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COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK

A Clean Planet for all
A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy

1. INTRODUCTION – THE URGENCY TO PROTECT THE PLANET

Climate change is a serious concern for Europeans[1]. The current changes in our planet's climate are redrawing the world and magnifying the risks for instability in all forms. The last two decades included 18 of the warmest years on record. The trend is clear. Immediate and decisive climate action is essential.

The impact of global warming is transforming our environment, increasing the frequency and intensity of extreme weather events. Europe experienced extreme heat waves in four of the last five years. This past summer, temperatures above the Arctic Circle were 5°C higher than usual. Large parts of Europe suffered from severe droughts while flood events have particularly affected Central and Eastern Europe in recent years. Climate related extremes such as forest fires, flash floods, typhoons and hurricanes are also causing massive devastation and loss of lives, as hurricanes Irma and Maria proved in 2017 when they hit the Caribbean, including a number of European outermost regions. This is now affecting the European continent with storm Ophelia in 2017 being the first strong East Atlantic hurricane ever to reach Ireland and in 2018 storm Leslie bringing destruction to Portugal and Spain.

The Intergovernmental Panel on Climate Change (IPCC) issued in October 2018 its Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways. Based on scientific evidence, this demonstrates that human-induced global warming has already reached 1°C above preindustrial levels and is increasing at approximately 0.2°C per decade. Without stepping up international climate action, global average temperature increase could reach 2°C soon after 2060 and continue rising afterwards.

Such unconstrained climate change has the potential to turn the Earth into a "hothouse", making large-scale irreversible climate impacts more likely. The IPCC report confirms that approximately 4% of the global land area is projected to undergo a transformation of ecosystems from one type to another at 1ºC of global warming, increasing to 13% at 2°C temperature change. For example, 99% of coral reefs are projected to disappear globally at a temperature increase of 2ºC. Irreversible loss of the Greenland ice sheet could be triggered at around 1.5°C to 2°C of global warming. This would eventually lead to up to 7 meters of sea level rise affecting directly coastal areas around the world including low-lying lands and islands in Europe. The rapid loss of Arctic sea ice during summer is already happening today, with negative impacts on biodiversity in the Nordic region and the livelihood of the local population.

This would also have severe consequences on the productivity of Europe's economy, infrastructure, ability to produce food, public health, biodiversity and political stability. Weather-related disasters caused a record € 283 billion in economic damages last year and could affect about two-thirds of the European population by 2100, compared with 5% today. For instance annual damages due to river floods in Europe could reach € 112 billion, from the current €5 billion. 16% of the present Mediterranean climate zone may become arid by the end of the century and in several Southern European countries outdoor labour productivity may decline by around 10-15% from present-day levels. It is also estimated that reductions in projected food availability are more significant at 2ºC than at 1.5°C of global warming, including in regions of key importance to EU security such as Northern Africa and the rest of

[1] According to the Eurobarometer report on climate change, published in September 2017, around three-quarters of European Union (EU) citizens (74%) consider climate change to be a very serious problem and more than nine in ten (92%) see it as a serious problem.

the Mediterranean. This could undermine security and prosperity in the broadest sense, damaging economic, food, water and energy systems, and in turn triggering further conflicts and migratory pressures. Overall, failing to take climate action will make it impossible to ensure Europe's sustainable development and to deliver on the globally agreed UN Sustainable Development Goals.

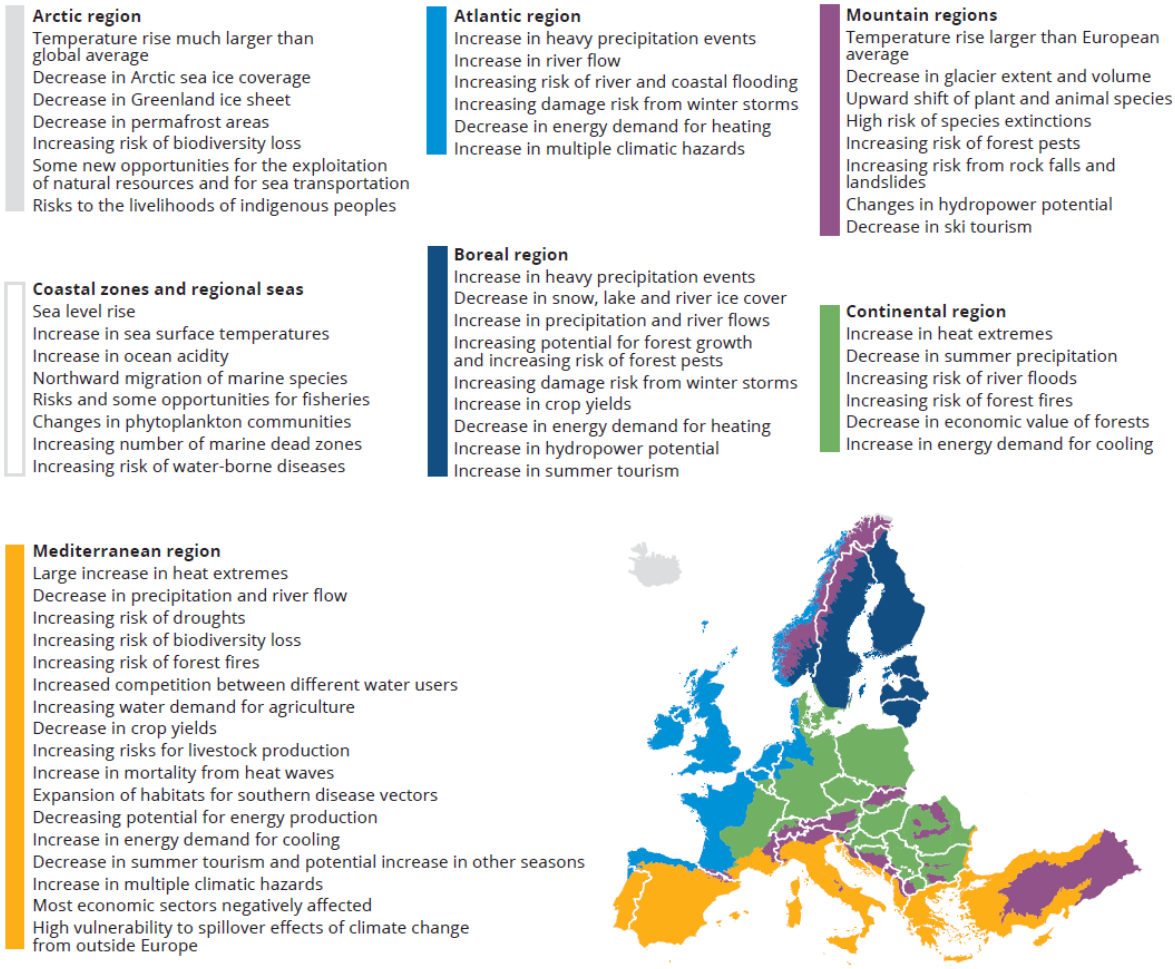

Figure 1. Climate change impacts in Europe

2. A EUROPEAN VISION FOR A MODERN, COMPETITIVE, PROSPEROUS AND CLIMATE NEUTRAL ECONOMY

The aim of this long-term strategy is to confirm Europe's commitment to lead in global climate action and to present a vision that can lead to achieving net-zero greenhouse gas emissions by 2050 through a socially-fair transition in a cost-efficient manner. It underlines the opportunities that this transformation offers to European citizens and its economy, whilst identifying challenges ahead. The proposed Strategy does not intend to launch new policies, nor does the European Commission intend to revise 2030 targets[2]. It is meant to set the direction of travel of EU climate and energy policy, and to frame what the EU considers as its long-term contribution to achieving the Paris Agreement temperature objectives in line with UN Sustainable Development Goals, which will further affect a wider set of EU policies. The Strategy opens a thorough debate involving European decision-makers and citizens at large as

[2] European Commission Work Programme for 2019 (COM (2018)800), page 4.

to how Europe should prepare itself towards a 2050 horizon and the subsequent submission of the European long-term Strategy to the UN Framework Convention on Climate Change by 2020.

The EU has been at the forefront of addressing the root causes of climate change and strengthening a concerted global response in the framework of the Paris Agreement. The Paris Agreement, ratified by 181 parties, requires strong and swift global action to reduce greenhouse gas emissions, with the objective to hold global temperature increase to well below 2°C and to pursue efforts to limit it to 1.5°C. It also has the goal to achieve a balance between emissions by sources and removals by sinks of greenhouse gases on a global scale in the second half of this century. All parties are to present long-term low greenhouse gas emission development strategies by 2020 that deliver on its objectives.

The European Council, in June 2017, strongly reaffirmed the commitment of the EU and its Member States to swiftly and fully implement the Paris Agreement, underlining that the Agreement "is a key *element for the modernisation of the European industry and economy*" and subsequently, in March 2018, invited the European Commission *"to present by the first quarter of 2019 a proposal for a Strategy for long-term EU greenhouse gas emissions reduction in accordance with the Paris Agreement, taking into account the national plans*".

In October 2017 the European Parliament also invited the European Commission "*to prepare by COP24 a mid-century zero emissions strategy for the EU*". Finally, the Regulation on Governance of the Energy Union agreed by the European Parliament and Council calls on the Commission to present an EU long-term strategy by April 2019.[3]

The EU, responsible for 10% of global greenhouse gas emissions, is a global leader in the transition towards a net-zero-greenhouse gas emissions economy. Already in 2009, the EU set its objective to reduce emissions by 80-95% in 2050.[4] Europeans have managed to successfully decouple greenhouse gas emissions from economic growth in Europe for the past decades. Following the peak in EU greenhouse gas emissions in 1979, energy efficiency, fuel switch policies and the penetration of renewables reduced emissions significantly. In consequence, between 1990 and 2016, energy use was reduced by almost 2%, greenhouse gas emissions by 22% while GDP grew by 54%.

The clean energy transition has spurred the modernisation of the European economy, driven sustainable economic growth and brought strong societal and environmental benefits for European citizens. The EU's pursuit to achieve its 2020 energy and climate targets already delivered new industries, European jobs and increased technological innovation, driving down technology costs. The renewable energy revolution is the best example of this. The share of renewable energy in final energy consumption increased from 9% in 2005 to 17% today. EU leadership demonstrates to other parts of the world that this transition is both possible and beneficial beyond the fight against climate change.

The EU is broadly on track to achieve its 2020 greenhouse gas, renewable energy and energy efficiency targets. However, continued focus is necessary in order to overcome the recent stagnation of energy efficiency improvements and greenhouse gas emission reduction trends.

The EU is advancing with its Energy Union Strategy and finalising a modern, advanced and cost-effective regulatory framework to achieve its 2030 greenhouse gas reduction targets and its clean energy transition delivering on the Juncker Commission's objective to put energy

[3] Art (15) of the Regulation on the Governance of the Energy Union and Climate Action.

[4] In the context of necessary reductions of the developed countries as a group.

efficiency first and become a global leader in renewables. This is an investment in our prosperity and in the sustainability of the European economy. Regulatory stability is an important element for public authorities and private operators alike to achieve full implementation of this framework. Ambitious policies have been agreed at European level, including a reformed EU emissions trading system strengthening the price signal for CO_2. For all other sectors, national greenhouse gas emission reduction targets have been set and legislation established to maintain the EU land and forests sink which absorbs more CO_2 than it emits. On the side of energy, the targets to improve the EU's energy efficiency by at least 32.5% and to increase renewable energy to at least 32% of the EU's final energy consumption by 2030 are now approved and the proposed legislation to improve the CO_2 efficiency of cars, vans and trucks will spur the transition in the transport sector.

Combined, these climate and energy policies will deliver on the EU's contribution under the Paris Agreement to reduce emissions by at least 40% by 2030 compared to 1990. In fact, when the agreed EU legislation is fully implemented, total greenhouse gas emission reductions are estimated to reach around 45% by 2030. The policies put in place today will have a continued impact after 2030 and will therefore already go a long way, with projected emissions reductions of around 60% by 2050. This is, however, not sufficient for the EU to contribute to the Paris Agreement's temperature goals.

The IPCC report confirms that the world needs to limit climate change to 1.5°C to reduce the likelihood of extreme weather events. It also emphasises that emissions need to be reduced with far more urgency than previously anticipated. In order to limit temperature increase to 1.5°C, net-zero CO2 emissions at global level needs to be achieved around 2050 and neutrality for all other greenhouse gases somewhat later in the century. At this point, any remaining greenhouse gas emissions in certain sectors need to be compensated for by absorption in other sectors, with a specific role for the land use sector, agriculture and forests. This provides an opportunity for the EU to step up its action to show leadership and reap the benefits of first mover advantage. This would require the EU to achieve greenhouse gas emissions neutrality by 2050.

The status quo is not an option. Countries should act together to protect their citizens against climate change. Delivering on the transformation towards a net-zero greenhouse gas emissions economy thus requires early long-term planning, improving knowledge of the opportunities for transforming our entire economy and building trust within our society and all economic actors that this change is possible and opportune.

The IPCC report provides us with this encouraging message: limiting global temperature increase to 1.5°C is doable, provided we act now and coherently use every tool at our disposal. The strong scientific basis of the IPCC report to decision makers across the globe for tackling climate change, modernising the economy, promoting sustainable development and eradicating poverty has been duly taken into account by the European Commission when preparing this EU Strategy for long-term greenhouse gas emission reduction.

The Strategy therefore outlines a vision of the economic and societal transformations required, engaging all sectors of the economy and society, to achieve the transition to net-zero greenhouse gas emissions by 2050. It seeks to ensure that this transition is socially fair – not leaving any EU citizens or regions behind – and enhances the competitiveness of EU economy and industry on global markets, securing high quality jobs and sustainable growth in Europe, while providing synergies with other environmental challenges, such as air quality or biodiversity loss.

To do so, the Strategy looks into the portfolio of options available for Member States, business and citizens, as well as into how these can contribute to the modernisation of our economy and improve the quality of life of Europeans, protect the environment, and provide for jobs and growth.

3. PATHWAYS FOR THE TRANSITION TO A NET-ZERO GREENHOUSE GAS EMISSIONS ECONOMY AND STRATEGIC PRIORITIES

The threats and risks of climate change are known, and so are many ways to prevent them. This Strategy provides a number of solutions that could be pursued for the transition to a net-zero greenhouse gas emissions economy by mid-century. These options will radically transform our energy system, land and agriculture sector, modernise our industrial fabric and our transport systems and cities, further affecting all activities of our society. In this context, citizens play a central role. Climate change can only be tackled if people actively engage, as consumers and as citizens. The success of the transformation will also depend on how our society takes care of those who are more vulnerable during this transition.

The transition towards a net-zero greenhouse gas economy gives energy a central role as it is today responsible for more than 75% of the EU's greenhouse gas emissions. In all options analysed, the energy system moves towards net-zero greenhouse gas emissions. It relies on a secure and sustainable energy supply underpinned by a market-based and pan-European approach. The future energy system will integrate electricity, gas, heating/cooling and mobility systems and markets, with smart networks placing citizens at the centre.

The transition also requires further scaling-up of technological innovations in energy, buildings, transport, industry and agriculture sectors. It can be accelerated by breakthroughs in digitalisation, information and communications, artificial intelligence and biotechnology. The expansion of new systems and processes, with cooperation across sectors, is also required. A good example of such system-oriented approaches is the circular economy, which will harness a range of advanced solutions and foster new business models. It will also require cooperation at different levels among regions and among Member States to maximise synergies by pooling resources and knowledge together. European manufacturing is still competitive today, but is also under pressure from both developed and emerging economies. Yet, Europe is at the top of the league when it comes to new high-value patents for low-carbon energy technologies, is seen as a global leader in these sectors and has to transform this scientific advantage in commercial success. Delayed and uncoordinated action would increase the risks of lock-in to carbon intensive infrastructure and stranded assets and make this inevitable transformation costlier.

The portfolio of options is based on existing, though in some cases emerging, solutions and is large enough to offer alternatives to assure policymakers and our citizens that a net-zero greenhouse gas emissions economy can be reached by mid-century. The assessment builds upon scientific literature and inputs from a wide range of stakeholders – business, non-governmental organisations, think tanks and the research community – as well as integrated modelling allowing to better understand the transformation of and complex interactions between the energy, industry, buildings, transport, agriculture, forestry and waste sectors.

Overview of the analysed scenarios

The starting point of the analysed pathways is a common baseline reflecting the 2030 energy and climate policies and targets as recently agreed as well as the Regulation on Governance of the Energy Union and

Climate Action.[5] This includes a reformed EU emissions trading system, national greenhouse gas emission reduction targets, legislation to maintain the EU land and forests sink, the agreed 2030 targets on energy efficiency and renewable energy, as well as the proposed legislation to improve the CO_2 efficiency of cars and trucks. These policies and targets are projected to reach reductions of greenhouse gas emissions of around -45% by 2030 and around -60% by 2050. This is not sufficient for the EU to contribute to the long-term temperature goas set in Paris Agreement. To achieve those goals, eight additional pathways – all in line with the Paris Agreement – were assessed.

The eight scenarios build upon no regret policies such as strong usage of renewable energy and energy efficiency.

Five of them look at different technologies and actions which foster the move towards a net-zero greenhouse gas economy. They vary the intensity of application of electrification, hydrogen and e-fuels (i.e. power-to-X) as well as end user energy efficiency and the role of a circular economy, as actions to reduce emissions. This allows exploring their common features as well as different impacts on the energy system.

In all these pathways electricity consumption increases, but notable differences exist. Pathways that focus more on electrification in end-use sectors see also need for high deployment of storage (6 times today's levels) to deal with variability in the electricity system; but pathways which deploy more hydrogen require more electricity to produce the hydrogen in the first place. Pathways that use the highest amounts of electricity are those that see the expansion of e-fuels, resulting in almost 150% more electricity production in 2050 compared to today. Instead, pathways that address the demand side, such as high end-use energy efficiency or the circular economy, require the least increase in electricity generation (ca. 35% more by 2050 compared to today), the lowest needs for storage and the deepest energy savings in the residential or industrial sectors. All these pathways additionally see varying needs for investments and transformation at sectoral level. Pathways more reliant on carbon-free energy carriers require less transformation and investment in the end-use sector, but also the highest investment needs in the energy supply sectors. Conversely, pathways focused on demand side change require the least investments in the energy supply sectors.

These five scenarios achieve just above 80% greenhouse gas emission reductions, excluding land use and forestry, by 2050 compared to 1990. Including the sink of land use and forestry sectors which absorb more CO_2 than they emit, these scenarios achieve around 85% net greenhouse emissions reductions by 2050 compared to 1990. This is still 15 percentage points short of a climate neutral or net-zero greenhouse gas economy.

The scenario combining all five options but at lower levels, reaches net greenhouse gas reductions as high as 90% (including the land use and forestry sink). Still, this scenario does not achieve greenhouse gas emissions neutrality by 2050. This is because some greenhouse gas emissions will remain, notably in the agriculture sector. The agricultural and forestry sectors are unique as they can also remove CO2 from the atmosphere. These annual removals today are significant, resulting in a net sink in the EU of around 300 million tonnes of CO2. But this is not big enough to compensate for the remaining emissions without additional measures strengthening the role of our land. Therefore additional action need to be explored on how biomass can be supplied in a sustainable way while enhancing our natural sink or in combination with carbon capture and storage that both can lead to increased negative emissions.

The seventh and eighth scenarios therefore explore explicitly these interactions to assess how to reach greenhouse gas neutrality (net-zero emissions) by 2050 and net negative emissions thereafter. The seventh scenario pushes all zero-carbon energy carriers as well as efficiency, and relies on a negative emissions technology in the form of bioenergy combined with carbon capture and storage to balance remaining emissions.

The eighth scenario builds upon the previous scenario but assesses the impact of a highly circular economy and the potential beneficial role of a change in consumer choices that are less carbon intensive. It also explores how to strengthen the land use sink, to see by how much this reduces the need for negative emissions technologies.

Modelling assessments indicate that the deployment of no-regret options such as renewables including sustainable advanced biofuels, energy efficiency, impetus towards circular

[5] COM (2016) 759

economy alongside individual options such as electrification, hydrogen and alternative fuels or new approaches to mobility, are not sufficient for a net-zero greenhouse gas emissions economy by 2050. Under such technology scenarios, emissions reduce only by 80% by 2050 compared to 1990. While combining all these options can reduce net emissions by around 90% (including the land use and forestry sink), some greenhouse gas emissions will always remain notably in the agriculture sector. Reaching net-zero greenhouse gas emissions will require maximising the potential of technological and circular economy options, the large scale deployment of natural land based carbon sinks including in the agricultural and forestry sectors as well as shifts in mobility patterns.

The road to a net-zero greenhouse gas economy could be based on joint action along a set of seven main strategic building blocks:

1. Maximise the benefits from Energy Efficiency including zero emission buildings

Energy efficiency measures should play a central role in reaching net-zero greenhouse emissions by 2050 reducing energy consumption by as much as half compared to 2005. Energy efficiency digitalisation and home automation, labelling and setting standards have effects that go far beyond the EU as appliances and electronics are imported into the EU or exported to foreign markets, making producers abroad use the EU standards.

Energy efficiency will play a central role in decarbonising industrial processes but much of the reduced energy demand will occur in buildings, in both the residential and services sectors, which today are responsible for 40% of energy consumption. Given that most of the housing stock of 2050 exists already today, this will require higher renovation rates, fuel switching with a large majority of homes that will be using renewable heating (electricity, district heating, renewable gas or solar thermal), diffusion of the most efficient products and appliances, smart building/appliances management systems, and improved materials for insulation. Sustainable renewable heating will continue to play a major role and gas, including liquefied natural gas, mixed with hydrogen, or e-methane produced from renewable electricity and biogas mixtures could all play a key role in existing buildings as well as in many industrial applications. To achieve and sustain higher renovation rates, adequate financial instruments to overcome existing market failures, sufficient workforce with the right skills and affordability for all citizens are of central importance. An integrated approach and consistency across all relevant policies will be necessary for the modernisation of the built environment and mobilisation of all actors. Consumer engagement, including through consumer associations, will be a key element in this process.

2. ***Maximise the deployment of renewables and the use of electricity to fully decarbonise Europe's energy supply***

Today the major part of the energy system is based on fossil fuels. All scenarios assessed imply that by mid-century this will change radically with the large-scale electrification of the energy system driven by the deployment of renewables, be it at the level of end-users or to produce carbon-free fuels and feedstock for the industry.

The clean energy transition would result in an energy system where primary energy supply would largely come from renewable energy sources, thereby significantly improving security of supply and fostering domestic jobs. Europe's energy import dependence, notably as regards imports of oil and gas, standing today at ca. 55% will fall in 2050 to 20%. This would positively impact EU's trade and geopolitical position as it would result in a sharp reduction of fossil fuel import expenditures (currently € 266 billion), with imports falling by over 70% in some scenarios. The cumulative savings from a reduced import bill will amount to € 2-3

trillion over the period 2031-2050, freeing resources for further potential investments into the modernisation of the EU economy.

The large-scale deployment of renewables will lead to the electrification of our economy and to a high degree of decentralisation. By 2050, the share of electricity in final energy demand will at least double, bringing it up to 53%, and electricity production will increase substantially to achieve net-zero greenhouse gas emissions, up to 2.5 times of today's levels depending on the options selected for the energy transition.

Fundamental progress has already been made in transforming Europe's electricity production. The global expansion of renewable energy, instigated by EU leadership, led to massive cost decreases in the last 10 years, in particular in solar and on- and off-shore wind. Today, more than half of Europe's electricity supply is free from greenhouse gas emissions. By 2050, more than 80% of electricity will be coming from renewable energy sources (increasingly located off-shore). Together with a nuclear power share of ca. 15%, this will be the backbone of a carbon-free European power system. These transitions are similar to global pathways analysed in the IPCC report. Electrification will open up new horizons for European companies in the global clean energy market worth today ca. € 1.3 trillion. Several sources of renewable energy are still to be harnessed, notably ocean energy. For the EU, which currently hosts 6 of the 25 largest renewable energy businesses and employs almost 1.5 million people (out of 10 million worldwide), this will be a unique business opportunity. It will also give an important role to consumers that produce energy themselves (prosumers), and local communities to encourage residential take-up of renewables.

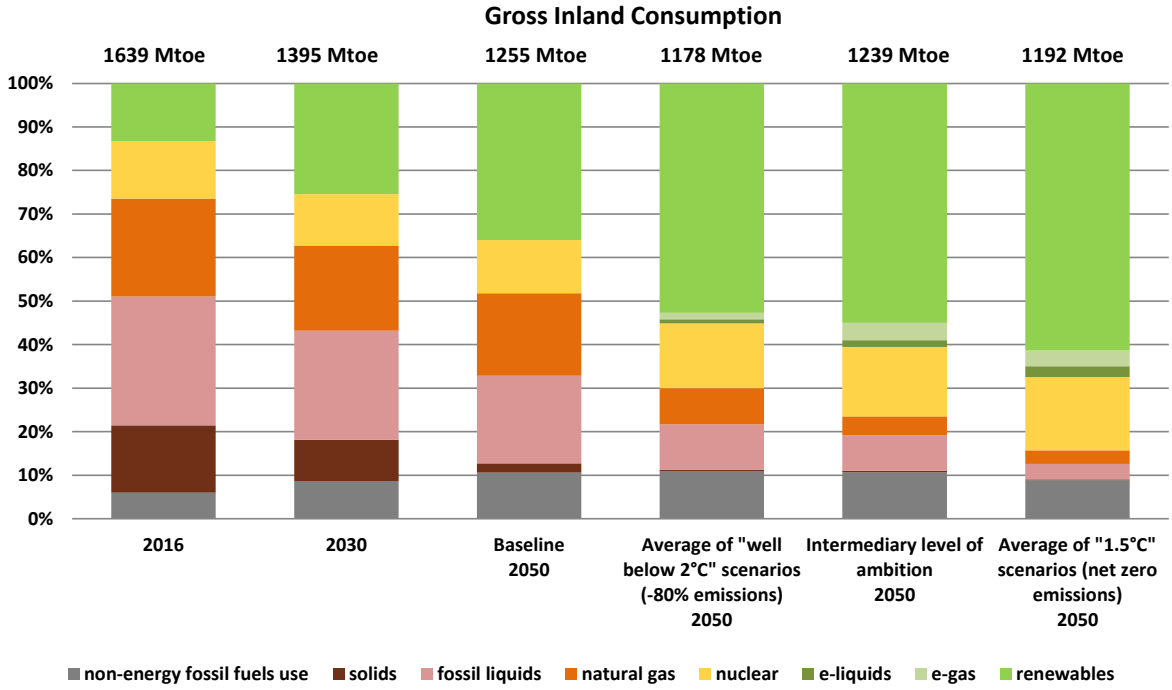

Figure 2. Fuel mix in Gross Inland Consumption

The competitive deployment of renewable electricity also provides a major opportunity for the decarbonisation of other sectors such as heating, transport and industry, either through direct use of electricity or indirectly through the production of e-fuels through electrolysis (e.g. e-hydrogen), when direct use of electricity or sustainable bio-energy is not possible. The potential advantage of power-to-X is that synthetic fuels can be stored and used in multiple

ways across different economic sectors, where it is otherwise hard to decarbonise (e.g. industry and transport). In niche applications and with a fully decarbonised electricity system, these technologies could use CO_2 as a feedstock captured from industrial processes. If captured from sustainable bio-energy or even directly from the air (recognising, however, that these technologies are yet untested at scale), they have the capacity to deliver on zero emissions fuels.

Hydrogen and Power-to-X (P2X)

Hydrogen has long been used by the chemical industry as a feedstock in industrial processes. Its role is likely to become more prominent in a fully decarbonised energy system. To play this role, hydrogen will have to be produced by water electrolysis using carbon-free electricity or from natural gas steam reforming using Carbon Capture and Storage. Hydrogen thus produced can then contribute to decarbonise various sectors: first, as storage in the power sector to accommodate for variable energy sources; second, as an energy carrier option used in heating, transport and industry and, finally, as a feedstock for industry such as steel, chemicals and e-fuels in those sectors that are most difficult to decarbonise.

Power-to-X technologies refer to technologies that allow transforming electricity into synthetic gases (hydrogen, methane or other gases) and liquids. Hydrogen produced with carbon-free electricity combined with CO_2 from sustainable biomass or Direct Air Capture can make a carbon-neutral alternative of the same molecules as natural gas or oil, and thus can be distributed via existing transmission/distribution system and used by existing installations and applications. These technologies become attractive in the context of abundant electricity generated from carbon-free sources (renewables and nuclear). The drawback is that their production is energy intensive.

The transition towards a largely decentralised power system based on renewables will require a smarter and flexible system, building on consumers' involvement, increased interconnectivity, improved energy storage deployed on a large scale, demand side response and management through digitalisation. The expansion and smartness of the electricity system, production and applications using power will require keeping the adequacy of the single energy market design high on the energy agenda in the coming decades to achieve zero carbon power in a cost-effective way and avoid stranded assets. The transition will also need to be safeguarded from any increased cyber security risks.

3. Embrace clean, safe and connected mobility

Transport is responsible for around a quarter of greenhouse gas emissions in the EU. All transport modes therefore need to contribute to the decarbonisation of the mobility system. This requires a system-based approach. Low and zero emission vehicles with highly efficient alternative powertrains in all modes is the first prong of this approach. Just as for renewable energy in the previous decade, the automotive industry already today heavily invests in the emergence of zero and low emission vehicle technologies, such as electric vehicles. A combination of decarbonised, decentralised and digitalised power, more efficient and sustainable batteries, highly efficient electric powertrains, connectivity and autonomous driving offers prospects to decarbonise road transport with strong overall benefits including clean air, reduced noise, accident-free traffic, altogether generating major health benefits for citizens and the European economy. Electrification of short sea shipping and inland waterways is also an option, where the power to weight ratio makes it feasible.

Based on today’s knowledge and technologies, electrification using renewables alone will not be the single silver bullet for all transport modes. Batteries have so far a low energy density, and for now their high weight makes the technology ill-suited for aviation and long distance

shipping. Also for long-haul trucks and coaches it is currently unclear whether batteries will reach the required cost and performance level, though prospects exist to electrify with catenary lines. Railway remains the most energy efficient solution for carrying freight over medium to long distances. Therefore, rail freight should become more competitive compared to road transport by eliminating operational and technical barriers between national networks and by fostering innovation and efficiency across the board. Until we see emerge new technologies that will allow to electrify more modes than today, alternative fuels will be important. In addition, hydrogen-based technologies (such as electric vehicles and vessels based on fuel cells) may become competitive in the medium to long-term. Liquefied natural gas with high blends of bio-methane could also be a short-term alternative for long-distance haul. Aviation must see a shift to advanced biofuels and carbon-free e-fuels, with hybridisation and other improvement in aircraft technology having a role in improving efficiency. In long distance shipping and heavy-duty vehicles, not only bio-fuels and bio-gas but also e-fuels can have a role provided that they are carbon-free throughout their production chain. E-fuels can be used in conventional vehicle engines, relying on the existing refuelling infrastructure. Further significant steps in research and development are needed in production of decarbonised fuels as well as the vehicle technologies such as batteries fuel cells and hydrogen gas engines.

Second, a more efficient organisation of the entire mobility system based on digitalisation, data sharing and interoperable standards is of utmost importance to make mobility cleaner. This will allow smart traffic management and increasingly automated mobility in all modes, reducing congestion and increasing occupancy rates. Regional infrastructure and spatial planning should be improved to realise the full benefits of increased use of public transport.

Urban areas and smart cities will be the first centres of innovation in mobility not least because of the predominance of short-distance journeys and air quality considerations. With 75% of our population living in urban areas, city planning, safe cycling and walking paths, clean local public transport, the introduction of new delivery technologies such as drones, and mobility as a service, including the advent of car and bike sharing services, will alter mobility. Combined with the transition to carbon-free transport technologies, reducing air pollution, noise and accidents, this will result in large improvements in the quality of urban living.

Behavioural changes by individuals and companies must underpin this evolution. For long distance travel, developments in digital technologies and video conferencing may well mean that for certain purposes like business travel, preferences will change and demand for travel may be reduced compared to what is expected today. Well-informed travellers and shippers will make better decision, especially when all transport modes are put on an equal footing, including in regulatory and fiscal terms. Internalising the external costs of transport is a prerequisite for making the most efficient choices in terms of technology and transport mode.

The transition towards net-zero in 2050 also requires the necessary infrastructure, i.e. the completion of the Trans-European core network (TEN-T) by 2030 and the comprehensive network by 2050. Future investments need to focus on the least polluting modes, promote synergies between transport, digital and electricity networks to enable innovations such as vehicle-to-grid services, and include smart features such as the European Railway Traffic Management System (ERTM) upfront. That would enable for instance high-speed train connections to become a real alternative to aviation for short and medium distance passenger travel within the EU.

Europe should remain the champion of multilateralism. Given the intrinsically global character of the shipping and aviation sectors, the EU needs to work with global partners to

encourage further efforts and build on the progress that has been recently achieved in the International Maritime Organisation (IMO) and the International Civil Aviation Organisation (ICAO) with a view to have them secured, as an essential first step towards the decarbonisation of these sectors. Further efforts will however be necessary.

4. A competitive EU industry and the circular economy as a key enabler to reduce greenhouse gas emissions

The EU industry is already today one of the most efficient globally and this is expected to continue. A competitive resource-efficient and circular economy will need to develop to keep it so. The production of many industrial goods like glass, steel and plastics will see further significant reductions in energy needs and process emissions, particularly with increasing recycling rates. Raw materials are indispensable enablers for carbon-neutral solutions in all sectors of the economy. Given the scale of fast growing material demand, primary raw materials will continue to provide a large part of the demand. But a reduction of materials input through re-use and recycling will improve competitiveness, create business opportunities and jobs, and require less energy, in turn reducing pollution and greenhouse gas emissions. Recovery and recycling of raw materials will be of particular importance in those sectors and technologies where new dependencies might emerge, such as a reliance on critical materials like cobalt, rare earths or graphite, whose production is concentrated in a few countries outside Europe. But also strengthened EU trade policy has a role to ensure sustainable and secure supply of these materials to the EU.

New materials will play an important role as well, whether rediscovering traditional uses such as wood in construction, or new composites replacing energy intensive materials. Consumer choices will also matter for product demand. Some may come from other ongoing transformations, such as digitalisation reducing paper demand. Others will be more climate conscious choices, such as customers increasingly asking for climate and environmentally friendly products and services. This requires more transparent information to consumers about carbon and environmental footprints of products and services so that they can make informed choices.

Becoming greenhouse gas emissions free will often mean significantly modernising existing installations or completely replacing them. This investment will constitute part of the next industrial revolution. The modern, competitive and prosperous EU industry, by staying at the forefront of the transition, would be able to strengthen its presence in a global economy that will inevitably become increasingly carbon constrained. Digitalisation and automation are seen in the short term as some of the more promising and effective avenues to increase competitiveness, leading both to efficiency gains and to greenhouse gas reductions. A combination of electrification, the increased use of hydrogen, biomass and renewable synthetic gas can reduce energy related emissions in the production of industrial goods, just as in any other end-use sector.

Many industrial process-related emissions will be very difficult to eliminate. Some options to mitigate them nonetheless exist. CO_2 can be captured and stored and used. Instead of fossil fuels, both renewable hydrogen and sustainable biomass can be a feedstock for a number of industrial processes, such as steel production and certain chemicals.

Carbon Capture and Utilisation in industry refers to processes where CO_2 is captured and then converted into a new product. E-fuels can be an example where the CO_2 gets released again when the fuel is combusted, displacing emissions of fossil fuels. Other CCU products such as plastic and building materials exist, which contain the CO_2 for long periods of time.

Steel, cement and chemicals dominate industrial emissions. In the next 10 to 15 years, technologies that are already known will need to demonstrate that they can work at scale, and some of them are indeed already being tested at small scale, e.g. hydrogen-based primary steel production.

Research, development and demonstration will significantly reduce costs of breakthrough technologies. This will lead to genuinely new products replacing today's industrial products, such as carbon fibre or stronger cements reducing the volume of production while increasing product value. A net-zero greenhouse gas emissions economy will see new business concepts develop with re-use and additional services at its core.

5. Develop an adequate smart network infrastructure and inter-connections

A net-zero greenhouse gas emissions economy will be achieved only with an adequate and smart infrastructure ensuring optimal interconnection and sectoral integration across Europe. Increased cross-border and regional cooperation will allow reaping the full benefits of the modernisation and transformation of Europe's economy. There needs to be further focus on the timely completion of the Trans-European Transport and Energy Networks. As a minimum, there should be sufficient infrastructure to support the major developments framing the energy transmission and distribution landscape of tomorrow: smart electricity and data/information grids, and where needed, hydrogen pipelines, supported by digitalisation and further sector integration, starting with the modernisation of Europe's main industrial clusters in the coming years. This will in turn spur further clustering of industrial installations.

Transitions in the transport sector will require accelerated deployment of relevant infrastructure, increased synergy between transport and energy systems with smart charging or refuelling stations that enable seamless, cross-border services.

For existing infrastructure and assets, retrofitting can ensure their continuous use, fully or partly. At the same time, opportunities are rising from the timely replacement of ageing infrastructure and assets with carefully designed ones, which are compatible with the deep decarbonisation objective.

6. Reap the full benefits of bio-economy and create essential carbon sinks

In a world with a 30% higher population in 2050 compared to today, and with a changing climate affecting ecosystems and global land use, EU agriculture and forestry will have to provide sufficient food, feed, and fibres as well as support the energy and various industrial and construction sectors. All are crucial for Europe's economy and way of life.

Sustainable biomass has an important role to play in a net-zero greenhouse gas emissions economy. Biomass can directly supply heat. It can be transformed into biofuels and biogas and when cleaned can be transported through the gas grid substituting natural gas. When used in power generation, CO_2 emitted can be captured creating negative emissions when stored. And it can substitute for carbon intensive materials, particularly in the building sector but also through new and sustainable bio-based products such as biochemicals (e.g. textiles, bioplastic and composites)

A net-zero emissions economy will require increasing amounts of biomass compared to today's consumption. This is confirmed by both global and European assessments of low carbon economy pathways. This assessment confirms this but depending on technologies and actions chosen, significant differences exist, with highest projections seeing an increase in bio-energy consumption by around 80% by 2050 compared to today.

Even with improved sustainable management practices, existing EU forests alone could not deliver that amount without a substantial decline of the EU's forest sink and its other ecosystem-services, which needs to be avoided. Increasing biomass imports could also raise concerns indirectly related to emissions from land use change in exporting countries. Increased biomass production thus will need to come from a combination of sources while ensuring our natural sink is maintained or even enhanced.

Agricultural production will always result in non-CO_2 greenhouse gas emissions but they can be reduced by 2050 thanks to efficient and sustainable production methods. Innovation will play an increasingly important role. Digitalisation and smart technologies are the basis for precision farming and precision agriculture optimising fertiliser and plant protection products application. Significant differences still exist in the productivity of cattle herds in the EU, offering scope for continued improvements. Treatment of manure in anaerobic digesters would reduce non-CO_2 emissions and produce biogas. There is also a considerable potential in agriculture land to sequester and store carbon.

Farmers are increasingly seen as providers of resources and providers of essential raw materials. There are new business opportunities through the circular bio-economy. Better farming systems including agroforestry techniques that efficiently use nutrient resources exist, enhancing not only soil carbon but also biodiversity and improving resilience of farming to climate change itself. These measures typically increase productivity, reduce input needs, and other environmental pressures such as eutrophication and air pollution. Carbon stocks in agricultural soils can be increased through zero-tillage and the use of cover crops, reducing soil disturbances and soil erosion. Adapting certain agriculture activities on organic soils and restoring peatlands and wetlands, still hotspots of carbon soil emissions, can drastically reduce emissions.

Afforestation and restoration of degraded forest lands and other ecosystems can further increase absorption of CO_2 while also benefiting biodiversity, soils and water resources and increase biomass availability over time. Farmers and foresters are the key stakeholders that can achieve such results and should be encouraged and supported to do so.

Carbon sinks are as important as reducing emissions. Maintaining and further increasing the natural sink of forests, soils, and agricultural lands and coastal wetlands is crucial for the success of the Strategy, as it allows the offsetting of residual emissions from sectors where decarbonisation is the most challenging, including agriculture itself. In this context nature based solutions and ecosystem-based approaches often provide multiple benefits regarding water management, biodiversity and enhanced climate resilience.

New demand for woody biomass could further diversify today's farming business up to 10% of EU agriculture land. This will offer new opportunities for bringing abandoned land back into cultivation, as well as for converting land currently used for food-based bio-fuels. This will improve farm productivity and income, and most likely increase the value of arable land accordingly.

However, a biomass-based transition is limited by the availability of land. Depending on the biogenic material from which the biomass is produced, the impacts on land use, the EU natural sink, biodiversity and water resources can differ substantially. The transition of our economy will always have to be careful how to make best use of scarce land and other natural resources and ensure that biomass is only used in the most efficient and sustainable way.

In order to alleviate the multiple demands on the EU's land resources, improving the productivity of aquatic and marine resources will play an eminent role in capturing the full range of opportunities of the bio-economy for tackling climate change. This includes for

instance the production and use of algae, and other new sources of protein which have the potential to relieve the pressure on agricultural land.

7. Tackle remaining CO2 emissions with carbon capture and storage

Carbon Capture and Storage (CCS) was previously seen as a major decarbonisation option for the power sector and energy intensive industries. Today this potential appears lower, considering the rapid deployment of renewable energy technologies, other options to reduce emissions in industrial sectors and issues concerning social acceptance of the technology itself. However, CCS deployment is still necessary, especially in energy intensive industries and – in the transitional phase - for the production of carbon-free hydrogen. CCS will also be required if CO_2 emissions from biomass-based energy and industrial plants are to be captured and stored to create negative emissions. Together with the land use sink, it could compensate for remaining greenhouse gas emissions in our economy.

Considering the lock-in of fossil fuel technologies, e.g. a plant that is built today will likely still be operational in 2050, the ability to roll out carbon removal technologies increases the credibility of the EU's long-term strategy. CCS has not yet reached the commercialisation stage, hampered by lack of demonstration of the technology and economic viability, regulatory barriers in some Member States and limited public acceptance. If CCS is to materialise at scale within the coming decade a much larger research, innovation and demonstration effort will also be needed to ensure its deployment in conjunction with the options mentioned above, i.e. the energy intensive industry, biomass and carbon-neutral synthetic fuel plants. In addition, CCS requires new infrastructure, including related to transport and storage networks. For CCS to deliver on its potential, a coordinated and forceful action is necessary to secure the building of demonstrators and commercial facilities within the EU as well as addressing concerns of public opinion in some Member States.

Pursuing all these strategic priorities will contribute to making our vision a reality. Nevertheless, the management of the transition will require a scaled-up policy effort. An enabling framework is needed to spur research and innovation, to scale up private investments, provide the right signals to the markets, and ensure social cohesion so that that no region and no citizens are left behind.

4. INVESTING INTO A SUSTAINABLE SOCIETY – A EUROPEAN ENABLING FRAMEWORK FOR THE LONG TERM TRANSITION

The development of the options and actions explored will to a large extent depend on the speed of their initial deployment, the extent to which citizens become active participants in the transition, the public acceptance of certain low and carbon free technologies and how fast sufficient scale can be reached. This justifies putting in place a number of adequate policies and an enabling framework that is conducive to stimulating this change. Building on the work done putting in place the Energy Union, this framework should take into consideration all major trends that define the future of the EU economy and society such as climate change and environment, digitalisation, ageing and resource efficiency.

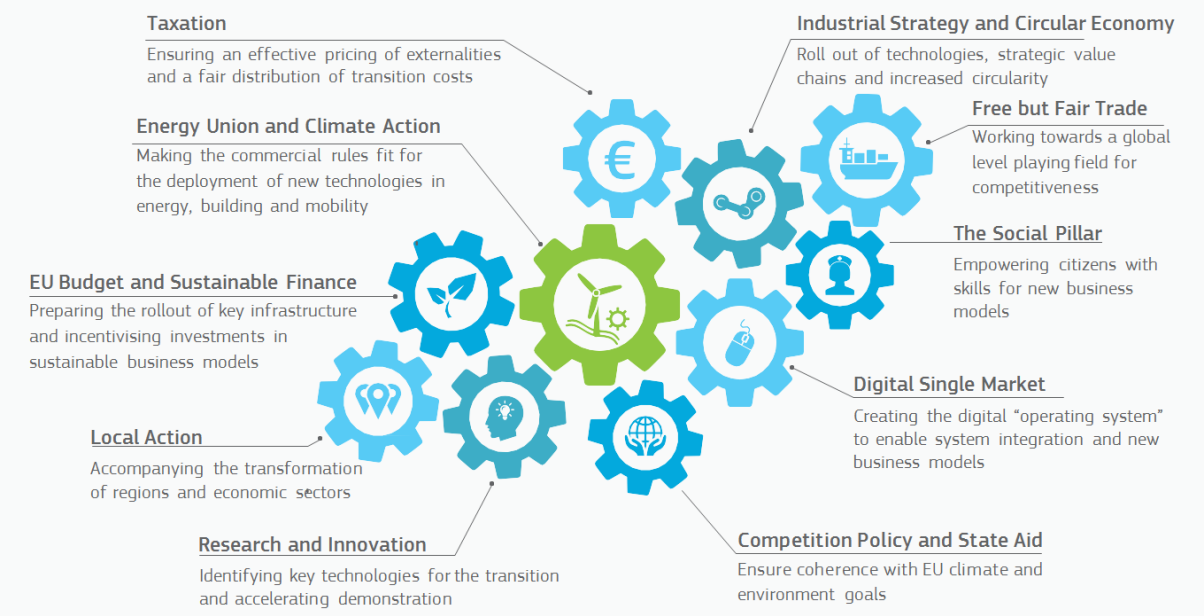

Figure 3. Enabling framework. Source: EPSC

Investment and finance

Modernising and decarbonising the EU's economy will stimulate significant additional investment. Today around 2% of GDP is invested in our energy system and related infrastructure[6]. This would have to increase to 2.8% (or around € 520-575 billion annually) in order to achieve a net-zero greenhouse gas economy. This means considerable additional investments compared to the baseline, in the range of € 175 to 290 billion a year[7]. This is also in-line with the IPCC special report that estimated that between 2016 and 2035 investments are needed in the energy system representing about 2.5% of world GDP. However, certain options such as a rapid transformation towards circular economy and behavioural changes have the potential to reduce the need for additional investment.

At the same time, significant health costs can be saved. Today, air pollution in the EU causes severe diseases and almost half a million pre-mature deaths annually with fossil fuels, industrial processes, agriculture and waste being the main sources of pollution. These activities are also the main sources of greenhouse gases. Achieving a net-zero greenhouse gas emissions economy on top of existing air pollution measures will reduce pre-mature deaths caused by fine particulate matter by more than 40% and health damage by around € 200 billion per annum.

[6] Excluding investments needed to replace vehicles.

[7] Including investments needed to replace vehicles.

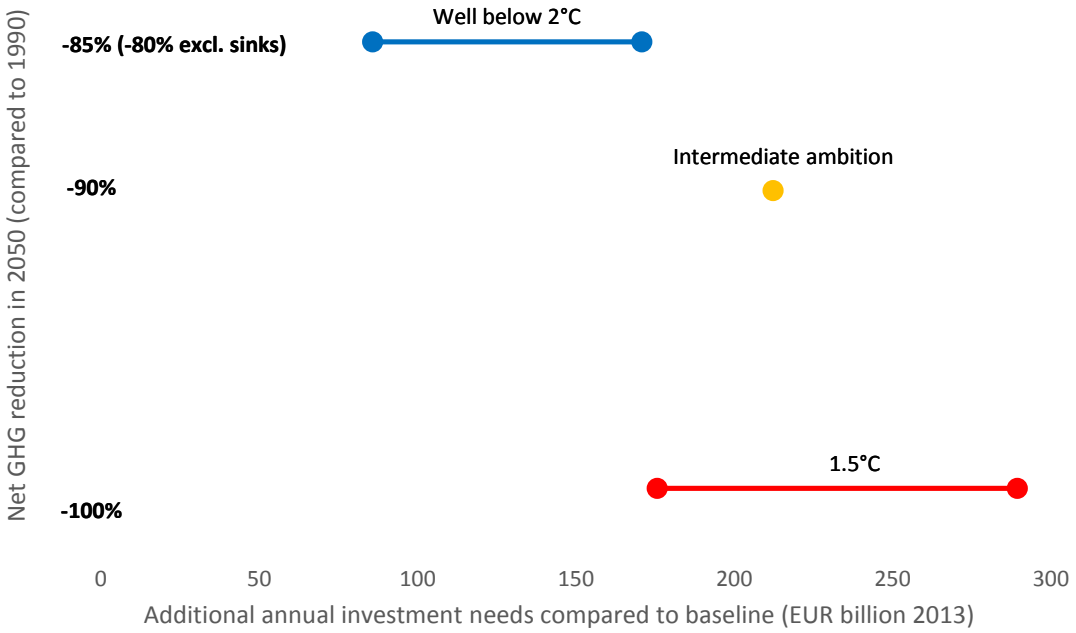

Figure 4. Investment requirements

Private business and households will be responsible for the vast majority of these investments. To foster such investment, it is crucial for the European Union and Member States to offer clear, long-term signals to guide investors, to avoid stranded assets, to raise sustainable finance and to direct it to clean innovation efforts most productively. Providing a vision will entrench the direction of where financial and capital flows need to go. In this perspective, transparent stakeholder engagement in planning for a low-carbon future is indispensable. The new Governance of the Energy Union integrates this need by foreseeing the involvement of stakeholders in the preparation of the national energy and climate plans, which need to be consistent with long-term strategies as well as the estimate of the investment needs.

Environment, resource and energy efficiency are already very prominent sectors of the Investment Plan for Europe – the Juncker Plan – a pillar of which has been the European Fund for Strategic Investment (EFSI) and the EU cohesion policy funds through which the EU provides ca. € 70 billion for the implementation of the Energy Union Strategy. EFSI 2.0 focuses even more on sustainable investments in all sectors to contribute to meeting the Paris Agreement's objectives and to help to deliver on the transition to a resource efficient, circular and low-carbon economy. At least 40% of EFSI projects under the infrastructure and innovation window should contribute to the EU's commitments on climate action in line with the Paris Agreement's objectives and InvestEU will reinforce that focus. New financial instruments, addressing both large and small-scale investments (such as energy communities), will also help the energy transition.

The European Commission proposal to step up climate mainstreaming to at least 25% in the next Multiannual Financial Framework demonstrates the EU budget would continue to act as a catalyst to leverage sustainable private and public investment and channel EU support for the clean energy transition to where it is most needed. It is also a key part of the EU's

credibility in advocating for net-zero greenhouse gas emissions in 2050. Swift progress in the MFF negotiations would further stabilise this ambition level.

The financial sector has a key role to play in supporting the transition towards net-zero emissions as it can reorient capital flows and investments towards the necessary solutions while improving efficiency of production processes and reducing the cost of financing. Reorienting private capital to more sustainable investments requires a well-functioning Capital Markets Union. In particular the Action Plan on Sustainable Finance will help connect finance with the EU's agenda for sustainable development, while the European Commission's proposal for a unified classification system (taxonomy) on sustainable economic activities, proposed rules for low-carbon benchmarks and improved disclosure requirements for investment products will enhance transparency and help investors with targeting the right investments. Transparency will help prevent the risks that assets which are energy intensive and/or dependent on fossil fuels are depreciated before the end of their economic life. Apart from the financial sector itself, also the supervisory authorities and central banks, including the European Central Bank, can play an active role in this re-orientation. Innovative solutions to mobilise investment supported by patient capital and venture capital in a long-term perspective will need to be developed.

Environmental taxation, carbon pricing systems and revised subsidy structures should play an important role in steering this transition. Taxation is amongst the most efficient tools for environmental policy. Therefore, taxes and carbon pricing should be employed to account for negative environmental impacts and focus on increasing energy efficiency, reducing greenhouse gas emissions and enhancing the circular economy. It is important that environmental taxation remains socially fair. A common approach between the EU and the Member States would be crucial to avoid relocation risks and loss of competitiveness. The implementation of the Strategy will require sustainable public finances and alternative ways of financing public infrastructures. For this, new sources of funding will have to be explored, for example charges resulting from a consistent application of the 'polluter-pays' principles and the phasing out of existing fossil fuel subsidies in line with the EU's G20 commitments. Reforms that support an efficient allocation of resources towards low-carbon high-productivity activities, such as facilitating the entry for new businesses and fostering competition in product markets, will allow for a transformation that strengthens competitiveness and economic growth.

Research, innovation and deployment

Today, the costs of some of the advanced low-carbon energy carriers and technologies remain high, and their availability is limited. A massive research, coordinated and innovation effort, built around a coherent strategic research and innovation and investment agenda is needed in the EU within the next two decades to make low and zero-carbon solutions economically viable and bring about new solutions not yet mature or even known to the market. In this context, a forward-looking research and innovation strategy should be guided by zero-carbon solutions that have the potential to be deployed by 2050. Climate is at the heart of Horizon Europe, the European Commission’s proposal for the new EU's research and innovation programme. The European Commission proposes to invest 35% of the near € 100 billion budget in climate objectives, through the development of innovative and cost-effective zero-carbon solutions. The approach to supporting projects and innovations needs to allow for financing high-risk disruptive innovation. The EU is putting in place such new instruments. One of these instruments is the European Innovation Council, which will focus on radically new, breakthrough products, services and processes. The European Institute of Innovation and Technology will also continue to support young innovators and start-ups across Europe.

On top of this, the Innovation Fund under EU Emission Trading System will support commercial-scale demonstration of breakthrough technologies. To help business innovate and connect with research organisations, the cohesion policy will continue to provide support following the smart specialisation approach. These are opportunities for a solid set of research, innovation and deployment activities over the next decade. The European Commission will explore how the assets of the European Coal and Steel Community in liquidation could support breakthrough technologies for low-carbon steelmaking.

EU research should focus on transformational carbon-neutral solutions in areas such as electrification (renewables, smart networks and batteries), hydrogen and fuel cells, energy storage, carbon-neutral transformation of energy intensive industries, the circular economy, the bio-economy and sustainable intensification of agriculture and forestry. Costs will come down with increased deployment but at a time of rising global trade distortions a pro-active European industrial innovation and modernisation strategy needs to define how initial deployment can be further supported. To this end, fully exploiting the Single Market and respecting international obligations, e.g. through clean public procurement and targeted time-bound state aid will be key. Drawing on initiatives such as the European Battery Alliance, the EU should build strong value chains, supported through enabling technologies such as new materials, digitalisation, artificial intelligence, high performance computing, and biotechnology.

Economic and social impacts

Even without the net-zero greenhouse gas emissions transformation, Europe's economy and society will look significantly different in 2050 from the way it does today. Demographics indicate that our society will be ageing significantly, with potential implications on the sustainability of public finances. On the other hand, our population will be generally better equipped for working with information and communication technologies. Such trends will facilitate the transition.

Overall economic impacts of the deep transformation are positive despite the significant additional investments required in all sectors of our economy. The EU economy is expected to more than double by 2050 compared to 1990 even as it fully decarbonises. A trajectory compatible with net-zero greenhouse gas emissions, together with a coherent enabling framework, is expected to have a moderate to positive impact on GDP with estimated benefits of up to 2% of GDP by 2050 compared to the baseline. Very importantly, these estimates do not include the benefits of avoided damage of climate change and related adaptation costs.

The transition will spur growth in new sectors. 'Green jobs' already represent 4 million jobs in the EU. Further investment into the industrial modernisation, the energy transformation, the circular economy, clean mobility, green and blue infrastructure and the bio-economy will create new, local, high quality employment opportunities. Actions and policies to implement the EU's 2020 climate and energy targets already added between 1% and 1.5% to the EU labour force and this trend will continue.

Whereas the number of jobs increases in construction, farming and forestry and renewable energy sectors, for a number of sectors the transition can be difficult. Particularly affected could be the regions whose economies depend on activities that either are expected to decline or will have to transform in the future. Areas such as coal mining, oil and gas exploration are likely to be affected. Energy intensive sectors such as steel, cement and chemicals as well as car manufacturers will see a shift to new production processes with new skills required.

Regions which depend economically on these sectors will be challenged, of which many are located in Central and Easter Europe, often in lower income Member States.

Other existing jobs will have to be transformed and adapted to the new economy. Managing this change requires taking into account a possibly shrinking and ageing labour force in the EU and increasing substitution of labour due to technological changes including digitalisation and automation. Rural areas for instance will need to maintain a sufficiently skilled workforce to meet growing and changing demands in the agriculture and forestry sectors, while being confronted with a decreasing rural population. For small and medium enterprises, the transition is an opportunity, but also creates specific challenges such as access to skills and finance that need to be addressed.

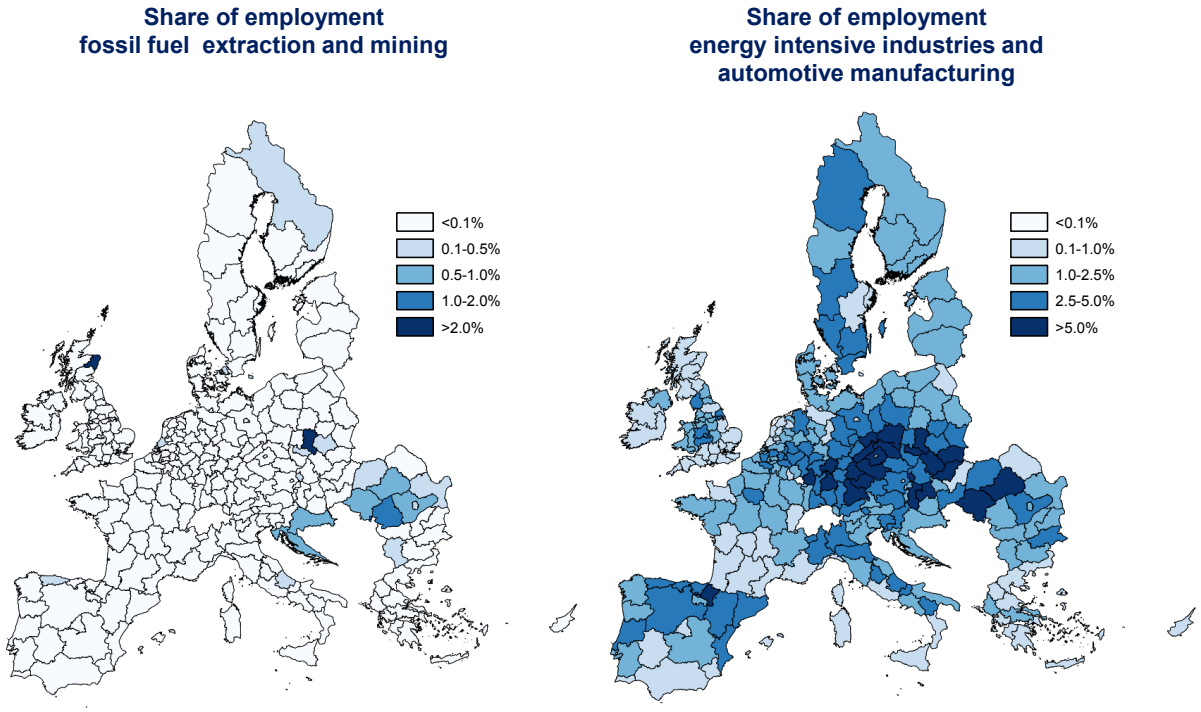

Figure 5. Regional employment in fossil fuel extraction and energy intensive industries (NUTS2 level)

These challenges have the potential to increase social and regional disparities in the EU as well as hamper the decarbonisation efforts. Therefore, the ensuing deep modernisation process will have to be managed well, ensuring a fair and socially acceptable transition for all in the spirit of inclusiveness and solidarity. The social consequences of the transition cannot be addressed post factum. Both the EU and the Member States must take into account social implications from the outset and deploy all relevant policies to the fullest to mitigate this challenge. The EU budget, employment and social policies as well as cohesion policies can reduce economic, social and territorial disparities across the Union. Ongoing regional initiatives launched by the Juncker Commission, such as the platform and pilot projects on coal and carbon-intensive regions in transition mark a step in this direction and should be reinforced in anticipation of future needs. Moreover, the involvement of social partners in the preparation of such transition measures should be ensured.

Support for the just transition is provided under the European Pillar of Social Rights, with its focus on supporting transitions with adequate social protection systems, inclusive education, training and lifelong learning. Skills development is essential. People will not only need specific professional skills but also ‘key competences’ from fields such as science,

technology, engineering, mathematics (STEM) skills. Investing in reskilling and upskilling of our population is essential so that we do not leave anybody behind.

Unless adequate regulatory or mitigating measures are in place, the transition bears the risk to disproportionally affect people with low income, leading to the emergence of some form of energy poverty. This risk has to be addressed. In most Member States, vulnerable customers can benefit from regulated energy tariffs, but these tariffs can distort market signals and reduce the effectiveness of policies on energy efficiency or hamper the deployment of technologies such as smart meters. These social issues are generally better addressed through the social policy and welfare systems, the financing of which could benefit from tax shifts and revenue recycling.

The EU's global role

The success of EU efforts in leading a successful low-carbon transition at global level and fighting climate change ultimately depends on international cooperation. This is the driving force for the Paris Agreement, which heralds a shift from action by the few to action by all. The EU's long-term strategy cannot be pursued in isolation. The EU must therefore promote worldwide uptake of policies and actions to reverse the currently unsustainable emissions trajectory, and to manage an orderly transition to a worldwide low carbon future. The EU should continue leading by example as well as foster multilateral rule-based cooperation. This remains the best means for the EU to address this inherently global challenge, underlining the importance to implement the Paris Agreement and making it a global success.

This means anticipating and preparing for the geopolitical and geo-economic shifts inherent in the low carbon transition, such as new and changed dependencies that will derive from the move away from fossil fuels, altering current economic relations, as well as the management of climate-security risks, which will multiply even under the most optimistic predictions of temperature increase.

At the same time, the EU must take all necessary measures to safeguard and boost its own prospects for economic and social development as well as to address its own vulnerabilities emanating from climate change or from harmful unilateral policies by other global players.

The EU will use its external action, trade policy and international cooperation to support global transformation to low-carbon sustainable development pathways, in line with the European Consensus for Development. This will require continued efforts to mainstream climate change and environment into public policies, as well as a reliable investment framework in EU partner countries.

While dependent on energy imports, the EU is the world's biggest exporter of manufactured goods and services. In downstream sectors like chemicals, machinery and transport equipment, the EU is a leading global exporter. At the same time, the EU is also a major importer fully integrated in global value chains.

As the world's largest single market, the EU's high environmental standards on products have effects that go far beyond the borders of the EU. This underlines the role for continued EU leadership on regulatory standards, putting European companies at the forefront of developing new technologies and business models.

Open markets, a globalised world and multilateralism are a precondition for the EU to be able to benefit from the clean energy transition domestically and also globally. With the clean energy transition, new types of assets and resources are becoming strategic, such as critical raw materials necessary for renewable energy, electro-mobility, digital appliances, and patents. Proactive or corrective policies may be needed to ensure a fully competitive and

level playing field in line with international obligations. Just as the EU remains open for climate-friendly investment and trade it should also defend its right to reciprocal, fair and transparently governed access to partner countries' markets, infrastructure and critical raw materials.

This starts with enhancing the EU energy and climate diplomacy, and with further mainstreaming climate change objectives and considerations in political dialogues, including in the area of migration, security and development cooperation. Based on the European Commission's Trade for All strategy, the EU's trade policy is already contributing to sustainable development in the EU and in third countries. Fair and rules-based trade can contribute to the global uptake of climate-friendly technologies, facilitate the energy transition, and help secure supplies of the necessary raw materials, including those used in low-carbon technologies. The EU should also continue to catalyse non-State actors, for example through the Global Covenant of Mayors.

The role of citizens and local authorities

Making the transformation towards a net-zero greenhouse gas economy happen is not just about technologies and jobs. It is about people and their daily lives, about the way Europeans work, transport themselves and live together. Moving towards a net-zero greenhouse gas economy can only be successful with citizens that embrace change, get engaged and experience it as beneficial for their lives and that of their children. Local ownership of investments is a good case in point. Consumers have a powerful role to play in driving the transformation forward – advancing towards a net-zero greenhouse gas economy. Currently, there is an increasing willingness of consumers to engage in sustainable activities. Each person's choice in buying a house, choosing energy supplier, a new vehicle or domestic appliances and equipment impacts his or her carbon footprint for many years to come. Personal lifestyle choices can make a real difference, while improving quality of life. Regulatory measures, corporate responsibility initiatives and emerging societal trends can support each other, allowing for rapid change as demonstrated for instance by the successful EU energy labelling system being replicated in many parts of the world.

Cities are already the laboratories for transformative and sustainable solutions. City refurbishment and better spatial planning including green spaces can be major drivers to renovate houses and attract people to live again close to work, improving living conditions, reducing travel time and associated stress. To protect Europe's citizens from the adverse effects of the changing climate, planning and building public infrastructure to withstand more extreme weather events will be an imperative no regret option. In this respect, the EU should capitalise on and expand the role of regions, cities and towns. The EU Covenant of Mayors representing 200 million European citizens is an example of a collaborative platform that allows local authorities to learn from one another. The joint European Commission and European Investment Bank URBIS initiative is a tangible example of EU assistance for cities in the development of their investment strategies. The Urban Agenda for the EU, which reinforces the urban dimension of relevant EU policies can also play a role.

5. CONCLUSION AND NEXT STEPS

The EU has already started the modernisation and transformation towards a climate neutral economy and will continue to lead global efforts to this end. In order to respond to the recent IPCC report and contribute to stabilising the climate in this century, the EU should by 2050 be among the first to achieve net-zero greenhouse gas emissions and lead the way worldwide. To do so, the EU needs to step up its efforts.

Climate change is a global threat, and Europe alone cannot stop it. Cooperation with partner countries will therefore be essential to reinforce greenhouse gas reduction pathways that are consistent with the Paris Agreement.

Nevertheless, the EU has a vital interest in working towards a net-zero greenhouse gas emissions economy by mid-century and demonstrating that net-zero emissions can go hand in hand with prosperity, having other economies follow its successful example. It should be based on the empowerment of all citizens and consumers in making change possible and proper information to the public.

This represents a tremendous opportunity to channel the response to the challenges of the 21st century in a strategic manner, rather than submit and adapt to the inevitable coming change. Ensuring a socially fair transition is crucial to ensure a politically feasible transition. This will be challenging, but nowhere as challenging as facing the economic and social consequences of failing to act. The purpose of this strategic vision is not to set targets, but to create a vision and sense of direction, plan for it, and inspire as well as enable stakeholders, researchers, entrepreneurs and citizens alike to develop new and innovative industries, businesses and associated jobs.

Starting to plan early for such a vision towards a net-zero greenhouse gas emissions Europe will allow Member States, business and citizens to make choices, and tailor the eventual pathway to national circumstances, resource endowments, innovation of industries and consumer preferences.

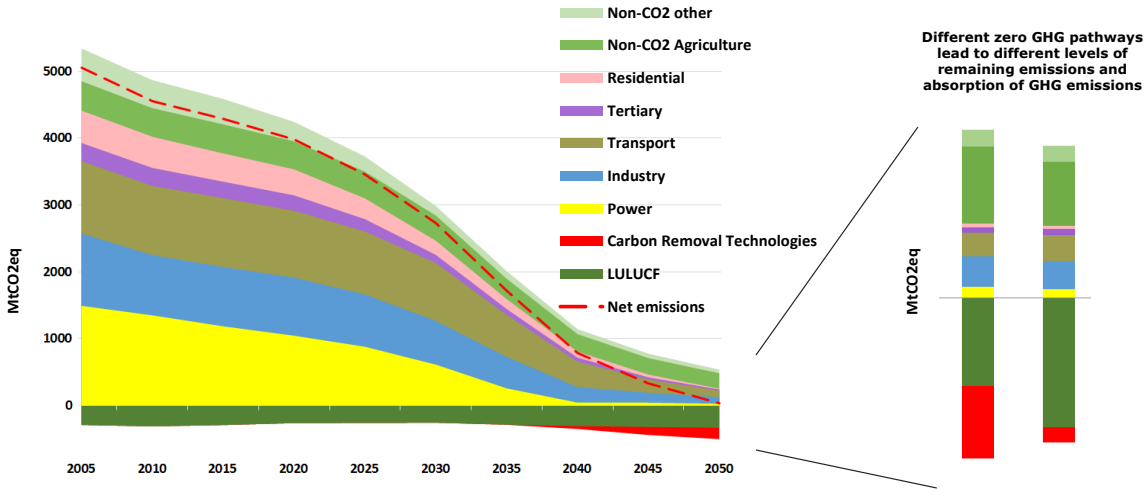

Figure 6. GHG emissions trajectory in a 1.5℃ scenario[8]

There are a number of pathways for achieving a climate neutral net-zero greenhouse gas emissions in line with our vision: all are challenging, but could be feasible from technological, economic, environmental and social perspective. Reaching this objective requires deep societal and economic transformations within a generation touching every sector of the economy. Applying the principles of a competitive, inclusive, socially fair and multilateral European approach, a number of overriding priorities, fully consistent with the Sustainable Development Goals, should be guiding for the transition to a climate neutral Europe:

[8] Bars represent the emissions and absorptions in 2050 of the 7th and 8th scenario.

- Accelerate the clean energy transition, ramping up renewable energy production, high energy-efficiency and improved security of supply, with increased focus on reducing cyber security threats, while ensuring competitive energy prices, all of which power the modernisation of our economy;
- Recognise and strengthen the central role of citizens and consumers in the energy transition, foster and support consumer choices reducing climate impact and reap collateral societal benefits improving their quality of life;
- Roll out carbon-free, connected and automated road-transport mobility; promote multi-modality and shifts towards low-carbon modes such as rail and waterborne transport; restructure transport charges and taxes to reflect infrastructure and external costs; tackle aviation and shipping emissions using advanced technologies and fuels; invest in modern mobility infrastructure and recognise the role of better urban planning;
- Boost the EU's industrial competitiveness through research and innovation towards a digitalised and circular economy that limits the rise of new material dependencies; start testing at scale breakthrough technologies; monitor the implications on the EU's terms of trade, in particular for the energy intensive industries and suppliers of low carbon solutions, ensure competitive markets that attracts low carbon industries, and in line with international obligations alleviate competitive pressures that could lead to carbon leakage and unwanted industrial relocation;
- Promote a sustainable bio-economy, diversify agriculture, animal farming, aquaculture and forestry production, further increasing productivity while also adapting to climate change itself, preserve and restore ecosystems, and ensure sustainable use and management of natural land and aquatic and marine resources;
- Strengthen infrastructure and make it climate proof. Adapt through smart digital and cyber-secure solutions to the future needs of electricity, gas, heating and other grids allowing for sectoral integration starting at local level and with the main industrial/energy clusters;
- Accelerate near-term research, innovation and entrepreneurship in a wide portfolio of zero-carbon solutions, reinforcing the EU's global leadership;
- Mobilise and orient sustainable finance and investment and attract support from "patient" capital (i.e. long-term venture capital); invest in green infrastructure and minimise stranded assets as well as fully exploit the potential of the Single Market;
- Invest in human capital in the next decade and beyond, equip current and future generations with the best education and training in the necessary skills (including on green and digital technologies) with training systems that quickly react to changing job requirements.
- Align important growth-enhancing and supporting policies, such as competition, labour market, skills, cohesion policy, taxation and other structural policies, with climate action and energy policy.

- Ensure that the transition is socially fair. Coordinate policies at EU level with those of Member States, regional and local governments allowing for a well-managed and just transition that leaves no region, no community and no worker and citizen behind;
- Continue the EU's international efforts to bring all other major and emerging economies on board and continue creating a positive momentum to enhance global climate ambition; share knowledge and experience in developing long-term strategies and implementing efficient policies so that collectively the objectives of the Paris Agreement are accomplished. Anticipate and prepare for geopolitical shifts, including migratory pressure, and strengthen bilateral and multilateral partnerships, for instance by providing support to third countries in defining low-carbon resilient development through climate mainstreaming and investments.

Member States will submit to the European Commission, by the end of 2018, their draft National Climate and Energy Plans, which are central for the achievement of the 2030 climate and energy targets and which should be forward-looking and taken into account in the EU long term strategy. In addition, an increasing number of regions, municipalities and business associations are drawing up their own vision for 2050, which will enrich the debate and contribute to defining Europe's answer to the global challenge of climate change.

The European Commission invites the European Parliament, the European Council, the Council, the Committee of the Regions, the Economic and Social Committee and the European Investment Bank to consider the EU vision for a climate neutral Europe by 2050. In order to prepare EU Heads of State or Government for shaping the Future of Europe at the Special Summit on 9 May 2019 in Sibiu, all relevant Council formations should hold extensive policy debates on the contribution of their respective policy areas to the overall vision.

In parallel, in the first half of 2019, the European Commission will take the debate on the necessary deep economic transformation and the profound societal change in an open and inclusive manner to all EU Member States. National Parliaments, business, non-governmental organisations, cities and communities, as well as citizens at large and the youth should participate in Citizens Dialogues discussing the EU's fair contribution to the efficient achievement of the temperature goals of the Paris Agreement in the long-term, and to identify key building blocks to achieve this transformation.

This EU-wide informed debate should allow the EU to adopt and submit an ambitious strategy by early 2020 to the UNFCCC as requested under the Paris Agreement.

Internationally, over the coming year the EU should expand its cooperation closely with its international partners, so that all parties to the Paris Agreement develop and submit a long-term national mid-century strategy by 2020 in the light of the recent IPCC Special Report on 1.5° Celsius.