplines jointly develop solutions, decarbonised technologies, and systems through interdisciplinary research. As the aim is to implement solutions in practice, it will also require involvement of practitioners and stakeholders for implementing and deploying solutions through transdisciplinary science. Both inter- and transdisciplinary knowledge production are thus needed. R&I should develop (better) interaction, processes, and guidelines that can support these two types of knowledge production.

R&I priority 2.3: Develop tools and methodologies that foster effective interdisciplinary and transdisciplinary knowledge production
Interdisciplinarity and inclusion of Social Sciences and Humanities (SSH) is a prerequisite for addressing a number of societal challenges, which are cross-cutting by nature. R&I should develop tools and methodologies that foster effective interdisciplinary and transdisciplinary cooperation and knowledge production for transformation towards climate neutral systems. Insight is still lacking in effective step-by-step processes for interaction, requirements for facilitators of these processes, and tools that effectively bridge the divide between the

disciplinary languages, cultures, and ways of working. This same recommendation holds for transdisciplinary processes that are aimed at bridging science and practice. A research effort that systematically evaluates and encourages inter- and transdisciplinary research projects for decarbonisation, for instance in the frame of Horizon Europe, should provide these insights. Consideration of such a metric should be considered in project scoring and funding consideration.

Expected impact
Dedicated tools and guidelines for inter- and transdisciplinary knowledge production are a requirement for integrated knowledge production for system transformation. These processes are important for R&I that is aimed at realising decarbonised systems to reach climate-neutrality by 2050.

2.4 Digitalisation

Challenge
Digitalisation is key to deploying innovation at system level across all traditional sectors. Information and Communications Technology (ICT) is an important enabler for systems integration, systems management, data and information exchange, service innovations, and communication and dissemination to foster decarbonisation. A targeted digitalisation effort should support sectors, cities, and groups to implement and manage decarbonised systems for climate-neutrality.

R&I priority 2.4: Develop dedicated ICT and ICT-applications to advance and implement intelligent and flexible energy systems and further integration with other systems
R&I should support development of intelligent and flexible energy systems and further integration with other systems (mobility, built environment, industry, cities) through enhanced digitalisation. Sensors, Artificial Intelligence (AI), Internet of Things (IoT), ICT platforms and other applications (e.g. Building Information Modelling – BIM) are important in this respect. Examples of where digitalisation could play a role are energy systems management, smart vehicle charging, smart heating in buildings, flexible operation of appliances, industrial processes, and "smart cities" in general. These smart applications should be accompanied by new modes of governance to implement agreements that are needed to really make it work (see also 2.2). ICT can foster the exchange of data (also big data) and information among involved actor groups to enable evidence-based management, strategies, or policies. R&I should develop efficient ways for this.

R&I priority 2.5: Develop ICT-applications for accelerated and enhanced service innovation to support climate neutrality in the built environment (cities), mobility, food, industry and business sector
Digitalisation should support service innovation in the built environment (cities), mobility, food, industry and business sector to aim for climate neutrality. Services should support behaviour or efficient performance with a lower carbon footprint. Specific business models will also be required to make them economically and socially attractive. R&I should support

the development of these service innovations and should also investigate (and counter) possible rebound effects. Furthermore, digitalised applications should be developed to disseminate information and to deliver concrete advise to consumers to support decarbonisation.

R&I priority 2.6: Counter adverse impacts of ICT for the decarbonisation of the European economy
R&I should target possible adverse impacts of digitalisation. Two fields of research are important with this respect. First of all, ICT uses a significant share of energy. Therefore, R&I should be targeted at reducing the energy use of ICT and increasing the energy efficiency of ICT applications and data centres. Secondly, ICT-applications could impact the privacy of its users. R&I should be directed towards developing ICT applications that are compliant with the General Data Protection Regulation (GDPR).

Expected impact
Efficient smart and intelligent (digitalised) tools and systems that support system management, system integration, and service innovation are required for deep decarbonisation of energy systems and other connected systems in relation to the objectives of the European Green Deal. These digitalised techniques and systems must be energy efficient, should be compliant with privacy regulations and orientated around creating consumer trust.

2.5 Adapting and learning to transform

Challenge
Achieving the objectives of the Paris Agreement requires far reaching system changes in both technological and social terms. There is no precedent for this, and no "recipe" or "blueprint" for how to implement these changes. Therefore, a targeted R&I effort is needed that helps to navigate towards climate neutrality and is aimed at supporting adaptation and learning and capturing lessons learned and is guided through dedicated monitoring.

R&I priority 2.7: Facilitate dedicated "learning programmes" to increase the capacity of involved actors to navigate towards climate neutrality
Implementation of the required system changes within multiple sectors (energy, built environment (cities), mobility, industry, food and agriculture) should be accompanied by learning programmes for the actors that are involved in these changes. In these learning programmes the involved actors discuss the experiences with implementation of measures, and with new methodologies to deal with these system changes, and should be aimed at capturing lessons learned. The learning programmes should be informed by systematic monitoring of the impacts of policy implementation at national and local level in a broad sense (see R&I priority 9.5). To accelerate the energy transition, the captured lessons should be disseminated to the target groups that are involved in the system changes.

Expected impact
The learning programmes will lead to better implementation of the measures aimed at system changes for decarbonisation and to better understanding of what is being achieved among the involved actors. It is expected that the learning programmes will also lead to greater support by the involved actors.

2.6 Establish Transition Super-Labs in regions that are difficult to transform

One of the cross-cutting recommendations of the High-Level Panel of the EDPI, aimed at systemic innovation and local transformation to climate neutrality, is to establish Transition Super-Labs in areas that are difficult to transform, such as regions that are dependent on fossil fuels (mining areas, certain industrial clusters/areas, …), intensive agricultural areas or cities with inefficient building stock. The Transition Super-Labs are real-life laboratories where research, business, administration and civil society jointly develop transition plans, monitor the transition, develop policy responses and co-produce integrated solutions tailored to the local situation. Transition Super-Labs have an important role in local capacity building, providing the evidence base, monitoring the transition and developing adequate policy responses.

With this aim, Transition Super-Labs:

- Develop the capacity to make the transition happen faster;
- Create support for the expected changes in the relevant networks;
- Research obstacles and benefits of the local transition;
- Do foresight to explore decarbonisation options from a wider systemic perspective and to assess possible negative impacts for instance for the labour force and certain social groups;
- Develop supportive policy measures and transition plans for smooth local change with involved networks;
- Monitor the transition (in a broad sense);
- Develop policy responses and adjusted transition plans in case unwanted impacts are occurring.

The Transition Super-Labs in different EU-regions may have a different focus but could apply a common methodological approach. Together, they will form a European Network of Transition Super-Labs that can act as a European observatory of regional transitions and is able to generate lessons learned, to mitigate any adverse or negative impacts, and to provide feedback to the implementation of the EU Green Deal.
The activities of the Transition Super-Labs should be funded from a portfolio of sources – merging European, national, regional and private funds - for a long time period under the supervision of Horizon Europe.

3 Clean, affordable, and secure energy

3.1 Introduction

Providing clean, affordable and secure energy is a sine qua non of reaching net greenhouse gas neutrality by 2050. Accordingly, the EU Green Deal expresses the need for a **clean power sector based on renewable energy**. A challenge to this objective is the variable nature of renewable energy sources, which requires a **better integration, across regions, through storage, and via other flexibility options such as demand response from newly-electrified demands**.

While the power sector offers the largest potential for rapid and substantial emission reductions, more than half of energy-related CO_2 emissions originate from non-electric energy uses in transport, buildings and industry. The EU Green Deal thus mentions the need to develop **options for decarbonising gas, e.g. via renewables-based hydrogen and synthetic fuels (e-fuels)**. A further building block of a decarbonised energy system is the provision of **smart infrastructure that facilitates cross-border cooperation and enables innovative decarbonisation technologies**. Finally, all of the current net-neutral strategies require a certain amount of **net negative emissions options** to offset residual emissions that are too costly to abate. Most of these options are still in early to medium Technical Readiness Level (TRL), which makes their successful deployment contingent on further R&I efforts.

The success of the zero-carbon transformation envisaged in the EU Green Deal relies on the development and implementation of **credible, robust policies and their integration with well-functioning markets**, as was demonstrated by the impressive scale-up of renewable electricity over the last decades in EU Member States with effective support policies. Decarbonisation of energy supply will only happen if there is credible commitment to a sufficiently high CO_2 price or other strong policy signals and regulations, otherwise private companies will not be able to develop new business models and technologies. The success of new storage technologies, demand flexibility and sector-coupling hinges on regulation and market designs that does not impede these new developments. Accordingly, the EU Green Deal emphasizes the central role of updating key policies and regulations, such as the Emissions Trading System (ETS), the Energy Taxation Directive (ETD), and the Trans-European Networks (TEN-E) Regulation, as well as updating and integrating the European energy markets.

The main knowledge and technology gaps for policies and markets to guide transformation are:

- Ex-post evaluation of Energy Policies;
- Prospective development of integrated and consistent sets of energy policies;
- New market designs.

The main knowledge and technology gaps for Variable Renewable Energy (VRE) integration and sector coupling are:

- Flexible electrification in buildings, industry, and transport;
- System-level strategies for VRE integration.

The main knowledge and technology gaps for renewables-based hydrogen and synthetic fuels are:

- E-fuel technology development;
- System-level strategies for E-fuels.

The main knowledge and technology gaps for smart energy infrastructures for a low carbon future are:

- System-level Strategies & Roadmaps for Smart & Clean Infrastructures.

The main knowledge and technology gaps for carbon-negative technologies are:

- System-level comparative analysis of different Carbon Dioxide Removal (CDR) options;
- Technology development for Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Capture with Carbon Storage (DACCS);
- Development of land-use-related CDR options.

3.2 Policies and markets to guide the transformation

Challenge

A key R&I need for realising the transformation towards a clean, affordable and secure energy supply is research on policies and markets to guide the transformation. Over the last decades, a large number of energy and climate policies have been enacted on European Union (EU) and Member State (MS) level, often without real analysis of the long-term effects and interactions with other policies, which sometimes led to policy retractions or the need for repeated reforms. Although there exists a body of literature on policies, the knowledge is neither comprehensive nor conclusive [24]. The state of both consolidated ex-post analysis as well as ex-ante evaluations of policies is substantially too weak, given the paramount role that policies and markets have on how trillions of Euros to be spent until 2050.

Two prime examples for this knowledge gap are efficiency standards and labelling. Although the European Commission has enacted such policies over the last decades e.g. for appliances, buildings and vehicles, there is limited consolidated scientific knowledge about the ex-post effectiveness and efficiency of these approaches in the various sectors [25]. This missing knowledge leads to the current situation where the choice of a specific policy instrument, e.g. pricing vs. standards, seems to more depend on political world views rather than sound scientific evidence, which leads to wasteful policy inconsistency and increases the likelihood of policy reversals when political majorities in Member States change.

Another key example is the EU Emissions Trading System (EU ETS), its interactions with other energy policies and the implementation of the MSR, which will become even more important

in the future. The EU Green Deal discusses extending the scope of the ETS and shifting the burden between ETS and Effort Sharing Regulation (ESR) sectors, which will have fundamental repercussions on CO_2 prices, resilience and robustness of the ETS, industry & power decarbonisation - but limited analysis that exists on these crucial questions is far from consolidated and conclusive.

R&I priority 3.1: Ex-post evaluation of Energy Policies
This R&I priority collects, consolidates and develops new knowledge about the implementation, effectiveness, robustness and efficiency of different types of policies. It covers all relevant policies, such as taxation, emission markets, efficiency standards, labelling, information campaigns, public procurement, etc. It pursues ex-post analyses of effectiveness and costs in different countries, as well as collecting information about the implementation processes of each policy – what worked, what didn't, and why so? The aim would be to develop "cooking recipes" for governments and administrations planning to implement a certain policy.

R&I priority 3.2: Prospective development of integrated and consistent sets of energy policies
This R&I priority focuses on developing and analysing new sets of policies that work consistently towards the aims of the EU Green Deal [26]. Importantly, the interactions between the various policies at EU and national level need to be better understood. The EU ETS is a main pillar of energy supply decarbonisation, but over the last decade, the price signal was not yet enough to lead to substantial decarbonisation action, partially due to the price-weakening effects of additional climate policies (e.g. Renewable Energy Systems, energy efficiency policies) in addition to a lax emissions cap. While the recent Market Stability Reverse (MSR) reform has strengthened the ETS price, current research shows that the MSR cancellation rules will likely lead to unwanted positive feedbacks [27], green paradox effects [28], and to the result that national policies like a coal-phase-out can actually increase total ETS emissions [29]. A deeper ex-ante analysis of such interactions will allow the development of more consistent policy mixes that reduce the amount of counterproductive interactions and thus the amount of costly and politically challenging reforms.

R&I priority 3.3: New market designs
R&I is needed to develop new market designs and taxation rules for the different energy carriers that support rather than hinder zero-emission innovations. Most current energy markets were only marginally updated over the last decades and do not cater to the needs of the Green Deal. As an example, in many Member States storage and demand response options cannot compete on a level playing field due to power market designs and taxation regulations. The implementation of new market designs should be preceded and accompanied by intense scientific research to make them as robust as possible. Otherwise repeated adjustments and interferences by the regulator will be required, which each create insecurity and weaken investor confidence, thus endangering the necessary investments into the transformation.

Expected impact
The combination of ex-post analysis of implemented policies and modelling-based ex-ante assessments of both direct effects as well as interactions between policy instruments at EU and Member State level will provide decisionmakers with insights on the impacts of various design parameters of different policy options and will thus enable the development of more effective, robust and efficient policy mixes [30].

Research on past implementation processes of climate and energy policies in different countries, regions and cities will provide best-practice examples and cooking recipes on how to best implement a certain policy, thereby reducing the costly repetition of trial-and-error learning in each Member State.

Without market designs that do not hinder but rather encourage new low-carbon solutions and sector-integration, few of the required technologies will be able to gain market shares and realise their potential, even if they are technologically fully mature.

3.3 VRE integration and sector coupling

Challenge
A rapid and deep decarbonisation of power supply is a pivotal element of efficient climate protection strategies: while cost reductions of wind and solar mean that technologically mature and affordable low-carbon electricity technologies are available [31][32], electrification is an important option for decarbonising energy demands of buildings, industry and transportation [33].

The most critical limitation of wind and solar power is the variability of their supply. At the same time, electrifying a large share of the energy demands of buildings, industry and transportation could provide substantial demand flexibility that could balance this supply-side variability, if a) the right technologies are brought to market-readiness and b) market designs and tax regulations are changed in such a way that the demand has enough incentives to react to supply scarcity/surplus [26].

R&I priority 3.4: Flexible electrification in buildings, industry, and transport
Currently, most final energy demanded in the three demand sectors is non-electric. Given that many electrification technologies are still in medium TRL, further research is needed to understand the extent to which this demand can be electrified by 2030 and 2050. Special focus should be given to analysing the potential of shifting this additional demand in time to allow for easier integration of variable renewables.

R&I priority 3.5: System-level strategies for VRE integration
Although some studies exist, further research at higher detail is needed to improve the understanding of power sectors with high (60-100%) share of variable renewable energies, in order to bridge the gap between theoretical knowledge and actual implementation. Projects should develop and refine approaches for stable system operation, for example via demand flexibility, grid expansion, and storage systems. This priority covers individual technology

options, system-level pathways, as well as economically sound policy approaches for incentivizing renewable energy integration and sector coupling.

Expected impact
Research projects will

- Provide a better understanding of expected future aggregate electricity demand as well as 'shiftable' demand, which is necessary to define renewable deployment targets, provide production capacity and estimate storage and integration needs;
- Prioritise amongst technologies that provide a flexible use of electricity in industry, buildings to ensure that research and development money has the highest impact by being spent on technologies most critical for deep decarbonisation of the full system;
- Develop the coordination algorithms and market designs needed to ensure that increased electrification does not hinder, but rather facilitates VRE integration;
- Provide comprehensive roadmaps combining regional detail with EU-wide coverage to allow for integrated coordination and planning of an EU-wide VRE-based power system.

3.4 Renewables-based hydrogen and synthetic fuels

Challenge
Residual emissions from use of liquids and gases in transport, industry and buildings are a key challenge to deep emission reductions [33]. While preliminary research has shown that flexible and smartly operated e-fuels production might be a solution to this challenge and additionally have strong synergies with power system decarbonisation [34], these technologies are not yet market-ready and suffer from high costs [35]. Furthermore, high input energy demand due to low conversion efficiencies, as well as potential sustainability and land availability challenges imply that e-fuels will not be a silver bullet for the full energy system, but will need to be targeted strategically towards the highest priority use cases.

R&I *priority 3.6: E-fuel technology development*
This R&I priority focuses on direct technology improvement, with a focus on efficiency, flexibility and scalability of technologies for e-fuel generation,

R&I priority 3.7: System-level strategies for E-fuels
This priority explores system-level strategies for their deployment, as well as benefits and potential adverse side effects. It also develops pathways for international cooperation to enable large-scale renewable energy imports in the form of e-fuels.

Expected Impact
Projects to fill this R&I gap will develop, assess and improve technologies for e-fuel generation. They will further explore system-level strategies for their deployment, as well as benefits and potential adverse side effects, as well as the scope for renewable energy imports in the form of e-fuels. This line of research will foster strategic energy planning by policymakers and businesses with regards to the scope of indirect electrification (via e-fuel

deployment) vs. direct electrification (via e-mobility, heat pumps and other end use technologies).

3.5 Smart energy infrastructures for a low carbon future

Challenge
The transition towards an energy system relying heavily on deep electrification of many end uses, wide-spread 'prosumage' from varying renewable sources as well the use of hydrogen as an additional energy carrier will require a fundamental and integrated restructuring of transmission and distribution infrastructures. For instance, a much-strengthened trans-European electricity transmission grid might be necessary to cope with temporal and spatial variations of renewable energy supply. District heating systems have considerable potential for increasing energy efficiency and the transition to renewable energy sources, but their expansion requires a great deal of coordination across multiple energy policy areas. The emerging hydrogen economy will require a new pipeline infrastructure, or a conversion of existing gas infrastructures. Similarly, pipelines might be needed for carbon capture and storage or utilisation. These infrastructure transformations are highly coordination-intensive and characterized by long planning horizons as well as high up-front investments.

R&I priority 3.8: System-level Strategies & Roadmaps for Smart & Clean Infrastructures
Research projects will address one or several priority areas of infrastructure development for the energy transition. They will be explicit about the spatial patterns of infrastructure expansion, priority areas and costs. Beyond technology assessments, projects also address barriers and opportunities to infrastructure expansion, such as public acceptance and finance.

Expected Impact
The results of these projects will provide policymakers and regulators at EU and national levels with a comprehensive understanding of the infrastructure required for a clean energy system. This will enable them to coordinate the provision of this infrastructure, develop the necessary standards and regulations and tackle international coordination requirements as well as local citizen involvement early enough for a timely deployment.

3.6 Carbon-negative technologies

Challenge
Achieving climate neutrality by 2050 is inevitably connected with at least a moderate amount of Carbon Dioxide Removal (CDR) from the atmosphere to offset residual emissions, e.g. from industrial processes or the agricultural sector. Integrated research at a global level has thus far (1) mostly focused on the potential for achieving global system-wide net-negative emissions in the long term, and (2) predominantly considered Bioenergy in combination with Carbon Capture and Storage (BECCS) as a technology option in Integrated Assessment Scenarios [36]. Regarding (1) recent research and policy discourse has emphasized the need

for a rapid transition to greenhouse gas neutrality, which implies a much earlier demand for CDR as a carbon-offsetting option, as well as the necessity of early upscaling to have the options available at large-scale when needed [37][38]. As for (2) it becomes increasingly clear that a much larger portfolio of options exists, some of which combine CDR with environmental co-benefits, such as sustainable forest management, agro-forestry, or soil carbon sequestration. If the EU wants to meet its target without depending on other countries for the much-needed offsets, it is fundamental to assess the carbon removal potentials of different options, their side effects, costs, and governance requirements.

R&I priority 3.9: System-level comparative analysis of different CDR options
This priority explores system-level potentials and deployment pathways for the different CDR options, performing holistic analyses including expected co-benefits or negative effects on sustainability criteria, the respective upscaling time scales, direct costs, import dependencies and governance challenges.

R&I priority 3.10: Technology development for BECCS and DACCS
This R&I priority focuses on increasing the TRL and deploying large-scale demonstration plants of the technology-centred CDR options bioenergy-based carbon capture and storage, as well as direct air carbon capture and storage (DACCS).

R&I priority 3.11: Development of land-use-related CDR options
This R&I priority focuses on further developing the procedures and technologies required for implementation and monitoring land-use related CDR options such as sustainable forest management, agro-forestry, or soil carbon sequestration.

Expected Impact
An assessment of CDR options and their potentials, costs, and effects will inform the debate on which options are suitable for Europe and which steps need to be taken to have them available in time. The analysis of potentials and positive and negative side-effects is valuable to prioritise options to be tested and implemented. Investigating governance requirements and legal issues will lead to insights regarding the timing of different measures, e.g. relating to investments into CO_2 transport infrastructure or negotiations regarding the trade of CO_2 across national borders. Research to increase the TRLs of potential CDR options is required if any of the options are to have a relevant impact on 2050 emissions.

4 A Clean and Circular Industry

4.1 Introduction

Industry has exhibited a strong trend in emissions reduction and energy savings in the past (see *Figure 2*). Modelling suggests that current plans and policies may lead to a 55-65% reduction of GHG-emissions in 2050 compared to 1990 [39]. Mitigation efforts in the industrial sector need to be accelerated to achieve compliance with the Paris Agreement and related European targets from the EU Green Deal.

The EU Green Deal addresses a number of important topics regarding industry. The first topic is the crucial aspect of timing for the transformation to a climate neutral industry. As 2050 is only one investment cycle away for heavy industries in Europe, the first actions for radical transformation need to be taken in the next five years. However, to achieve short term targets, **continued effort is needed for energy and material efficiency overcoming barriers hampering implementation of existing energy saving technologies**.

Secondly energy intensive industries, such as steel, chemicals and cement, are indispensable to Europe's economy, as they supply several key value chains. However, radical **transformation of industrial processes** are needed in these sectors to bring emissions down. Electrification of processes is part of this transformation.

Thirdly **the European industry needs to become more circular**. The EU Green Deal states that only 12% of the materials used in industry come from recycling. Boosting this number is one of the key challenges for industry. This requires on the one side new circular industrial processes and on the other side new circular products .

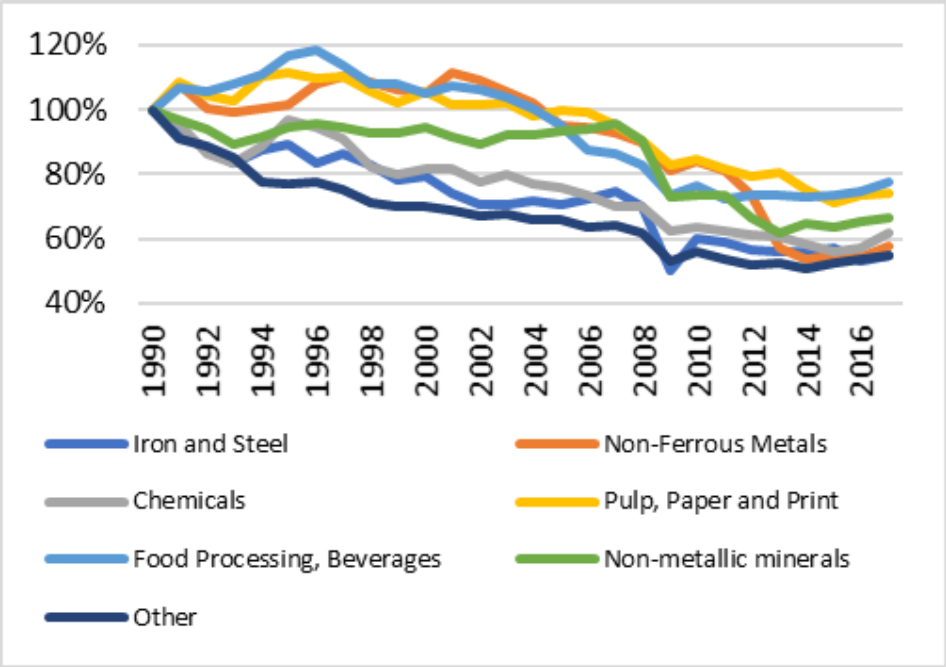

Figure 2: Change of CO_2 emissions in different EU industries compared to 1990 levels [40].

Lastly, the deep decarbonisation for industry can be turned into an unprecedented opportunity if existing green technologies are more consistently deployed and R&I investments are strategically targeted towards the development of breakthrough **zero carbon industrial technologies and business models**. Employment in Eco-industries has already increased by 20% in Europe since 2000 [41]. The EU industry has the opportunity to become the leader in this transition. This would also provide a competitive advantage, creating important cost savings and spurring innovation. Nevertheless, European R&I initiatives must accelerate urgently in order to enable gains from first-mover advantages as EU competitors are already increasing their R&I expenditure significantly.

The knowledge gaps in energy efficiency and material savings are:

- Actions to overcome the barriers in deploying energy efficiency and material saving technologies;
- Increasing reliability and reduce costs of close-to-market decarbonisation technologies;
- Developing support for upscaling and deployment of close-to-market solutions.

The knowledge gaps in the deep electrification of industrial processes are:

- Development and de-bottlenecking of high TRL electrification technologies and low cost electrolysers;
- Development of specific electrification technologies for production processes in energy intensive sectors;
- Integration of electrification options for industry in the broader ecosystem.

The knowledge gaps in embedding industrial processes in the circular economy are:

- Development of circular and bio-based feedstocks;
- Connect circular product design to energy intensive industries.

The knowledge gaps in Innovation in zero-carbon breakthroughs for process-based emissions industries are:

- Development of sector specific disruptive technologies.

4.2 Speed up deployment of energy efficiency and materials saving technologies

Challenge

Although a wide range of low- and zero-carbon technology options are currently available for industry, many have yet to be sufficiently deployed. The deployment of energy efficiency technologies has been progressing steadily since the 1990's [42]. While industry has already implemented many 'low hanging fruit' or no regret technologies, still many technologies

which require only moderate investments or adjustments in industrial processes, are not implemented.

R&I priority 4.1: Identify barriers for deployment of energy efficiency and material savings technologies in industrial sectors and devise effective ways to overcome them
Many of these technologies have not yet reached significant levels of market penetration due to many market and non-market barriers. By identifying these barriers policies to overcome them can be put in place. The deployment rate varies strongly over different industrial sectors and countries. Examples include efficient lighting, motor systems efficiency and clinker substitution by fly ashes. For instance, in many cases the initial investment can be a barrier even if the life-cycle costs are reduced. Small Medium Enterprise (SME)'s face significant barriers in deployment of low carbon solutions as they often lack the funds to invest in these technologies or cannot accept an enhanced risk of downtime of installations.

R&I priority 4.2: Cost reduction, improving performance and reliability of close-to-market decarbonisation technologies in order to scale up their deployment
According to the International Energy Agency (IEA), global improvement of energy efficiency in industry slowed in 2018 [43]. Though this can be attributed to events occurring outside of the EU, this shows R&I is still needed for continuously improving energy efficiency of existing production processes. Especially digitalisation of industrial processes may offer opportunities in the form of improved process control, analytics and system optimisation.

R&I priority 4.3: Develop effective support for close to market R&I in the form of Public-Private Partnerships (PPP) in innovation hubs for testing, prototyping and demonstrating these high Technology Readiness Levels (TRL 4-7) decarbonisation technologies
R&I priority 2 should be taken up as a public private undertaking, thereby accelerating the learning curves of targeted decarbonisation technologies. By sharing experiences in the application of decarbonisation technologies deployment can be accelerated.

Expected Impact
The impacts are an increase in the implementation of energy efficiency technologies. Deployment of these technologies may not be limited to Europe. A rise in the number of pilot and demonstration facilities is foreseen, with special attention for follow up and scaling up of existing pilot technologies.

4.3 Deep electrification of industrial sectors

Challenge
To reach the goal of carbon neutrality in industry by 2050 the use of fossil fuels must be minimised. Industrial processes should be electrified when possible, to make use of carbon free renewable electricity which is expected in the long term to be widely available.

R&I Priority 4.4: Support further development and de-bottlenecking of high TRL electrification technologies

A wide range of electrification options for industry is currently being developed differing in focus on baseload versus flexible application and core processes versus utilities [44]. Especially power-to-heat (P2H) options are relatively well developed and could be deployed in the short term. Examples of these technologies are electric boilers, mechanical vapour recompression, e-magnetic radiation, high temperature heat pumps.

R&I Priority 4.5: Support development of specific electrification technologies for production processes in energy intensive sectors
The step towards successful decarbonisation requires a radical transformation of European industrial sectors where it is possible to convert some of the energy input for processes to electricity use. Electrification would significantly reduce emission in 'classical' sectors like steelmaking, by for instance using electric furnaces [45]. For certain industrial sectors electrification may require major changes on the system level of industrial sites, as industrial processes are often interconnected for instance in using waste heat, or waste gas from other processes in the chain.

R&I Priority 4.6: Support development of low cost electrolysers (P2H2-technologies)
As direct use of electricity for industrial processes will not always be possible or efficient, conversion of electricity to hydrogen, which can then be used in industrial processes will be an important solution. R&I should focus on conversion technologies for clean hydrogen (green). An important part of this research should target the production of low-cost electrolysers, for instance in finding alternative materials for iridium as the high costs of this rare metal form a major hurdle in the further application of electrolysers.

R&I Priority 4.7: Investigate new organisation models and roles for the integration of electrification options for industry in the broader ecosystem in terms of feedstock, production processes, timing, availability and business cases
The potential of many electrification options should be optimized by the integration in the wider energy stem. This may require the entrance of new parties and new roles for energy suppliers delivering energy services.

Expected Impact
Currently many electrification technologies for industry are economically unfeasible. This research pillar should develop examples of positive economics for relatively mature electrification technologies such as waste heat upgrading and chemicals specialties production. In the longer term the use and production of hydrogen in industry should be a focus.

4.4 Embedding industrial processes in the circular economy

Challenge
The transition from linear raw material-to-waste production to closed loop production using waste as a resource is long term perspective of the EU. In the medium-term, energy efficiency improvements, materials savings and electrification should be part of this broader, longer-

term strategy of embedding industrial processes in the circular economy. This perspective [43] implies that most material fluxes currently supporting the economy are converted from linear processes into closed loops.

R&I Priority 4.8: Connect circular product design to energy intensive industries
Most energy intensive industries do not manufacture final consumer products. However the design of these final consumer products determines the environmental impact of industry to a large extend. Energy intensive industrial sectors should be actively engaged in research into product design targeted at waste minimisation, longer lifespans, eco-design and recyclable materials.

R&I Priority 4.9: Further development of circular and bio-based feedstocks including collection schemes
R&I programmes should be geared towards circular and bio-based feedstocks and fuels in industry. Circular feedstocks relate to the use of waste materials instead of feedstock such as naphtha or natural gas. Bio based feedstocks relate to the conversion of cellulose-based, nonedible biomass and agricultural waste into clean and affordable high-value fuels or chemicals. Innovative collection and recycling systems are needed to scale up promising circular pilots. For instance, the collection of used plastics for circular plastics production now requires huge geographical areas.

R&I Priority 4.10: Assessment of good and bad circular practices
R&I programmes should also focus on industrial clustering and industrial symbiosis. Industrial waste-heat recovery is a key technology in clustering. Recent developments in heat networks show a shift to multiple source, multiple user heat networks. The organisation of these networks poses a major hurdle. Good examples are urgently needed. In general R&I is needed to understand how the concept of the circular economy can be implemented on a practical level. Future research should thus focus on good and bad practices to assess what has worked well and not so well in the past.

R&I Priority 4.11: Support development of Carbon Capture and Utilisation (CCU) technologies as carbon feedstock for industrial processes (in the long-term)
R&I efforts should include the development of Carbon Capture and Utilisation technologies that may constitute an additional dimension to the concept of a circular economy. CCU can provide the chemical and plastics industry with solutions to permanently store CO_2 emissions by using captured emissions as a feedstock for polymers and other chemicals or by trapping carbon in cement. In the long term (2050) decarbonisation of the chemical industry could be required when fossil feedstock is no longer used.

Expected Impacts
Inclusion of circular technologies in mainstream production processes requires substantial effort to reach the long-term vision of a circular economy. With these R&I actions, waste minimisation, eco- and recycled materials and longer lifespan of products will be achieved.

4.5 Targeting zero-carbon breakthroughs in process-based emission industries

Challenge

Process-based industries such as chemical, steel and cement face particularly hard challenges with respect to decarbonisation. Current production processes are highly energy intensive and cost efficient, near-zero-carbon technological options and processes are currently not available on the market.

R&I Priority 4.12: Support development of sector specific disruptive technologies which can decouple production from process emissions in energy-intensive sector

Developing alternative production processes for energy intensive sectors like steel, cement, chemicals is of crucial important. Incremental innovations for existing processes can only provide a limited CO_2-reduction. As these sectors typically face fierce global competition consistent long term R&I support is needed to avoid carbon leakage. In most sectors first pilot projects for new technologies are in place. However it requires long term support to help these technologies to develop further.

R&I Priority 4.13: Investigate the potential of using renewable hydrogen in energy-intensive production processes

R&I programmes on renewable hydrogen are of key importance for industry. The use, production, conversion, distribution and storage of hydrogen are highly likely to be important in many energy intensive industrial processes [46]. R&I should be directed, in particular, at improving green hydrogen production technologies (including new materials and catalysts as well as new processes) and methods (e.g. plasma methods), lowering production costs, finding more efficient hydrogen carriers (e.g. solid storage, liquid hydrogen organic compounds) and materials that will enable tanks to store hydrogen at higher pressures (e.g. composites). Many of the critical future breakthrough technologies will be developed and utilised by SMEs. Therefore, R&I programmes should promote low-carbon and zero-carbon innovation by SMEs.

Expected Impact

Zero carbon breakthroughs are essential for the EU energy intensive process-based industries like chemicals, iron, and steel. Besides Carbon Capture and Storage (CCS), zero carbon breakthroughs are the only option for Europe to reduce CO_2-footprints significantly, as opportunities for improving process efficiency are limited. However large-scale deployment of these technologies will likely take more than a decade. Assessment of CO_2-reduction demands deriving from legislation versus development of CO_2-reduction options (both technical and businesswise) is of importance and could accelerate deployment. Applying gradual higher CO_2-reduction demands through industrial standards may force companies to CCS technology rather than to zero carbon breakthroughs.

5 Promoting climate-neutral and smart cities

5.1 Introduction

Cities play a key role in fighting climate change since they are responsible for 60 to 80% of the global GHG emissions [47]. In Europe, around three quarters of citizens currently live in urban areas and this number is only going to increase to about 84% in 2050 [48]. Cities hold the key to understanding the citizens, businesses and civil society, and finding the appropriate solutions that can be implemented effectively and efficiently at the local level.

The EU Green Deal presents the R&I needs in cities in several ways. First of all, the EU Green Deal aims to empower regional and local communities and provide assistance to cities to help them make best use of opportunities to develop sustainable urban development strategies. One example is the harmonisation of the work on reducing local pollution from transport and decarbonisation. Therefore, the first area of R&I suggested in this research agenda is the **harmonisation of cities´ climate action across sectors through governance and urban planning**. In parallel, the EU strategy on climate change adaptation focuses on climate-proofing, resilience building, where cities can support investors, businesses, citizens to develop instruments to integrate climate change in their activities. Furthermore, the Green Deal mentions that cities can support decarbonisation with the smart integration of technologies and strategies, such as local energy production and supply, use of data and information. One of the priorities of the EU Green Deal is the focus on buildings, so that they are created and renovated in an energy and resource efficient way. Consequently, the second R&I area of focus will be **the smart and integrated technologies for low carbon cities**. Finally, focus is given on the engagement with citizens and businesses – for instance in the Just Transition Fund – to leave no one behind also through the engagement and knowledge of citizens and businesses. That results in the third and final focus of this research agenda, the **engagement of citizens and businesses through living labs**.

Moreover, Horizon Europe will contain a mission on 'Climate-neutral and smart cities' [49] – suggesting the high importance of Cities in the decarbonisation efforts.

The main knowledge gaps in the harmonisation of cities´ climate action across sectors through governance and urban planning are:

- Climate policy is often not harmonised with other policies and strategies at the local, national and EU level;
- The cities regulatory power varies significantly across cities, sometimes limiting their power to steer and implement climate actions;
- A large share of the emissions caused by cities are generated outside of their borders, and many times neither accounted nor targeted in cities climate actions.

For the smart and integrated technologies for low carbon cities the gaps are:

- Best practices and strategies on smart and circular cities needs testing and sharing across diverse cities;

- Building stocks in different areas differ in age, level of energy efficiency and digitalisation – creating several challenges for their decarbonisation;
- There is scattered knowledge on how local production of electricity and heat can be embedded in cities.

Finally, for the engagement of citizens and businesses through living labs the key gaps are:

- Gaps in knowledge on how to best engage citizens and businesses into buying in and being proactive in climate action;
- Lack of large-scale testing (e.g. living labs) on strategies to achieve zero carbon cities.

5.2 Harmonisation of cities´ climate action across sectors through governance and urban planning

Challenge
Cities´ climate action embeds several challenges that span across sectors. Firstly, cities in the European Union are very diverse (in terms of technical context, affordability of low carbon investment, governance, etc.). There is no one-size-fits-all approach that can be applied [50]. Secondly, for decarbonisation action in cities to work, all actors and citizens must embrace the transition – which might not be trivial with a diverse population and competing interests [51]. For that, policy coordination across development priorities and citizens engagement is crucial for success. Finally, limited knowledge is shared across cities on best practices for decarbonisation [50].

R&I priority 5.1: understand how to best harmonise and mainstream climate policy across sectors in cities
R&I should tackle issues around policy coordination, and research on the cross-benefits (and potential trade-offs) of climate policy with other development outcomes in cities including, but not limited to, the local achievement of all the UN Sustainable Development Goals. Supported by such R&I, local governments can create a shared, ambitious long-term vision of the low-carbon transition as a way to align the actions of multiple local actors towards a joint goal. They can also take a variety of other actions, such as implementing regulatory standards, providing financial incentives, establishing public-private partnerships and organising informational and networking events. Best practices in zero-carbon urban planning should also be shared across cities and regions. R&I can support mapping these by creating a portal for sharing best governance practices. Furthermore, as the coordination and integration of policy actions and instruments across local, national, and European scales is key in order to steer their interplay towards low-emission outcomes, R&I is needed to craft processes of the multi-level governance (both vertical and horizontal).

R&I priority 5.2: research how cities can use their regulatory powers to stir climate action
Cities have different and sometimes limited regulatory power for financing climate action and for stimulating private partners and consumers to do so. R&I could be used to create and assess new types of procurement procedures, Public-Private Partnerships (PPP) or public

entrepreneurship activities and investigate suitable ways for cities to access funding despite their risk-profile. To achieve ambitious targets such as climate neutrality, long-term (local) PPP are essential. Most cities are struggling to find enough financial means (especially investments for asset heavy innovations) to realise their ambitions. Adding up all what is needed to achieve the climate goals, public funds are by far insufficient, so new investment schemes and business models are needed that build upon/ are aligned with the public sector investments and incentives.

R&I priority 5.3: create methods to account for all GHG emissions in cities
R&I is needed for cities to have clear rules to account for all emissions caused by its citizens, and not only those happening within their borders. This may include methods to account for the ´traded´ emissions or so called ´carbon leakage´. As a matter of fact, a large share of the connection between urban activities and both climate adaptation and mitigation run through city supply chains beyond city borders. 'Embedded' emissions of imported goods are argued to be important to consider in city GHG inventories – and subsequent mitigation efforts [52]. Few policies and research programs address the issue of ´carbon leakage´ of cities, even if it is estimated that 12% to 35% of the EU's consumption-based GHG emissions occur abroad [53].

Expected impact
Harmonisation of cities´ climate action across sectors through governance and urban planning will improve the liveability and health outcomes in cities, which can also result in decarbonisation, and vice versa [54]. By sharing best practices between cities, through lighthouse projects, cities will gain more knowledge on the ways in which local actions support the transition to climate neutrality. The research on identifying clear rules for all emissions will increase the accountability of cities´ emissions, and re-focus cities climate impacts to the global scale.

5.3 Smart and integrated technologies for low carbon cities

Challenge
It is well known that no silver-bullet solution will achieve zero-carbon cites [50]. A combination of technologies and interventions will be needed to effectively achieve decarbonisation goals in diverse cities [50]. Concepts of ´smart cities´ [2] and ´circular economy´ [55][56] in cities will be crucial to integrate technologies and materials and energy flows. However, to date, the challenge is how to integrate the technologies above to cost-effectively achieve socially accepted zero-carbon cities. Furthermore, the building sector is the single largest energy consumer in the EU and 75% of the EU's buildings are energy inefficient [54]. While across the EU buildings´ efficiency has been rising in time, and the EU has set the target of having all new buildings nearly zero energy by 2020 [57], most of Europe's existing building stock has yet to be affected by energy performance requirements [58]. Therefore, decarbonising EU's building stock is a key role in the transition to a climate neutral economy.

R&I priority 5.4: research and share best practices on smart and circular cities
R&I is needed on how to develop cities as an integrated zero-carbon system. Key R&I actions should address how renewable energy, electric mobility, and efficient and smart buildings can be integrated in a single smart city ´organism´ with the support of digitalisation and machine intelligence [59]. R&I should also explain how this integration could differ in cities that vary by location, size and existing building stock and transportation infrastructure.
Complementary to the above, R&I is needed to understand the potential role and application of the circular or ´semi-circular´ economy in cities. There is a need to better understand how outputs from one process can feed another. For that to happen, there is a need to map the efforts towards the circular economy in different countries and cities, to understand differences and capture best practices.

Finally, to understand decarbonisation efforts in cities, continuous efforts will be needed to monitor, collect and share data on building efficiency, energy usage and citizens' behaviour both within and across cities. Developing measurable Key Performance Indicators (KPIs) for climate neutral cities will be crucial for this.

R&I priority 5.5: map, share and adopt best practices in buildings efficiency
Continuous R&I will be needed for promoting both the refurbishment of existing non-efficient buildings and the design of innovative strategies for near zero-energy building. While innovative business models around renovation (energy efficiency as a service) exist, they often face a challenge of high upfront capital needs. That will also include the design of new smart urban spatial strategies, when new cities and quartiers will be expanded. In this sense, ICT solutions should be supported to improve energy efficiency in buildings and ensure citizens have access to them in order to reduce energy use.

R&I priority 5.6: understand the role of cities in the local production of electricity and heat
With cities being hotspots of energy demand, local electricity production with solar, bioenergy, waste and wind sources can be harnessed. As for heat, several renewable heat sources can be integrated (from Biomass-based combined heat and power (CHP), to solar thermal, and geothermal heat). The integration of such technologies within cities is a priority area of research.

Expected impact
More cities designed and working towards being integrated, smart and circular zero or low-carbon systems. Improved knowledge and actions on energy efficiency and integration of renewable energy both in electrical and heat system in cities.

5.4 Engagement of citizens and businesses through living labs

Challenge
Very little is known today about the citizens' visions of low-carbon cities and low-carbon societies in Europe and how these visions could be integrated into broadly legitimized and realistically implementable low-carbon strategies that mobilize the critical capacity of the

citizens [60]. Low-carbon innovations in cities have so far primarily included technical innovations in energy and transport fields [61], however in order to truly tailor zero-carbon strategies for every specific city, local processes of citizen engagement are irreplaceable. Climate change mitigation outcomes will depend on behavioural and lifestyle changes. Citizen consultations and digital crowdsourcing of citizens' ideas could help develop such an overarching zero-carbon vision. In response, cities can become incubators of behavioural and lifestyle change – in so called ´living labs´ [62].

R&I priority 5.7: understand the most effective strategies for engaging citizens, and how the location and size of a city influence such strategies
R&I is needed for understanding how information, economic incentives, policy and regulation can nudge the citizens towards more active participation in zero-carbon action. The evolution of corresponding business models (business model innovation) should be supported to mobilize industry in the endeavour. That also includes topics such as the understanding of citizens behaviours in using energy and on climate policy. New mechanisms for fostering bottom-up social innovation and adoption of low-carbon lifestyles should be experimented with.

Furthermore, knowledge on best practices to engage citizens need to be shared across cities, again through a dedicated programs and platforms.

R&I priority 5.8: test climate strategies at the local level in living labs
The EU can engage in a race to the top in cities, by developing a series of zero-carbon living labs where new zero-carbon urban solutions can be tested and replicated. Such labs engaging every actor, from citizens to academia, local businesses and the municipality, could be created in cities to test innovation in practice.

Expected impact
Improved knowledge on how to engage and nudge citizens for cities´ climate action. Improved buy in for climate policies in cities and increase in bottom-up decarbonisation efforts by citizens. Tested best strategies in living labs to be replicated at a larger scale.

6 Accelerating the shift to sustainable smart transport systems

6.1 Introduction

The EU Green Deal [1] focuses on smart and sustainable mobility in Europe including a 90% reduction of transport-related GHG emissions by 2050 [63]. Besides climate change mitigation, the EU Green Deal also addresses local air pollution in cities, industrial, and mobility hot spots. Consumers (mobility users) are the centre of the EU Green Deal with the objective to promote mobility services in a more affordable, environmentally friendlier and healthier way. The EU Green Deal emphasises the responsibility and obligation of all transport modes to deliver on these goals. Related to this, a major topic of the EU Green Deal concerns **automated and connected multi-modal mobility solutions,** including the shift of road-freight transport to rail and inland waterways (75% of today's inner-EU road freight transport should be shifted). In-line with this topic, the EU Green Deal emphasises digitalised mobility systems, which can provide new services (Mobility as a Service) embedded into smart traffic systems. Intermediate targets are set-out for deployment of low-carbon vehicle technologies (e.g. one million public charging and fuelling stations for 13 million zero and low-emission vehicles by 2025) and stringent CO_2 emission standards are imposed on new vehicles sales in the EU. Achieving these ambitious targets requires full scale commercialisation all value chains of **efficient and clean transport technologies, low-carbon transport fuels, and the corresponding infrastructure**. Such a substantial technological transformation requires revision of the existing regulatory framework applicable to the transport sector and related sectors [64][65]. The EU Green Deal addresses adjustments of transport sector policy instruments, such as fuel taxation to reflect environmental and health impacts, as well climate policy instruments, such as the EU-ETS which may be expanded to the transport sector. Ultimately, new mobility solutions and market configurations are to be incentivised and shaped by **new transport sector policies.**

The main knowledge gaps related to automated and connected multi-modal mobility solutions concern:

- Interplay of digitalisation and mobility demand;
- Smart trip and traffic planning platforms;
- Low-carbon mobility solutions enabled through Mobility as a Service (MaaS).

Knowledge gaps related to efficient and clean transport technologies and fuels, and the corresponding infrastructure are:

- New large-scale transport and fuels infrastructures;
- Next generation batteries;
- Low-carbon aviation technology and fuels;
- Electrification of water-borne transport;
- New materials for more efficient transport technologies.

Knowledge gaps on new transport sector policies comprise:

- Holistic assessment of integrated and sustainable transport systems;
- New transport sector policy instruments and market design.

6.2 Automated and connected multi-modal mobility solutions

Challenge
New lifestyle patterns may result in changing mobility behaviour translating into different priorities regarding modal and technology choice and also regarding the needs for physical transport. Even though digitalisation has developed rapidly over the recent past, its impact on transport demand is not fully understood and needs further research. Research on future transport demand developments and innovative sustainable consumption patterns is important as they can shed insights on an improved understanding of the mobility-related effects of societal changes [64][65]. To what extend can digitalisation play an effective role in mitigating freight and passenger transport demand (e.g. through advanced telecommunications, 3D printing) and how can digitalisation facilitate smart and consumer-friendly connectedness of multiple transport modes?

R&I priority 6.1: Interplay of digitalisation and mobility demand
Increasing levels of digitalisation is one of the characteristics of today's society [66]. R&I on new digital solutions should identify effective reduction options for physical transport of passengers and goods (e.g. on-line shopping, video streaming, teleconferencing). As such, digitalisation is directly connected to mobility demand. This relationship needs further R&I on new digital solutions which provide communication services in a quality that personal travel can effectively be reduced. Analysing mobility demand dynamics requires new analytical tools incorporating data-driven and consumer-focused approaches such as digital twins.

R&I priority 6.2: Smart trip and traffic planning and operation platforms
Smart trip and traffic planning and operation platforms should be developed to enable agile movement of goods and passengers while using transport systems and existing infrastructure as efficient and environmentally-friendly as possible. This requires an analysis of transport demand of various mobility stakeholder groups (e.g. commuters, tourists, leisure travellers, logistics companies, individual business mobility). This should start with a focus at the city level, followed by the integration of city-to-city level in order to identify multi-modal transport options for passengers and goods that facilitate shifts towards low-carbon transport modes [64][65]. Such analyses should link to a holistic spatial-temporal management of passenger and vehicular flows in terms of vehicles, parking facilities and various travel modes, including routes choices [67]. R&I is needed to identify new infrastructure requirements along major existing and new transport corridors, both for long-distance travel (e.g. ports, airports, or even hyperloop) and urban transport (e.g. logistic hubs, intermodal hubs), in order to unlock synergies and efficiencies between different transport demands.

R&I priority 6.3: Low-carbon mobility solutions enabled through MaaS
Building on R&I priority 6.2, research is needed on mechanisms, IT systems and governance structures that moves transportation from an asset-based (economic) activity into a service product (Mobility as a Service-MaaS) integrated into existing (national/regional) digital transport planning [67]. R&I should identify and evaluate options for the integration of low-carbon MaaS technologies (such as automated vehicles, sharing mobility, and the Internet of things), and the development of new concepts of mobility, which can offer seamless and instant accesses to revolutionised individual and collective Smart mobility – framed as a personalised "service" available "on demand" [66].

Expected Impact
R&I insights on the interaction between digitalisation and transport demand can enable market-based transport infrastructure. At the same time, they can help to identify strategies for reducing rebound effects. The behaviour related research can provide insights on the potential and benefits in a broader economy. E.g. when decentralised on-site production of equipment (e.g. spare parts) through advanced 3-D printing contributes to effectively reducing freight transport. Any integrated planning tool can enable a shift from private car-based travel to public transport, shared mobility or MaaS.

6.3 Efficient and clean transport technologies and fuels, and the corresponding infrastructure

Challenge
Deployment of electricity-based transport technologies and the roll-out of synthetic low-carbon transport fuels across Europe is an imperative to achieve a decarbonised transport system. While development of electric cars has advanced much over the recent past, heavy-duty road transport operated on electricity or hydrogen face severe barriers related to their costs and performance [68][69][70]. Batteries and fuel cells need to become more powerful, lighter, cheaper and long-lasting, and at the same time, they should use materials which lead to an overall sustainable life cycle performance [71][72]. New large-scale infrastructure systems, such as new high-speed rail and hydrogen supply infrastructure have long lead times. For hydrogen, the role and use of the current gas grid requires closer examination. Compared to road transport, aviation and shipping require different decarbonisation options [70][73][72]. While being one of the hardest modes to decarbonise, aviation is also experiencing rapid growth demand. The aviation sector has high safety standards translating into long lead time to bring new technologies on to the market, which makes it more challenging to introduce technology innovation rapidly.

R&I priority 6.4: Develop new large-scale transport and fuels infrastructures
In order to decarbonise freight transport, dedicated electricity-based freight infrastructure systems need to connect the main logistics hubs across Europe. This includes high-capacity rail-based freight transport, as well as new systems, such as cargo-tubes and electrified highways as a clean road-based solution [74][75]. Complementary to new transport

infrastructure systems, R&I should address new fuel infrastructures, specifically for hydrogen as hydrogen is an energy-efficient option for indirect electrification allowing to largely keep today's mobility usage patterns a sufficient coverage of the hydrogen infrastructure [70].

R&I priority 6.5: Next generation batteries
R&I to develop electro-mobility technology in Europe should focus on strengthening research on ultra-high-performance battery technology, aiming at increasing energy density, which results in lighter and more energy and cost-efficient transport systems. Research on battery technology should include the complete cradle-to-grave life cycle (e.g. battery re-usage and re-cycling of batteries) in view of reduced environmental impacts. Moreover, the next generations of batteries need to limit the usage of scarce materials to avoid significant geopolitical dependencies of a European battery industry. R&I on batteries should also address safety and reliability of batteries for which embedded sensing and self-healing needs to be developed further.

R&I priority 6.6: Develop low-carbon aviation technology and fuels
R&I on energy-efficient airplane designs and airplanes operating on alternative fuels, such as synthetic kerosene, hydrogen or electricity, should be intensified in view of a long-term perspective of the transformation of the aviation sector with an emphasis on technical and safety standards [73][72]. Complementary, near- and mid-term bridging solutions based on incumbent combustion technologies are needed to facilitate early decarbonisation. In this regard, biokerosene or electricity-based fuels produced with high efficiencies need to be researched [76] considering broader sustainability aspects of bioenergy production (related to energy, water, land, biodiversity and pollution) [77]. To produce synthetic hydrocarbon fuels (i.e. e-kerosene), which need carbon as an input to the process, research should concern carbon dioxide removal from the atmosphere (e.g. using direct air capture technologies) in order to achieve a CO_2 emission-neutral conversion chain.

R&I priority 6.7: Electrification of water-borne transport
Electrification of water-borne transport and ports should be a further technology-related research priority which entails not only electric short-distance ships and ferries but also the build-up of the corresponding fast-charging infrastructure along the main European waterways and ports. Safety requirements need to be explicitly considered in battery research for electric ferries and ships. Research on hydrogen and ammonia powered vessels should support the decarbonisation of longer distance shipping [78].

R&I priority 6.8: New materials for more efficient transport technologies
Alternative light-weight materials, such as composites, can replace 20%–30% of the overall automobile weight and thereby contribute to energy efficiency. Therefore, advanced materials with more functionalities and safety should be equally promoted in the automotive sector as well as for aviation [79].

Expected Impact
The development of low carbon vehicles/fuels is expected to accelerate climate change mitigation in Europe and may also serve as stepping stone for the re-industrialisation of parts

of the EU economy creating better job opportunities and fuel a sustained economic growth. Particularly any technology breakthrough in aviation (and marine transportation) will also have impact on regions outside Europe, where considerable growth in aviation is foreseen. Development of low-carbon transport technology not only has the potential to reduce GHG emissions but also to improve air quality especially in the urban space.

6.4 New transport sector policies

Challenge
The policy framework in many European countries provide insufficient incentives for low-carbon mobility solutions and changes in consumer behaviour. Externalities are not internalised fully, and in some sectors, such as aviation, taxing schemes are to the disadvantage of modal shifts to cleaner options, such as rail. The EU's emission performance standards concern new vehicles while existing vehicles can still be operated and incentives to replace old technologies with new ones are rather limited. A better understanding of effects of transport sector policy instruments is needed, in particular in combination with policy instruments of other energy sectors, in order to provide support to political decision makers on effective re-designs of transport sector policies.

R&I priority 6.9: Holistic assessment of integrated and sustainable transport systems
Against the background of increasing sector integration policies need to be coordinated more closely across domains to which science can contribute by providing evidence on systemic interdependencies. To support an improved understanding of the inter-sectoral dependencies, research on the integration of new transport systems into a low-carbon interconnected European energy system should be promoted. Integrated systems analysis is needed to identify smart ways to integrate new transport technologies and to unlock the systemic flexibility potential that arises from electricity-based mobility. For example, how controlled changing and discharging of e-mobility can support integration of variable renewable via vehicle to grid services and relief potential stresses on the electricity grid. Such research requires advances in new quantitative analytical tools that represent the sectoral interdependencies at high technological detail while having a high temporal and spatial resolution for Europe. Moreover, and in order to capitalise on the co-benefits that decarbonised transport systems offer in avoided negative externalities (e.g. impact on air quality, human health, and biodiversity), integrated system analyses should address impacts from a broader sustainability perspective. This is an important research topic as it contributes to wider environmental impacts and directly links to the ambitions of the EU Green Deal to improve the living conditions and to make European cities a better place to live. This also relates to new planning paradigms and tools to convert existing cities into low-carbon cities (mobility and buildings) following people-centred approaches.

R&I priority 6.10: New transport sector policy instruments and market design
Research priorities should also concern development and testing of new policy instruments to incentivise sustainable transport structures and to remove barriers for the deployment of a

clean transport sector. While developing novel technologies, related environmental standards and the regulatory framework should be established [69]. R&I is required on the incorporation of all externalities (not only related to climate but also capturing other sustainability and resilience goals) into policy instruments as well as on the effectiveness of measures (e.g. fuel taxation, emission performance standards and expansion of the EU-ETS towards selected transport sectors) to bring new technologies on the markets and to facilitate user-driven modal shifts. The impact of possible rebound-effects of new mobility trends, such as automated driving and MaaS equally require attention. Also, in relation to regulatory frameworks new legal concepts are needed for autonomous driving (related to liability and insurances, for instance) and for multi-modal travel and logistics.

Expected impact

R&I on new integrated transport systems is expected to facilitate policy designs that enable high penetration of electro-mobility as well as synthetic fuels and hydrogen within energy systems with high shares of renewables. Integrated systems analysis particularly can facilitate zero-carbon mobility technologies and provide insight on investments and infrastructure needs in the broader energy system. This research will help identify the systemic requirements (e.g. in terms of grid enhancements) to support the decarbonisation of the transport sector.

The identification and incorporation of mobility related environmental effects through appropriate policy instruments is expected to alleviate market barriers related to price and geographical disparity; and thereby facilitate a faster rollout of clean mobility solutions, i.e. in terms of technology and modal choice. The policy-related research can facilitate coordination and harmonisation of transport policy in order to mitigate any sectoral carbon leakage and to foster efficient and competitive markets which are needed for developing new and emerging infrastructures.

7 A fair, healthy and environmental-friendly food system while preserving and restoring ecosystems and biodiversity

7.1 Introduction

It is not without reason that the Commission's ambition to tackle climate and environmental related challenges is titled the EU Green Deal. One of the key elements of it "is the aim to protect, conserve and enhance the EU's natural capital in order to protect the health and well-being of citizens from the environmental related risks". The EU Green Deal is paving the way for transforming the EU into a fair and prosperous society and economy, where there are **no net emissions of greenhouse gasses** in 2050 and where economic growth is decoupled from resource use. It is furthermore widely understood that the **functioning and productivity of the food system is closely interlinked with the wider ecosystems and biodiversity**. Current agricultural production systems are to a great extent depending still on natural resource depletion, excessive use of synthetic fertilizers, destructive pesticides, including use of growth-stimuli and preventive use of medication for feedstock.

Contemporary farming models are the result of (i) an agronomic vision based on limiting factor which is the foundation of intensive agriculture, (ii) a context of international competition and rent seeking and (iii) institutional governance and finance schemes. For effectively reducing the negative climate effects of the agricultural sector as well as the underlying causes, a deep transformative policy design is required. It is recognised in the EU Green Deal that it is required "to increase the value given to protecting and restoring natural ecosystems, to the sustainable use of resources…". The suggested **"From Farm to Fork strategy"**; designing a fair, healthy and environmentally-friendly food system presents the stakeholders and policy makers with a number of unsolved issues still.

An urgent need emerges to reorient agriculture priorities away from producing high quantities of food to producing healthy and local food. This requires also strengthening **urban-rural relation**, in order to establish local market functioning, requiring less transportation and waste along the way from farm to fork.

R&I should help to find solutions and generate the knowledge for helping to address the following aspects.

For local implementation of "From Farm to Fork" strategy, the main challenges are:

- How to reshape the current functioning of the agricultural sector towards a more circular *modus operandi*?;
- New strategies and technologies to reduce the losses and waste at the source;
- Developing new technologies and processes for conversion of residues in agriculture production process.

Knowledge gaps to further reduce the GHG emissions and restore the absorption capacity of agricultural assets:

- The yield performance of alternative production models against conventional agriculture, both in levels and stability;
- How to effectively change behaviour in shifting peoples' dietary preferences to more plant based proteins?;
- Design of effective compensation schemes;
- Strengthening the scientific evidence of the benefits of increasing soil organic carbon across a range of different soils, agro-ecosystems and climatic zones.

Understanding the relationship and trade-offs between agriculture and other sectors poses a need for:

- Development of new assessment framework enabling local tailoring and adjustment.

7.2 From farm to fork – implementing Circular Concepts in the agricultural sector

Challenge
Existing agricultural business models are designed for increase of production output, increased economies of scale and reduced costs but can eventually lead to depletion of soils and agricultural resources. It furthermore generates substantial amount of waste and residues, as a by-product of this model.
The overall potential for reducing food waste along the chain from farm to fork is significant, given the enormous volumes of biomass involved. The circular economy approach aims ultimately at limiting the growth rate of material flows at global scale by promoting recycling and reducing the consumption of resource intensive products.
This approach is of environmental interest as it envisions human activity in the form of a cycle mimicking the natural ones, breaking with the dominant extractives' model. However, the circular model will only be able to generate environmental benefits under the appropriate conditions, that should be further investigated and piloted within a R&I policy or regional super-lab.

R&I priority 7.1: New strategies and technologies to reduce losses and waste at the source
Reducing food losses and waste at the source should be the priority of a sustainable strategy for future agriculture, with the aim of avoiding land use and fertilizer -emissions as well as the many emission sources associated with the supply chain (e.g. refrigeration, transport). Further reduction of the environmental footprint of food production, could be established through reducing the share of ultra-processed agricultural products.

R&I priority 7.2: Develop new conversion processes
Developing new processes for the conversion of residues, by-products and side streams into systemic and regenerative bioproducts, food/feed and high-quality organic fertilisers,

including the capture and valorisation of CO_2 and clean digestate from biorefinery and bioenergy plants.

Expected impact
R&I projects will quantify the merits of circular farming models, providing knowledge, lessons and scientific evidence on the actual reduction in GHG emission, waste and residual production. Also, potential trade-offs and rebound effects will be monitored and can be mitigated in the case these have a potential negative effect on the (regional) environment. Emphasis on re-establishing the local rural-urban link between farmer and consumer, will contribute to a positive sector image, and could generate greater employment in the sector.

7.3 Reduce the GHG emissions of agricultural sector, and increasing the capacity of land, forestry and agriculture systems to promote further negative emissions and absorb carbon

Challenge
As emissions from the livestock farming represent most of the agricultural emissions in Europe, the priority for R&I should be to reduce the direct emissions of livestock. A wide range of options exist including refining nitrification inhibitors and/or feed compound. European geographical territory includes a large variety of land /soil types and climate zones, and therefore, research and innovation are required with respect to increase knowledge of optimal farming models and crop & breeding strategies dedicated to regions characterized by specific conditions. Alternative models to conventional agriculture, such as agroecology, organic farming and agroforestry, are currently under scrutiny, but offer interesting prospects regarding increasing production per unit area, if considering sustainability aspects. Supporting the ongoing refinement of high-performance agroecological and agroforestry systems should be a key R&I priority.
Soil carbon sequestration represents a synergetic way to enhance crop productivity while preserving carbon stocks. However, scientific evidence of the benefits of increasing soil organic carbon across a range of different soils, agro-ecosystems and climatic zones is still insufficient. It is especially important to increase knowledge about the role of grasslands and on best ways to include cover crops in rotation. Storage permanence of carbon is also a key issue that needs to be addressed from a interdisciplinary perspective. Within the EU and at a Global level all ambitious climate mitigation pathways rely strongly on negative carbon emissions, and as a result on restoring the carbon stocks in soils and vegetation.

R&I priority 7.3: Design of effective compensation schemes
Design of effective compensation schemes, such as carbon rights and trading platforms, to ensure a certain income for farmers for the sustainable use of their lands should be further investigated.

R&I priority 7.4: Develop new models and technologies for the monitoring and evaluation of soil-organic-matter dynamics
Further development of new models and techniques to monitor and evaluate soil-organic-matter dynamics in different soils and developing tools to plan adequate decarbonisation strategies. Given the opportunities of Earth observation systems with satellite imaging and measurements, regional soil and climate differences, and as a result tailoring of local production techniques will become evidence based.

R&I priority 7.5: Sustainable and resilient intensification methods
Developing a set of more sustainable and resilient (adaptable to different climate zones and agricultural traditions and regions) methods for intensification of crop and livestock production, while preserving biodiversity through the adoption of innovative precision-farming and breeding techniques enabled by digital services, input reduction, implementation of low-impact management protocols.

R&I priority 7.6: How to effectively change human behaviour in shifting peoples dietary preferences to more plant based proteins?
Identification, testing and rolling out effective strategies to increase awareness of healthier food patterns and positive impacts on the environment and quality of animal life; or subsequent pathways for policy intervention to encourage, stimulate and favour more environmentally friendly food consumption alternatives.

Expected impact
R&I will help build an extensive evidence-based knowledge repository of tailored farming methods and techniques that suit the specific soil type and climate conditions of most regions in Europe, and possibly beyond. In the context of climate change impacts, dedicated crops (resistant) and breeding techniques are key for food security in the future. Adaptation strategies, including shifting food (supply) patterns (less animal protein, more plant based), will further help sustain a balanced European agricultural sector, and significantly reduce direct GHG emissions.

Research and innovation will contribute to significantly increasing the capacity of soils and agriculture sector to capture and sequestration carbon. As recent efforts of replanting trees and replenishing forests in Europe already result in negative GHG emissions for the land-use and forestry sector, the potential for scaling-up is considerable. Providing farmers with enough incentives or compensation through carbon rights, and registration schemes, will further enhance the agricultural capacity for carbon storage permanence.

7.4 Understanding the relation and trade-offs between the agricultural sector and Bio-energy and materials

Challenge
Increased natural and bio-material demands from other sectors in transition towards more sustainable production systems, may add additional strains to existing land use system; and if not managed properly could result in increasing competition for natural-resources.

The use of bioenergy with carbon capture and storage in future energy systems is particularly debated within the academic community. The scientific literature being divided between the outlook of a better management of natural resources, by displacing fossil fuels and possibly generating negative emissions, and the impacts of the large-scale development of bioenergy from dedicated energy crops on land carbon stock may potentially result in net increases in GHG emissions.

R&I priority 7.7: develop new assessment framework
R&I is required to improve the environmental assessment of dedicated energy crops and to better evaluate the sustainability impacts in different regions of using different bioenergy feedstocks other than biomass from dedicated plantations (e.g. organic waste and/or agricultural/forestry residues). Research should also investigate all possible energy carriers for biomass, including biohydrogen and the conditions for efficient production of methane (e.g., size of installation, risk of leakage).

Expected impact
R&I projects will assess and evaluate the relationships and trade-offs between the various sectors in the move away from fossil fuels, to cleaner energy and bio-products. Impact will contribute to a better understanding of the role of agricultural ambitions for generating circular farming and new production methods, while offering farmers possible new business opportunities.

8 Green finance and investments

8.1 Introduction

To deliver on the EU Green Deal, and the associated **'just transition'**, the EU must carry out swift and substantial action to harness and redirect both public and private investments towards large-scale, low-carbon and zero-carbon technologies, projects and business models. This will effectively and radically push the EU economy away from high-carbon, resource-intensive and polluting sectors in favour of low-carbon economies. It will also secure net benefits and co-benefits for workers and communities, including better lifestyles, secure employment, increased productivity and global competitiveness. Yet, these changes are clearly not taking place at an enough pace in any productive sectors nor in relation to energy demand and consumption. Furthermore, the speed of change is not homogenous across Europe. In this context, **mobilising public and private investment for the energy transition needs to be a long-term commitment**. It is paramount that the EU establishes a stable system which focuses on the long-term consequences of financial practices and does not disrupt them by short-term value extraction. Indeed, reaching the target of a 40% decrease in GHG, will require 260 bn€ of additional investments per year by 2030 [80]. Overall, Europe is relatively well placed to promote a huge redirection of investments away from fossil-based and towards zero-carbon societies. Europe's banks, insurance companies, institutional investors and stock exchanges have been significant players in the evolution of green (and sustainable) finance over the past 25 years. This process has accelerated over the past few years in the context of the Action Plan on Sustainable Finance and of the so-called EU taxonomy, for which a political agreement between the European Parliament and Member States has been reached in December 2019. Other examples of the European role in green and sustainable finances can be found, for instance the leading role of the European Investment Bank a world leader in issuing Green Bonds (EUR 27.7bn since 2007 and EUR 3.4bn in 2019 alone [81]). However, the challenge is not only **to find capital at the required scale** but also to **ensure low costs of capital and operational and trustworthy financial institutions**. The importance of **financial availability to low-carbon projects and the overall cost of the transition** has been assessed for specific technologies and regions [82][83], yet more research is needed in order to **support the long-term redesign of the current financial system** in light of the EU Green Deal.

In the following sections, we give recommendations on R&I actions to foster the mobilisation of green finance and investment levels required for the successful implementation of the EU Green Deal along with a better understanding of macroeconomic implications that will enable a just transition. The following topics underpin the main knowledge gaps that relate to the design of a comprehensive strategy to finance sustainable and inclusive growth in the next decades.

The main knowledge gaps related to the ensuring of low-cost, large-scale financial availability and of well-informed assessments of investment needs and macroeconomic implications are [84][85]:

- High quality data and knowledge for decision making;
- Sophisticated model-based assessments of investments needs and macro-economic impacts.

The main knowledge gaps related to supporting the long-term redesign of the current financial system are [84][86][87]:

- Identify innovative approaches for establishing financial institutions;
- Ensure coherent and predictable policy and regulatory framework;
- Promoting concerted action in the innovation value chain.

8.2 Ensuring low-cost, large-scale financial availability and well-informed assessments of investment needs and macroeconomic implications

Challenge

Inadequate and inconsistent data on financial requirements and financing opportunities are hindering forward-looking action by investors. Projects should collect data and information which allows to expand our knowledge regarding the specific geographical, technological and business-model areas where investments to support the zero-carbon transition are needed the most. Access to sustainability-related risks is limited and a dedicated project taxonomy is only slowly being developed. In parallel, more evidence-based assessments of macroeconomic implications of the transition, taking into consideration the role of financing and fiscal policies, will enable a well-informed policy formulation towards a just transition. Sophisticated model-based assessments that consider the financing challenges, could contribute towards the development of ways to redirect capital flows to promote mitigation while capitalising on decarbonisation co-benefits, including increased competitiveness, improved labour market outcomes among others.

R&I priority 8.1: High-quality data and knowledge to support decision making

R&I should be devoted to the definition and implementation of harmonised metrics, data quality requirements, availability and access guidelines, but also further develop and implement the taxonomy for sustainable financing. Funding should also be devoted to understanding how to improve disclosure rules and procedures. Specifically, research should highlight new, forward-looking disclosure rules concerning sustainability-related financial risks which would allow the EU to engage in experimentation. This will almost certainly require some trial and error by companies, as well as capacity building and promotion of best practice by all the key institutions involved, governments included. A successful example in this respect is that of the Task Force on Climate-related Financial Disclosures (TCFD), the first industry-led framework with the potential to become a 'new normal' of climate disclosure. Momentum behind the guidelines is growing fast, with more than 230 companies representing a combined market capitalisation of over €5.1 trillion having voiced their support for the TCFD recommendations. Further, projects should propose new, forward-looking disclosure rules for climate- and sustainability-related financial risks. Research will

also have to explore the barriers to large-scale finance flowing into these areas, and how these barriers may be removed.

R&I priority 8.2: Sophisticated model-based assessments of investment needs and macroeconomic impacts

Macroeconomic models have so far been used by different stakeholders for policy support purposes. R&I actions should focus on strengthening economic models analyses to ensure informed policy making. Potential directions of model developments include first and foremost the detailed representation of the financial system, but also the representation of endogenous technological change through learning mechanisms, the inclusion of a labour market structure and human capital development through skill attainment as well as the integration of climate damages and mitigation co-benefits. Models should be enhanced to reflect interactions between low-carbon technology innovation and investment risk reduction strategies, including also a sectoral and regional differentiation in the cost of capital. A clear R&I priority in this respect should be to better understand which instruments can be put in place to ensure that capital markets respond to policy and other signals (such as technological change, physical disruption and social expectations), thereby anticipating change in the real economy and allocating capital faster and more efficiently. Forward-looking economic models are key tools in this respect, but the ones available nowadays lack a detailed description of the financial system. Importantly, these tools can be used to study if and how the EU can gain a leadership role to ensure that financial and trade flows into the EU consider sustainability appropriately and do not undermine fair competition that would hurt European employment.

Expected Impact

Policy making will be based on high-quality data and information, resulting in enhanced knowledge on investments that are needed the most. Removing the barriers to large-scale finance will release capital into areas that are currently experiencing barriers. Data availability and taxonomy will attract investors to low-carbon actions. They will also allow the identification of practical solutions to ensure that financial decision-making can anticipate the shifts that will arise from transformational sustainability and capture future opportunities while minimising their related risks. Policy makers and other stakeholders would benefit from advanced impact assessment tools that enable an analysis of alternative financing strategies, policy tools and innovative frameworks so as to improve policy design to a successful and just Green Deal. Advanced modelling frameworks models will be instrumental in improving our understanding of the socioeconomic implications and overall feasibility of policy tools. These tools should also allow for simulation of the financial needs for the low-carbon transition.

8.3 Supporting the long-term redesign of the current financial system

Challenge

A restructuring of the financial sector is required so as to meet the large-scale, long-term funding challenges of the transition and combat the short-term bias of financial systems. Behavioural barriers need to be identified and policies that actors can appreciate as coherent and stable need to be identified. Importantly, investments need to be diverted towards innovations for low-carbon technologies and processes. Innovation is inherently a highly uncertain endeavour. Private investors, public investors and Public Private Partnerships acting in concert as an innovation eco-system can address this uncertainty. For the private sector to be willing to commit substantial capital, investments for the low-carbon transition will need to earn a standard risk-reflective return.

R&I priority 8.3: Identifying behavioural barriers and how to overcome them

R&I actions should promote the understanding of the barriers which hinder the flow of finance towards decarbonisation efforts, low-carbon technologies and low-carbon business models. These include not only barriers in the financial markets per se, but also behavioural barriers affecting producers and consumers investment decisions. Furthermore, R&I efforts should improve our understanding of how to modify the financial market myopia (short-sightedness) which characterizes investors and financiers. Such myopia draws investments away from long-term value creation and undermines the financing of deep decarbonisation. It hampers investments in real assets that are amortised over many years and the development of technologies and business models that will drive the transition to sustainable development. On the one hand, the long-term horizon of end-beneficiaries (such as pension funds, household savers and sovereign wealth funds) is currently not widely reflected by financial intermediaries (due, for instance, to principal-agent issues and misaligned performance metrics and incentives). On the other hand, the needs of businesses for enduring capital are undermined by an excessive focus on short-term price performance, particularly on listed equity and bond markets. Stakeholder interactions carried out within the DEEDS project show that investments by citizens, as can be observed in Sweden, can be a means to both unlock financial means and at the same time contribute to the empowerment of citizens. R&I should investigate the means to replicate across EU-27.

R&I priority 8.4: Develop a coherent and predictable policy and regulatory framework

R&I efforts should be devoted to the design of a coherent and predictable policy and regulatory framework promoting the restructuring of the financial sector and the alignment of funding with long-term climate targets. Furthermore, investments should be devoted to understanding barriers to implementation of such a framework. This is absolutely crucial to allow financiers to allocate savings to low-carbon technologies and business models with confidence, thus ensuring that the private sector plays a major role in closing the decarbonisation investment gap. Optimal strategies and policy instruments to overcome the short-termism in stock and bond markets should be studied, so as to allow stronger capital flows towards long-term investments. Financial instruments that secure movement of capital

at scale are needed, with a focus on tools that ensure the inclusion of long-term and climate-related considerations in investment strategies, risk management, governance and asset allocation. This entails ensuring that long-term considerations on low-carbon investments are included in investment strategies, risk management, asset allocation, governance and stewardship. Practical examples in this respect include promoting and incentivising the adoption of double bottom-line (considering the conventional bottom-line related to fiscal performance as well as social impact) or even triple bottom-line (adding environmental impact as a third bottom-line) accounting.

R&I priority 8.5: Promoting concerted action in the innovation value chain
As regards public investment, the European Commission intends to use the full range of instruments available under the Horizon Europe programme to support the research and innovation efforts needed, in particular through the European Innovation Council. Public financing mechanisms like the Innovation Fund, are already designed to assume risk partially, e.g. in "first of a kind" demonstration to further decarbonisation business cases (product, services, business models) and promote the influx of private capital during later stages of technological development. Public Private Partnerships, like the Knowledge and Innovation Communities that have developed over the past decade, should be targeted at supporting the lab-to-market phase as well as scale-up. The Just Transition Mechanism (JTM) will ensure that the regions and sectors that are most affected by the transition because they depend on fossil fuels or carbon-intensive processes will not be left behind.

An R&I priority in that respect should be in establishing the right "interfaces" between the players along the innovation value chain (co-investment or similar) and monitoring results in terms of impact (on de-carbonisation, but also economic) of such innovation eco-systems, both at regional level (physical innovation eco-systems), possibly national, and EU level (European innovation eco-system). Investor risk profiles should be assessed and complemented to assure seamless market uptake of innovation. Common risk management tools, like portfolio management considerations, should be identified and their usefulness assessed. Orientation towards the "customer", i.e. the innovator and investor risk profiles can be meaningful, too.

Expected Impact
Through sustainable finance at all scales of investment, the EU will be able to reap the full spectrum of co-benefits associated with decarbonisation. Europe's financial institutions will become more resilient, and Europe's businesses will access better priced and more patient capital, so they will be able to develop the products, skills and innovations that are increasingly needed to deliver a healthy financial sector and promote growth and employment. European citizens will see their sustainability values expressed in their financial choices, and their needs met. Abroad, first-mover advantage will grant a position of leadership to the EU, which has the opportunity to act as a champion of international policy reform for low-carbon and sustainable finance.

Projects can develop practical solutions to limit the role and influence of short-term traders and investors in stock and bond markets that create undue volatility and hamper long-term

investments. Crucially, R&I actions may identify how such policy instruments can be coupled with an even stronger orientation towards mobilising investment to address the long-term needs of the real economy not only in terms of climate mitigation, but also with respect to other priorities such as employment, education, and savings.

By promoting the concerted action of public investors, private investors and Public Private Partnerships as an innovation eco-system, the EU will be able to foster innovation along the full innovation value chain towards market take-up and scale-up. Projects could deliver clear assessment on gaps in the innovation chain and what works or not in bridging them and can assess the "customer-orientation" along the full innovation chain, as a means to ensure impact.

9 A fair and inclusive energy transition

9.1 Introduction

One of the cornerstones of the EU Green Deal is a fair and inclusive transition towards climate neutrality in 2050: [..]"It must put people first, and pay attention to the regions, industries and workers who will face the greatest challenges" (p.2) [..] Whilst European society as a whole will benefit from the transition to decarbonised energy systems, there will inevitably be European regions, industrial sectors and certain social groups that could be disadvantaged. In the EU Green Deal the Just Transition Mechanism is proposed to mitigate unwanted impacts. Moreover, a negative impact of the energy transition on regions, industries or people will lead to "erosion" of support for the transition that will hamper the implementation of technologies and policy measures for decarbonisation. Therefore, voluntary measures for the transition by citizens, citizens collectives, and businesses should be welcomed. Citizens can change their **behaviour and lifestyle** in such a way that they reduce their carbon footprint while keeping control over (perceived) fairness and inclusiveness of the changes. Consumer choice and human behaviour, are important determinants for future CO_2 emissions [88][89][90][91]. Furthermore, citizens and businesses can start or support **social innovation** initiatives that will lead to CO_2 reduction in certain domains or areas and by nature will create (local) support for deployed activities. "Social innovation" will be essential, in particular how to engage citizens in the decarbonisation challenge as convinced actors in this transition, and to promote living-lab experiments [92]. Finally, authorities and businesses can take measures to secure that **no one and no region is left behind**. R&I should address knowledge gaps on these three topics.

The main knowledge gaps on behavioural and lifestyle change are:

- Quantifying the actual impact on reduction of CO_2 reduction depending on the context of behaviour [93][94];
- Effective strategies (information campaigns, eco labelling [95], social influence games, etc.) to change behaviour [96][97][98].

For social innovation the gaps are:

- Empirical evidence of saved CO_2 emissions of social innovation initiatives [99][100][101];
- Upscaling or replication of social innovation [102][103][104][105][106].

For the fair and inclusive energy transition many knowledge gaps exist. The main strategy is then:

- In line with the "learning programs" in section 2.5 develop a broad monitoring program for the energy transition to spot possible adverse impacts that should be tackled;
- Create (local) capacity to mitigate unwanted impacts of the energy transition through social innovation, capacity building and Transition Super-Labs;

9.2 Behaviour and lifestyle change

Challenge
Although much research on behaviour related to energy use and "sustainable consumption" has been done [93][94], the research is still quite fragmented, and outcomes cannot be generalised over certain contexts or situations. Equally, modelling by Integrated Assessment Models undertaken to inform global pathways consistent with the Paris agreement do not comprehensively assess the potential for lifestyle and behaviour changes on emissions [93].

R&I should deliver insight in the actual impact on CO_2 emissions of different types of behaviours in specific contexts and situations. It should reveal possible intervention moments, from which intervention strategies can be developed that should be further optimised through continuous monitoring.

R&I priority 9.1: Develop an European knowledge base on actual impact of different behaviours on CO_2 emissions and relate these data to options or moments for intervention
R&I should develop a better insight in behavioural patterns and in intervention options or moments for changing lifestyles in a sustainable way in various situations and contexts. Consumption patterns play a key role in future outcomes of climate change [91]. To develop effective programs that can promote sustainable and carbon-neutral lifestyles, research is needed to gather empirical evidence across behaviour types and countries to estimate the reduction of the carbon footprint through specific behaviour and lifestyle changes and estimate which interventions shall be prioritised for the most effective outcomes. This research should make use of various new ways to collect data, including use of big and bottom-up data from real-world studies and living labs. Co-creation of knowledge about intervention moments with citizens will increase the credibility of the outcomes.

R&I priority 9.2: Develop effective information strategies or programs for voluntarily reducing carbon footprints by EU citizens
Awareness raising should continue to be a vital element of guiding consumers towards reduced carbon footprints by educating consumers from an early age through daily practices and choices [92]. Develop effective information strategies or programs to promote sustainable climate-neutral behaviour and lifestyles. Such strategies or programs should make use of the available evidence base and of top-down modelling assessments to assess the potential impact of scaling up at national and European scales. New approaches should be developed and tested in real life, such as for instance feedback mechanisms on the carbon footprint, ICT applications, gamification & serious gaming, 'disruptive communication strategies', neighbourhood labs or other types of community-based approaches. The research requires co-development with both technical and social sciences. Specifically of interest are prosumers that already have access to testing solutions in practice, and that could play a pivotal role in the energy transition. This research should be accompanied by a monitoring program that focuses on testing, evaluating and capturing lessons learned. To this aim a network of 'living labs' could be set up throughout Europe that identifies relevant indicators or information, harmonises data collecting (strategies), exchange of experiences

and "good and bad" practices, and sets up analyses in a systematic way, as to distil learnings and change strategies that can be replicated and further disseminated.

Expected impact
The developed knowledgebase, the programs on reducing people's carbon footprint and subsequently improvement of these programs could lead to a considerable reduction of CO_2 emissions related to behaviour in the range of 10-20% [88][89][90][91].

9.3 Social innovation

Challenge
Social innovation through bottom up initiatives can result in greater participation in the governance of systems transitions and increase support for technologies, practices and policies that are part of the global response to limit warming [93]. An actual EU-wide and structured overview of types of social innovations and their quantitative impact on CO_2-emissions is not yet available [101]. As social innovations are typically developed in a specific local context, replication to other localities and upscaling of social innovations is a challenge. R&I should support a systematic evaluation and develop options for replication and upscaling.

R&I priority 9.3: Empirical evaluation of different social innovations and their impact on CO_2 emissions
R&I should focus on the actual quantitative impact on CO_2 emissions of different types of social innovations as this is rather not well researched. A framework for social innovations should be developed that links different types of social innovations to factors for successful development and implementation, and consequently to the impact on CO_2 emissions. To this aim social innovations, with the objective to reduce energy demand, to implement sustainable energy supply, or to reduce carbon footprints in general, should be researched along this developed framework.

R&I priority 9.4: Develop upscaling and disseminating mechanisms for social innovations that work throughout Europe
Specific business models, new forms of organisations or cooperatives, cooperation with businesses and/or public authorities, and development of targeted strategies should support replication and upscaling of social innovations throughout Europe. There is a need for research on replication and upscaling strategies and actions as to gain more insight in applicable mechanisms. These strategies and actions should be co-produced between social innovation initiatives and relevant other parties such as businesses or local/regional authorities. Furthermore, a network of "Social Innovation Labs" should be established that assists local groups or champions starting social innovation initiatives, supports existing initiatives and monitors success factors and actual impacts on the carbon footprint. In this way an "European Academy" of social innovations is created that keeps track of social innovations and impacts, collects lessons learned, disseminates these lessons, trains social innovators, and assists in replication and upscaling social innovations.

Expected impact
Numerous social innovation initiatives create a "bottom-up" movement that is aimed at reducing CO_2 emissions to attain the objectives of the Paris Agreement. This will lead to activities that are locally rooted and that also will create local support with citizens and businesses.

9.4 Leaving no one and no region behind

Challenge
Certain regions, industrial sectors, or social groups can be impacted in a negative way by the transformation to carbon neutrality. Research and innovation should make these impacts visible by monitoring the impacts of the energy transition on certain groups and regions and help to mitigate possible adverse impacts, for instance on the existing labour force or on energy poverty, through specific actions such as capacity building.

R&I priority 9.5: Develop a system to monitor the transformation to a climate-neutral society in the broadest societal sense (well-being, "Beyond GDP", "broad welfare")
A system should be developed to monitor the transformation to a climate-neutral society in the broadest societal sense (well-being, "Beyond GDP", "broad welfare") that is able to make impacts visible on different levels (international, national, regional/local). This will require a harmonised methodology, understanding the causality between actions and impacts in different domains, and good data quality. Cooperation with statistical offices in the Member States as well as with organizations such as EUROSTAT and OECD should be established. Transparency, objectivity and integrity of monitoring on all levels should be assured. The monitoring system should help to address all relevant aspects of a socially fair, just energy transition in the National Energy and Climate Plans of the EU Member States.

R&I priority 9.6: Create (local) capacity to mitigate possible negative impacts of the energy transition and create new jobs
Different R&I activities should be set up: investigate the possible roles of grassroots social innovation, local experiments and Transition Super-Labs.

R&I is needed to understand how grassroots social innovation could counterbalance the negative impact of the energy transition in disadvantaged regions and how to include potentially socially and economically disadvantaged groups into these initiatives. Moreover, actions should aim at setting up regional/local experiments with monitored outcomes to mitigate unwanted impacts of the energy transition. The broader perspective of monitoring involves policy domains such as health, environment, education, labour, that makes it possible to create a bigger picture of gains and losses and how to compensate among these. The experiments in different regions of the EU should inform all involved stakeholders (regional and local governments, firms (industries and small businesses), citizens and societal organisations) on progress and impacts of the energy transition. The experiments should foster joint interpretation of the monitoring results with involved stakeholders and consequently joint local action for mitigation of any unwanted impacts. This creates an

enduring climate action that is supported by the people and ensures that no one is left behind. Transition Super-Labs (see 2.6) in EU regions that could be negatively impacted by the energy transition are also a means to monitor the energy transition, to identify possible unwanted impacts, create jointly the capacity, and formulate joint measures to solve any problems that might occur. Research and Innovation in the context of the Transition Super-Labs requires an integrated approach on questions and problems at stake in the areas, such as capacity and labour skills, specific governance problems, or energy poverty.

Expected impact

European regions that are vulnerable for the energy transition have the necessary capacity and knowledge, structures and methodologies to deal with unwanted impacts. European regions and social groups are resilient and have the capacity to adapt and change with respect to the social and technological changes induced by the energy transition. Possible adverse impacts on groups or regions are mitigated by joint action of the local actors in such a way that net no jobs are lost.

List of acronyms

AI: Artificial Intelligence

BECCS: BioEnergy with Carbon Capture and Storage

BIM: Building Information Modelling

CDR: Carbon Dioxide Removal

CCU: Carbon Capture and Utilisation

CHP: Combined Heat and Power

DACCS: Direct Air Capture with Carbon Storage

EDPI: European Decarbonisation Pathways Initiative

ESR: Effort Sharing Regulation

ETD: Energy Taxation Directive

ETS: Emissions Trading System

EU: European Union

EUROSTAT: EUROpean STATistics

GDP: Gross Domestic Product

GDPR: General Data Protection Regulation

GHG Emissions: GreenHouse Gas Emissions

HLP: High-Level Panel

ICT: Information and Communication Technologies

IEA: Internation Energy Agency

IoT: Internet of Things

JTM: Just transition Mechanism

MaaS: Mobility as a Service

MS: Member State

MSR: Market Stability Reverse

NECP: National Energy and Climate Plans

OECD: Organisation for Economic Co-operation and Development

P2H: Power-to-Heat

P2H2T: Power-toHeat-to-Technologies

PPP: Public Private Partnership

R&I: Research and Innovation

SME: Small Medium Enterprise

SSH: Social Sciences and Humanities

TCFD: Task Force on Climate-related Financial Disclosures

TEN-E Regulation: Trans-European Networks Regulation

TRLs: Technical Readiness Levels

UN: United Nations

VRE: Variable Renewable Energy

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