EERA CETP SRIA REPORT: A SUMMARY OF THE STAKEHOLDER ENGAGMENT PROCESS

List of authors:

Manuel Baumann, KIT
Michael M. Belsnes, SINTEF
Marco Ferraro, ITAE CNR
Lorenzo Malerba, CIEMAT
Petter Støa, SINTEF
Asgeir Tomasgard, NTNU
Pieter Vingerhoets, Vito,
Laurens de Vries, TU Delft

Ganna Gladkykh, EERA Secretariat
Adel el Gammal, EERA Secretariat

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List of Acronyms

CAPEX	Capital Expenditure
CCUS	Carbon Capture Utilization and Storage
CET	Clean Energy Transition
CETP	Clean Energy Transition Partnership
CHP	Combined Heat and Power
CSP	Concentrated Solar Power
CST	Concentrated Solar Thermal
DH	District Heating
DHC	District Heating and Cooling

ETIP	European Technology and Innovation Platform
ETS	Emissions Trading System
IRENA	International Renewable Energy Agency
IWG	Implementation Working Group
LCOE	Levelized Cost of Electricity
LCOH	Levelized Cost of Heat
LNG	Liquefied Natural Gas
NZEB	Net Zero Energy Buildings
O&M	Operation, Maintenance and Installation
OPEX	Operating Expenses
PV	Photovoltaic solar energy
PVT	Photovoltaic and Thermal
R&I	Research and Innovation
RHC	Renewable Heating and Cooling
RES	Renewable Energy Sources
SET-Plan	Strategic Energy Technology Plan
SDH	Solar District Heating
SHIP	Solar Heat for Industrial Processes
SRIA	Strategic Research and Innovation Agenda
SRL	Social Readiness Level
ESTTP	The European Solar Thermal Technology Panel
TRL	Technology Readiness Level

I. Introduction

CETP SRIA context

The Clean Energy Transition Partnership (CETP) is one of the Candidates for European Partnerships in climate, energy and mobility under the Horizon Europe Programme[1]. This document presents a Summary of the stakeholder engagement in the CETP SRIA collaborative writing process, where a group of stakeholders defined the key CET R&I challenges associated with reaching the goals of the CET in Europe.

The process of collaborative CETP SRIA development started on 26 May 2020 and continued through the summer. In Sep 2020, a version of the CETP SRIA resulting from this stakeholder collaboration was finalized. From that point, it was delivered to the EU Member States and Associated Countries representatives for them to further develop the SRIA based on common EU and national interests.

The main goal of publishing this Status Paper is making the text of CETP SRIA, produced from the expert stakeholder collaborative work, public and available as a reference for coming discussions to the wider stakeholder community. The final and official SRIA will be the result of the ongoing process run by the EU Member States and Associated Countries involved in the CETP within the Horizon Europe Programme. It is neither a document owned by EERA nor an expression of EERA's official view of what the SRIA should contain. It presents the result of a large number of experts opinions, largely capitalizing

1 https://ec.europa.eu/info/horizon-europe/european-partnerships-horizon-europe/candidates-climate-energy-and-mobility_en

on existing EU R&I initiatives, put on the table for the policymakers to use as a basis for prioritising and reshaping.

CETP SRIA development process

Stakeholders involved in the process of CETP SRIA collaborative writing included interested representatives of the EU Member States and Associated Countries, SET-Plan IWGs, ERA-NETs, EERA Joint Programmes. EERA was invited to act as research coordinator and main editor of the document. The process was organized around developing five thematic "Input Papers" (the topics of the input papers are presented in fig. 1). The topics of the input papers aimed to cover the key areas of CET in Europe. Each stakeholder involved in a co-writing process contributed into one or several input papers depending on their professional background and interests. Each input paper was assigned an editor from the EERA expert team involved into the CETP SRIA development process. In total, there were 134 contributors to the CETP SRIA input papers development that played the roles of editors, co-authors, commenters or discussants. Fig. 1 presents a scheme portraying the connections between the CETP SRIA thematic input papers, CETP SRIA final document and this Report.

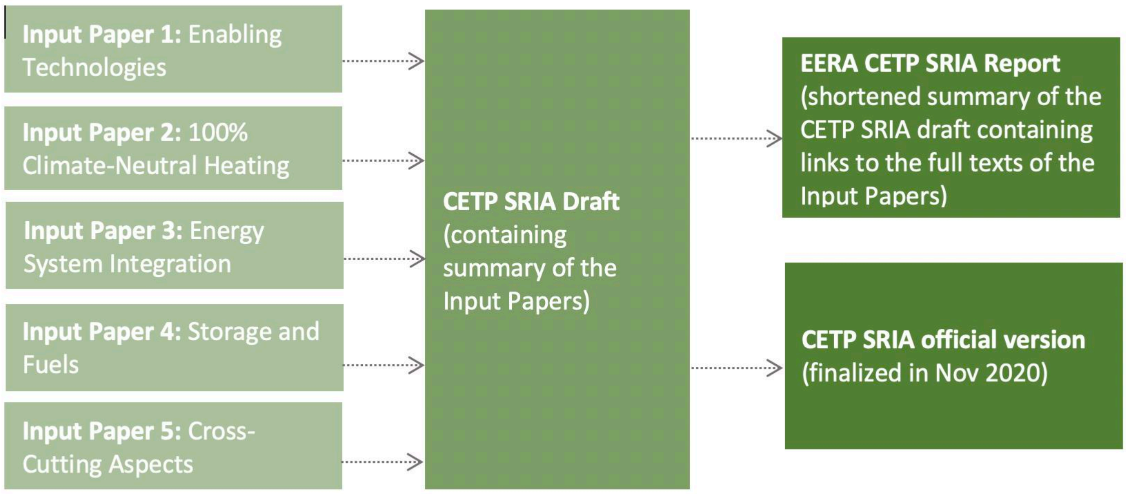

Fig. 1. *Connections between the Input Papers CETP SRIA and EERA CETP SRIA Report*

II. Summary of CETP SRIA draft resulted from stakeholder engagement

This part provides the summaries of the five CETP SRIA input papers. This is the shortened version of the inputs papers which contains the main CET challenges identified, as well as R&I needs, and expected impacts associated with them.

Additionally, in this part, the links to the full texts of the inputs papers as well as to the full lists of contributors are provided. Full list of challenges, associated impacts and R&I needs is provided in Annex 1.

1. Enabling technologies: summary of the main challenges

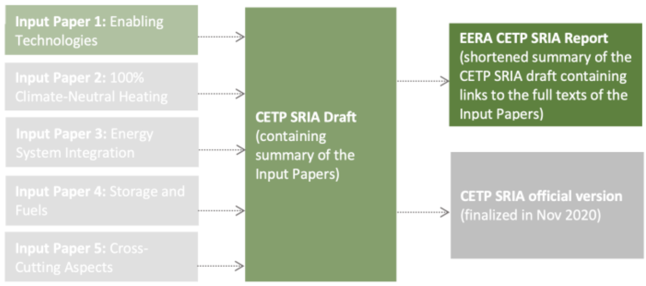

Fig. 2. *Enabling technologies input paper as a part of CETP SRIA*

Full text of the CETP SRIA input paper on enabling technologies is available here.

The structure of the Enabling Technologies input paper, in contrast to other input papers, was not organized around specific challenges, but around particular technologies.

This input paper provides the list of challenges and R&I needs associated with each of the key enabling technologies needed to drive the CET. These technologies are: CSP, PV, Offshore Wind, Onshore Wind, Geothermal Energy, Bio Energy, CCUS, Ocean Energy, Hydropower and Solar Heating.

The challenges discussed in connection to each technology are targeted at enabling a cost efficient energy transition pathway, while ensuring early emission reductions and industrial development opportunities. Technologies can have different capabilities to enable CET. Some technologies can deliver electricity; some can provide energy and storage; while others can be carbon sinks or even can both be carbon sinks and energy carriers.

The selected technologies do not represent the full scope of technologies enabling the CET. Most of the technologies not addressed in the CETP are covered by other R&I instruments, including a.o. other HEU Partnerships. Some of those technologies not addressed in the CETP include notably (non-exhaustive list): batteries and other forms of energy storage, hydrogen, demand side management technologies, power-to-x technologies, nuclear energy, to mention a few.

The enabling technologies share the common challenge of cost reductions and energy market integration. Their potential for delivering affordable, secure energy and technology advantages in the CET is best assured in a levelized cost playing field only adjusted for necessary technology support and regional differences and opportunities needed for a just transition.

1.1 CSP

Expected impact

CSP plants need to reduce their LCOE to become more competitive with other renewables (i.e., wind and PV) or develop hybrid solutions in combination with other technologies. Specific targeted impacts to achieve this objective are:

- LCOE reduction of CSP technology to 0,09 EUR/kWh in Southern Europe locations (around 2050 kWh/m^2/year), without any additional constraint by 2025, targeting 0,08 EUR/kWh by 2030, providing competitive dispatchable solar power (e. g. during night).
- Feasibility of novel material approaches via validation in lab or demonstration in relevant environment (liquid, solid, PCM or TCS media).

- Cheaper thermal energy storages achieving, by 2030, at least 10% of heat consumed in industrial processes in Europe delivered through concentrated solar technologies.
- Thermal energy cost ≤ 0.03 EUR/kWh (T<400ºC, small scale applications) and ≤ 0.02 EUR/kWh (T>600ºC, large scale applications).
- Demonstration of H_2 solar thermal production viability (target cost of 3 €/kg H_2 by 2030).

R&I needs

1.1.1 Developing central receiver and line-focusing power plants with lower LCOE

- Advanced heat transfer fluids for higher working temperatures.
- Receivers for average solar fluxes > 1MW/m^2 and T >600ºC, with efficiency > 85%.
- Self-calibrating and cheaper heliostats, below 90 EUR/m^2 (installed).
- Components with lower maintenance cost and longer lifetime.
- High precision heliostat field and automated control for long focal distance and/or high temperature applications up to 1200°C.
- Innovative plant configurations achieving better use of solar energy resource
- Cheaper line-focusing collector designs.

1.1.2 Developing reliable and cost-effective medium and high-temperature thermal storage systems

- Thermal storage systems and materials for T < 550°C with improved cost effectiveness.
- Suitable thermal storage systems and materials for T > 600ºC and T > 750ºC, with investment cost < 15 EUR/kWh.
- Suitable and cost-effective PCM thermal storage systems for 200–300ºC.
- Cost-effective and highly autonomous medium- and high temperature systems for industrial solar heat applications.
- Autonomous and smart solar fields, providing solutions to satisfy 24h operation.
- Collector designs with investment cost <400 EUR/m2 for small line-focus solar fields.
- More reliable and cost-effective receiver tubes (even non-evacuated).
- Cost-effective polygeneration solar systems (e.g. desalination and hydrogen production), including hybridization by integrating power generation from the produced industrial heat or from waste heat.

1.1.3 Developing turbo-machinery for specific conditions of solar thermal power plants

- Specific steam turbine developed for CSP applications (< 200MW).
- Supercritical CO_2 turbomachinery.

1.1.4 Ensuring reliable and cost-effective solar fuels production

- Suitable high temperature (600-1000°C) receivers adapted to fuel production.
- Innovative fuel production processes.
- Materials and functional materials for increased robustness, efficiency and durability.

1.2 PV

Expected impact

The proposed research related to PV will enable and facilitate large-scale deployment of PV and generation of renewable electricity, which is a cornerstone of the future sustainable energy system. This supports realizing policy goals for emission reduction in the short, medium and long term. Moreover, the research will help seizing the economic opportunities related to the energy transition by providing the basis for a highly innovative and globally competitive European PV industry sector over the entire value chain.

R&I needs

The challenges to be addressed in relation to PV can be divided into three clusters, which relate to the PV technology and its deployment, to the PV industry sector, and to energy system and cross-cutting issues.

1.2.1 Powering the energy transition

Renewable electricity is a cornerstone of the global and European sustainable energy system of the future. Solar energy and wind energy are key technologies to make electricity available in large quantities, at affordable cost and in an environmentally and societally sustainable way. To enable this, energy system integration (including storage and P2X) and thus further reduction of generation cost and enhanced flexibility and diversification are needed, as well as integration into our living environment and circularity in all parts of the value chain.

Underlying sub-challenges are as follows:

- Performance enhancement at module (silicon, thin films, tandems) and Balance-of System/system levels, for efficient use of available areas and as lever for cost reduction
- Cost reduction at component, system and LCOE levels, in particular to enable large-scale deployment of integrated PV applications, storage and solar Power2X
- Further enhance lifetime, quality and reliability, safety and so sustainability
- Flexible solutions for PV integration (buildings, infrastructures, vehicles, landscapes, etc.) and for floating PV, based on modules/ foils and semi-fabricates.

1.2.2 Supporting economic recovery and building the value chains for renewables

Achieving the aim of the European Green Deal to make Europe’s economy sustainable offers great opportunities to support economic recovery from the crisis and to build the strategically important value chains of renewables, including PV solar energy. For the EU industry to be successful in the global competition, excellent technology and rapid innovation are essential. These are proven strengths of the EU PV ecosystem that must be ambitiously developed further, jointly between research and industry and between member states.

Underlying Challenges are:

- Advanced industrial technologies and manufacturing concepts for the PV value chain (‘PV made in Europe’).

Cross-cutting and system level challenges that are also important for PV

- Implementing Industry 4.0 concepts
- Societal acceptance and participation
- Options for flexibility and electrification
- Energy and electricity market design.

1.3 Offshore Wind

Offshore wind is positioned to fuel Europe's energy transition. Targeted R&I support will strengthen the leading role of the European industry in the global market and can lead to the development of a 450 GW offshore wind sector.

Expected impact

- Offshore wind turbines will grow to 20-30 MW leading to further cost reduction and improved system integration.
- By technology development and cooperation with storage solutions offshore wind farms will be able to deliver power on demand.
- By sector coupling the massive amount of offshore wind energy will be the backbone to produce bulk renewable hydrogen.
- In 2050, the yearly investments in European offshore wind is around €45bn.
- In 2030, there will be 451,000 green jobs related to European onshore and offshore wind sectors.
- Implementation of offshore wind power requires positive business cases: increasing the market value and reduction of cost of electricity and reduced uncertainties of revenue.
- Improved wind turbine technology leading to lower cost and improved system integration.
- Sector coupling for uptake of the massive amount of offshore wind power: production of renewable hydrogen and electrification of the industry is an urgent research task.
- Creating a 450 GW offshore wind sector requires opening new areas at sea: developments in bottom fixed in deeper water and development of floating wind power is essential.
- The large offshore wind sector needs to become completely circular: recycling of blades, re-manufacturing and CO^2-free shipping are areas that require developments.
- Nature-inclusive building of offshore wind farms and multi-use of the space they occupy requires intense research and development.

R&I needs

1.3.1 Improving wind turbine technology

- Integrated design of next-generation large-sized wind based on accurate comprehensive simulation of the machine and its environment.
- Optimal design life based on a comprehensive understanding of the degradation and damage mechanisms (materials and components).

1.3.2 Supporting offshore wind farms and systems integration

- Validated energy system science models to assess the value of wind power in markets with 100 % variable renewable energy supply in the future electricity grid, including energy system integration (power-to-X) and industrialisation.
- Dynamic operation of very large wind power clusters providing power quality and stability in (offshore wind farm) converter-based systems.

1.3.3 Developing floating offshore wind; wind energy O&M; industrialisation

- New concepts and validation methods for integrated design models for floating wind power plants considering site-specific structural and electrical design conditions, soil damping, breaking waves, soil-structure-fluid interaction, air-sea interaction, and wind conditions.
- Wind Energy O&M.

- Condition-based maintenance based on accurate reliability models that predict the remaining lifetime or failure probability for a given load history.
- Extension of service life through optimised human or robot-assisted O&M procedures based on (big-)data analysis of automated and remote inspections.

1.3.4 Addressing ecosystem, social impact and human capital agenda for offshore wind

- Technologies and designs to improve recycling and end-of-life solutions, embedded in the overall ecological and economic policy and legal framework.
- Maintaining social acceptance by understanding the mechanisms behind it, e.g. socio-economic benefits, environmental impact assessments and by high-quality education and employment.

1.3.5 Conducting basic wind energy sciences activities for offshore wind

- Improving the understanding of atmospheric and wind physics using high-performance computing, digitalisation and measurements to develop exact experimental and numerical models.
- Aerodynamics, structural dynamics (including new materials), and offshore wind hydrodynamics of enlarged wind turbines.

1.4 Onshore Wind

Onshore wind is the backbone of Europe's energy transition. Targeted R&I support will strengthen the leading role of the European industry in the global market towards 750 GW onshore wind capacity by 2050.

Expected impact

- Onshore wind turbines will grow to 6-7 MW and become more flexible resulting in further cost reductions and improved system integration.
- Onshore wind farms will further increase flexibility through technical developments.
- Through sector coupling the onshore wind energy will be able to decarbonise the mobility and heating sectors.
- Through spatial planning optimal use of land for onshore wind will be achieved.
- Development of hybrid renewable centrals delivering flexibility (wind + X)
- Improved business case through reduction of costs despite electricity price uncertainty.
- System integration and reduced uncertainty in electricity prices: increase the uptake of onshore wind power by production of renewable hydrogen, coordination with electric transportation and heating sector.
- Simplification of permitting process (including repowering procedures and environment) to sustain the growth of the onshore wind sector.
- Archive a circular onshore wind energy sector. Components that require developments are: recycling of blades, remanufacturing of components and CO_2-free transportation.
- Increased sustainability with regards to nature use, environment and society.

R&I needs

1.4.1 Developing wind turbine technology

- Novel flexible turbine designs including optimal design life based on simulation and a comprehensive understanding of the degradation and damage mechanisms of modern and new materials, as well as electrical and mechanical components.

1.4.2 Designing grid & systems integration solutions

- Integrated forecasting of power production, power demand and short-term storage.
- New system services and innovative hybrid solution for increased flexibility.

1.4.3 Developing wind energy O&M solutions

- Smart and dispatchable operation, monitoring and control of wind farms.
- Lifetime assessment, extension of service life, robot-assisted maintenance and predictive maintenance through digital tools and models.

1.4.4 Addressing ecosystem, social impact and human capital agenda

- Improved installation, transportation, recycling, and end-of-life solutions.
- New design, planning and operation of wind farms centred on increased social acceptance and minimize the environmental impact throughout the life cycle.

1.4.5 Advancing basic wind energy sciences for onshore wind

- Improved understanding of atmospheric boundary layer and flow physics by using high-performance computing, digitalisation and measurements to develop experimental and numerical models suitable for very large turbines.
- Multi-physics (aerodynamics, aeroacoustics, structural dynamics, material science, and electrical system) and multi-scale modelling and testing of very large and flexible onshore wind turbines/subsystems.
- Disrupting wind turbine technology and systems engineering for integration of wind energy for applications outside of the electricity sector.

1.5 Geothermal Energy

The Deep Geothermal Implementation Plan[2] has defined 8 challenges that will unlock the technical and economic potential for geothermal energy.

Expected impact

- Established procedures to ensure that public and societal benefits are identified and realized.
- Increased reservoir performance in sustainable yield for at least 30 years lifetime and reduced the power demand of operating facilities.
- Improved overall geothermal energy conversion efficiency by 20% in 2050.
- Ensured production costs below 10 €ct/kWhel for power and 5 €ct/kWhth for heat by 2025.
- Demonstrated technical and economic ability of innovative exploration approaches and tools to increase the drilling success rate by 20% in 2025 and 50% in 2030 compared to 2015.
- Reduce the unit cost of drilling by 50% in 2050 compared to 2015.
- Demonstrate the technical and economic value of flexible geothermal plants for power, heating, cooling and high-temperature energy storage.

[2] https://setis.ec.europa.eu/system/files/setplan_geoth_ip.pdf

R&I needs

1.5.1 Designing optimal integration solutions for geothermal heat in urban areas

- Demonstrate new heating concepts for urban areas and how to convert conventional district heating networks of urban areas into renewable heating systems;

1.5.2 Supporting role of geothermal electricity and heating and cooling in the energy system responding to grid and network demands

- Improve design and operation methods to allow for fluctuations of heat and power demand.
- Find the best way to integrate geothermal capabilities in the energy system, including: heating, cooling, energy storage, power generation and flexibility provision.

1.5.3 Improving overall geothermal energy conversion performance for electricity production, heating and cooling

- Improved design of improved heat exchangers and pumps, optimized selection of materials, new working fluids, increases in expander efficiency etc.

1.5.4 Developing full reinjection electric and heating & cooling plants integrated in the circular economy

- Develop and operate geothermal zero emission plants with capture of greenhouse gases, storage and reinjection schemes for the development and exploitation of geothermal reservoirs with high content of non-condensable gases.

1.5.5 Developing methods, processes, equipment and materials to ensure the steady availability of the geothermal resources and improve the performance of the operating facilities

1.5.6 Developing geothermal resources in a wide range of geological settings

- Development and demonstration of innovative methods and techniques for reservoir development and exploitation in a wide range of geological settings, including complex and untested geological conditions.

1.5.7 Developing advanced drilling/well completion techniques

- Develop novel and advanced drilling technologies based on automation, new drilling fluids minimizing reservoir damage and introduction of improved cementing and cladding; including percussive drilling for deep/hot wells, e.g. fluid hammers, and non-mechanical drilling technologies such as: laser, plasma, hydrothermal flame drilling.

1.5.8 Developing innovative exploration techniques for resource assessment and drilling target definition

- Digitalization offers unparalleled opportunities through improved software, computing power, big data management, machine learning and knowledge discovery.
- Piloting and demonstrating new tools and techniques coupled with innovative modelling techniques, increasing measurement precision and acquisition rates, and applying faster analysis, processing, inversion and integration of acquired data to achieve useful yet accurate models of potential subsurface reservoirs.

1.6 Bioenergy

Biomass provides 67% of the total primary energy production of renewable energy in the EU-28, offering sustainable electricity, heat, and fuels. An increase is needed especially within aviation and marine fuel, but also in bio-based industries for chemicals and products. Currently about 40.000 people in Europe are working on Bioenergy and Biofuels and a similar amount on biomaterials.

Expected impact

There is a big potential to strengthen the industry around biomass where bioenergy can play a significant role in the energy transition. Impacts of proposed research include:

- Achieving full potential of circular bio-economy
- Optimized and balanced use of biomass as a scarce but renewable resource
- Obtaining public acceptance and addressing the concerns
- Realizing employment opportunities from biomass use
- Supporting cost reduction by technology development for energy, fuels and industry applications
- Ensuring the competitiveness of extension of the carbon cycle and carbon negative solutions
- Supporting market uptake of new technologies, market organisation and trade
- Enabling tailored, flexible integration of bioenergy concepts with local infrastructure.

R&I needs

1.6.1 Developing sustainable biomass solutions

In the Circular Bio-Economy fossil carbon is left in the ground while above-ground biogenic carbon circulates without accumulating or even depleting carbon in the in the atmosphere. Biomass is the source of sustainable carbon, now and in the future. Development of circular and carbon negative technology solutions in bioenergy are therefore important challenges in the energy transition.

- Investigating and supporting the role of bio-energy from society (public, scientific) perspective.
- Improving the efficiency of biomass production in a circular economy:
  - Increasing the feedstock availability and accessibility at competitive costs.
  - Using crop residues for energy and other bio-based uses while preserving soil quality
  - Developing dedicated crops, growing methods and technologies to use marginal and released land for production of advanced bio-fuels and bio-based materials.
- Linking biomass resources to markets in a cost-effective way (developing tradable intermediates and market organisation).
- Innovative ways to integrate bioenergy and biomaterial uses to circularity.
- Providing sustainable carbon for CCU enabling negative emissions:
  - Combine increase of biomass resources and sustainable biomass use with end of life carbon capture and permanent storage, Bio-CCS known as BECCS.

1.6.2 Integrating biomass to future sustainable energy system

- Ensuring benefits from bioenergy in enabling smooth transition:
  - Bioenergy can be used for balancing the grid and providing storage options, acting thus as a stabilising factor in the renewable power and heat supply system.
  - Implementation of biofuels for decarbonisation of the transport sector especially long-distance transport such as long haul, jet- and marine fuels.

1.7 CCUS

Expected impact

CETP is crucial to set a commercially viable basis for the industrial-scale deployment of CCS and CCU technologies, reducing costs of the technologies while raising efficiency and scaling up. R&I activities on CCS and CCU are crucial to achieve climate change mitigation and carbon dioxide removals within this decade, delivering climate benefits for European citizens while, at the same time, safeguarding existing jobs and creating new ones, protecting industrial manufacturing activity and welfare in many EU regions where energy-intensive industries are based.

Undertaking R&I activities on CCS, CCU will be critical to address current challenges on the commercial framework, legal and regulatory issues, technical development of CCS, CCU, and in parallel, to support the EU to become a global leader in low-carbon economy. Creating awareness and involving citizens to make informed decisions is another crucial task for the years ahead.

R&I needs

Challenges to the large-scale deployment of CCS and CCU technologies still exist, but R&I activities can support the development and large-scale deployment of the technologies in a decisive way.

1.7.1 Getting the commercial framework right

Standardised CO_2 specifications

- Incentives for carbon negative solutions and low-carbon products
- CO_2 stream composition, including technical considerations such as pressure, temperature and physical state and MMV
- Methods for measuring biogenic/fossil CO_2 ratio
- Data on emissions from CO_2 capture technologies
- Harmonization of legal standards / regulations relevant for the development of a European CO_2 transport- and storage-network.

1.7.2 Accelerating timely deployment at scale of CCS and CCU technologies

- Adaptation of current capture methods to new areas as well as development and deployment of higher TRL capture
- CCU technologies at commercial scale to achieve carbon circularity
- The role of CCS in enabling clean hydrogen
- The role, feasibility and scale of Carbon Dioxide Removals
- Flexible Power Generation
- Projects of Common interest
- Value-chain analyses of CCS and CCU transport systems
- Developing European CO_2 storage by Computational tools in process engineering and intensification (e.g. AI-driven process control, machine learning for catalyst development).

1.7.3 Driving costs down – through R&I, learning by doing and economies of scale

- High-TRL CO2 capture technologies (from TRL 5-6 to TRL 7-9)
- Next generation CO2 capture technologies
- CO2 capture in industrial clusters and energy applications.

1.7.4 Enabling rapid scale-up to deliver on the climate goals

- This refers to the whole array of CCS and CCU research needs.

1.7.5 Enabling EU citizens to make informed choices regarding the benefits that CCS and CCU bring

- Harmonised guidelines for life cycle sustainability assessment.
- Public awareness and social acceptance of technology solutions towards achieving climate neutrality goals.
- Engaging communities in local projects through development of participatory monitoring programmes.

1.8 Ocean Energy

Expected impact

The following challenges represent a set of R&I fields that the ocean energy sector has identified with highest importance and largest impact regarding research investment during the next period of 4-5 years. Design and validation of ocean energy devices have the highest priority.

R&I needs

1.8.1 Moving forward design and validation of ocean energy devices

The primary focus of this challenge is the demonstration of wave and tidal energy technologies, and the challenge encompasses the research, design, development, demonstration and validation of ocean energy devices and their subsystems.

- New innovative designs for ocean energy
- Design validation with updated research infrastructure
- Demonstration cases of ocean energy
- Reduction in operation and maintenance procedures for ocean energy
- Increase Europe's global lead and accelerate commercialization of Europe's world-leading ocean energy technologies, companies and projects.

1.8.2 Improving foundations, electric connections, and mooring

This challenge focuses on improving device mooring and foundation solutions and the best solutions for bringing ocean power ashore to the energy system.

- Optimised design for foundations, connections, and mooring
- Improved installation, operation, and maintenance of mooring solutions
- Increased survivability in extreme weather events.

1.8.3 Improving logistics and marine operations

Ocean energy operates in an inaccessible, corrosive environment with tough weather conditions. This challenge the ocean technology through the whole value chain from: technology development and demonstration to installation, operation, maintenance, and decommissioning of ocean energy devices.

- Collect and share operation experiences of ocean energy devices and define best practice solutions.
- Improve installation, operation, and maintenance of ocean energy devices getting more energy, longer lifetime, lower cost and lower environmental footprint.

1.8.4 Developing solutions for integrating ocean energy in the energy system

Ocean energy is not yet making a massive contribution to the European energy system. However, in view of a higher contribution in the medium-long term, some challenges should be addressed now:

- What socio-economic benefit can ocean energy provide?
- How can ocean energy best contribute to the energy transition in terms of the level of grid connection, installation size?
- What support can ocean energy provide for other renewables such as solar and wind energy?

1.9 Hydropower

Expected impact

Today, hydropower generates about 36% of the renewable electricity in the EU and the storage capacity exceeds 185 TWh.

- Hydropower can balance the variable output from wind and solar power plants, and store excess energy when variable renewables generate more than needed and support the system when generation from renewables are low.
- Hydropower is the largest provider of medium to long term storage and with targeted research hydropower can increase the ability to balance and support the energy system and greatly reduce the cost of the energy transition.
- The proposed research activity focuses on increasing the flexibility of hydropower plants, the expansion of energy storage capacity, social acceptance and application of sustainable environmental design of hydropower.

R&I needs

1.9.1 Increasing flexibility from hydropower plants

- This includes research on fatigue and lifetime of technical installations, how to increase the ramping rates, and develop new innovations for the electrical layout with controls that give a strong grid support. It will also be important to find solutions that combines hydropower energy storage technologies, batteries, H2, compressed air energy storage, etc.

1.9.2 Improving utilization and expansion of European hydropower storage capacity

- Increasing storage capability through research on dam safety, moderate expansions and flexible operation of existing reservoirs, and increased power output.

1.9.3 Improving markets and services for hydropower capabilities

- Ability to use and expand hydropower capabilities in the energy transition requires research to develop models for estimating future revenues, tools for the estimation of the remaining lifetime of hydropower plant components are important. In addition, the development of tools to support assessment of the long-term hydropower resources and its associated risk in river basins with multiple water users under present and future climate situations is needed.

1.9.4 Improving environmental sustainability of hydropower

- This includes the development of environmental design for multiple interests of the water in the system, which includes fish passage technologies, water resources availability, planning and regulation, and optimization of storage of water resources. Development of new tools for estimating and compensating lost ecosystem services and biodiversity in rivers and reservoirs, development of guidelines to include environmental constraints in hydropower operation and scheduling models, and optimization of existing hydropower infrastructure to changing climatic conditions due to climate change.

1.9.5 Handling hydropower sediment

- Today's largest challenge for hydropower installations in many parts of Europe is the sediment deposits in reservoirs and erosion of the technical installations. To cope with this, research within innovative designs of hydraulic structures, flushing techniques, sediment bypass systems, and the environmental impacts are needed.

1.9.6 Addressing cross-cutting issues for hydropower

- Digitalisation: There are multiple cross-cutting issues within the future R&I priorities for hydropower. The digitalization of hydropower plants will have common research topics with other technologies (e.g. wind power).
- Cross sectional: Hydropower can mitigate climate change and must be seen in connection with land use and food production.
- Social acceptance: The social aspects can be addressed through common research on all renewables with focus on the acceptance of new renewable technology and its need for flexible operation.
- Material Sciences: Improved understanding of material that can endure high fatigue loads over many years is needed together with numerical tools for fatigue analysis of key components. Develop materials/coating to reduce sediment erosion.

1.10 Solar heating

ESTTP, part of the ETIP RHC, identified a set of priorities which will enhance the role of solar thermal heating in the EU energy framework, providing a significant contribution to the energy demand for space heating, domestic hot water heating, industrial process heating and district heating and cooling. Main advantages of solar thermal systems include the exploitation of locally available solar irradiation, the integration with thermal energy storage and the consequent opportunity of exploiting storage capacity to provide flexibility to the power grid. Solar thermal is widely manufactured in Europe and has always had excellent acceptance among European citizens as one of the 100% renewable technologies. There are currently more than 10 million solar thermal systems in Europe, corresponding to an installed heat generation capacity over 36 GWth and thermal energy storage capacity equivalent to 180 GWhth.

Expected impact

By effectively addressing the challenges listed in the following paragraph, a strong impact on the adoption of solar thermal technologies across different applications will be reached and a total solar energy supply equivalent to 31,000 TOE will be reached by 2040.

Among the more specific expected impacts are the following:

- Improved business models reducing initial investment costs for end users, supporting efficient integration of solar thermal systems into existing heat generation and distribution systems and correctly valorising feed-in of thermal energy in thermal networks

- Increased number and average size of large scale systems, with reduced planning and implementation periods

- Developed concepts to support a sustainable and healthy use of land around cities and industrial areas for solar thermal energy
- Enhanced methodologies for design, operation, monitoring and evaluation (including economic parameters), especially of large solar thermal system
- Coupling heating-electricity, allowing to unlock additional economic benefits for solar thermal and other renewable technologies, both at product level (hybrid systems) and system level.

R&I needs

1.10.1 Developing SDH solutions

District heating and cooling is a powerful tool to integrate renewable and use excess heat/cold and supply homes, offices and industries. The potential of solar thermal in district heating (DH) is clearly being demonstrated in 200 SDH systems across Europe[3]. What this technology needs for a full take-off in all European countries includes the following:

- Integration of large solar thermal systems and storages in medium and high temperature DH networks in large (often coal-fired) and medium size (often natural gas CHP) DH systems as well as in DH clusters.
- Developments in system components, involving performance, price and reliability.
- Improved technical aspects related to the design and operation of large SDH systems, with emphasis on hydraulic optimisation, improvement of network control and optimisation of thermal storage capacity.
- Tackling non-technical issues, including environmental impact assessment, improvements in the fields of area screening and development, multi-coding of areas, participation, and innovative business models.

1.10.2 Developing SHIP

According to IRENA[4], industrial process heat accounts globally for more than two-thirds of total energy consumption in industry, and half of this process heat demand is low- to medium-temperatures (< 400°C). Solar thermal can therefore cover part of that energy demand by exploiting locally available solar irradiation. As such, it should be considered as a key technology in future regulations affecting energy supply in industry (e.g. minimum RES shares in industry).

SHIP is a well-known technology, but still in its early stage of commercial development. Some essential developments needed for an increased deployment include:

- Reduction of systems' complexity by standardisation and modularization of solar process heat systems that will reduce cost and time of SHIP projects
- Increased solar fractions in processes below 120°C, improving the combination of heat recovery with solar thermal, shared heat storages (including seasonal storage) and eventually heat pumps to cover 100% of the industrial process needs
- Improving, for medium and high temperatures, the combined solutions including tandem use of low and higher temperature collectors and other renewable sources, such as biomass, deep geothermal or renewable electricity

[3] https://www.solar-district-heating.eu/en/plant-database/

[4]https://irena.org/-/media/Files/IRENA/Agency/Publication/2015/IRENA_ETSAP_Tech_Brief_E21_Solar_Heat_Industrial_2015.pdf

- Implementing large scale demonstration pilots of SHIP in unexplored processes under key industrial sectors (e.g. building materials, food processing) and in new critical processes such as water treatment (e.g. in mining or in pulp and paper)
- Improving sector coupling concepts involving SHIP to cover a large share of an industry's heating demand while offering flexibility and stability services to the electricity grid
- Integration in urban planning concepts, processes and guidelines and local energy roadmaps, assuming the sustainable energy supply of industries (and industry districts) as fundamental.

1.10.3 Improving solar thermal use in buildings

Solar thermal systems used at building level, either residential or commercial, cover space and water heating and also solar cooling applications. These are the most common solar thermal systems, ranging from thermosiphon solar water heaters of 1.4 kWth very common in Greece, to combi-systems for space and water heating between 7 and 14 kWth in single family houses, popular in central Europe to larger systems (up to 500 kWth) in multifamily houses or even bigger ones for commercial uses. The integration into buildings and NZEB concepts, the combination with other solutions in hybrid products and the use as enablers of sector coupling are functionalities that will be important for the development of such solutions, for which improvements at component level are also relevant. These include:

- Hybrid solutions, including new thermal energy storage concepts and combination with other technologies, such as air- and ground-source heat pumps or biomass boilers.
- Improved hybrid collectors, such as PVT and new collectors with temperature-controlled performance.
- Increase simplicity of installation with intelligent and cost-efficient components (pumps, storages, controllers, pipes and valves.) and intelligent controllers for system surveillance and diagnosis
- Improved retrofit solutions, including enhanced and simplified integration with other heating solutions.

1.10.4 Developing financing/business models for solar thermal

Solar thermal applications range from small domestic systems (few kWth or m_2) to medium-large large industrial plants (up to 12 MWth already existing), up to very large district heating installations (largest in Europe reaching 110 MWth). Different technologies, hydraulic integration concepts and typologies of clients (B2C, B2B), available incentives are therefore to be considered, which calls for innovative and differentiated business models, taking into consideration:

- Better identification and parameterisation of risks for large scale solar systems, enhanced certification processes, facilitating contractualisation and guarantees.
- Innovative BM exploiting demand-response mechanisms on the electricity grid and the certified origin of renewable heat

Improved investment decision-support-tools available on the market and used by investors, integrating LCOH calculations using standardised and simplified rules for the calculation of operation and maintenance costs, residual value, auxiliary energy consumption, among other parameters.

2. 100% climate-neutral heating and cooling: summary of the main challenges

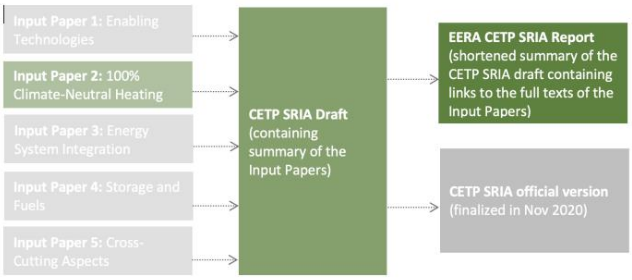

Fig. 3. *100% climate-neutral heating and cooling as a part of CETP SRIA*

Full text of the CETP SRIA input paper on 100% climate-neutral heating and cooling is available here.

Below, there is a description of the main challenges identified in connection to 100% climate-neutral heating and cooling.

2.1 Towards 100% renewable heating and cooling of individual buildings

Expected impact and R&I needs

2.1.1 One of the main challenges is the development of collective retrofit strategies for large sets of buildings. Enlarging the scale of renovations to collective scale (streets/districts…) can greatly enhance its cost effectiveness.

2.1.2 Secondly, smart building management systems can increase the building heating efficiency. Smart decision tools are needed to evaluate the optimal technology choices where the building energy management is integrated in the context of a positive energy districts.

2.1.3 A third aspect is the more seamless integration of renewable energy technologies in the urban environment such as building integrated solar (PV, solar thermal or PVT) , or several types of storage solutions. CHP technologies on fossil-free gaseous fuels such as hydrogen or synthetic gases need to be further optimized to improve the integration of historic districts or hard-to-retrofit buildings in the energy system.

2.2 Heating/cooling in climate-neutral Energy Districts

Expected impact

This challenge addresses the dual target of creating climate-neutral Energy Districts that generate integrated electric and thermal energy systems, with increased use of local renewables, as well as generate local support among citizens and professional stakeholders to make the districts sustainable in the long term. Climate-neutral Energy Districts, increasingly independent from greenhouse gas emission during fuel combustion, will contribute to increased uptake of renewables and the decarbonisation of the local energy system. They will form part of integrated local energy systems and will span across energy vectors, leading to positive impact on the wider energy infrastructure, such as increased flexibility and reduced peak loads.

R&I needs

The target of achieving climate-neutral Energy Districts requires solving of a distinct set of innovation challenges:

2.2.1 *Active management of energy consumption and production in the buildings within a neighbourhood (new, retro-fitted or a combination of both) as well as active management of the energy flows between the buildings and the regional/wider energy system.*

2.2.2 *Define and calculate the energy balance of the district, the geospatial potential for renewable energy technologies and the boundary conditions, including technological, spatial, social, economic, regulatory and other innovation perspectives. Flexible energy planning tools need to be developed to support cities and municipalities pursuing the appropriate energy choices taking into account all above mentioned local factors.*

2.2.3 *Create standardized packages of energy efficiency, flexibility and generation measures (materials, equipment, demand response, storage, smart grids, e-mobility, distributed ledger technologies etc) that can be customized according to local conditions (demographics, building stock, heritage and other societal value, local availability of RES etc). The main challenge is the combination of the scale advantage of the standardized approach while still accounting for the diversity of the local societal and geographical situation in European cities.*

2.2.4 *Organise experimental facilities such as regulatory sandboxes, testbeds, and living labs to develop, test, implement and monitor innovative solutions faster. Low-regulation zones can be an important enabler to test new tariff schemes, social acceptance and market design.*

2.3 Next generation of DHC systems

Expected impacts

DH and cooling systems will play a crucial role in densely populated areas and also in specific other applications such as greenhouse farming. The next generation of district heating systems includes many different sources of waste and renewable heating and cooling energy, it includes connections to thermal storage systems, and delivers heating and cooling to the end-user at maximum efficiency. The road to 100% climate-neutral district heating and cooling systems requires innovations and demonstrations in all constituent parts of the collective systems.

R&I needs

2.3.1 Including less conventional low temperature sources (e.g. sewers, cooling facilities, water treatment plants, metro lines, data centres…) can greatly enhance the efficiency of the system.

2.3.2 To a certain extent, a well-insulated building stock, the district heating network itself and the decentralized storage tanks in buildings can be used as a storage system providing thermal flexibility and to balance the heating demand with renewable sources. Other local chemical or man-made underground thermal storage solutions can contribute to more long-term heat storage options.

2.3.3 Digitalisation in district heating and cooling networks will play an important role: (1) large scale collection of data located throughout the DHC production, transport, distribution and users chain, (2) using state-of-the-art machine learning algorithms to further process the data for optimal to control of the network and to support the analytics (real-time monitoring, analysis, fault detection and visualisation).

2.3.4 This aspect includes system design and innovative business models where the heating/cooling sector is integrated with other sectors. These business support tools and strategies can enable the maximal use of RES and residual heat, support other energy networks and reduce the operational costs of the system.

2.4 Towards 100% renewable industrial heating

Expected impact

The majority (69%) of current industrial energy use is for process heating and cooling purposes, meaning that sustainable supply and efficient use of heat should be a priority for the industry. R&I in industrial heating and cooling is therefore key for the reducing the greenhouse gas emissions of the European industry.

The challenge for R&I for industrial heating and cooling is to develop and demonstrate the next generation heating and cooling technologies, which will lead to 100% climate-neutral industrial heating and cooling systems in 2050.

R&I needs

The road towards climate-neutral industrial heating and cooling requires innovations and demonstrations in the different topics:

2.4.1 For widespread adoption of heat pumps for industrial heating, the challenges are to reduce the capital investment cost, development of cost-effective systems in the megawatt scale and cost-effective integration of heat pumps in industrial processes.

2.4.2 For robust and efficient industrial electrical heating the objective is to demonstrate (TRL9) industrial electrical heating at high temperatures and using advanced heating technologies before 2040, with emphasis on reducing CAPEX and increasing energy efficiency.

2.4.3 To deliver highly reliable and automated solar thermal heating in industrial applications, especially in the 60-300°C temperature range and at smaller, industrial scale plant sizes, further research and digitalisation of concentrating solar thermal plants is needed. Other challenges are further cost reductions of SHIP systems, materials and receivers for high temperature CST, heat transfer fluids and storage.

2.4.4 Demonstration projects are needed to advance the integration of renewable heat (such as solar heat, and geothermal) and renewable fuels (renewable hydrogen, bioenergy, waste and other new renewable fuels) in the industrial environment at different scales and temperature ranges.

2.4.5 For heat storage, there is a specific focus on technologies that allow heat storage for both one day and longer term, e.g. over a week, to increase the flexibility of the process industries. The objective is to develop materials for compact, large capacity high-temperature heat energy storage and to integrate these technologies in the process industries.

Aside from R&I challenges in the industrial sector, other challenges and barriers exist. For instance, one of the major barriers for improving the energy efficiency of the system and integrating the urban and industrial environment is the lack of bottom up data on industrial excess heat. Top-down studies which assess the technical potential are often not replicable using a bottom-up method, where reliable data are not publicly available or in practice exporting the excess heat from the industrial site might require significant investments.

3. Energy system integration: summary of the main challenges

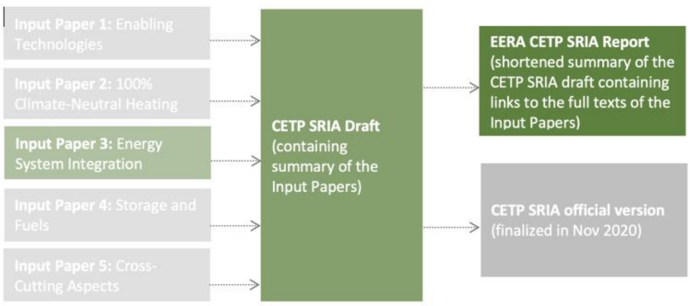

Fig. 4. *Energy system integration as a part of CETP SRIA*

Full text of the CETP SRIA input paper on Energy system integration is available here.

All research related to energy technology development itself (several forms of renewable generation, storage, grids etc.) is taken up in the other chapters of the CETP SRIA. Energy system integration part investigates the relation between the technologies themselves, the relation to consumers and to the market. The central questions are the following:

- Which technologies, energy vectors and energy infrastructure do we need in a long term and how to incentivize deployment ? (3.1)
- How can different energy vectors and technologies be integrated from operational point of view without compromizing security of supply levels? (3.2)
- Which market design and regulations do we need to achieve the investments needed and facilitate a fully integrated energy system? (3.3)
- Which role can the prosumer play in the energy system? (3.4)

3.1. System planning: designing the seamlessly integrated energy system of the future

Expected impact

The overall expected impact associated with this challenge is designing and planning an integrated energy system where the silos-based thinking is overcome, including the silos among energy vectors, between system levels, across borders and between infrastructure operators and market parties that exist in society. Challenges pertain to:

- Infrastructure planning and financing;
- Energy market design, e.g. to achieve efficient investment in and operation of all the different types of flexibility;
- Network tariffication: to coordinate between energy networks and the market;
- The design of policy instruments and their interactions, such as renewable energy support policies, the ETS and capacity remuneration mechanisms (for electricity system adequacy).

R&I needs

3.1.1 Computer models are an inevitable tool for understanding many of the decisions that are to be made by the different stakeholders in the energy system, such as network operators, policy makers, industrial sectors, prosumers etc. The current modelling toolbox needs development. There is a large need to develop better knowledge and tools for long term planning of the infrastructure investments while still ensuring interoperability, interaction and compatibility of the different technologies in the system (co-existing renewables and conventional synchronous generation, multi-energy generation, responsive demand, energy storage, active interconnections, etc.).

The scientific challenge is not focused on technical aspects or the physics of energy systems, but is aimed at presenting understandable explanations of the technical, economic and policy challenges to energy systems integration. These models are essential for designing regulations, to ensure a safe and reliable operation of the system.

The planning and regulation of energy infrastructures will need to be adjusted for several reasons. Firstly, in an integrated energy system, the investments in different energy infrastructures will need to be coordinated, whereas they currently are not. In particular, the development of cross-border infrastructures with a European interest needs to be improved with respect to planning, regulation (e.g. of tariffs) and financing.

3.1.2 Secondly, the modelling of infrastructure needs and policy impact has to be improved for long-term energy system planning. High-level studies (e.g. Clean Planet for All) have indicated techno-economic pathways for reaching carbon neutrality in Europe, in a second step these studies need to be complemented by bottom-up studies with more detail and including the decisions made on national/regional level. The CETP can be an important instrument for the member states to assess long term infrastructure needs and energy system investment planning consistent with the European ambitions.

3.2. System operation: operational integration of integrated energy systems

Expected impact

Tools and systems for the development of the overall energy system control architecture (central and decentralized) and optimal operation need to be integrated between system levels (distribution, transmission and cross-border). They will need to be able to cope with progressively increasing variability and uncertainties. Particular attention needs to be paid to extreme weather events, as they increasingly affect both the supply and demand sides, while their magnitude varies significantly from year to year. Tools and devices for system monitoring, control and protection need to be improved and their data shared, leveraging the advanced forecasting capabilities in all sectors.

R&I needs

3.2.1 For maintaining operational reliability, new devices, algorithms, components, decision support and systems are required that – to a certain extent – operate seamlessly under different conditions and provide a certain autonomy in operation. Artificial intelligence and other aspects of digitalization provide opportunities as well as risks that need to be understood better.

3.2.2 New modelling and simulation techniques are necessary to represent the effects of renewables, sector coupling, new types of flexibility as well as new market designs and consumer interfaces. Such models should be connected to market simulations (co-simulation) to analyse the reciprocal impact between markets operation and systems operation. New operational solutions will need to be tested in field trials before they can be implemented at full scale.

3.3 Governance, market design and regulation of an integrated energy system

Expected impact

The goal of market design and regulation for an integrated energy system is to achieve the necessary coordination between all actors and energy vectors to achieve the most cost-efficient and reliable integrated energy system. Therefore, efficient market design needs to reflect all energy vectors and their markets. A fundamental challenge in this respect is how to internalise expected long-term costs, e.g. of climate change, into the current market design and regulation. It requires careful reconsideration of how the incentives that are provided by the energy market design and network regulation influence the investment and the operational decisions of market parties, consumers and network operators. As consumers and energy communities become more flexible, particular attention needs to be provided to the interface between consumers – whether individual, in energy communities, co-operations or via aggregators – and the energy system.

R&I needs

3.3.1 New market designs, and new modes of coordinating the planning of energy networks with the markets, need to be developed. The challenge is how to design the incentives the sector: between network operators and market parties, from wholesale to household, across borders and across energy vectors, operational and investment. The performance of the energy system should not only be evaluated in terms of reliability, economic efficiency and emissions; the social aspects for just energy transition also need to be considered. Market-based sector integration will require innovative regulation to find its way in practice. New and changing roles in the system can be envisioned. The development of a step-wise regulatory and policy roadmap towards the implementation of a well-functioning market design for integrated energy systems is required.

3.3.2 The many European member states serve as a natural laboratory for changes to market design and policy instruments. However, because such experiments can be costly, they should be preceded by detailed computer modelling and then tested in in pilots. Holistic system modelling is needed, as was described under the previous challenge, but with the inclusion of markets and the behaviour of market parties, consumers and network operators. The resulting modelling scope is so large that a modular approach, based on model coupling, should be investigated. To deal with uncertainty, models should also consider robust pathways that 'satisfice' the requirements in a feasible manner. To test expected policy impacts, agent-based models that simulate the behaviour of the market players, network companies and consumer in relation to the physical systems are needed. While this modelling challenge is substantial, the cost of these models is a fraction of the cost of misguided investment decisions in the energy sector. Participatory modelling, in which the stakeholders are involved from the beginning of the modelling process, can help support the policy making process and improve the social acceptance of the results.

3.3.3 Regulation-free zones and demonstration pilots involving energy communities will be essential for evaluating innovative tariff schemes and local – regional market concepts. In addition, the High-Level Panel of the European Decarbonisation Pathways Initiative advocates the development of 'Transition Super-Labs', which are 'very-large-territory initiatives of real-life management of the transition from typical fossil-fuel-based local economies to zero-carbon ones'[5].

3.4. Consumer markets, prosumers and energy communities

Expected impacts

The complex relation of the consumer and prosumer (be it an individual, a community, a commercial user, an industry) with the energy system spans from the societal changes characterised by a progressively increase of environmental consciousness that triggers behavioural and process changes, addresses the relationship of the consumer towards energy system technologies and covers the solutions in the hand of the consumer that enable to be an actor in the energy system. In the future energy system, the prosumer plays a central role, influencing the system not only by investment decisions, but also by adapting its behaviour with respect to flexibility and mobility. Industrial flexibility is a key factor in integrating more renewable energy sources in the system. In the residential environment, user comfort is a key factor for driving and adopting innovative technological solutions such as e.g. smart management of building heating systems.

[5] European Commission. 'Final Report of the high-Level Panel of the European Decarbonization Pathways Initiative'. Brussels, 2018.

R&I needs

3.4.1 Giving the consumer a central role in the energy system requires the set-up of bottom-up demonstration projects which are supported by industrial, commercial and/or residential consumers. A key challenge is to leverage on scalability and replicability of demonstration projects, while still acknowledging the different geographical and social situations in urban environments. In the cross-cutting challenges summary part, the R&I needs with respect to consumers and energy communities are further elaborated on.

4. Storage and Fuels: summary of the main challenges

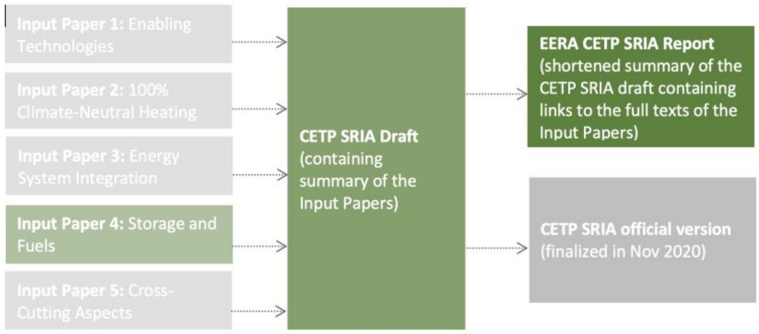

***Fig. 5.** Storage and fuels input paper as a part of CETP SRIA*

Full text of the CETP SRIA input paper on Energy system integration is available here.

Given the current diverse nature of separate energy markets within Europe, including differing energy policies, meteorological conditions (sunny regions, windy region, cold climate etc.), generation mixes and demands, energy storage solutions in different member states are likely to play different roles and rely on different technologies.

In any case, a good understanding of energy supply and demand and potential renewable electricity and thermal surpluses are required to, e.g., develop and implement short-term to inter-seasonal storage and fuel solutions. This entails knowledge about the magnitude of RES fluctuations, ramp rates, local infrastructure, loads, markets and regulations to exploit opportunities for transnational partnership, needs and potentials of different regions instead of working in isolation. Doing so enables supporting the construction of transnational EU markets and partnerships to exploit the potential of each region and avoid the creation of redundant infrastructures. Furthermore, storage sizing and location (also hybrid technologies) depend on applications and their characteristics (CAPEX, OPEX, cycling, lifetime, efficiency, interconnection with other energy carriers, environmental and social aspects). Relevant drivers to determine the need and benefit of energy storage and fuel technologies include the following aspects:

- Spatial dimension: Transport of energy (including fuels), demand vs. supply location
- Consideration of different time frames:
  - short term storage (seconds to minutes up to some hours)
  - long term / seasonal storage (days, weeks up to months)
- Levels of system integration: decentralized, centralized

  - different needs at building, local and regional level
  - single or inter-sectoral integration
- Different application fields and corresponding business cases
  - Corresponding technological characteristics as e.g. capacity, power capacity, storage duration, CAPEX, OPEX, round-trip efficiency and conversion efficiency, environmental impacts.

Identified challenges and R&I needs

The thematic priority focuses on the development of cost-effective, integrated storage and fuel systems and supports solutions answering to various identified sub-challenges within this area. This includes sustainable, integrated storage and fuel solutions for short- and long-term storage and different system integration levels within technical areas such as electrical storage, electrochemical storage, material storage, thermal storage, mechanical storage, power to X and renewable fuels and the hybridization of energy storage technologies.

The challenges in the field are identified and clustered alongside different energy storage technologies dealing with different energy forms and carriers (heat, electricity, natural gas, biomass and fuels, hydrogen, other chemicals) trying to understand and manage the complexity of the entire European energy system. Beside this more sectoral perspective, inter-sectoral and hybrid solutions as e.g. power to X are seen as a promising possibility for long-term and large-scale storage, making use of existing infrastructure (e.g., methane and oil infrastructure) to substitute fossil fuels in an efficient and environmentally friendly way. Although this type of technology is seen in close interplay with other storage solutions, new approaches to inter-sectoral and hybrid energy storage should also be explored. Without a doubt, a holistic system perspective is required to find optimal solutions and combinations of different energy storage and fuel technologies covering the different vectors.

4.1. Reliable and cost-effective mid- to long-term thermal storage systems

Expected impact

The development of TES capacities and smart energy management systems is crucial for the clean energy transition. TES can match the heating and cooling demand profiles and supply profile fluctuations over various timescales - hourly to seasonal - and size scales - from building to city level. Advanced reliable and cost-effective low, medium and high-temperature thermal storage systems are needed. The aim of this challenge is to develop advanced storage systems that allow to foster counter-seasonal integration of heat sources (seasonal surplus heat resources such as solar thermal, geothermal, heat from thermal treatment of waste or industrial surplus heat and seasonal surplus cold sources such natural cooling, industrial surplus cold or cold from LNG terminals), but also develop other thermal storages that have a relevant role in the energy system.

R&I needs

The challenge is broken down in the following Sub-Challenges or R&I needs:

4.1.1 Development of large-scale underground TES.

4.1.2 Development of cost-effective large-scale TES in man-made constructions (tank- and pit thermal storages etc.).

4.1.3 Development of low temperature, mid- to long-term small TES.

4.1.4 Large-scale day-to-month TES at temperatures > 120°C.

4.2 Development of efficient storage technologies for electric power grids based on renewables

Expected impact

Among the different tools available in the portfolio of network operators for real-time balancing of generation and demand, different technologies of storage will be crucial to support system stability. Energy storage technologies for energy and power applications seem to be still far from meeting technical and economic targets. The aim of this challenge is to optimise and demonstrate cost-effective and sustainable storage technologies able to cover seconds to minutes up to intra-week and seasonal modulation needs. This includes existing as well as radical newly solutions for different application scenarios.

R&I needs

4.2.1 Developing reliable and cost effective electrochemical technologies for long term electricity storage.

4.2.2 Increasing the European hydro-power potential for energy storage.

4.2.3 Supporting conventional power generators through storage technologies.

4.3. Renewable Fuels

Expected impact

Renewables-based liquid and gaseous fuels are an important flexibility option required to achieve a sustainable energy system. The provision of such fuels is crucial for industry and residential and transport sectors. Here, the major goal is to develop, improve, establish and launch technologies for the large scale production of sustainable, renewable fuels which are either compatible with the existing vehicle fleet and fuel infrastructure (replaceable, drop in) or possess better technical properties. Such new solutions have to be produced at lower costs for the needs of specific market segments (heavy duty road transport, shipping, aviation, heat and power generation) and require a clear market entry strategy.

R&I needs

4.3.1 Producing advanced biofuels/bioenergy from sustainable biomass.

4.3.2 Integrating bio-fuels and bioenergy production solutions with Power to Gas (e.g. biogas upgrading) and CCUS.

4.3.3 Producing thermochemical Solar Fuels.

4.3.4 Producing electrochemical Solar Fuels (sunlight direct conversion).

4.4 Development of Cross-sectoral and hybrid energy storage solutions

Expected impact

The interplay of several generation, fuel conversion and storage technologies on different system levels is a precondition to achieve a clean energy transition. 'Cross-sectoral' storage solutions will promote the efficient inclusion of high shares of renewable and excess energy sources into the energy system. Developing and demonstrating such solutions is urgent. Examples include power-to-X; and the combination of different storage technologies. The integration of such solutions will also require advanced digital techniques to optimise system performance. This challenge aims to obtain carbon-free, breakthrough technologies for integrated hybrid solutions covering multiple time scales and sectors allowing an optimal exploitation of renewable energy sources.

R&I needs

4.4.1 Development of Hybrid energy storage solutions.

4.4.2 Development of reliable and cost effective P2X technologies for fuels and gas.

4.4.3 Development of integrated decentralized energy storage solutions.

4.5 System integration and cross-cutting issues for energy storage

Expected impact

The robustness and resiliency of the European future energy system increasingly depends on the flexibility with which energy production, transport, conversion and consumption can respond to each other in the short term and long term. Technical solutions such as storage, energy conversion technologies (e.g. Power-to-X), sector coupling, demand-side management and distributed generation need to work together seamlessly. This requires a high degree of systems integration across all of its dimensions. The integration of energy storage and fuel technologies plays a crucial role in this systemic perspective and is covered in detail in the input paper for system integration covering issues as integrated operation of infrastructures, market design and regulation. modelling approaches and network operation.

Because of the central role played by the energy storage systems and fuel technologies in the Clean Energy Transition, there are several cross-cutting issues that are highly relevant to achieve a sustainable, reliable and resilient energy system requiring a wide set of multidisciplinary approaches covering several technological, techno-economic, socio-technical and environmental research dimensions.

Some of the named aspects are joint for a number of individual technologies. Naturally some might be more crucial for certain technologies and have to be stressed where necessary in the challenges.

R&I needs

4.5.1 Assessing potential solutions for energy storage and fuels in a holistic approach for a CET.

4.5.2 Optimizing lifespan of storage systems and the failure modes, including stochastic cycling profiles, CAPEX, OPEX, efficiency and environmental impact.

5. Cross-cutting aspects: summary of the main challenges

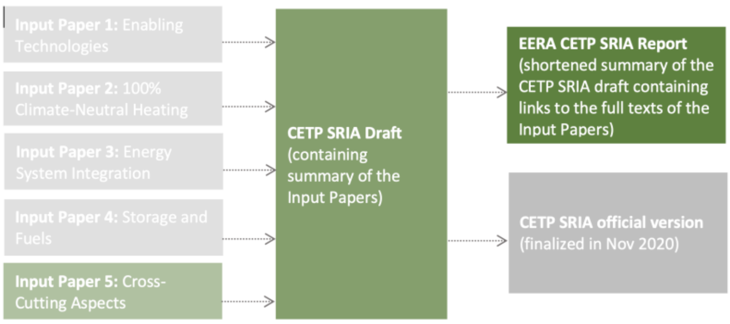

Fig. 6. *Cross-cutting aspects input paper as a part of CETP SRIA*

Full text of the CETP SRIA input paper on Cross-cutting challenges is available here.

A number of cross-cutting issues are central in the energy transition, as the energy system plays a key role in the transition of other sectors in society like transport, the built environment and industry. At the core of the CET is the integration of a number of renewable technologies and storage into a distributed but still reliable and resilient energy system where consumers play a central role. Addressing this transition requires multidisciplinary approaches bringing together research from technological, techno-economic, socio-technical and environmental domains. Importance of integrating all these dimensions is reflected in the cross-cutting challenges described in this part.

Below, there is a description of the main cross-cutting energy transitions challenges that were identified.

5.1. Robust transition pathways for an integrated European energy system

Expected impact

A large variety of transition strategies could potentially achieve carbon-neutrality by 2050, taking into account regional diversities and different policy and technology strategies towards 2030 and 2050, as well as specific territorial, political, societal and industrial factors. There is a need to present alternative pathways as a basis for public and private decision makers for future proof industrial investment strategies, infrastructure investment, and a robust set of national policies. Combined pathways consisting of model scenarios and qualitative storylines to support them may provide a fundament to identify Robust and feasible strategies.

Pathways should utilize and respect regional differences. They need to recognize how technology acceptance and energy citizenship can shape policy creation and implementation. Other important dimensions in the pathways are how they support fair and inclusive transition, how they affect macro-economic aspects and competitiveness and their impact on environment and health.

The CETP may become an ideal instrument for connecting bottom-up national modelling exercises to the consistent European model results and for exploring the consistency and feasibility of different national strategies. Expected social impacts include identification of robust strategies for arriving at the net zero society in 2050, while respecting intermediate socio-economic and environmental objectives. Frameworks for analysing the transition must be designed in a holistic and consistent way respecting both technological feasibility and socio-economic aspects such as welfare, fairness, justice, democracy and environmental targets.

R&I needs

5.1.1 *Developing a set of pathways to support the energy transition for Member states and at the EU policy level.*

5.1.2 *Developing the models and methodologies to support the energy transition, combining modelling and social sciences.*

5.1.3 *Managing uncertainty in the long-term planning of the integrated energy system.*

5.1.4 *Establishing open platforms for sharing data and models in support of the energy transition.*

5.2. Accelerated transition through innovation ecosystems

Expected impact

Accelerated energy transition processes are essential for reaching the objective of a net zero society in 2050 and achieving the objective for the Paris agreement. The process of accelerated energy transition primarily includes (i) radical system and service innovations and (ii) massive deployment of integrated energy systems combining existing technologies.

The current trend in the European energy transition is characterized by moving towards an integrated, renewable and decentralized energy market structure. Energy transition solutions are expected to be (i) financially attractive, (ii) with a minimum negative environmental impact, (iii) based on the digitalization advancement, (iv) favourable towards reaching the goals of public wellbeing (including public health and economic recovery goals).

Successful energy transitions require (i) fast growing investments, (ii) full integration of local sustainable energy resources as well as (iii) an integrated view on industrial policy, climate policy and energy policy. Active engagement of the relevant actors, especially outside the traditional energy sector, is crucial for successful implementation of the energy transition towards climate-neutral Europe.

The overall challenge is aligning transition and industrial goals to mobilize businesses boosting socio-economic impacts of the energy transition and address the bottlenecks for accelerated implementation. This includes a focus on education through professional training, joint master programmes and PhD courses supporting the entire TRL/SRL scales and enabling professionals from different sectors to develop interdisciplinary projects together covering technological, social, spatial, economic, regulatory and other innovation perspectives.

Expected social impacts associated with this challenge include (i) boosting the potential for European leadership in value and welfare creation from the energy transition, (ii) creating regulatory and standardisation frameworks capable of being the backbone of the energy transition and (iii) empowering and supporting key energy transition actors.

R&I needs

5.2.1 *Identifying included and excluded actors driving and hampering the energy transition, developing cooperation models.*

5.2.2 *Co-create and reinforce local and regional stakeholder innovation ecosystems, supporting their integration with global value chains.*

5.2.3 *Developing Social Readiness Levels (SRLs) assessment framework and corresponding funding structures.*

5.2.4 *Setting-up policy, regulatory and standardization frameworks for accelerated innovation using experimental regulatory mechanisms.*

5.2.5 *Building capacity for Interdisciplinary education and cross-sectoral training.*

5.2.6 *Creating networks of energy transition demonstration sites and activities to achieve synergies between innovation activities in the different member states and regions.*

5.3. Market design, tariffs and regulation in support of the energy transition

Expected impact

The ultimate goal of market design and regulation is to achieve cost-efficient resource allocation both in the long run and in the short run. This includes incentives to ensure optimal investments and operations for a secure and reliable integrated energy system consisting of a number of energy vectors.

Infrastructure development and operation are guided by national, sectoral regulation. Market design for an integrated energy system needs to take a holistic approach (as opposed to defining optimal market design for separate energy vectors or member states) and take into account the specifics of different energy vectors in order to achieve cost-effective decarbonisation of the EU economy. To understand the potential effects of policy changes in this area, holistic system modelling is needed. The geographical diversity from local or microgrid level (e.g. local energy communities) to the

European level gives rise to a large variety of possible markets, where geographical scopes and non-energy characteristics like ramping, duration, activation time will play an important role. As the technology and governance of the energy sector change, the business models for the different actors, products and services along the entire value chain, i.e. generation, transport, data analytics/mining conversion, storage, metering, delivery, prosumers, energy conservation and use etc., need to be innovated. Impact: Support for creating policy, governance structures, regulation and markets consistent with the net zero society and the objectives in the Green Deal.

R&I needs

5.3.1 How to design the integrated and complementary tariffs and markets needed to address the complexity of different energy sources, different energy carriers, and energy infrastructures.

5.3.2 How to design for the interdependency of different energy products within each energy carrier and between energy carriers.

5.3.3 How to use digitalization and build-in resilience to ensure operation of the energy system in case of natural disasters or cyber-attacks.

5.3.4 Design and operate the digital market infrastructure supporting empowerment for citizens, the industry, and the public sector.

5.3.5 Establish and test the new business models created by interacting digital platforms.

5.3.6 Innovative pilots and demonstrators.

5.4. Policies and actions to ensure a fair, just and democratic transition

Expected impact

Fairness and justice principles (including procedural, recognition and distributional ones) should be at the centre of designing and implementing clean energy technology transition solutions. For this, relevant methods and tools from social sciences and humanities need to be applied. The main questions to be explored with the regard of this challenge relate to (i) inclusive policy-making process, (ii) acknowledging societal groups who beneficiaries and losers of particular transition strategies are, (iii) understanding potential levels of these impacts and how to measure them.

Among the obstacles associated with fairness and justice transition challenge is (i) the absence of clear understanding of what justice and fairness in the EU policy documents as well as (ii) lack of understanding what are potential injustices and ethical dilemmas associated with specific renewable energy technologies and carbon neutral transitions overall. At the same time, there are important enablers favouring realizing fairness and justice transition challenge, among which is (i) recognition of the techno-optimist mindset limitations for realizing sustainable transitions as well as (ii) availability of relevant methods and tools provided in social sciences and humanities that can be incorporated into the policy-making frameworks at the EU level.

Societal impact associated with the implementation of this challenge include (i) transforming the role of energy consumers/prosumers/energy citizens in designing and implementing clean energy transition solutions, (ii) supporting local economies and fair jobs creation while transitioning to a carbon-neutral energy system in the EU, (iii) securing technological leadership in Europe without compromising ethical, social and environmental justice performance.

R&I needs

5.4.1 *Defining justice and fairness applied for clean energy transitions policies.*

5.4.2 *Defining a set methods and tools to measure and monitor (ex-post and ex-ante) justice and fairness goals/sub-topics and possible policy actions.*

5.4.3 *Establishing methodological support for projects funded under the CETP in questions on justice and fairness at crucial times for the projects (at least beginning and at important milestones).*

5.5. A resource efficient and sustainable energy system based on circularity

Expected impact

Circularity is a paradigm that, acknowledging resource scarcity (materials and energy), strives to make the best of available resources, extracting from them the maximum benefit possible through appropriate choice of materials, development of materials with better performance to increase component/device lifetime, monitoring materials' health during component/device operation, materials recycling/reuse and energy recuperation. Achieving this is crucial for a sustainable CET as it will minimize waste, reduce costs and limit environmental impact. This requires that we take action to make technologies work with acceptable raw materials and develop environmentally friendly and circular extraction technologies. Crucially, a full assessment of the actual level of circularity and negative impact on environment and society requires the collection of accurate data at all stages of the life cycle, which is currently difficult to obtain.

This challenge connects closely with the heating and cooling section. Intelligent hybrid systems combine different technologies, which are managed in such a way that complementary technologies are used at the appropriate time, compensating for each other's limitations, so as to guarantee a constant output of electricity and heat, potentially including combination of renewable and nuclear technologies.

Expected social impacts resulting from implementing the circularity principle include: availability of safer, more efficient and durable technologies, more sustainable in terms of optimised use of resources, both in the sense of materials and energy resources, with higher level of reuse and recyclability and thus minimal negative environmental impact; sustainable transition (best possible use of resources); increase social and geopolitical acceptability of technologies; reduce costs; reduce negative environmental impact; better informed decision-making process.

R&I needs

5.5.1 Accelerating development of advanced materials, solutions and fabrication processes to support circularity, using modern approaches which include autonomous materials optimization or discovery.

5.5.2 Designing technological solutions that enable and optimise recycling of a wider spectrum of materials needed for CET technologies. This challenge is technology-specific.

5.5.3 Designing regulatory frameworks that incentivise re-use, recycling and circularity. Redesign installations/components/devices for energy generation/storage/conversion/distribution aiming to reuse and recycle parts and materials.

5.5.4 Study the feasibility of intelligent hybrid systems.

5.6. Cost reduction, market integration and user empowerment in the energy transition through digital transformation

Expected impact

Digitalization is affecting all economic sectors and can play a fundamental role to support and accelerate CET. There are many parts of the existing European energy systems with low digitalisation levels and a big effort is needed to achieve appropriate digital levels so as to allow real market integration, energy system integration and user empowerment. For optimal use of resources, cost minimization, possibility of citizens to decide from where to take energy, new business models for interaction with citizens, better market integration in Europe; help to better design relevant legal frameworks, energy systems robustness, or avoidance of failures. For a better plant/component lifetime management (e.g. timely component replacements) thanks to intelligent systems, accident/failure prevention, higher safety standards, longer lifetime, higher efficiency, lower costs, new materials, or optimal operation of facilities (digital twins) For faster production and installation, faster production and replacement of damaged parts, more efficient systems thanks to better materials, produced in faster, cheaper, better controlled way, higher efficiency, and lower costs. The mission of this challenge is to design a digital transformation that will integrate not only the energy research entities and companies, but also the citizenship in a way in which all actors will be actively and proactively involved. Thus, the challenge (and the underlying strategy to pursue it) itself is not the mere application of digitalization for a CET, but also the full integration of citizens as final users and actors in this strategy.

R&I needs

5.6.1 Improving the ways of energy-relevant data collection, interpretation, diffusion to achieve reliable, complete, and transparent information for decision and policy making and enabling citizen decisions. Intelligent (artificial intelligence driven) generation, distribution and storage of energy (renewable electricity, carbon-free gas, heating/cooling).

5.6.2 Designing AI solutions for generation, distribution and storage of energy.

5.6.3 Designing solutions for monitoring (through sensors) of materials and components, digital twins for the simulation of their behaviour.

5.6.4 Enabling industry 4.0, advancement and automatization through digitalization.

III. Final remarks

Publishing EERA's summary of CETP SRIA, together with the links to the full texts of the CETP SRIA input papers provided, is seen by EERA as an important step that adds to communication of the CETP SRIA development process. This document can be used as a reference text containing the results of a collaborative work of a broad group of stakeholders including the representatives of the EU Member States and Associated Counties, ERA-NETs, SET-Plan IWGs, EERA and other contributors representing research, policy and industry. For example, this document can be compared to the latest versions of the CETP SRIA to provide better insights on changes made at different stages of the CETP SRIA development by various interested parties.

In 2021 – 2022, independently from this report, EERA is planning to publish series of White Papers related to the priorities and challenges related to the CET in the EU. In those papers, EERA's research community will provide its own opinion independent from any other parties.

IV. Annex 1. Full list of the CETP SRIA challenges, expected impacts and R&I needs

1. Enabling technologies: Summary of Expected Impacts and Research and Innovation needs

Enabling technology	Expected Impacts	Research and innovation needs
1.1. Concentrated Solar Power (CSP)	Making CSP plants more competitive by reducing their (LCOE) and developing hybrid solutions in combination with other technologies.	1.1.1 Developing central Receiver and Line-Focusing power plants with lower LCOE 1.1.2 Developing reliable and cost-effective medium and high-temperature thermal storage systems 1.1.3 Developing turbo-machinery for specific conditions of solar thermal power plants 1.1.4 Ensuring reliable and cost-effective solar fuels production
1.2. Photovoltaic (PV)	Enabling and facilitating large-scale deployment of PV and generation of renewable electricity by providing the basis for a highly innovative and globally competitive European PV industry sector over the entire value chain.	1.2.1 Powering the energy transition 1.2.2 Supporting economic recovery and building the value chains for renewables
1.3. Offshore Wind	Strengthening the leading role of the European offshore wind industry in the and EU carbon-neutral transitions and in the global market.	1.3.1 Improving Wind Turbine Technology 1.3.2 Supporting Offshore Wind Farms & Systems Integration 1.3.3 Developing floating Offshore Wind; Wind Energy Operation, Management & Installation; Industrialisation 1.3.4 Addressing Ecosystem, Social Impact & Human Capital Agenda for Offshore Wind 1.3.5 Conducting Basic Wind Energy Sciences activities for Offshore Wind
1.4. Onshore Wind	Strengthening the leading role of the European offshore wind industry in the and EU carbon-neutral transitions and in the global market.	1.4.1 Developing Wind Turbine Technology 1.4.2 Designing Grid & Systems Integration solutions 1.4.3 Developing Wind Energy Operation, Maintenance & Installation solutions 1.4.4 Addressing Ecosystem, Social Impact & Human Capital Agenda 1.4.5 Advancing Basic Wind Energy Sciences for Onshore Wind

1.5. Geothermal Energy	Unlocking the technical and economic potential for geothermal energy.	1.5.1 Designing optimal integration solutions for geothermal heat in urban areas 1.5.2 Supporting role of geothermal electricity and heating & cooling in the energy system responding to grid and network demands 1.5.3 Improving overall geothermal energy conversion performance for electricity production, heating & cooling 1.5.4 Developing full reinjection electric and heating & cooling plants integrated in the circular economy 1.5.5 Developing methods, processes, equipment and materials to ensure the steady availability of the geothermal resources and improve the performance of the operating facilities 1.5.6 Developing geothermal resources in a wide range of geological settings 1.5.7 Developing advanced drilling/well completion techniques 1.5.8 Developing innovative exploration techniques for resource assessment and drilling target definition
1.6. Bioenergy	Achieving full potential of circular bioeconomy, including especially bioenergy and biofuels use for aviation and marine fuel, in bio-based industries for chemicals and products.	1.6.1 Developing sustainable biomass solutions 1.6.2 Integrating biomass to future sustainable energy system
1.7. CCUS	Making CCS and CCU commercially viable for the industrial-scale deployment.	1.7.1 Getting the commercial framework right 1.7.2 Accelerating timely deployment at scale of CCS and CCU technologies 1.7.3 Driving costs down – through R&I, learning by doing and economies of scale 1.7.4 Enabling rapid scale-up to deliver on the climate goals 1.7.5 Enabling EU citizens to make informed choices regarding the benefits that CCS and CCU bring
1.8. Ocean Energy	Bringing wave and tidal energy technologies to demonstration level.	1.8.1 Moving forward Design and Validation of Ocean Energy Devices 1.8.2 Improving Foundations, Connections and Mooring 1.8.3 Improving Logistics and Marine Operations 1.8.4 Developing solutions for integrating ocean energy in the Energy System
1.9. Hydropower	Making hydropower more environmentally and socially	1.9.1 Increasing flexibility from Hydropower plants 1.9.2 Improving Utilization and expansion of European hydropower storage capacity

	sustainable as well as strengthening hydropower storage capacity to serve the needs of renewable energy system.	1.9.3 Improving markets and services for hydropower capabilities 1.9.4 Improving environmental sustainability of hydropower 1.9.5 Handling hydropower sediment 1.9.6 Addressing cross-cutting issues for hydropower
1.10. Solar thermal heating	Enhancing the role of solar thermal heating in the EU energy framework, providing a significant contribution to space heating, domestic hot water heating, industrial process heating, district heating and cooling.	1.10.1 Developing Solar District Heating (SDH) solutions 1.10.2 Developing Solar Heat for Industrial Processes (SHIP) 1.10.3 Improving Solar thermal use in buildings 1.10.4 Developing financing/business models for solar thermal

2. 100% climate-neutral heating and cooling: Summary of Expected Impacts and Research and Innovation needs

Main challenges	Expected Impacts	Research and innovation needs
2.1. Towards 100% renewable heating and cooling of individual buildings	Developing cost-effective renewable heating and cooling solutions for individual buildings.	2.1.1 Developing collective retrofit strategies for large sets of buildings. 2.1.2 Developing smart building management systems to evaluate the optimal technology choices in the context of a positive energy districts. 2.1.3 Developing seamless integration solution of renewable energy and storage technologies in the urban environment. Developing solutions for integrating historic districts or hard-to-retrofit buildings in the energy system.
2.2. Heating/cooling in climate-neutral Energy Districts	Creating climate-neutral Energy Districts that will use local renewable resources, get local support and will form part of integrated local energy systems leading to positive impact on the wider energy infrastructure.	2.2.1 Developing solutions for active management of energy and consumption and production in the buildings; energy flows between the buildings. 2.2.2 Developing flexible energy planning tools for cities and municipalities for calculating the energy balances of the districts, the geospatial potential for renewable energy technologies and the boundary conditions. 2.2.3 Creating standardized packages of energy efficiency, flexibility and generation measures that can be customized according to local conditions. 2.2.4 Organising experimental facilities (e.g. regulatory sandboxes, testbeds, living labs) to develop, test, implement and monitor innovative solutions faster.

2.3. Next generation of District heating and cooling systems	Developing the next generation solutions for densely populated areas and for other specific applications that deliver heating and cooling to the end-user at maximum efficiency.	2.3.1 Enhancing the efficiency of the system by including less conventional low temperature sources (e.g. sewers, cooling facilities, water treatment plants, metro lines, data centres). 2.3.2 Designing chemical or man-made underground thermal storage solutions that can contribute to more long-term heat storage options. 2.3.3 Improving digitalisation solutions in district heating and cooling networks (i.e. large-scale collection of data, machine learning use for optimal network control). 2.3.4 Developing system design solutions and innovative business models for integrating heating and cooling with other sectors.
2.4. Towards 100% renewable industrial heating	Developing and demonstrating the next generation heating and cooling technologies, which will lead to 100% climate-neutral industrial heating and cooling systems in 2050 (considering that 69% of total industrial energy is used for heating and cooling).	2.4.1 Developing cost-effective systems in the megawatt scale and cost-effective integration of heat pumps in industrial processes. 2.4.2 Developing demonstration projects on industrial electrical heating at high temperatures and using advanced heating technologies before 2040. 2.4.3 Delivering highly reliable and automated solar thermal heating in industrial applications, especially in the 60-300°C temperature range and at smaller, industrial scale plant sizes. 2.4.4 Developing demonstration projects on integrating renewable heat (e.g. solar, geothermal) and renewable fuels (e.g. renewable hydrogen, bioenergy) in the industrial environment at different scales and temperature ranges. 2.4.5 Developing materials for compact, large capacity high-temperature heat energy storage and integrating these technologies in the process industries.

3. Energy Systems Integration: Summary of Expected Impacts and Research and Innovation needs

Main challenges	Expected Impacts	Research and innovation needs
3.1. System planning: designing the seamlessly integrated energy system of the future	- Overcoming silos-based thinking in designing energy systems; - Improving energy systems infrastructure planning and financing; - Improving energy market design;	3.1.1 Improving the current modelling toolbox focusing the scientific and modelling effort on presenting understandable explanations of the technical, economic and policy challenges to energy systems integration as well as on presenting coordination of investments in different energy infrastructures. 3.1.2 Improving the modelling of infrastructure needs and long-term policy impact. Improving the ways of connecting high-level studies (e.g. Clean Planet for All)

	- Providing better solutions for network tariffication; - Improving design of energy policy instruments and their interactions.	including techno-economic pathways for reaching carbon neutrality in Europe with the bottom-up studies with more detail and including the decisions made on national/regional level.
3.2. System operation: operational integration of integrated energy systems	- Integrating the tools for the energy system control architecture between system levels (distribution, transmission and cross-border); - Designing and improving the tools and devices for system monitoring, control and protection within progressively increasing variability and uncertainties (e.g. extreme weather events).	3.2.1 Improving understanding of risks associated with artificial intelligence and other aspects of digitalization. 3.2.2 Developing new modelling techniques and field trials to represent the effects of renewables, sector coupling, new types of flexibility as well as new market designs and consumer interfaces.
3.3. Governance, market design and regulation of an integrated energy system	- Achieving the necessary coordination between all actors and energy vectors; - Internalizing expected long-term costs, e.g. of climate change, into the current market design and regulation; - Understanding the influence of the incentives provided by the energy market design and network regulation on the market parties, consumers and network operators.	3.3.1 Developing new market designs, and new modes of coordinating the planning of energy networks with the markets. Designing market incentives: between network operators and market parties, from wholesale to household, across borders and across energy vectors, operational and investment. 3.3.2 Developing holistic energy system models that include markets, the behaviour of market parties, consumers and network operators (e.g. agent-based and participatory modelling). 3.3.3 Creating regulation-free zones and demonstration pilots involving energy communities for evaluating innovative tariff schemes and local – regional market concepts. Developing 'Transition Super-Labs' that are 'very-large-territory initiatives of real-life management of the transition from fossil-fuel-based local economies to zero-carbon ones'.
3.4. Consumer markets, prosumers and energy communities	- Supporting the role of consumer and prosumer as a central actor in the future energy system; - Influencing the system not only by investment decisions, but also by	3.4.1 Setting-up bottom-up demonstration projects supported by industrial, commercial and/or residential consumers aiming to leverage projects scalability and replicability.

	adapting its behaviour with respect to flexibility and mobility; - Increasing industrial flexibility as a key factor in integrating more renewable energy sources in the system; - Driving adoption of innovative technological solutions by increasing consumer comfort.	

4. Storage and fuels: Summary of Expected Impacts and Research and Innovation needs

Main challenges	Expected Impacts	Research and innovation needs
4.1. Reliable and cost-effective mid- to long-term thermal storage systems	Ensuring availability of sufficient thermal energy storage (TES) capacities to realize the clean energy transition objectives.	4.1.1 Developing large-scale underground TES. 4.1.2 Developing cost-effective large-scale TES in man-made constructions (e.g. tank- and pit thermal storages). 4.1.3 Developing low temperature, mid- to long-term small TES. 4.1.4 Developing large-scale day-to-month TES at temperatures > 120°C.
4.2. Development of efficient storage technologies for electric power grids based on renewables	Providing cost-effective solutions for sustainable storage technologies able to cover seconds to minutes up to intra-week and seasonal modulation needs.	4.2.1 Developing reliable and cost effective electrochemical technologies for long-term electricity storage. 4.2.2 Increasing the European hydro-power potential for energy storage. 4.2.3 Supporting conventional power generators through storage technologies.
4.3. Renewable Fuels	Providing renewables-based fuels for industry, residential and transport sectors.	4.3.1 Producing advanced biofuels/bioenergy from sustainable biomass. 4.3.2 Integrating biofuels and bioenergy production solutions with Power to Gas (e.g. biogas upgrading) and CCUS. 4.3.3 Producing thermochemical Solar Fuels. 4.3.4 Producing electrochemical Solar Fuels (sunlight direct conversion).
4.4. Development of Cross-sectoral and	- Developing carbon-free, breakthrough technologies for integrated hybrid solutions covering	4.4.1 Developing Hybrid energy storage solutions. 4.4.2 Developing reliable and cost effective P2X technologies for fuels and gas. 4.4.3 Developing integrated decentralized energy storage solutions.

hybrid energy storage solutions	multiple time scales and sectors allowing an optimal exploitation of renewable energy sources; - Promoting solutions allowing interplay of several generation, fuel conversion and storage technologies on different system levels.	
4.5. System integration and cross-cutting issues for energy storage	Ensuring high degree of systems integration across storage, energy conversion technologies, sector coupling, demand-side management and distributed generation.	4.5.1 Assessing the potential solutions for energy storage and fuels in a holistic manner. 4.5.2 Optimizing lifespan of storage systems and the failure modes, including stochastic cycling profiles, CAPEX, OPEX, efficiency and environmental impact.

5. Cross-Cutting Challenges: Summary of Expected Impacts and Research and Innovation needs

Main challenges	Expected Impacts	Research and innovation needs
5.1. Robust transition pathways for an integrated European energy system	Identifying robust strategies for net zero society in 2050 that respect socio-economic and environmental objectives and take into account regional differences.	5.1.1 Developing a set of pathways to support the energy transition for Member states and at the EU policy level. 5.1.2 Developing the models and methodologies to support the energy transition, combining modelling and social sciences. 5.1.3 Developing solutions to manage uncertainty in the long-term planning of the integrated energy system. 5.1.4 Establishing open platforms for sharing data and models in support of the energy transition.
5.2. Accelerated transition through innovation ecosystems	- Developing an integrated view on industrial policy, climate policy and energy policy; - Actively engaging relevant actors of the transition process, especially outside the traditional energy sector; - Boosting the potential for European leadership in value and welfare	5.2.1 Identifying included and excluded actors driving and hampering the energy transition, developing cooperation models. 5.2.2 Co-creating and reinforcing local and regional stakeholder innovation ecosystems, supporting their integration with global value chains. 5.2.3 Developing Societal Readiness Levels (SRL) assessment framework and corresponding funding structures. 5.2.4 Setting-up policy, regulatory and standardization frameworks for accelerated innovation using experimental regulatory mechanisms.

	creation associated with the energy transition; - Creating regulatory and standardisation frameworks capable of being the backbone of the energy transition.	5.2.5 Building capacity for Interdisciplinary education and cross-sectoral training. 5.2.6 Creating networks of energy transition demonstration sites and activities to achieve synergies between innovation activities in the different member states and regions.
5.3. Market design, tariffs and regulation in support of the energy transition	- Ensuring a holistic approach to market design taking into account the specifics of different energy vectors; - Introducing innovative business models that correspond to the technological and governance changes of the energy sector; - Ensuring optimal investments and operations for a secure and reliable integrated multi-vector energy system.	5.3.1 Improving holistic energy system modelling practice to better understand the potential effects of policy changes. 5.3.2 Finding the ways to design the integrated and complementary tariffs and markets addressing the complexity of different energy sources, energy carriers, and energy infrastructures. 5.3.3 Finding the ways to design for the interdependency of different energy products within each energy carrier and between energy carriers. 5.3.4 Supporting digitalization and build-in resilience to ensure operation of the energy system in case of natural disasters or cyber-attacks. 5.3.5 Designing and operating the digital market infrastructure supporting empowerment for citizens, the industry, and the public sector. 5.3.6 Developing and testing the new business models created by interacting digital platforms.
5.4. Policies and actions to ensure a fair, just and democratic transition	- Placing consumers/ prosumers/ energy citizens at the center of designing and implementing clean energy transition solutions; - Supporting local economies and fair jobs creation while transitioning to a carbon-neutral energy system in the EU; - Securing technological leadership in Europe without compromising ethical, social and environmental justice performance.	5.4.1 Defining justice and fairness applied for clean energy transitions policies. 5.4.2 Defining a set methods and tools to measure and monitor (ex-post and ex-ante) justice and fairness goals/sub-topics and possible policy actions. 5.4.3 Establishing methodological support for projects funded under the CETP in questions on justice and fairness at crucial times for the projects (at least beginning and at important milestones).

5.5. A resource efficient and sustainable energy system based on circularity	Designing technological solutions and processes for CET that without compromising environmental sustainability.	5.5.1 Accelerating development of advanced materials, solutions and fabrication processes to support circularity. 5.5.2 Designing technological solutions that enable and optimise recycling of a wider spectrum of materials needed for CET technologies. 5.5.3 Designing regulatory frameworks that incentivise re-use, recycling and circularity.
5.6. Cost reduction, market integration and user empowerment in the energy transition through digital transformation	Application of digitalization for a CET ensuring the full integration of energy research entities and companies as well as citizens as final users and actors in the transition strategy.	5.6.1 Improving the ways of energy-relevant data collection, interpretation, diffusion to achieve reliable, complete, and transparent information for decision and policy making and enabling citizen decisions. 5.6.2 Designing AI solutions for generation, distribution and storage of energy. 5.6.3 Designing solutions for monitoring (through sensors) of materials and components, digital twins for the simulation of their behaviour. 5.6.4 Enabling industry 4.0, advancement and automatization through digitalization.