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A Systemic Approach to the **Energy Transition** in Europe

Group of Chief Scientific Advisors
Scientific Opinion No.11, June 2021

Independent
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Report

Research and Innovation

A Systemic Approach to the Energy Transition in Europe

Group of Chief Scientific Advisors

European Commission
Directorate-General for Research and Innovation
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Chief Scientific Advisors
INDEPENDENT SCIENTIFIC ADVICE FOR POLICY MAKING

A Systemic Approach to the **Energy Transition** in Europe

Scientific advice to strengthen the resilience of the European energy sector

Group of Chief Scientific Advisors
Scientific Opinion No.11, June 2021
(Informed by SAPEA Evidence Review Report No. 9)

Brussels, 29 June 2021

2021 Directorate-General for Research and Innovation

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The scientific advisors in charge of preparing this opinion were Nebojsa Nakicenovic (lead), Carina Keskitalo (co-lead, until 15 May 2021), and Rolf Heuer (former Chair of the GCSA, until 15 November 2020).

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EXECUTIVE SUMMARY

The fight against climate change is arguably one of the defining global efforts of our time. The Paris Climate Agreement, which was signed by 196 Parties at COP 21 in 2015, aims to limit global warming to 1.5 degrees Celsius compared to pre-industrial levels. To make this possible, greenhouse gas emissions should reach their peak as soon as possible and the whole world should become climate neutral by mid-century.

The EU is leading the way: one of the Commission's six priorities is the European Green Deal, an action plan aiming to reach net-zero greenhouse gas emissions in Europe by 2050. The plan also aims to make the EU's economies sustainable by turning climate and environmental challenges into opportunities and transforming into a modern, resource-efficient and competitive EU. As part of this reform, the Commission has tabled the 'Fit for 55' package that aims at reducing greenhouse gas emissions by at least 55 % by 2030. Achieving this while maintaining economic competitiveness should ensure that Europe leads the way in achieving a sustainable future for all, fostering diversity across an EU that is united through common goals and catalysing the global transformation toward zero greenhouse-gas emissions.

A condition to achieving these ambitious targets is that the EU energy systems must undergo fundamental change; including:

- the energy systems must be fully decarbonised and integrate a very large share of variable renewable energy sources,
- the transport and industry sectors must be almost fully decarbonised;
- the building sector must ensure major improvements to the energy efficiency of buildings.

Substituting fossil fuels will require investing in renewable plants, grids and pipelines, storage facilities (batteries, fuel cells), carbon-free energy carriers (blue and green hydrogen and methane), boosting the energy performance of buildings, efficient industrial processes and appliances, as well as ensuring new transportation technologies and smart systems. Reducing the overall energy demand will be key to achieving all this without critically stressing the generation and transmission networks.

Under this framework, the opinion on the '*A systemic approach to the energy transition in Europe*' is provided in support of the College of the European Commission. The scoping paper which sets out the mandate for this opinion focuses on the following question:

"How can the European Commission contribute to the preparation for, acceleration, and facilitation of the energy transition in Europe given the present state of knowledge on the possible transition pathways?"

The recommendations below are informed by an extensive review of scientific literature, the Evidence Review report (ERR) prepared by the consortium of European Academies funded through the SAPEA grant agreement, as well as meetings with leading energy experts, Commission staff and stakeholders.

Recommendation 0

Design EU energy policy clearly aimed towards achieving climate neutrality and sustainability, without leaving anyone behind.

Use a holistic approach to maximise synergies and avoid trade-offs and barriers across technologies, regulatory and market measures, and social and behavioural changes.

Recommendation 1

Develop flexible, efficient, and resilient EU energy systems for delivering clean, accessible, and affordable energy services by integrating decarbonised energy sources, electrification and the use of green and blue hydrogen.

1.1 Develop energy systems that are flexible in terms of pathways, different technologies, and scales of implementation;

1.2 Support investments in integration of infrastructures and general-purpose technologies, including energy generation, transmission, storage, and end-use systems;

1.3 Support European research and innovation as a world leader in new technologies and smart systems.

Recommendation 2

Recognise the roles of all actors and stakeholders in creating an inclusive and participatory environment that incentivises and supports low-carbon energy choices.

2.1 Incentivise energy efficiency and reduce of energy use while ensuring sufficient services for all;

2.2 Support direct participation and innovation among all actors and stakeholders from the public and private sectors to individuals and households, at local, national, European and international levels;

2.3 Redistribute the additional revenue created by energy taxation and carbon pricing to support low-income groups and promote sustainable energy systems.

Recommendation 3

Support a coordinated combination of policies, measures and instruments, including carbon pricing as a driving force, to shape an effective, consistent and just regulatory system.

3.1 Use a coordinated combination of regulatory measures and incentives to drive the European energy transition;

3.2 Make a clear political commitment and undertake supporting actions to steadily move towards very high carbon (and other greenhouse gas) prices to cover all social and environmental costs;

3.3 Insist on reciprocal climate commitments by other countries to form 'decarbonisation clubs' and introduce a World Trade Organization-compatible border adjustment mechanism for carbon.

1. INTRODUCTION AND BACKGROUND

1.1. Introduction

The EU has set ambitious targets for reducing greenhouse gas (GHG) emissions from human activities to zero to avert climate change. GHGs include carbon dioxide, methane, nitrous oxide, and other radiatively active substances such as particulate matter, aerosols, ozone and water vapour. About two thirds of global warming caused by GHGs is due to carbon dioxide, mostly originating from the use of fossil fuels. The EU is leading the global fight against the climate crisis and with its Green Deal has launched a strategy to become climate neutral by 2050, requiring, among others, measures the complete decarbonisation of energy systems. Also of high relevance are the EU's commitments towards the UN's 2030 Agenda with its 17 sustainable development goals (SDGs) and the 2015 Paris Agreement under the UN Framework Convention on Climate Change (UNFCCC).

Although these are long-term goals, successfully achieving them hinges on decisions and action taken in the next few years (IEA, 2021). The European Green Deal (COM 2019/640) is one of the six Commission priorities for 2019-2024, and sets out an action plan aiming to make the EU's economy sustainable by turning climate and environmental challenges into opportunities in all policy areas through transformational change. As part of the European Green Deal, the Commission has tabled the 'Fit for 55' package aiming at reducing emissions by at least 55% by 2030 compared to 1990.

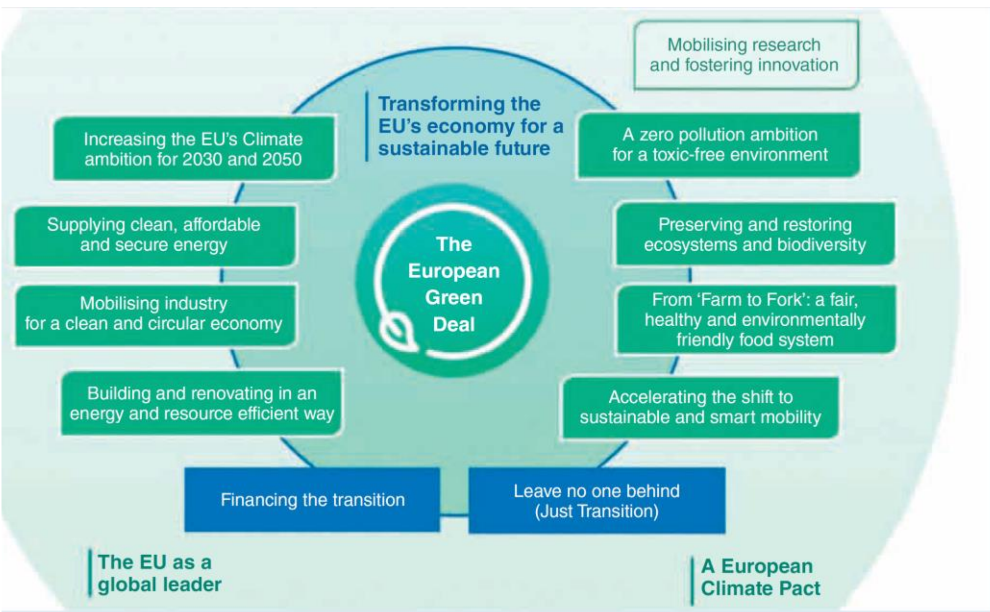

Figure 1: The European Green Deal sets out an action plan to boost the efficient use of energy and resources by moving to a clean, circular economy, restore biodiversity and cut pollution. The plan outlines the investments needed and the financing tools available. It explains how to ensure a just and inclusive transition without leaving anyone behind. Importantly, it calls for supplying clean, affordable and secure energy as well as building and renovating in an energy and resource efficient way. The EU aims to be climate neutral by 2050. Source: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en

Whereas energy systems are only one of the policy priority areas in the European Green Deal (Figure 1), their role is key in driving progress across virtually all other priority areas. Achieving a competitive, clean, circular, resource-efficient economy with net-zero GHG emissions by 2050 will require fully decarbonising the energy sector, electrifying transport and industry, and vastly improving the energy efficiency of buildings (e.g. heating and cooling), as well as finding novel ways to provide and share services benefiting from digitalisation and reducing the energy use. Achieving this vision in a just and inclusive way, improving the EU economy's global competitiveness without leaving any person or place behind, is obviously an enormous challenge. However, in view of the recent commitments to fight climate change by other major global players such as China and the United States, it presents the EU with a unique opportunity to lead the world toward a green, digital and sustainable future for all.

1.2. Scope and objectives of the opinion

Following their earlier work – specifically on 'Novel carbon capture and utilisation technologies' (GCSA, 2018), 'Food from the oceans' (GCSA, 2017), 'Towards a sustainable food system' (GCSA, 2020a), and 'Adaptation to health effects of climate change in Europe' (GCSA, 2020b) the GCSA was given the mandate (see Annex 1) to provide scientific advice on the energy transition.

The main question in the scoping paper, the document describing the background to the question to be addressed by the GCSA and which directed the Opinion (Annex 2) is:

'*How can the EC contribute to the preparation for, acceleration, and facilitation of the energy transition in Europe given the present state of knowledge on the possible transition pathways?*'

As in previous Opinions, the systemic approach taken in this work reflects important differences across the EU Member States; in this case, it also encompasses all dimensions of energy systems illustrated by the three exemplary definitions in the literature. The Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) states that "The energy system comprises all components related to the production, conversion, delivery, and use of energy" (Allwood et al. 2014). In a process view, an energy system consists of "an integrated set of technical and economic activities operating within a complex societal framework" (Hoffman and Wood 1976). In the European context the energy systems are part of a complex social, economic, cultural and legal framework, interlinked with all other policy areas like food, mobility, security, justice, trade and agriculture. The energy systems differ across Europe but all have in common their complexity and the crucial purpose to provide resilient energy services to end users.

Making the energy system carbon neutral requires a fundamental transition or transformation (Hölscher et al. 2018 and references therein). From the social, economic, and technological point of view, many different processes will have to be reshaped to fully decarbonise and improve efficiencies of energy conversion, transport and end use, such as mobility, buildings, industry and agriculture. Major investment decisions will be required by many different actors, from consumers to industry, from communities to regions and from different governmental levels to enterprises whether global, national or small and local. This shift involves broader social changes and requires an overarching approach to encompass new regulatory frameworks, norms, and behaviours; the related legal, economic, technological and financial innovations should be driven by a people-centred approach (Burke and Stephens 2018). The goal is to achieve synergies and avoid undesirable lock-ins in order to pave the way for desirable change.

A smart, fast and systemic energy transition in the spirit of the EU strategy on adaptation to climate change[1] would need to reflect the rich differences which exist amongst the energy systems across Europe (see Figure 2). This variety is both an opportunity and a challenge. Heterogeneous initial conditions can help maintain a certain diversity (for example in terms of available technologies), which in turn can make the transformation more resilient. However, there is also a need for supporting congruence in the systems change, ranging from clean and resource-efficient sources (and carriers) of energy to sustainable, efficient and sufficient energy end use. Pervasive electrification would play an important role in achieving these ambitious and aspirational goals (IEA, 2021).

Digitalisation may further enable possibilities for harmonisation of intermittent renewables, local and decentralised systems with continental grids (IEA, 2017). Replacing fossil fuels will require investments in renewable plants, grids and pipelines, storage facilities such as batteries, fuel cells, carbon-free energy carriers such as green and blue hydrogen and methane, as well as the rehabilitation of buildings, efficient industrial processes and appliances, new transportation technologies and smart systems. The envisioned transition also provides an opportunity for new sustainable economic development, as long as Europe is in a position to produce domestically and implement investment in a cost-effective manner.

One significant co-benefit would be the reduced dependence on imported fossil energy, but there are risks of new dependencies such as for rare earths and other resources and of a potential shift of the environmental burden outside Europe, e.g. if activities with the risk of stranded assets (investments that are made but which are no longer able to generate an economic return as a result of changes in the regulatory

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[1] https://ec.europa.eu/clima/policies/adaptation/what_en

environment)[2] are moved outside Europe. Circular economy and recycling of materials offer an opportunity to improve resource and energy efficiency throughout Europe; smart systems and digitalisation can enhance these benefits, although it is necessary to ensure that their contribution outweighs the extra energy demand that they create and does not introduce critical vulnerabilities. Suitable financing conditions, stable environments for future markets, and policy coordination (including effective regulation) are all necessary to implement new technologies and move along their steep learning curves (SAPEA 2021)[3].

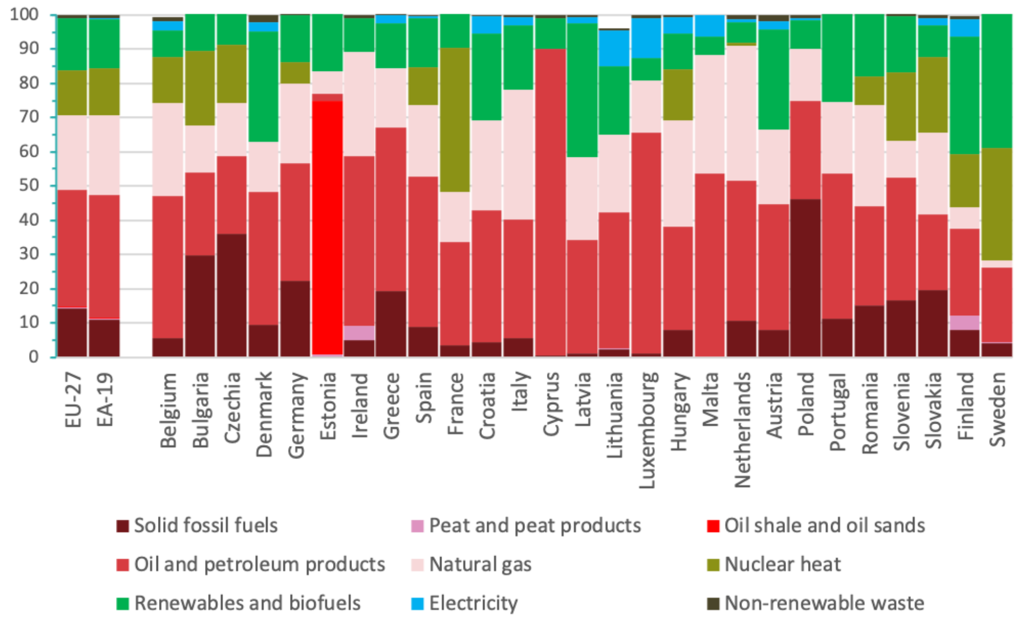

Figure 2: Share of energy sources in the final energy use in 2018, indicating great diversities across the Union. Latvia, Sweden and Finland have the largest shares of renewables, France and Sweden largest shares of nuclear, Cyprus the highest share of oil; only in Estonia shale oil is a significant source of final energy. Poland and Czechia have the highest share of solid fuels, mostly coal. On average in EU-27 and EA-19 solid fuels are about a tenth of all final energy and would need to be replaced by clean and affordable sources of energy forms or completely decarbonised. The largest share is taken by oil followed by natural gas. Carbon-free sources are close to a third with renewables having the largest share of about a sixth. Source: (Eurostat, 2020)

Developing an energy system based almost in full on variable renewable energy such as wind and solar is a challenge. The potential in available energy has been assessed

[2] Stranded Assets and Renewables: How the energy transition affects the value of energy reserves, buildings and capital stock - a REmap working paper (irena.org)
[3] DOI 10.26356/energytransition, URL: www.sapea.info/energy

to be more than enough to meet world demand; however, to realise the technical potential requires overcoming political, economic and technical barriers [4].

Many of the necessary technologies and options are well known, whereas some may still be at an early technological stage, which makes their possibilities of dissemination at the scale needed by 2030 or even 2050 uncertain (Bento et al., 2016, 2018). Rapid developments in the digital world will play a significant role in the future energy systems; for instance the Internet of Things, advanced data processing, machine learning, and artificial intelligence could help pave the way towards new zero-emissions energy, transport, production and settlement systems. However, such smart systems may also contribute to vulnerabilities, including in data security, privacy and new import dependencies, and raise energy usage (Fraunhofer ISI, 2019). How to successfully scale up and govern such features is a challenge and a high priority.[5]

The geopolitical angle adds another layer of complexity. So far, it has often been countries with limited domestic resources of fossil fuels which have significantly reduced the latter's share in their primary energy supply. The EU as a whole has a good record on this, but is very heterogeneous both at the Member-State and at the regional levels; some places have more of the conditions needed for a fast track towards decarbonisation, whereas others have less favourable starting points. The same is true for different industrial sectors, some of which will require long-term investments which would only be economically justified in presence of equally long-term political commitments. The role of fossil fuels in some local and national economies and the regressive nature of energy taxation and price of carbon risk putting most of the burden of the transition on the lower-income groups and households (Murauskaite-Bull and Caramizaru, 2021). New social nets and compensations are required to make sure that no person or region is left behind (SAPEA 2021, 3.9).

The transition to carbon neutrality requires to successfully coordinate a large number of voluntary decisions by different actors, in particular because reducing energy demand and use toward sufficiency and increasing energy efficiency is of utmost importance. This coordination can be achieved through a combination of regulatory measures (such as technology standards, incentives and subsidies with sun-set clauses) and market instruments (such as carbon pricing). In line with the policies and priorities already being set in place through the Green Deal, this may present opportunities for policy and legislative innovation. Effective and clear active national climate policies help also to coordinate corporate climate actions as it has been shown in the adoption of higher internal carbon prices by companies from areas where such approach was adopted (Bento et al., 2021). The knowledge needed for change may also be reflected in education and effective communication on the multiple benefits of achieving the energy transition. Various pathways are possible depending on the

[4] The Sky's the Limit: Solar and wind energy potential - Carbon Tracker Initiative
[5] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en

relative importance given to regulatory and market instruments, but it is important to guarantee the consistency of policy measures (SAPEA, 2021, 3.2).

1.3. Policy context

1.3.1. The global context

The EU energy system is part of a global context, whether it concerns climate change, energy security, interconnectivities, raw materials, or the risk of shifting the carbon burden outside the EU.

Mitigating climate change requires international cooperation. The Paris Agreement, aiming to limit warming to 1.5 °C above the pre-industrial level, was adopted by 197 nations during the COP21 conference in December 2015. This marked a historic turning point for global climate action. The Paris Agreement is a legally binding framework established to substantially reduce GHG emissions and steer the world towards a global clean energy transition. The EU formally ratified it in 2016 (COM 2016/110).

The EU is also committed to the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015. The Agenda defines 17 Sustainable Development Goals (SDGs). SDG 7 is specifically related to energy, and aims to ensure access to affordable, reliable and modern energy services; increase substantially the share of renewable energy; double the global rate of improvement in energy efficiency; enhance international cooperation; and expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all. The energy system is however also relevant for almost other goals, e.g. SDG 1, ending poverty (and energy poverty), SDG 2, which includes sustainable agriculture, SDG 8, on inclusive economic growth, SDG 9, on sustainable industrialisation, SDG 12, on sustainable consumption patterns, SDG 13, on combating climate change and SDG 14 on the sustainable use of oceans.

In 2017 the European Council presented its conclusions on how to strengthen synergies between EU climate and energy diplomacies as part of the European Union's Foreign and Security Policy (EUGS) [6]. This includes "better utilising EU and Member States' financial and technical assistance instruments, and strengthening the links with other important policy areas, including economic diplomacy, sustainable development cooperation, nuclear safety, migration, water and food security, ocean and marine resources, disaster preparedness, research and innovation" and involves partnerships both with state and with non-state actors.

The European energy system is also technically interconnected with that of its neighbours, through interconnections of electricity grids and gas lines. For example,

[6] Implementing the EU Global Strategy - strengthening synergies between
EU climate and energy diplomacies and elements for priorities for 2017 pdf (europa.eu)

the Nordstream system of offshore natural gas pipelines runs under the Baltic Sea connecting the energy systems of Russia and Germany (and which could also be converted to transport hydrogen in the long run)[7]. The European Neighbourhood Policy is a foreign relations instrument of the European Union (EU) which seeks to tie those countries to the east and south of the European territory of the EU to the Union. Part of the policy, the Eastern Partnership, is an initiative to help Armenia, Azerbaijan, Belarus, Georgia, Moldova, and Ukraine increase economic, political, and cultural links with the EU. It includes interconnectivity (energy and transport), energy efficiency, environment and climate change in its priorities.

1.3.2. EU's competence to act on energy

Energy was central to the creation of the European Union, with the European Coal and Steel Community (ECSC), created in 1951 to organise the free movement of coal and steel, and Euratom, created in 1957 with the original purpose of creating a specialist market for nuclear power in Europe. The treaty of Lisbon (2007) introduces a mandatory and comprehensive EU Energy Policy, separate from the areas of the common market and environment.

The current basis for the EU Energy Policy is Article 194 of the Treaty on the Functioning of the European Union (TFEA)[8] of 2012 which states that union policy shall establish the measures necessary to a) ensure the functioning of the energy market, b) ensure security of energy supply in the Union, c) promote energy efficiency and energy saving and the development of new and renewable forms of energy, and d) promote the interconnection of energy networks. It also states that "Such measures shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply…", meaning that energy is a shared responsibility between EU Member States and the EU. Specific provisions include the security of supply, energy networks, a protocol on coal and the Euratom treaty, as well as provisions on the internal energy market and external energy policies.

1.3.3. Energy-relevant policies of the EU

The energy policy of the EU is now part of the overarching European Green Deal, which was presented in December 2019 and will be an integral part of the Fit for 55 package. One of the Green Deal's eight priority areas is 'Supplying clean, affordable and secure energy'. However, similar as for the SDGs, energy is also relevant for the seven other objectives. The Green Deal aims to make the EU's economy sustainable, ensure there are no net emissions of GHGs by 2050, decouple economic growth from resource use, leaving no person and no place behind. The legislative proposals of the Green Deal build on earlier frameworks, but with increased ambitions.

[7] Transportation of Hydrogen by Pipeline (eolss.net)
[8] Treaty on the Functioning of the European Union

The EU Emission Trading System (ETS) is a tool for carbon pricing and a cornerstone of the EU's policy to combat climate change. It is a key tool for reducing greenhouse gas emissions cost-effectively. It was set up in 2005, and works on the 'cap and trade' principle. A cap is set on the total amount of certain greenhouse gases that can be emitted by the installations covered by the system. The cap is reduced over time so that total emissions fall. The legislative framework is spelled out in the ETS Directive (Directive 2003/87/EC). The EU ETS is the world's first international emissions trading system, and has inspired the development of emissions trading in other countries and regions.

Among the earlier frameworks on energy, the EU adopted in 2014 'A policy framework for climate and energy in the period from 2020 to 2030' (COM 2014/015), a strategy focusing on the transition to a low-carbon economy. Actions included measures addressing GHG emissions, high energy prices and energy imports, and GHG reduction targets. Also the Energy Union package of 2015 (COM 2015/080) sets out a strategy to build an energy union that provides EU consumers – households and businesses – secure, sustainable, competitive and affordable energy. The package includes the communication 'The Paris Protocol – A blueprint for tackling global climate change beyond 2020' setting out the EU's objectives for the Paris climate conference (COM 2015/081). The Energy Union strategy has five interrelated dimensions:

- Energy security, solidarity and trust;
- A fully integrated European energy market;
- Energy efficiency contributing to moderation of demand;
- Decarbonising the economy, and
- Research, Innovation and Competitiveness.

As part of the Energy Union the Commission published in 2016, the Fourth Energy package – also known as the Clean Energy for All package (COM 2016/860). The package comprised initiatives on energy performance of buildings, risk preparedness in the electricity sector, renewable energy, energy efficiency, the internal market for electricity, as well as on the role of the Agency for the Cooperation of Energy Regulators (ACER) (SAPEA 2021).

The Energy Performance of Buildings Directive (EPBD) 2010/31/EU and the Energy Efficiency Directive (EED) 2012/27/EU were revised in 2018. Taken together, some of the main points of the directives are: 1) reinforced long-term renovation strategies for EU countries, 2) nearly zero-energy buildings, 3) energy performance certificates, 4) consideration for health and well-being (air pollution), e-mobility (e-charging points) and smart technology (smart meters, self-regulation equipment) in new buildings.

The amending Directive on Energy Efficiency[9] of 2018 sets an efficiency target for 2030. It requires that states draw up national energy and climate plans to achieve this. Also in 2018, measures relating to national long-term renovation strategies are covered under the amended Energy Performance of Buildings Directive (EU)2018/844. Under the Green Deal the European Commission adopted in 2020 a Circular Economy Action Plan. The next revision of the Energy Performance of Buildings Directive and the extension of the scope of the EU-ETS to buildings are opportunities for implementing increased ambitions. However, it has been noted that one of the key barriers in renovating buildings is the upfront cost, which may be difficult to sustain, and there may be a need for innovative financing instruments to overcome this barrier (Bertoldi et al. 2020). The EU Structural and Investment Funds, such as the European Regional Development Fund (ERDF), European Social Fund (ESF) and Cohesion Fund (CF) could play a major role in this respect, as they are already promoting sustainable energy projects.

In the recent Clean Energy Bill (2019) the EU intends to set the right balance between making decisions at EU, national, and local levels. Member States will continue to choose their own energy mix, but must meet new commitments to improve energy efficiency, reduce emissions and the take-up of renewables in that mix by 2030. Consumers (or *prosumers*, who both produce and consume energy) were already one of the main elements of the Clean Energy Package for all Europeans (2016): the rules make it easier for individuals to produce, store or sell their own energy, and strengthen consumer rights with more transparency on bills, and greater choice flexibility.

With the communication 'Powering a climate-neutral economy: An EU Strategy for Energy System Integration' (COM 2020/299) of 2020 the EU put forward that "Energy system integration – the coordinated planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors – is the pathway towards an effective, affordable and deep decarbonisation of the European economy…" Systems integration means linking the various energy carriers - electricity, heat, cold, gas, solid and liquid fuels - with each other and with the end-use sectors, such as households, buildings, transport or industry.

The EU Biodiversity Strategy for 2030 (COM 2020/380) also considers the impact of energy generation, stating that "more sustainably sourced renewable energy will be essential to fight climate change and biodiversity loss. The EU will prioritise solutions such as ocean energy, offshore wind, which also allows for fish stock regeneration, solar-panel farms that provide biodiversity-friendly soil cover, and sustainable bioenergy". It also promotes "the shift to advanced biofuels based on residues and non-reusable and non-recyclable waste" and warns that "the use of whole trees and food and feed crops for energy production – whether produced in the EU or imported – should be minimised."

[9] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2018:328:FULL&from=EN

Since the presentation of the Green Deal the Commission in 2019 has raised its medium-term climate ambitions by proposing to reduce GHG emission by 55 % in 2030, as presented in the communication 'Stepping up Europe's 2030 climate ambition - investing in a climate-neutral future for the benefit of our people' (COM 2020/562). In the meantime the European Council and Parliament have agreed to this target.

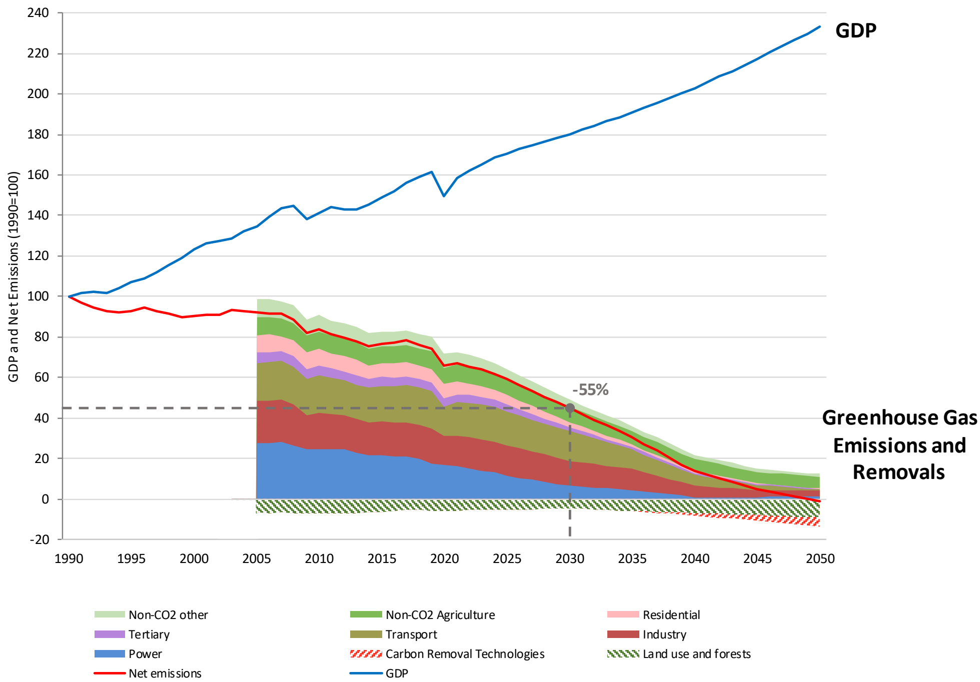

Figure 3: EU is scheduled to adopt the 'Fit for 55' legislation package for reducing greenhouse gas emissions to 55% (compared to 1990 levels) by 2030 and reach climate neutrality by 2050. The EU's pathway to sustained economic prosperity and climate neutrality is illustrated, with emissions declining in all sectors toward ten percent of 1990 levels by 2050 and being offset by an equal percentage of net-negative emissions (including nature-based solutions like land use changes and afforestation as well as carbon removal technologies). Significantly, the GDP is projected to continue growing at historical rates, reaching almost a 2.4-fold increase by 2050 while emissions decline toward net zero. Source: COM 2020/562.

In 2020 the Commission started to concretise its climate ambitions under the Green Deal by tabling the 'Fit for 55 package', which proposes a large number of legislative proposals. Many of these are planned for 2021:

- Revision of the EU Emissions Trading System (ETS), including maritime, aviation and CORSIA as well as a proposal for ETS as own resource

- Carbon Border Adjustment Mechanism (CBAM) and a proposal for CBAM as own resource
- Effort Sharing Regulation (Article 192(1) TFEU)
- Revision of the Energy Tax Directive
- Amendment to the Renewable Energy Directive and the Energy Efficiency Directive to implement the ambition of the new 2030 climate target (Article 194 TFEU)
- Revision of the Regulation on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry (Article 192(1) TFEU)
- Reducing methane emissions in the energy sector (Articles 192 and 194 TFEU)
- Revision of the Directive on deployment of alternative fuels infrastructure (Article 91 TFEU)
- Revision of the Regulation setting CO_2 emission performance standards for new passenger cars and for new light commercial vehicles (Article 192(1) TFEU)
- Revision of the energy performance of Buildings Directive (Article 194 TFEU)
- Revision of the Third Energy Package for gas (Directive 2009/73/EU and Regulation 715/2009/EU) to regulate competitive decarbonised gas markets (Article 194 TFEU)

Financing investment on the short term is crucial for achieving the goals of the Green Deal. The European Green Deal investment Plan, or Sustainable Europe Investment Plan, will mobilise €1 trillion in sustainable investments over the next decade. It will mobilise funding for the transition, create an enabling framework for private investors and support public administrations and project promoters in identifying, structuring and executing sustainable projects. As part of the Green Deal and with the aim of achieving the objective of EU climate neutrality in an effective and fair manner, the EU also established a Just Transition Mechanism[10] based on three pillars: the Just Transition Fund, a new financial instrument within the Cohesion Policy to support the territories most affected by the transition towards climate neutrality thus preventing an increase in regional disparities; a dedicated 'Just Transition' scheme under the InvestEU programme, which will provide a budgetary guarantee and a central entry point for advisory support requests to mobilise private-sector investments; and a new public-sector loan facility provided by the European Investment Bank to mobilise additional investments. In addition, NextGenerationEU, the temporary instrument designed to boost the recovery from the COVID pandemic intends to help rebuild a

[10] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/just-transition-mechanism_en

post-COVID-19 Europe that is greener, more digital and more resilient. It is the largest stimulus package ever financed in Europe, with a total budget of €1.8 trillion.

To direct investments towards sustainable projects and activities, a common classification system for sustainable economic activities was created (COM 2021/188). This 'EU taxonomy' helps with the implementation of the European Green Deal by providing appropriate and detailed definitions on which economic activities can be considered environmentally sustainable, to the benefit of companies, investors and policymakers. The activities included in the taxonomy are expected to make a substantial contribution to climate change mitigation and adaptation, while avoiding significant harm to the four other environmental objectives (sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention control, and protection and restoration of biodiversity and ecosystems).[11]

Other relevant legislative proposals for 2021 include the circular economy package and legislation on sustainable and smart mobility. Supporting this, the New European Bauhaus initiative is an environmental, economic and cultural EU project, aiming to combine design, sustainability, accessibility, affordability and investment in order to help deliver the European Green Deal.

Other relevant initiatives include the Trans-European Networks for Energy (TEN-E), a 2013 policy focused on linking the energy infrastructure of EU countries. As part of the policy, nine priority corridors and three priority thematic areas have been identified. The priority corridors concern those for electricity, gas and oil, and the priority thematic areas are smart grids, electricity highways and Cross-border carbon dioxide networks. The TEN-E policy is currently under revision. In relation, an example of a more global initiative supporting clean energy innovation in the field of energy is Mission Innovation[12]. It is a global intergovernmental initiative that was launched at the 2015 Paris Climate conference, and currently involves 24 countries and the European Commission (on behalf of the European Union). The initiative includes countries like China, Australia, Brazil and Canada, and focuses on topics like affordable heating and cooling and clean hydrogen.

1.4. Scientific context

1.4.1. The Evidence Review Report (ERR) by SAPEA

The central contribution which informed the present Opinion is the SAPEA Evidence Review Report (ERR) 'A systemic approach to energy transition in Europe' (SAPEA 2021), which contains a comprehensive analysis of the technical, economic and social aspects of the transition of the EU energy system towards net-zero emissions.

[11] https://ec.europa.eu/info/files/200309-sustainable-finance-teg-final-report-taxonomy_en
[12] Mission Innovation (mission-innovation.net)

In addition to the decarbonisation of the energy systems, all scenarios envisaged for achieving net-zero emissions by 2050 involve a significant reduction of energy demand, ranging from 30 % to 60 % (SAPEA 2021 5.1.2). On the supply side, the future energy mix will depend on local geographical specificities. However, in general terms the largest share will rely on variable renewable sources such as wind and solar, with other low-carbon sources (hydropower, waste heat, and others) also playing a significant role complemented with decarbonisation of remaining fossil energy in the system.

The ERR points to large-scale electrification as the most promising primary measure to improve efficiencies and radically reduce emissions for heating/cooling, transport and industry, whereas different approaches (e.g. hydrogen) will be limited to those sectors which are harder to decarbonise effectively (e.g. agriculture, aviation, shipping and some heavy industries). As a consequence, the overall electricity demand is expected to steeply increase; together with the need to quickly replace fossil-fuel generation with low- and zero-carbon sources, this could place energy systems reliability under immense stress if the transition is not properly managed. Possible ways to avoid this include exploiting synergies and minimising waste by system integration and sector-coupling approaches, limiting energy usage through energy-efficiency and energy-saving measures, and managing the complexity of the energy system by digitalisation and advanced data processing.

Large investments in the energy sectors, estimated at 2.5-3 % of GDP every year above business-as-usual, will be necessary during the transition, directed to both energy consumers and suppliers; clear priorities must be established to avoid lock-ins, but at the same time technology diversity should be maintained as much as possible to ensure maximum flexibility.

The ERR's assessment of different regulatory scenarios for the energy transition suggests an all-encompassing carbon pricing mechanism as the primary mechanism in the combination of policy measures (and ideally extended on a global scale as much as possible), but also that compensation schemes should be put in place in order to mitigate its regressive character.

From the geopolitical perspective, accelerating the energy transition will drastically reduce the EU's requirements of fossil fuels, but will also create new dependencies, for example related to key raw materials for low-carbon technologies such as copper, cobalt and lithium, the platinum group elements and rare earth element.[13] As crucial metals are mostly sourced outside Europe, recycling will support Europe's autonomy for crucial energy technologies (SAPEA 2021, 5.4). Mitigating policies include the promotion of recycling and urban mining as part of a wider shift towards a circular economy and the research on the possible substitution of the most critical materials with cheaper and more accessible alternatives.

[13] https://www.iea.org/reports/the-role-of-critical-minerals-in-clean-energy-transitions

Finally, the ERR states that behavioural change is another important aspect of our collective efforts toward full decarbonisation and can have a huge impact on energy consumption. The ERR highlights the need to promote conditions for innovations and their commercialisation, and notes that a shift towards a low-carbon lifestyle constitutes perhaps the most important area of energy transformation; yet, it is arguably also the most difficult from the point of view of policies for inducing the needed change in individual and societal choices and behaviour. A concept increasingly gaining traction in the scientific literature is 'sufficiency' (SAPEA 2021 5.1.3), which translates to stagnating level of services rather than constant growth, beyond a certain level of wealth. It does not imply a loss of well-being, as needs can be satisfied in a different, more sustainable way while conspicuous consumption is avoided.

1.4.2. Previous scientific opinions of the GCSA and related SAPEA evidence review reports relevant to the energy system

As the energy systems touch upon many policy areas, some of the previous GCSA Opinions contain recommendations that are also relevant for the energy transformation. In the opinion on how to achieve a sustainable food system it is argued that consumer behaviour is constrained and formed by many actors and aspects which are together referred to as 'food environment'. The SAPEA evidence review report 'A sustainable food system' (SAPEA, 2020) defines a 'food environment' as "the collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people's food and beverage choices and nutritional status". The actors that influence this includes non-governmental and industry actors, including producers, retail networks, storage and distribution actors, educators, influencers and information providers as well as individuals as food consumers and citizen-consumers. In general, evidence shows that choices people make and what people do is related strongly to the systems, influenced by many actors, including business and industry; people are not rational in any external 'economic person' sense but in relation to their social environments. This means that provision of information or voluntary means are not sufficient to change behaviour, and that behaviour change solely cannot be relied upon on its own. Power and inequality issues are inherent in all development, and it is relevant to consider impacts on different groups and rural-urban relations. This concept of the role the total social environment plays holds equally true for energy systems; supporting sustainable consumer choices requires that the 'energy environment' makes the most sustainable choices the default choices through the way these are incentivised, made available and presented.

The opinion on 'Adaptation to health effects of climate change in Europe' discussed the increased need for cooling in a warming world. With regard to building infrastructure and housing standards, key considerations include e.g. combining insulation and ventilation control improvements to increase efficiency of heating and cooling systems, changes in building design (orientation, layout, passive systems such as natural ventilation and cooling, thermal mass, external shutters) with the resulting reduction in energy consumption and a reduced need for the availability and use of air conditioning. There will be a need for upfront investments to make buildings net-zero, using e.g. heat pumps and district heating and cooling.

The opinion on 'Novel carbon capture and utilisation technologies' (GCSA, 2018) recommends to develop a methodology to calculate the climate mitigation potential of these technologies, and to define eligibility criteria for funding technological projects i.e. required energy needs to have a low-carbon origin and to develop a European regulatory and investment framework for the application of these technologies. This advice on criteria are also relevant more broadly in relation to a need for a coordinated combination of measures, including regulatory and investments.

The scientific opinion on 'Food from the oceans' (GCSA, 2017) similarly discusses the importance of viewing systems such as food from ocean and land in an integrated way, also in relation to the array of policy areas that these relate to, such as energy. The opinion amongst other discusses how mariculture can contribute to sustainability objectives through the production of food or biomass. The Opinion also states that increasing use of oceans for off-shore wind energy, transport of fuel, and potentially the production of energy from algae and other renewable sources means that for instance marine spatial planning and mariculture need to be included in a concerted policy framework.

Box 1 – Decarbonisation and the building sector

An important example of interconnection of the energy system with other sectors is building and urban and spatial planning. The building sector is crucial for achieving the EU's energy and environmental goals. Collectively, buildings in the EU are responsible for 40 % of our energy consumption and 36 % of GHG emissions, which mainly stem from construction, usage, renovation and demolition[14]. Roughly 75 % of the European building stock is energy inefficient. Renovating existing buildings could reduce the EU's total energy consumption by 5-6 % and lower carbon dioxide emissions by about 5 %. At the same time, better and more energy efficient buildings improve the quality of citizens' life while bringing additional benefits to the economy and the society.

In a delocalised energy system there is a large scope for efficient integration of different energy technologies at the local or building level, considering buildings and building blocks as complete systems, fully sustainable for their entire lifetime (construction, operation, and dismantling). Building regulations can however be a challenge, for example for the construction of off-grid autonomous climate-neutral buildings (Mikkonen et al., 2020). Therefore building regulations should be examined not only in the light of energy efficiency, but also in function of the needs for a circular economy, possible independence from procured energy, the possibility for building to become net energy producers, and in the light of developing social models for habitats. Although progress has been made in implementing the provisions of the Energy Efficiency of Buildings Directive, meeting the requirements, for example for public buildings, may be challenging and increased efforts are therefore needed to step up progress in and monitoring of the improvement of energy efficiency (Zangheri et al. 2019). As an example, if the extensive energy-efficiency renovations of existing buildings (Zangheri et al., 2020) were combined with retrofitting to protect them from seismic and extreme weather events, the overall payback period would be substantially reduced (Pohoryles et al., 2020). Another important synergy is the fact that reducing the electricity demand would have a greater benefit in terms of saving expected capital costs in grid reinforcement/expansion (Grubler et al., 2018). Beyond buildings, cities and urban planning are important and powerful levers for the energy transition. Asarpota and Nadin (2020) state that "The spatial and urban form of cities is a key factor in achieving more efficient energy production and consumption and becomes more important with rapid urbanisation across much of the world." An evaluation of the spatial planning systems of 32 European countries found that only about a quarter of the countries were found to have integration between energy policy and spatial planning policy at the local government level (Nadin et al. 2018).

[14] in_focus_energy_efficiency_in_buildings_en.pdf (europa.eu)

1.4.3. The energy system and energy technologies as part of society

As detailed in the preceding subsections, much previous work by the GCSA and SAPEA illustrates the interlinkage of sectors with energy, and the fact that energy and other systems must be seen as part of society. The energy system is complex, with many different actors, supply and demand, social, cultural, technological, economical, and industrial aspects and covers different scales, from the individual to the supra-governmental. Furthermore, it is deeply interlinked with policy areas like food, mobility, security, justice, trade and agriculture. For example, competition for freshwater (Magagna et al., 2019) and land use (two resources that could become scarcer due to the effects of climate change)[15] with the agriculture sector could put pressure on both food and energy production (GCSA, 2020a); on the other hand, phasing out fossil energy sources would decrease air pollution and reduce critical import dependencies, two important benefits for many sectors.

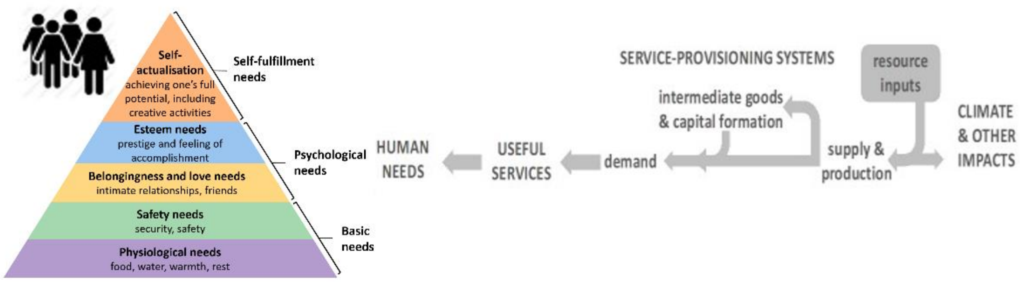

Figure 4: Transforming the provision of energy and other services to order to satisfy all human needs and improve well-being with fewer resource inputs. Human needs are illustrated with a pyramid based on Maslow where the base constitutes physiological needs such as food, water, warmth, rest. Building on these basic needs, are safety and security, on top of that are belongingness and love needs, building on these foundations are esteem needs and finally on top self-actualisation. To fulfil these needs sufficient, affordable, and safe resources need to be transformed with ever increasing efficiencies while reducing adverse impacts on environment (e.g. air pollution and planetary boundaries) illustrated in the flow diagram. Source: Adapted from Figure 14 in TWI2050 (2020).

The reliable estimation of the net benefits of decarbonisation is therefore difficult, and the attribution of costs and benefits to different groups of actors or to different regions and economies may be even more cumbersome (SAPEA 2021 4.1). However it is clear that there are countries, regions, companies and individuals that risk to lose out on the energy transition if no additional measures are taken. For example, the decommissioning of the coal industry will have an impact on labour, and will require

[15] https://www.ipcc.ch/srccl/

retraining of people affected (Vona 2019). Additionally, about 40 million people in Europe live in energy poverty. In 2019 6.9 % of Europeans stated that they did not have enough resources to heat their homes adequately[16]. This percentage varies from 1.8 % in Finland to 30.1 % in Bulgaria, showing also the large differences between countries. It is thus important to consider both the ways in which attribution of costs and benefits is made, and ways to compensate these as well as incentivise and support an integration of energy considerations. Many of these issues have to do with development and implementation of economic instruments, but many also have to do with integration of energy considerations in areas where an energy focus may not have been highlighted.

Thus energy governance can be defined more broadly, as not merely policy choices about energy technologies but also the processes and institutional arrangements through which policy choices are informed, made, and implemented (Miller et al., 2015). Governments (and the EU) play an important role, but the governance of an energy transition implies crossings between state and society. Supporting autonomy amongst local actors may enable them to react to varying conditions. Empowering local actors by dispersing political power across multiple levels may also enable local actors to draw on different governance levels, and thereby counterbalance and compensate for inaction or ignorance by one level by referring to another one (Ehnert el al., 2018).

In this light, technological constituents of the Energy System both cover a very broad field and require interlinkage with and understanding of the environment into which they are placed. The technologies involve energy generation or capture of energy, energy transmission, conversion, storage, and use. Digitalisation is important in one way or another for all these aspects. Some technologies needed to decarbonise the world are already operational, some are being developed and others are emerging on the horizon.

As the technologies of the energy system evolve, and as economic, social and political aspects are inherent to their design and use, it is perhaps not surprising that, also within the scientific community, there is considerable debate about whether specific technologies are important for pathways to decarbonisation (such as the use of hydrogen and of nuclear energy, SAPEA 2021). The 3rd Report prepared by The World in 2050 initiative, 'Innovations for sustainability pathways to an efficient and sufficient post-pandemic future' (TWI2050, 2020), examines science-based strategies and pathways toward achieving the SDGs, raising the key question whether the direction and purpose of innovations can be 'socially steered' toward a sustainable future for all. It describes invention as a systemic phenomenon that involves many people in a network in which all components, such as technology, society, institutions and culture work interactively and holistically bring about widespread transformative change:

> "Every technological innovation stands on a pyramid of previously available technologies and any future innovations are derived from presently available technologies. Innovations happen through combinations of existing

[16] https://ec.europa.eu/eurostat/en/web/products-eurostat-news/-/ddn-20210106-1

> technologies. They serve opportunity niches based on human needs and come with accompanying needs for infrastructure, skills, and processes. This is a continuous problem-solution circle that is flexible and ever-changing. Innovations, once they have successfully diffused, can lead to domino like collapses of the old for new technologies and industries."

Strengthening the cooperation and knowledge transfer between publicly funded institutions and the private sector may thus play a key role. The EU can support technical and digital innovation for instance by strengthening public-private partnerships to make technology transfer more effective and time-to-market shorter, and supporting the development of sustainable financing and investment systems.

There are also existing initiatives that support energy innovation (such as the intergovernmental Mission Innovation programme discussed above). Some of the challenges faced by such a program are to align funded initiatives to the requirements of the energy transition, not to be driven by what is technologically possible, and to effectively integrate national initiatives in a multi-level governance system (Eikeland & Skjaerseth 2021). Still, member countries in Mission Innovation strengthened their energy innovation institutions, increased RD&D activity and contributed to knowledge production around the world. Improved policy alignment, lesson sharing, and evaluation of the experience with international collaboration will improve such future initiatives (Myslikova & Gallagher 2020).

A holistic approach is thus needed to ensure that all potential synergies and sector couplings can be used with maximum possible efficiency across technological options, economic and market instruments and measures, and behavioural changes (IEA, 2021).

Box 2 – On-going scientific and political debate

Several energy challenges are subject of on-going discussion, both in the scientific literature and in public debate. These include the sustainability of nuclear energy, biomass and the widespread use of hydrogen as an energy carrier.

Despite producing roughly one-fourth of the EU's electricity, nuclear fission is an extremely controversial energy source, with some Member States such as Austria, Italy and Germany banning it due to public concern over radioactive waste management and catastrophic accidents. Even in those Member States which rely on nuclear energy extensively, such as France, the replacement of the ageing power plant fleet is slowing down due to cost uncertainty and different political priorities (SAPEA 2021, 6.2). On the other hand, the International Energy Agency considers nuclear as part of the global strategy to reach the Paris Agreement targets (IEA, 2021), and the European Commission's Joint Research Centre "did not reveal any science-based evidence that nuclear energy does more harm to human health or to the environment than other electricity production technologies already included in the Taxonomy as activities supporting climate change mitigation" (JRC, 2021). Some hope that the emergence of a new generation of small modular reactors, for example for large-scale local heat and electricity cogeneration, could be a turning point, as well as the possible advent of nuclear fusion in the long term (SAPEA 2021, 6.2).

Bioenergy is at present the only renewable source with the potential to directly replace fossil fuels in all energy sectors[17] and is therefore a promising option for applications, such as long-haul transport or heavy industry, for which electrification could be problematic to implement. Biomass can also act as a carbon sink, and the importance of the latter in curbing emissions will increase as we get closer to net-zero. Sustainable biomass in conjunction with carbon capture and storage is one of the few available options to achieve net-negative emissions, in addition to nature-based solutions like afforestation and land restoration; net-negative emissions might be needed in the long run if net-zero is not achieved globally by mid-century. However, the sustainability of expanding the biomass based on monocultures and intensive land use (such as agriculture and forestry in some cases) is heavily debated, and there is fear that such practices could make valuable land and freshwater resources unavailable for food production and biodiversity protection. Although a shift in bioenergy production away from the use of food crops and towards sustainably managed forestry plantations is envisaged, most notably by the EU Biodiversity Strategy for 2030 (COM 2020/380), critics argue that limiting bioenergy production to organic municipal waste and agriculture and forest by-products is the only way to avoid land-use conflicts and other negative impacts

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[17] https://www.iea.org/articles/what-does-net-zero-emissions-by-2050-mean-for-bioenergy-and-land-use

(SAPEA 2021, 6.2). Recent literature points to clear sustainability issues of cutting trees for biofuels.

Blue (from natural gas with CO_2 capture storage) and green (produced by splitting water using zero-carbon energy sources) hydrogen is another viable option to decarbonise hard-to-electrify sectors; it could also be used to store the excess production of variable renewable energy and to guarantee a stock of strategic fuel reserves (nuclear power can be linked to large-scale hydrogen production). Nevertheless, future hydrogen production (Moya, 2020) could require either a significant amount of carbon-free electricity (which would make it the sector with the largest power consumption), or a significant amount of natural gas (requiring carbon capture and storage to curb emissions). Great quantities of hydrogen are already needed in the chemical industries, and its use in innovative production processes for the steel sector is seen as the most effective way to decarbonise the latter (Somers 2020, JRC119415). On the other hand, despite the potential benefit of using the existing gas infrastructure, hydrogen is not considered a viable way of decarbonising the heating and cooling sector because of its lower efficiency with respect to competing technologies such as heat pumps.

2. RECOMMENDATIONS

Recommendation 0:

Design EU energy policy clearly aimed towards achieving climate neutrality and sustainability, without leaving anyone behind.

Use a holistic approach to maximise synergies and avoid trade-offs and barriers across technologies, regulatory and market measures, and social and behavioural changes.

The transformation of the energy system towards achieving the goals of sustainable development including net-zero emissions involves a myriad of different actors, whose choices and decisions will eventually shape the transition and be crucial for its success, and will be based on many different technologies, some of which are probably at a very early stage of development today. At the same time, this transformation is only one of the required goals to reach the main aim of the Green Deal and Fit for 55, namely EU carbon neutrality in 2050; for example, a recent study estimated that food systems are responsible for one-third of global anthropogenic GHG emissions (Crippa et al. 2021). In this sense, the EU energy policy should not focus only on achieving full decarbonisation (in terms of fossil carbon) of the energy system (a formidable task itself), but to do so in a way that also catalyses other sectors (e.g. agriculture, industry, …) to reach their own sustainable development targets.

Keeping an eye on the 'big picture' should also ensure that competition for resources (including land use) between different sectors is kept at a minimum. Renewable energy technologies such as wind and solar require raw materials (such as rare earths, cobalt and borates) which are also crucial for the e-mobility, digital and defence sectors. Facilitating the reuse of waste heat and agricultural residues, promoting 'recycling by design' and exploiting urban mining would pave the way towards a more circular economy; in turn, this would guarantee that the resources needed for the energy systems are available, and that their use does not impact negatively on the sustainable development goals. In this sense, a switch from the 'energy efficiency first' principle to a more general evaluation of the resource (and cost) efficiency to maximise impact could lead to a better overall system optimisation.

The EU energy systems are also influenced by (and have an impact on) global developments, and cannot be seen separately from transition implications and opportunities related to economic, environmental and social impacts including those outside of EU; some of these may significantly offset benefits within Europe. Security-of-supply, autonomy, and related recycling and circular economy shifts remain key issues as we change from fossil fuels to reliance on other materials. It is essential to manage the global nature of the energy transition, for example to develop sustainable financing and investment structures, ensure that EU raw material imports are truly beneficial for low income countries (and help achieving SDGs such as zero hunger and education for all) and to avoid that companies which benefit from European support for clean energy for its operations in Europe at the same time retain or outsource unsustainable activities and fossil-fuel assets outside the EU (Bos and Gupta 2019).

The complexity of the problem implies a multiplicity of possible solutions, so wide-ranging policies that encourage diversity and flexibility should be preferred, while the long-term goals of the European Green Deal and SDGs are kept as the main focus (SAPEA 2021, 7.5).

Recommendation 1:

Develop flexible, efficient, and resilient EU energy systems for delivering clean, accessible, and affordable energy services by integrating decarbonised energy sources, electrification and the use of green and blue hydrogen.

The European energy systems are very heterogeneous and each Member State has its own peculiarities, energy structure and lock-ins. Past experiences in the Member States shows that those with good access to energy storage capacity (e.g. hydropower reservoirs) have been able to effectively handle high shares of weather-dependent variable renewable electricity (VRE) and thus pursue a faster track in decarbonising their energy systems, whereas other countries are struggling to reach carbon targets. On one hand, a solution to this problem could be to potentiate the power transmission capacity between EU countries and to further integrate the electricity systems, thereby achieving more flexibility to increase shares of intermittent and decentralised sources and mitigate variability problems. On the other hand, interconnection can also be a source of potential vulnerabilities (as an example, similar adverse weather conditions could raise energy demand at the same time in several neighbouring zones, putting the overall supply into stress). This implies that regional and sub-regional energy production and distribution should be enabled to meet the local energy sufficiency needs even as electrification progresses.

While increasing the demand for energy services, digitalisation and smart systems may facilitate decentralisation and increase consumer participation and public engagement as well as the involvement of all governance levels (from household, municipality, region, and country to international level) concerned in the transition. The integration of various energy carriers – e.g. electricity, hydrogen, and heat – with each other and with the end-use sectors, such as buildings, transport or industry may be needed to support optimisation of the energy sector as a whole.

1.1 Develop energy systems that are flexible in terms of pathways, different technologies, and scales of implementation.

An integrated EU-wide energy system needs to be able to harbour different mixes of energy production in different countries and regions, and ensure that energy production and distribution meet the user demands to the extent possible.

Storage of energy is important to provide flexibility in variable conditions of energy production and use. Storage can be achieved in multiple ways, e.g. through hydro power reservoirs, the production and storage of hydrogen or in batteries (e.g. through vehicle to grid services). Particularly, the further development of demand-side storage as well as energy production at locality and increased efficiency (solar production, source heat pumps, fuel cells, extending and implementing requirements for building improvements and other innovations) can contribute considerably to the reduction of needs for centralised storage and for energy transmission.

Keeping the energy system flexible is also important in order to manage uncertainty in terms of future technological, economic and societal developments. This means that potential lock-ins should be identified and avoided. For example investments for the use of gaseous fuels need to be made now, but it is difficult to predict which fuels will dominate in 2050. Thus networks of gas pipes may well be needed also in the future, and their decommissioning now could block future development, or lead to large additional costs.

We recommend that the integrated EU energy system should be directional on sustainability, but flexible, in term of pathways, different technologies and scale of implementation. It should allow for both decentralised and centralised production of energy, thus enhancing its resilience and diversity of supply, remain flexible with respect to the (larger scale) introduction of new technologies, and ensure implementation of standards. This entails also supporting different options for energy carriers, like electricity and hydrogen, and for energy storage. It implies that efficiency may sometimes be less important than the ability to store or transfer energy, and that a relatively non-efficient technology might still be interesting if it allows energy to be stored that would otherwise be lost. For example the advantages of the storage capacity of hydrogen may outweigh the disadvantages of its relatively low efficiency as for the conversion of electricity from over-generation of electricity from variable renewable sources such as wind and solar.

1.2 Support investments in integration of infrastructures and general-purpose technologies, including energy generation, transmission, storage, and end-use systems.

Investments for the stability of the electricity grid and additional cross-border electricity transmission are needed to be able to integrate electricity from different renewable sources, at different scales. It requires an enhanced capacity to absorb large and distant sources of intermittent renewables. Investment in additional cross-border electricity transmission networks will reduce the need for national and regional infrastructures for managing peaks in electricity production and use. This will complement strategies and incentives to avoid demand peaks. The need for short-term investments should be balanced with the long-term requirements of industrial investment cycle.

The linking of the energy infrastructures of European countries is supported at EU level by the Trans-European Networks for Energy (TEN-E) policy, currently under revision, which deals with the transmission of electricity, gas, and oil. It is foreseen that the revised policy will further promote the integration of renewables and clean energy technologies through smart grid deployment. It should further connect remote regions and strengthen possibilities for existing cross-border interconnections, electricity highways, pipelines for gases from renewable sources, including hydrogen, and the potential for power transmission also from local/household units (such as solar sold back into the grid).

1.3 Support European research and innovation as a world leader in new technologies and smart systems.

Technologies play a key role in the energy transition. Thus technological research and innovation are critical for delivering solutions for system transformations, increasing the efficiency and integrating sustainability and circularity. The landscape of technologies is not static. The field is developing as science, technology, economics and social views are changing. Changes include for example the steep decrease in price for solar panels, a possible decrease in price for the production of fuel cells, first steps in the development of technologies to produce hydrogen directly with solar panels, reversible fuel cells and range from short-terms innovations to long-term projects like nuclear fusion. Any strategy that supports technical and digital innovation must allow for both incremental and for radical change.

Digitalisation, including the Internet of Things, advanced data processing, machine learning, artificial intelligence, etc. offer major possibilities to improve efficiency and manage complexity in energy systems (SAPEA 2021 5.1.5). Shared economy approaches and digitalisation could make it possible to have a fleet of autonomous, self-driving electric (or hydrogen) vehicles functioning like a mode of public transport, rather than as individually owned cars. Smartphones and apps opened a wide range of possibilities to reduce the carbon footprint (Wilson, 2020), most notably dematerialising appliances which have become redundant (Figure 5). Other areas where research and development could contribute to the digital transition are including 3d printing, deep learning, and recycling by design.

The European Commission has a long track record of supporting research and development of renewable energy technologies and energy efficiency solutions, providing a comparative advantage for European businesses. While in recent framework programmes energy research had a more modest share of funding, and a large share going to research on fusion, in Horizon Europe and under the Green Deal the ambition should be further increased.

Technological innovation involves huge investment in new energy technologies and systems, both by end users and by the energy industry. The ability to decide to invest now or in the near future depends on the firm commitment to achieve the 2030 and 2050 goals, and to a clear carbon pricing system (see recommendation 3) that can drive the system. Finally, societal evolution will not stop in 2050, and there is also a need for research on long-term visions. The EU should therefore provide direct funding in highly important emerging research fields associated to the energy transition.

Figure 5: A smartphone can replace numerous devices. The rapid progress of information and telecommunication technologies could be an indication of the path-breaking potential of next-generation digital technologies and their clustering in new activities and associated behaviours. A smartphone needs between 2.5 Watts in standby to some 5 Watts when in use, while the numerous devices that it can replace (portrayed in the Figure) need up to almost hundred times more power and almost thirty times more standby energy needs. There is about a factor 25 reduction of embedded energy required to produce the devices and a proportional reduction in emissions. Bundling of services from various devices in the smartphone can be regarded as an example of the power of digitalisation toward decarbonisation and energy efficiencies and its huge potential to increase resource efficiencies through new technologies and behaviours. Source: Adapted from Figure 2 in Grubler et al. (2018) based on Bento (2016) and visualisation of Tupy (2012).

Recommendation 2:

Recognise the roles of all actors and stakeholders in creating an inclusive and participatory environment that incentivises and supports low-carbon energy choices.

The energy system is not only technological in nature, but also social in its organisation and is an integral part of society. It is woven into societal, geographic, and geopolitical arrangements at scales from the individual and household to local, regional, national and international levels. The energy transition requires new approaches to energy policy and governance that can more effectively integrate the human and social dimensions of energy systems into energy analyses and choices, putting people central. People are fully part of the energy systems, and the social values, behaviours, relationships, networks, and institutions fashioned around the use of diverse kinds of energy should be part of the thinking.

Household consumption causes a considerable part of global emissions, and changes in practices (using higher-efficiency appliances, driving green cars, etc.) could significantly reduce this share. But choices are heavily shaped by what could be called an ‘energy environment’, the collective physical, economic, policy and sociocultural surroundings, opportunities and conditions that influence people’s energy choices in their multiple roles (e.g. as consumer, producers, or members of a community). The EU should inclusively involve city and town levels and the public as active participants in the fight against climate change, supporting informed choices and rewarding the avoidance of carbon-intensive activities. Understanding the cultural and social drivers of change in different contexts, supporting local energy generation and efficiency, and using policy interventions and standards development to eliminate the barriers against it are necessary steps towards this goal.

2.1 Incentivise energy efficiency and reduce of energy use while ensuring sufficient services for all.

Energy efficiency means using less energy to perform the same function whereas energy saving (or conservation) is any behaviour that results in the use of less energy (SAPEA 2021 section 5.1.1). Reducing energy use is mainly achieved through actions at regional, local, sector, company and household/individual level. Increased energy efficiency is mainly achieved through technological developments and structural changes, including for example sector-coupling of electricity (e.g. to heating/ cooling or transport) and increasing energy efficiency in buildings (building methods, insulation, heat pumps or other technologies). Energy savings are achieved by actors that make different choices or behave differently, and thus also by an environment that enables and supports these energy-saving choices. Such an environment can also minimise a rebound effect, where increased efficiency leading to a lower cost of use of e.g. a car, or household appliances, leads to an increased use (SAPEA 2021 5.1.4). However, if lower costs means that households in energy poverty can better meet their energy needs, rebound should not necessarily be avoided at all costs. A more circular economy will contribute to lowering energy demand, but may be even more important for the re-use of raw materials needed for e.g. batteries.

With the increased ambition of the European Green Deal there is a need to significantly step up efforts in energy efficiency, savings, and sufficiency. This will most likely require strong policy measures in diverse areas like digitalisation, food production, diet, urban planning (reducing heat islands), and building.

As heating and cooling constitute a large part of residential energy needs, the EU needs to support programs aiming at energy-efficient building renovation (see Box 1). The EU also needs to extend such initiatives to urban and spatial planning. While spatial or urban planning is primarily the province of local government and planning authorities, the EU can influence spatial planning through existing sectoral competencies and activities that influence spatial planning indirectly. These include parts of the EU legislation, incentives as e.g. EU funding and the agenda and discourse setting by European institutions (Gaugitsch et al., 2018). The EU can finance pilot projects, stimulate cross-learning and uptake of innovative approaches in urban planning and building architecture, in training and education, and supporting standards development and enforcement towards new energy goals. For instance, the New European Bauhaus initiative could specifically take up also the energy dimension of urban planning.

Other examples are the provision of information or the necessary infrastructure, for example by expanding local public transport. In developing targeted policies to steer energy demand and use to support sufficiency, the actual usefulness of the application should be taken into consideration).

Finally, as the cost of modifying current behaviours and adapting existing equipment for heating or mobility purposes is likely to be unevenly distributed, policy approaches should focus on transferring costs from sustainable choices to unsustainable ones (SAPEA 2021 Section 3.9), e.g. by properly earmarking the revenues from a carbon tax or tradable permits.

2.2 Support direct participation and innovation among all actors and stakeholders from the public and private sectors to individuals and households, at local, national, European and international levels.

The EU should recognise the hybrid relationships between people and energy technologies and the multiple roles as users, consumers, protesters, supporters and prosumers (Ryghaug et al. 2018 and references therein). Examples are the co-production of energy in collectives with domestic smart energy technologies or with photovoltaic solar panels, or the integration of photovoltaics, heat pumps and electric vehicles at the household level, where the production of energy at the local level is likely to support active involvement in energy systems (Caramizaru and Uihlein, 2020). Digitalisation is a crucial factor for enabling variety across and within energy systems through more flexible and adaptable integration. The evidence review report (SAPEA 2021 4.1) lists as core elements that are required for a transition that is equitable for individuals, communities and societies: investments in establishing low-emission and labour-intensive technologies and sectors, research and early assessment of the social and employment impacts of climate policies, social dialogue and democratic consultation of social partners and stakeholders, training and skills development for exposed workers, social protection alongside active labour markets policies, and local economic diversification plans.

The EU can support low-carbon choices by providing funding, coordination and information, for example for education and innovation initiatives and pilot actions. In order to achieve the objectives of the Green Deal Europe there will be a need to retrain people, e.g. so technicians can install solar panels, and architects can renovate buildings so as to become climate-neutral. The European Skills agenda aims to provide access to education, training and lifelong learning everywhere in the EU, and build resilience to react to crises. The EU can support learning processes at different levels, through a wide range of policies including the digital strategy, industrial policy, and the recovery plan for Europe.[18]

The EU should also acknowledge that a vast range of social, economic and legal perspectives and inequalities are inherent in energy development and use, and act on them. The role of local-level diversity and concerns as well as justice arguments should be recognised. The energy transition will impact the interlinkage between rural and urban systems, and put stress on cities. Urban energy systems are in many places traditionally built around a centralised production of energy (by fossil fuels) in rural or peri-rural areas. It is crucial that infrastructure and spatial planning facilitate and keep up with the decentralisation of the energy system where useful, ensuring that local production meets the local needs as much as possible (thus reducing the costs for transmission and distribution and increasing the resilience of the system at the granular level). A clear, visible, impact on the local communities could also help to deal positively with local resistance (for example against onshore wind farms: see Lamy et al., 2020), and reduce potential negative dynamics between rural and urban areas (or, areas where energy is mainly produced vs those where it is heavily used).

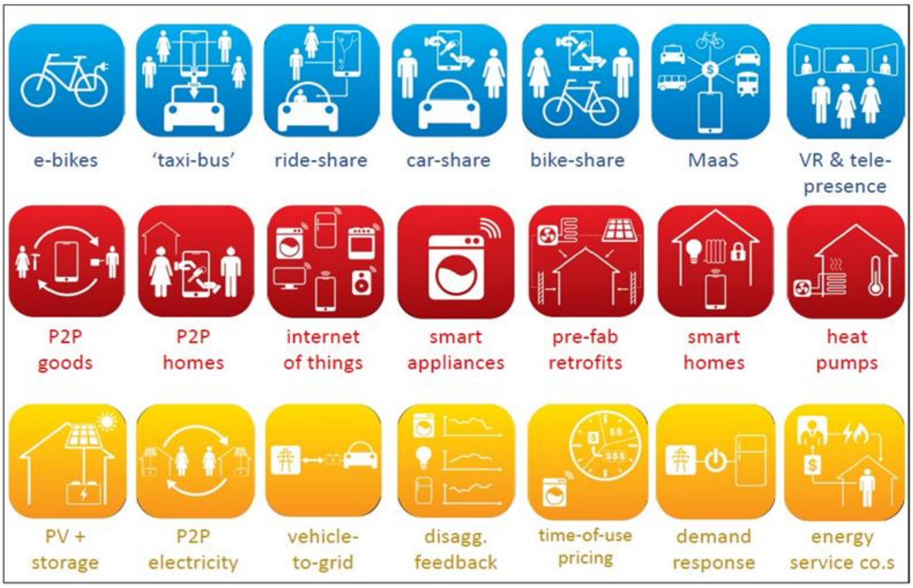

Figure 6: Digitalisation, digitally enabled consumer innovations and behaviours could be a powerful force to drive the energy transitions toward climate neutrality and sustainability. As also shown in Figure 5, they offer energy efficiency improvements, lower material use and emissions, better performance through new services and potentially also appeal for adoption. A shift from ownership to usership is an important characteristic of the innovations shown in blue symbols (except perhaps e-bikes and virtual reality and telepresence) and peer-to-peer goods,

[18] European skills agenda for sustainable, social fairness and resilience (2020) https://ec.europa.eu/social/BlobServlet?docId=22832&langId=en

homes electricity and energy services companies shown in red and yellow. Possible emergence of a shared economy is another characteristic illustrated by some of the same examples like bike, ride and car share and peer-to-peer goods, homes and electricity. More important than the individual examples of possible innovations is their convergence into new systems of provisioning consumer demands and behaviours (Wilson, 2018).

2.3 Redistribute the additional revenue created by energy taxation and carbon pricing to support low-income groups and promote sustainable energy systems.

Demand side technologies may have broad social implications, and this should be recognised while making choices on a wide range of policies including for research and infrastructure development. Certain groups of people, regions, or sector will bear a higher cost, particularly for those already living in energy poverty. This aspect should be taken into consideration from the beginning when developing strategies and the efficiency of compensation measures should be continuously monitored.

Without a compensation mechanism, energy taxation, bans on high emission cars, carbon pricing and other measures will have a regressive effect, with low-income households finding the transition to a low-carbon economy more burdensome, relative to their disposable income (SAPEA 2021 3.4). The SAPEA report states "One simply cannot escape the fact that virtually all policy measures entail distributional consequences". Policymakers should make sure that the additional revenue created by energy taxation and carbon pricing is redistributed in a way that targets low-income households as directly as possible, for example through social schemes like means-tested renovation subsidies that can reduce the energy poverty among the vulnerable populations while contributing to the emission reduction efforts. The currently ongoing revision of the Energy Taxation Directive could go in this direction. Striving for economic efficiency in these measures, i.e. focusing on those with the lowest societal cost and the highest impact, could provide the best overall outcome.

Recommendation 3:

Support a coordinated combination of policies, measures and instruments, including carbon pricing as a driving force, to shape an effective, consistent and just regulatory system.

Reaching the ambitious targets for the reduction of GHGs emissions requires the transformation of the whole energy system. Next to a clear sense of direction (e.g., through roadmaps and pathways) there is a need for decisive regulatory action to provide the appropriate incentives for investment decisions and consumption choices to shift in the direction of a carbon-neutral economy.

Combining carbon market pricing with measures such as efficiency and production standards, bans and subsidies can combine the virtues of both principal approaches, if carefully designed (SAPEA 2021 7.1).

Carbon pricing as has several advantages, not least that a well-functioning system, the European Emissions Trading System (EU-ETS), already exists for the energy and industry sectors. The most direct action in this sense would be to extend the EU-ETS to all other relevant emission sectors, *in primis* to mobility and heating. Carbon pricing is technologically neutral by design and, in terms of communication, it would be transparently reflecting the social costs of climate damages.

3.1 Use a coordinated combination of regulatory measures and incentives to drive the European energy transition.

Regulatory measures can include performance and technical standards, carbon pricing, incentives like adoption subsidies, innovation support, and information provision. Combinations should be carefully evaluated in terms of positive and negative synergies, (Van den Bergh et al. 2021), also in function of their order of implementation (Pahle et al. 2018).

Standardisation and certification are powerful and strategic tools for improving the efficiency of European policies. The Commission pays special attention to standardisation because standards can influence most areas of public concern. Generally standardisation should focus not only on interoperability and trade enhancement, but also on support to sustainability and energy policies. Thus one of the key instrument that can be used at EU policy on energy is the setting of standards for emissions and energy efficiency that are rooted in real performance rather than on idealised tests that today is still often the case. This requires the development of harmonised methods for e.g. assessing footprinting for carbon, methane and nuclear waste, as well as the availability of data that can be used for carbon border adjustment schemes.

The EU sets vehicle emission standards for exhaust emissions of new vehicles, defined in a series of EU directives. Euro 7, the final standard, is set to be announced in 2021 and enforced in 2025. The past has shown that it is important that such standards set realistic conditions for the measurement of emissions, and that these emissions are measured accurately in accordance to the vehicle uses on the road rather than in the lab.

There are indications that efficiency standards could lead to a rebound effect, if individuals or companies would increase their consumption if efficiency standards reduce the cost of this consumption (SAPEA 2021 5.1.4). This means that the long-term effect of efficiency standards can be lower than anticipated, and global energy scenarios could overestimate the impact of standards. Possible rebound effects should be tackled at multiple levels including with the price of carbon and should be taken into consideration when evaluating trade-offs between economic growth and ecological sustainability.

3.2 Make a clear political commitment and undertake supporting actions to steadily move towards very high carbon (and other greenhouse gas) prices to cover all social and environmental costs.

Making carbon pricing a central driving force of the energy transition gives a clear sense of direction. Firm long-term commitments provide security for short-term investment decisions that will enable the energy transition on the long term.

Carbon pricing as a crucial element of a combination of policy measures would have the following implications: overall emissions reduction would become the principal objective; market prices would reveal the cost of avoiding emissions for different actors and in different sectors and, hence, gather information; carbon pricing would lead to additional public revenue; carbon pricing would provide a means to prevent carbon leakage, since a carbon border adjustment mechanism could be based directly on observed prices, and in principle carbon pricing would preserve the principle of technology neutrality, since policy makers would not decide on the technologies employed to reach carbon neutrality (SAPEA 2021 7.2).

It should be noted that carbon pricing should cover the entire life-cycle of products, from the mining of rare metals and iron needed, production of steel and plastic materials, batteries, etc., putting the product together, marketing, and consumption of electric energy for operation, to final dealing with waste.

Carbon pricing does however require the political will to accept very high carbon prices by mid-century, since the difficulty of emission reductions will increase when approaching carbon neutrality. Making the connection between stipulating a carbon price and engaging into compensatory payments is likely to enhance acceptance for climate policy (see recommendation 2.3). In doing so, policymakers should find the appropriate combination of revenue recycling schemes, industrial and retraining policies as well as compensation packages to increase the support for such policies (Vona, 2019). The SAPEA ERR (SAPEA 2021 Section 3.9) evaluates different approaches for compensations, such as per-capita lump sum transfer, reduction of indirect taxes, increase of social transfers and reduction of direct taxes or social security contributions.

The EU Emission Trading System (EU-ETS) is a cornerstone of the EU's policy to combat climate change. It is the world's major carbon market. A total number of carbon allowances is available, and these can be traded between actors, within a margin limited by gradually and predictably declining cap (toward zero by mid-century) set for different installations. The effectiveness of the EU-ETS system would be enhanced by extending it to all sectors and activities from all forms of mobility and heating to cooling (SAPEA 2021 7.1). It would be even more effective and would support circular economy should the life-cycle emissions be included in the system.

3.3 Insist on reciprocal climate commitments by other countries to form 'decarbonisation clubs' and introduce a World Trade Organization-compatible border adjustment mechanism for carbon.

Whereas it is important for the EU to ensure that carbon pricing increases, it must be stressed that since by itself the EU only generates about 10 % of the global carbon emissions, it cannot mitigate climate change by acting alone. Also, in the past a significant fraction of reductions of carbon emissions in the EU were realised thanks to carbon leakage, by increasing imports of carbon-intensive commodities produced in China (industrial and electronic goods), Brazil (soybean, beef), South Asia (textiles) and other countries. It is essential that European decarbonisation not be replaced by such dependency on carbon-intensive imports. This implies the need for an appropriate carbon border adjustment mechanism (C-BAM).

Instead, by showing that it is possible to reach its highly ambitious emission reduction targets without harming its economic competitiveness (but also without offshoring carbon-intensive production) and without creating or worsening social imbalances, the EU would be in a good position to incentivise other economies and act as a driver of coordinated action. In this sense, whereas developed countries should pursue stricter targets than less developed ones in the Paris Agreement, the EU should insist on reciprocal commitments by other countries and in particular be wary of unilaterally over-achieving these targets, as research suggests that such a strategy would be ineffective. With recent developments on the international front there may however be a real opportunity to form alliances, and create a 'decarbonisation club'.

In the long term, the ambition should be to introduce a uniform carbon price at the global scale. A carbon border adjustment mechanism can be employed to prevent carbon leakage, but such barriers should be avoided wherever possible since Europe strongly benefits from international trade. International partners should be convinced of implementing climate policies analogous to the EU ETS – and if possible linked to it. A 'decarbonisation club' could have joint carbon border adjustment for non-members. Support programs for developing countries should also accompany the implementation of a carbon pricing scheme.

However as long as there are large differences in climate policies internationally attention should be paid to (SAPEA 2021 7.3):

- strengthening diplomatic efforts toward commitments to the Paris Agreement goal;
- The prevention of carbon leakage (e.g. imports of carbon-intensive commodities produced abroad) and the conservation of the competiveness of the European industry through a carbon border adjustment mechanism that is WTO compatible;
- Supporting the energy transformation in low-income countries.

Annex 1 – Methodology

The Group of Chief Scientific Advisors (GCSA) provides independent scientific advice to the European Commission to inform policy making. The advisors work closely with the Scientific Advice for Policy by European Academies (SAPEA) consortium, which gathers expertise in engineering, humanities, medicine and natural and social sciences from over 100 academies and societies across Europe. Together with a secretariat in the Commission's research and innovation department, the advisors and SAPEA constitute collectively the Scientific Advice Mechanism (SAM).

In this context, the GCSA has been asked to provide a scientific opinion on a systemic approach to the energy transition in Europe. The background to this request and the specific question to be answered by the advisors is laid down in the 'Scoping Paper' (Annex 2). The recommendations presented here by the GCSA build upon the Evidence Review Report (ERR, SAPEA 2021) developed by SAPEA, additional literature, and expert and stakeholder consultation (see Annex 3).

The scoping of the question included a (grey) literature search and was aided by consultations with scientific experts and expert practitioners, a limited web search and a scoping workshop. On this basis a Scoping Paper (Annex 2) was prepared, in consultation with Directorates-General responsible for energy policy, setting out the request for advice. The scientific advisors agreed to take up the work as detailed in the Scoping Paper (March 2020). Nebojsa Nakicenovic (from November 2020), Elvira Fortunato (until November 2020), Carina Keskitalo and Rolf Heuer led the development of the scientific opinion on behalf of the GCSA.

The scientific advisors were aided by SAPEA[19] which supplied the supporting evidence underpinning the scientific opinion. For this, it formed an expert Working Group that gathered and synthesised the scientific evidence, including expert knowledge, in the form of a peer-reviewed Evidence Review Report. Evidence from the SAPEA Evidence Review Report and further academic and 'grey' literature was supplemented with expert elicitation, covering academic experts, policy experts and expert practitioners (see Annex 3). SAPEA also organised an expert workshop with independent scientific experts.

The SAM Secretariat helped the Scientific Advisors in organising a discussion with policy experts of the European Commission on the scientific evidence and policy relevance and an expert 'sounding board meeting' on the draft scientific opinion.

Finally, the SAM Secretariat aided the Scientific Advisors in organising a stakeholder meeting, where the preliminary outputs of the SAPEA Evidence Review Report and the areas under consideration for the scientific opinion were presented by the SAPEA Working Group members and the Scientific Advisors, respectively.

[19] https://www.sapea.info/

This scientific opinion was thus informed by various sources of evidence, notably:

1. Scoping paper 'A systemic approach to the energy transition in Europe' (SAM, 2020)
2. Scoping workshop in a foresight format 'A systemic approach to the energy transition in Europe' (SAM, 2019)
3. Review of the scientific literature by SAPEA – (SAPEA, 2021)
4. SAPEA Expert workshop – January 2021;
5. Sounding Board Meeting – April 2021
6. Stakeholders Meeting – May 2021

Meeting reports or summarising notes are published online.

ANNEX 2 – SCOPING PAPER

Group of Chief Scientific Advisors

Scoping paper:

A systemic approach to the energy transition in Europe

18 March 2020

1. Issues at stake

The European Union has set ambitious climate targets and the need to decarbonise the economy is a primary political objective. The European Commission has proposed a target of net zero greenhouse gases (GHG) emissions in the EU by 2050. The goal is clear but the pathway to reach net zero emissions is not. It will require a major transition of the European energy system away from the current reliance on unabated fossil fuels towards low carbon or renewable sources of energy.

There are concerns from some that current policies are not sufficient while others fear that they are too expensive and may harm important branches of the economy. Moreover, parts of the European population articulate increasing resistance against new infrastructure, rising prices for energy, and potential or real job losses in certain sectors. Despite efforts at the European or national level to date, the need for the reduction of GHG emissions has grown in urgency and the extrapolation of current efforts indicates that targets will be missed significantly unless additional, more effective measures are taken.

In order to meet the targets, there will need to be a clear understanding of what is known, what is only partially known and what is currently unknown with respect to the European energy system. Although many features of the energy system are based on physical and technical realities, there is currently no decarbonised energy system at the national level. Progress has been made, particularly with some electricity systems, but the feasibility of the complete decarbonisation of society, including heating, mobility and industry has yet to be demonstrated at scale.

Multiple technological solutions will be required to decarbonise the energy supply and end uses of energy including transport and heating. Many of the elements required in terms of technology are well understood. However, how to successfully scale up and integrate these elements is still uncertain. Often, there are inflated claims made for individual technologies and their ability to offer a singular solution to the challenge. It is unlikely any such technology, either existing or in development, can deliver such claims on its own. Thus, there is no 'silver bullet' that will provide the solution and there are many uncertainties regarding the most effective policies. A systemic approach is needed to fully understand the interdependencies and developments in order to provide a robust information-based anticipation of future requirements and possible solutions.

Related to this is the question of how energy availability, in particular power generation, storage, and the mix of primary energy sources and carriers, will vary over time. Understanding this could lead to greater insight into the possible long-term scenarios for the future European energy system in 2050 and to an agreement on the fundamental characteristics of that system. In addition, the increased integration of different sectors and carbon neutral energy carriers will need to be better understood and exploited.

Changes in the extraction and the use of materials resulting from the energy transition will also be important. How to secure availability from global markets of affordable, environmentally friendly and socially acceptable supply of raw materials for the energy transition may become an important issue. This could also enable a move towards a more circular economy or one that has lower environmental impact while still delivering net zero GHG emissions. However, it might also imply 'trade-offs', for instance negative impacts on resource use, biodiversity or pollution.

Rapid developments in the digital world will play a significant role in the future energy system through smart grids, the internet of things, industry 5.0 and digitalisation. While increasing the demand for energy supply this could provide opportunities for greater control at the system level coupled with new and improved services that will facilitate decentralisation and may help increase consumer participation and end-user engagement.

Added to this are the wider factors that will influence the technical elements of the energy transition. Changes to energy markets and business models will be necessary and offer great potential but it is unclear which will be effective and acceptable. Within society, there is a range of companies and citizens from proactive consumers, 'prosumers', who will drive innovation to those who are less active or even hostile to change. Understanding how to engage with all citizens and encourage business participation will therefore be critical.

The range of interdependent issues noted above highlights the need for a systemic approach: this will involve technology, business, citizens and society, Member States and their institutions, local authorities, economic and fiscal mechanisms, legal factors, and geopolitics. It should provide added value beyond any single subject analysis and recommendations that are flexible, adaptable and deliverable.

Concerns over social equity will be central to ensuring the energy transition does not affect certain sections of society unfairly. It will also be important to understand the link between climate action and the Sustainable Development Goals (SDGs) as well as the different stages of technological and societal development across Member States.

Support for and participation in the energy transition by politicians, scientists, experts, citizens, business and other non-governmental organisations will be critical to success. What advice can be offered to make the transition acceptable and manageable for our society and business? This should include: how to build on the current unprecedented levels of public enthusiasm to tackle climate change; how to leverage the engagement of prosumers to impact wider society; and how to communicate the advantages of the energy transition in terms of improved services, cleaner environment and sustainability, and business opportunities.

2. EU policy background

The European Union already has a strong record of policy initiatives reducing its emissions of GHG while maintaining economic growth. In November 2018, the Commission adopted the 'clean planet for all' strategy[1], aiming for a prosperous, modern, competitive and climate-neutral economy by 2050. Emissions in 2018 were 23% lower than in 1990 while the Union's GDP grew by 61% over the same period.

In December 2019, the European Commission presented the European Green Deal[2], an ambitious package of measures designed to deliver a sustainable green transition. The Green Deal Communication sets the path for action in the months and years ahead – a roadmap for making the EU's economy sustainable by turning climate and environmental challenges into opportunities across all policy areas[3] and making the transition just and inclusive for all. The actions will be updated as needs evolve and policy responses are formulated.

The European Climate Law proposal (4 March 2020) aims to establish a legal framework for achieving climate neutrality in 2050. It also tasks the Commission to review existing policies and Union legislation in view of their consistency with the climate-neutrality.

On 10 March 2020, the Commission has adopted an EU industrial strategy to address the challenge of the green and the digital transformation, identifying crucial value chains that need to be developed in the EU. It also focuses on the need to ensure a just transition and considers the need

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52018DC0773
[2] https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
[3] https://ec.europa.eu/info/sites/info/files/commission-proposal-regulation-european-climate-law-march-2020_en.pdf

to equip workers with new skills and help communities dependent on these industries to manage the transition.

Together with the industrial strategy, a new circular economy action plan was adopted in March 2020 to help modernise the EU's economy and draw benefit from the opportunities of the circular economy domestically and globally. A key aim of the new policy framework will be to stimulate the development of lead markets for climate neutral and circular products, in the EU and beyond.

The Commission is also working on building a dynamic repository on data on clean energy technologies and solutions (current and expected status by 2030 and 2050, gaps, value chain analysis per technology, EU clean tech industry on the world map) in order to develop a common basis of understanding across services and feed into the Research and Innovation prioritization in the new context of the Green Deal.

The Commission will present a smart sector integration strategy in Q2 2020, exploring the potential of better linking the electricity, renewable and decarbonised gases, heating and cooling, transport, and industrial and agriculture sectors to reap the synergies and facilitate the timely and cost-effective decarbonisation of the energy system.

In 2021, the Commission will propose a Carbon Border Adjustment Mechanism to reduce the risk of carbon leakage, in full compatibility with the World Trade Organization (WTO) rule and will revise the Energy Taxation Directive aligned with climate objectives and providing a coherent policy framework.

All these packages set the framework for delivering on the European Green Deal, building on an increased emphasis on the need for climate action within the European Institutions. The implementation of these new or revised policies will need to rely on evidence and a clear understanding of the current state of knowledge and will require a systemic understanding of the social, economic and geopolitical issues. There is a desire to do it quickly but right.

3. Request to the EC's Group of Chief Scientific Advisors

In view of the above, an impartial, independent and systemic approach with insight of experts with a multidisciplinary background will be needed to fully understand the interdependencies and developments in order to provide a robust information-based anticipation of future requirements for the energy transition.

In this context, the European Commission's Group of Chief Scientific Advisors is asked to provide by the first quarter of 2021 a scientific opinion on a systemic approach to the energy transition in Europe. As energy transition pathways tend to differ across Member States, the main question to the European Commission's Group of Chief Scientific Advisors is:

> *How can the European Commission contribute to the preparation for, acceleration, and facilitation of the energy transition in Europe given the present state of knowledge on the possible transition pathways?*

Considerations should include constraints from technologies, services, primary energy sources, economics, raw materials availability, preferred pathways, social considerations and environmental boundaries. The scientific opinion will take account of previous work by the national academies through alliances such as the Euro-CASE report *Energy transition in Europe: common goals but different paths*[4].

[4] https://www.euro-case.org/platforms/platform-energy/

ANNEX 3 – LIST OF EXPERTS AND STAKEHOLDERS CONSULTED

Baer	**Christian**	**Europex**	*
Bel	Jean-Benoit	ACR+	*
Bento	Nuno	ISCTE – University Institute of Lisbon	
Bertoldi	Paolo	EC-JRC	
Cherp	Aleh	Central European University	
Collombet-Gourdon	Rémi	Ocean Energy Europe	*
De Coninck	Heleen	Eindhoven University of Technology	
Guerini	Raffaele	European Energy Research Alliance (EERA)	*
Hennig	Eva	Thüga AG	*
Hodne	Tor Eigil	Statnett / Roundtable for Europe's Energy Future (REEF)	*
JACQUES	Philippe	EMIRI	*
Krozser	Anna	EAPN (European Anti-Poverty Network)	*
Neij	Lena	Institute for industrial environmental economies, Lund Unversity	
Novikova	Aleksandra	Institut für Klimaschutz, Energie und Mobilität	
Paterson	Nathan	FORATOM (European Atomic Forum)	*
Petroula	Dora	Climate Action Network Europe	
Polillo	Vanessa	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)	*
Poretti	Fabio	CEWEP (Confederation of European Waste to Energy Plants)	*

Steg	Linda	University of Groningen Faculty of Behavioural and Social Sciences	
Strielkowski	Wadim	Prague Business School	
Van den Bergh	Jeroen	Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona	
Verwimp	Katrien	AIB - Association of Issuing Bodies	*

*Participated only in the stakeholder meeting

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This scientific opinion by the Group of Chief Scientific Advisors examines how the European Commission can contribute to the preparation for, acceleration, and facilitation of the clean energy transition in the EU. The European Green Deal aims to reach net-zero greenhouse gas emissions in Europe by 2050, a necessary step to limit global warming. Achieving this target is possible, but requires urgent and decisive action. The role of energy systems is key in driving progress across virtually all sectors in the transition towards a clean planet for all. Energy policy should therefore be clearly aimed towards achieving climate neutrality and sustainability. EU energy systems should be based on decarbonised energy sources.

The Group recommends to maintain future energy systems flexible in terms of pathways, different technologies, and scales of implementation, and to support European research and innovation as a world leader in new technologies and smart systems. Policy makers should recognise the roles of all actors and stakeholders (from the public and private sectors to individuals and households, at local, national, European and international levels) in creating an inclusive and participatory environment that supports low-carbon energy choices. Finally, the Group recommends supporting a coordinated combination of policies, measures and instruments, including carbon pricing as a driving force, to shape an effective, consistent and just regulatory system.

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