Integrated SET Plan

CETP

Clean Energy Transition Partnership

SET Plan Stakeholder Groups Dialogues

Summary Paper

Overview of Relevant RDI Challenges identified in the SET Plan Stakeholder Groups Dialogues in preparation of the CETP Strategic Research and Innovation Agenda

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Input Papers available at

https://expera.smartgridsplus.eu/Navigable%20Site%20Pages/SET-Plan.aspx

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1. CETP SRIA Stakeholder Dialogues and Input Paper Development

1.1. The CETP SRIA Process

The Strategic Research and Innovation Agenda (SRIA) of the Clean Energy Transition Partnership (CETP) will identify the main research and innovation challenges to reach clean energy transition in Europe within the next seven years. The CETP will implement the SRIA and address the identified CETP challenges.

The Strategic Research and Innovation Agenda (SRIA) of the Clean Energy Transition Partnership (CETP) was kicked off on the 26 May 2020 in a meeting inviting representatives of the SET Plan Implementation Working Groups (IWGs) and ERA-NETs engaged in relevant topics concerning clean energy production and usage. After the introduction of the CETP, its aims and governing structure, as well as the proposed timeline, the process towards a Strategic Research and Innovation Agenda (SRIA) has been presented to the attendees.

The SRIA process was designed to address the following principles:

- Co-creation of the SRIA: All interested Member States and Associated Countries, SET Plan Implementation Working Groups (IWGs) and ERA-NETs and national stakeholders are engaged in the process.
- Challenge-orientation of the SRIA: The SRIA of the CETP follows a challenge-oriented approach, identifying R&I challenges in clean energy transition.
- Commitment to the SRIA: Interested CETP Member States and Associated Countries generate ownership and commitment for implementation. Other stakeholders generate commitment for implementation.

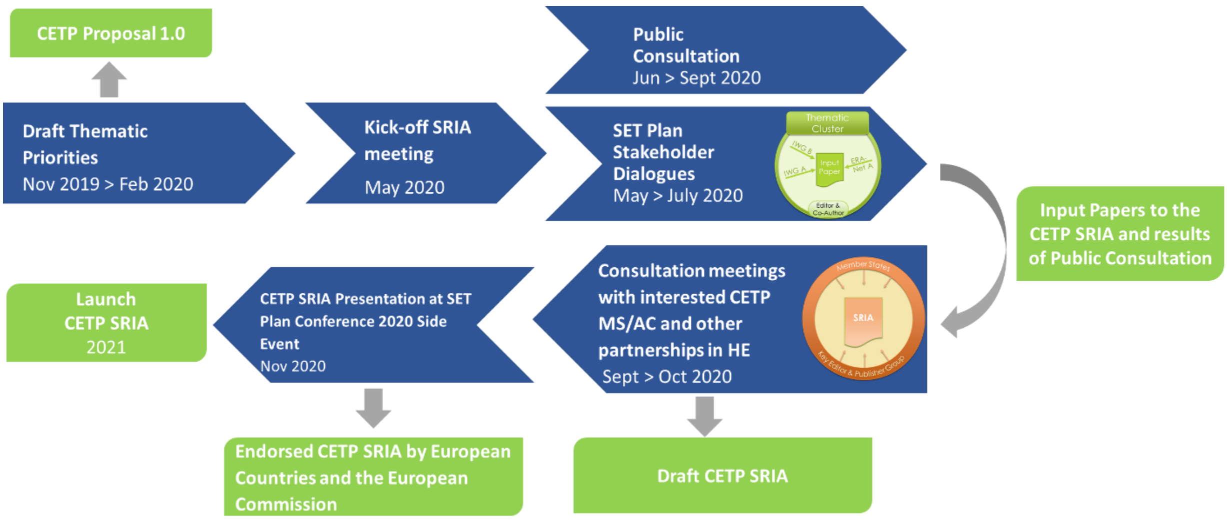

Figure 1: Description of the SRIA initiation process

The Kick-Off Meeting was followed by a public consultation and SET Plan Stakeholder Dialogues (see Section 1.1.2). Both deliver input to the CETP SRIA which will then be developed in consultation meetings with MS/AC and other partnerships driven by a CETP MS/AC Countries Editors- and Publisher Group. The CETP SRIA will be adopted during the SET Plan Conference 2020 by the interested CETP MS/AC and is scheduled to be launched in January 2021.

1.2 The CETP SRIA Stakeholder Dialogues

In order to engage the SET Plan IWGs and ERA-NETs to the CETP and learn about their already identified challenges and activities, CETP Stakeholder Dialogues have been organised from May to July 2020.

Thematic clusters have been developed and CETP stakeholder dialogues have been held for each cluster.[1] The CETP Stakeholder Dialogues provided all ERA-NETs and SET Plan IWGs with the opportunity to present themselves and respond to pre-defined guiding questions:

- What are the key challenges for the coming years in your field?
- What are particular challenges, where a collaboration of member states with their funding programmes can contribute / make difference in complementarity to the Horizon Europe calls?
- Who are the key stakeholders to address (including solution providers, but also „problem owners", „need owners", „potential buyers", intermediaries,
- What kind of accompanying measures (in addition to joint calls for transnational projects) can help to work on the challenge and maximise output and impact of RDI?
- Which concepts and strategies do already exist and could be adopted / transferred to / transformed into the CET Partnership?

Seven CETP Stakeholder Groups Meetings have been held, in which SET Plan IWGs and ERA-NETs have presented their members, past activities and current agendas.

CETP Stakeholder Dialogues on						
Renewable Technologies 1	**Renewable Technologies 2**	**Renewables additional**	**Heating & Cooling Solutions**	**System Integration**	**Storage Systems and Fuels**	**Crosscutting issues**
IWG Ocean Energy	IWG CSP	IWG Offshore Wind	IWG 5 Eff Buildings	IWG 4 Energy Systems	IWG 5 Eff Buildings	All IWGs and ERA-Nets
IWG PV	IWG Geothermal	ERA-Net Demowind	IWG Geothermal	JPP Smart Energy Systems	IWG Bioener & Fuel	
ERA-Net CSP	IWG CCUS	IWG BioEner & Fuel	IWG Bioener & Fuel	IWG 5 Eff Buildings	ERA-Net Bioener	
ERA-Net Ocean Energy	ERA-Net Geother	ERA-Net BEST	IWG 4 Energy Systems	IWG 3.1 Consumers	IWG 4 Energy Systems	
ERA-Net Solar	ERA-Net ACT	IWG CSP	JPP Smart Energy Systems	Joint IWG 3,4,5	JPP Smart Energy Systems	
			IWG CSP	IWG Bioener & Fuel	IWG CCUS	
				IWG PV + SOLAR-ERA.NET	IWG CSP	
				IWG Offshore Wind	IWG Deep Geothermal	
				IWG CSP	ERA-NET GEOTHERMICA	
				IWG CCUS		
29.05.2020	04.06.2020	10.06.2020	05.06.2020	19.06.2020	29.6.2020	03.07.2020
Attendance: 54 Persons	**Attendance: 45 Persons**	**Attendance: 63 Persons**	**Attendance: 52 Persons**	**Attendance: 61 Persons**	**Attendance: 32 Persons**	**Attendance: 54 Persons**

In agreement with the interested CETP MS/AC, SET Plan IWGs and ERA-NETs the development of joint Input Papers to the CETP SRIA based on the CETP Stakeholder Dialogues have been agreed.

1.3 Input Paper Development to the CETP SRIA

Each SET Plan Stakeholder Cluster has developed one CETP SRIA Input Paper:

1. Renewable Technologies;
2. Heating and Cooling Solutions;
3. System Integration;
4. Storage and Fuels and

[1] For renewable technologies an additional meeting was held due a high amount of participating interest and groups and time restrictions.

5. Crosscutting Issues.

The purpose of the input papers was to jointly identify high-level RDI challenges for clean energy transition from the perspective and experience of all SET Plan IWGs, ERA-NETs and stakeholders involved (Policy, Industry, Research). In order to allow for a collaborative working approach, online documents for each thematic cluster have been created on the online platform Expera. Due to the breadth of topic included in the Enabling Technologies cluster, 9 sub-clusters have been formulated to cover all relevant renewable energy sources. The ERA-NETs and IWGs have been assigned to the thematic priorities in the following fashion, with some presenting at multiple occasions.

Given the high number of participants in the strategic dialogues and plethora of interested parties in the input paper writing process, a nomination process for several different roles in the process has been established. The roles include:

Editors and co-authors (EERA experts):

- Every input paper has one or two editors provided by EERA, who are tasked with the general moderation and coordination of the input paper and its contents.
- They coordinate and collaborate in partnership with the co-authors
- Editors consolidate the inputs from co-authors and commenters towards a consistent input paper

Co-authors:

- Every IWG and ERA NET has the opportunity to nominate one co-author for each cluster and challenge.
- Co-authors develop text parts for input paper in the „Living Document" on the EXPERA platform.

Commenters

- IWG and ERANETs have the opportunity to nominate several commenters for each input paper, who have the opportunity to leave comments in the respective living documents.
- The comments can then be picked up by co-authors if considered valuable for the papers

Discussants

- Discussants are provided with the opportunity to give comments in the discussion forum for each input paper
- They are composed of national experts as well as national stakeholder groups other than ERANETs or IWG.

In total 146 experts have acted as editor, co-author and commenter in the development of the input papers across all involved SET Plan IWGs and ERA-NETs.

The input papers' structure has been split into three sections:

- **Section 1**: A general introduction into the cluster or challenge,
- **Section 2**: An overview of identified challenges discussed in the input paper, which have been condensed by the editors of the input papers and
- **Section 3**: Detailed description of the identified challenges.

Regular Meetings with Editors, Co-Authors, Commenters and the CETP Writing Group which yielded attendances around 50 persons were held in order to discuss the progress of the input papers and provide guidance in their future development.

2. Overview of identified challenges

The input papers to the CETP SRIA identified the following RDI challenges for clean energy transition (Table 1).

Input Paper	Identified challenge by stakeholder		
1. Enabling Technologies (link)	CH1.1 Concentrated Solar Power (link)	CH1.1.1	Central Receiver and Line-Focusing power plants with lower LCOE
		CH1.1.2	Reliable and cost-effective medium and high-temperature thermal storage systems.

		CH1.1.3	Turbo-machinery developed for specific conditions of solar thermal power plants.
		CH1.1.4	Reliable and cost-effective solar fuels production.
	CH1.2 Photovoltaics (link)	CH1.2.1	Powering the energy transition
		CH1.2.2	Supporting economic recovery and building the Strategic Value Chains for renewables (i.c. PV)
	CH1.3 Offshore Wind (link)	CH1.3.1	Improved Wind Turbine Technology
		CH1.3.2	Offshore Wind Farms & Systems Integration
		CH1.3.3	Floating Offshore Wind & Wind Energy O&M and Industrialisation
		CH1.3.4	Ecosystem, Social Impact & Human Capital Agenda
		CH1.3.5	Basic Wind Energy Sciences for Offshore Wind
	CH1.4 Onshore Wind (link)	CH1.4.1	Wind Turbine Technology
		CH1.4.2	Grid & Systems Integration
		CH1.4.3	Wind Energy Operation, Maintenance & Installation
		CH1.4.4	Ecosystem, Social Impact & Human Capital Agenda
		CH1.4.5	Basic Wind Energy Sciences for Onshore Wind
	CH1.5 Deep Geothermal Energy (link)	CH1.5.1	Optimal integration of geothermal heat in urban areas
		CH1.5.2	Role of geothermal electricity and heating & cooling in the energy system responding to grid and network demands
		CH1.5.3	Improvement of overall geothermal energy conversion performance for electricity production, heating & cooling
		CH1.5.4	Develop full reinjection electric and heating & cooling plants integrated in the circular economy
		CH1.5.5	Methods, processes, equipment and materials to ensure the steady availability of the geothermal resources and improve the performance of the operating facilities
		CH1.5.6	Development of geothermal resources in a wide range of geological settings
		CH1.5.7	Advanced drilling/well completion techniques
		CH1.5.8	Innovative exploration techniques for resource assessment and drilling target definition
	CH1.6 Bioenergy (link)	CH1.6.1	Sustainable carbon for the globe
		CH1.6.2	Integration of biomass to future sustainable energy system
	CH1.7 Carbon Capture Utilisation & Storage (link)	CH1.7.1	Getting the commercial framework right
		CH1.7.2	Accelerating timely deployment at scale of CCS and CCU technologies
		CH1.7.3	Driving costs down – through R&I, learning by doing and economies of scale
		CH1.7.4	Enabling rapid scale-up to deliver on the climate goals
		CH1.7.5	Enabling EU citizens to make informed choices regarding the benefits that CCS and CCU bring
		CH1.7.6	Production, optimisation and integration of blue hydrogen with CCUS
	CH1.8 Ocean Energy (link)	CH1.8.1	Design and Validation of Ocean Energy Devices
		CH1.8.2	Foundations, Connections and Mooring
		CH1.8.3	Logistics and Marine Operations
		CH1.8.4	Integration in the Energy System
	CH1.9 Hydropower (link)	CH1.9.1	Increased flexibility from hydropower plants
		CH1.9.2	Utilization and expansion of European hydropower's storage capacity
		CH1.9.3	Markets and services for hydropower's
		CH1.9.4	Environmental design
		CH1.9.5	Social acceptance
		CH1.9.6	Basic Hydropower Sciences
		CH1.10.1	Solar District Heating (SDH)
		CH1.10.2	Solar Heat for Industrial Processes (SHIP)

	CH1.10 Solar Thermal Heating & Cooling (link)	CH1.10.3	Solar thermal use in buildings
		CH1.10.4	Financing/business models for solar thermal
2. Heating and Cooling Solutions (link)	CH2.1 Towards 100% renewable heating and cooling of individual buildings		
	CH2.2 Heating/cooling in climate-neutral Energy Districts		
	CH2.3 Next generation of District heating and cooling systems		
	CH2.4 Towards 100% renewable industrial heating		
3.System Integration (link)	CH3.1 Develop an optimised integrated European energy infrastructure		
	CH3.2 Develop Integrated Local and Regional Energy Systems		
	CH3.3 System modelling as a fundamental tool for the integrated energy system development		
4. Storage & Fuels (link)	CH4.1 Reliable and cost-effective mid- to long-term thermal storage systems		
	CH4.2 Development of efficient storage technologies for electric power grids based on renewables		
	CH4.3 Renewable Fuels		
	CH4.4 Development of Cross-sectoral and hybrid energy storage solutions		
	CH4.5 System integration and cross-cutting issues for energy storage		
5. Cross-cutting challenges (link)	CH5.1 Robust transition pathways for an integrated European energy system		
	CH5.2 Accelerated transition and innovation ecosystems		
	CH5.3 Market design and regulation in support of the energy transition		
	CH5.4 Policies and actions to ensure a fair, just and democratic transition		
	CH5.5 A resource efficient and sustainable energy system based on circularity		
	CH5.6 Cost reduction, market integration and user empowerment in the energy transition through digital transformation		

Table 1 Overview of identified challenges

3. Short description of identified challenges

3.1 Enabling technologies for clean energy transition

This chapter is a summary of the main challenges defined in the technology chapters (Input Paper 1 Enabling Technologies), but also the challenges defined for how to include and utilise the technologies in the energy transition and a climate-neutral energy system (Input Paper System Integration). More details about the proposed research can be found in the technology chapters and the introduction.

This input paper describes research to enable a low-cost energy transition with early emission reductions and large industrial potential for a set of technologies. The technologies are: Concentrated Solar Power (CSP), Solar Thermal Heating (ST), Photovoltaic (PV), Offshore Wind, Onshore Wind, Geothermal energy, Bio energy, Carbon Capture Utilization and Storage (CCUS), Ocean Energy, and Hydropower. What binds them together is their connection to energy. The capabilities of these technologies as enablers in the clean energy transition is different. Some can deliver energy; some can provide energy and storage; while others can provide carbon sinks or even both be carbon sink and deliver energy.

The selected technologies are not the only enabling technologies in the energy transition, some of the obvious ones not mentioned in this section are storage technologies such as: batteries, hydrogen, and compressed air, but also the technology that will enable a more flexible demand, technologies adding to the electrification and a cleaner industry with power-to-x, including nuclear energy for countries that decide to make use of it. In the end it is the combination and the interplay between all these technologies that, through fair competition, will create green jobs, affordable energy, energy security resulting in a competitive Europe driving the energy transition forward.

Challenge 1.1 Concentrated Solar Power (CSP)

Expected impact:

CSP plants need to reduce their electricity cost (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).

Identified Challenges

CH1.1.1 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 life time (*see CC challenge 5, circularity*).
- 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.

CH1.1.2 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, including hybridization by integrating power generation from the produced industrial heat or from waste heat (*see CC challenge 5, circularity*).

CH1.1.3 Turbo-machinery developed for specific conditions of solar thermal power plants.

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

CH1.1.4 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 (*see CC challenge 5, circularity*).

Challenge 1.2 Photovoltaic (PV)

Expected impact:

The proposed research related to photovoltaic solar energy (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.

The challenges to be addressed in relation to photovoltaic solar energy (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, respectively:

Identified Challenges

CH 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 Challenges are:

- 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 (*see CC challenge 5, circularity*);
- Flexible solutions for PV integration (buildings, infrastructures, vehicles, landscapes, etc.) and for floating PV, based on modules/ foils and semi-fabricates.

CH 1.2.2 Supporting economic recovery and building the value chains for renewables (i.c. PV)

Achieving the aim of the 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 have to be ambitiously developed further, jointly between research and industry and between member states.

Underlying Challenges are:

- The Challenges for Cluster 1 are also key for this Cluster, but an additional Challenge is:
- 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.

Challenge 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 in size 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 2050 there will be 454,000-608,000 green jobs related to European onshore and offshore wind.

Ambition

- 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.

Identified Challenges

CH1.3.1 Improved 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).

CH1.3.2 Offshore Wind Farms & 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.

CH1.3.3 Floating Offshore Wind & Wind Energy Industrialisation

- New concepts and validation methods for integrated design models for floating wind power plants taking into account site-specific structural and electrical design conditions, soil damping, breaking waves, soil-structure-fluid interaction, air-sea interaction, and wind conditions.
- Wind Energy Operation, Maintenance & Installation (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 (*see CC challenge 5, circularity*).

CH1.3.4 Ecosystem, Social Impact & Human Capital Agenda

- Technologies and designs to improve recycling and end-of-life solutions, embedded in the overall ecological and economic policy and legal framework (*see CC challenge 5, circularity*).
- Maintaining social acceptance by understanding the mechanisms behind it, e.g. socio-economic benefits, environmental impact assessments and by high-quality education and employment

CH1.3.5 Basic Wind Energy Sciences 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.

Challenge 1.4 Onshore Wind

Onshore wind is the cheapest source of renewable energy and 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 in size 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)

Ambition

- 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.

Identified Challenges

CH 1.4.1 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 (*see CC challenge 5, circularity*).

CH 1.4.2 Grid & Systems Integration

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

CH 1.4.3 Wind Energy Operation, Maintenance & Installation

- 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 (*see CC challenge 5, circularity*).

CH 1.4.4 Ecosystem, Social Impact & 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.

CH 1.4.5 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.

Challenge 1.5 Geothermal Energy

The Deep Geothermal Implementation Plan 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.

Identified Challenges

CH1.5.1 Optimal integration of geothermal heat in urban areas

- Demonstrate new heating concepts for urban areas and/converting conventional district heating networks of urban areas into renewable heating systems;

CH1.5.2 Role of geothermal electricity and heating & 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.

CH1.5.3 Improvement of overall geothermal energy conversion performance for electricity production, heating & cooling

- Improved design of improved heat exchangers and pumps, optimized selection of materials, new working fluids, increases in expander efficiency etc (see CC challenge 5, circularity).

CH1.5.4 Develop 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, in particular those with high content of non-condensable gases (NCGs).

CH1.5.5 Methods, processes, equipment and materials to ensure the steady availability of the geothermal resources and improve the performance of the operating facilities

CH1.5.6 Development of 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.

CH1.5.7 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.

CH1.5.8 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.

Challenge 1.6 Bioenergy

Biomass provides 67% of the total primary energy production of renewable energy in the EU-28, offering sustainable electricity, heat and transport fuels. An increase is needed especially within aviation and marine fuel, but also in biobased 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 (See ETIP Bioenergy SRIA)
- 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

Challenges identified

CH1.6.1 Sustainable carbon for the globe

In the Circular Bio-Economy fossil carbon is left in the ground while aboveground 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 material 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.

CH1.6.2 Integration of 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 (long haul, jet fuels and marine fuels)

Challenge 1.7 CCUS

Expected outcome

This 7-year partnership is crucial to set a commercially viable basis for the industrial-scale deployment of CCS and CCU technologies, reducing costs of the technology 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.

Identified challenges

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.

CH1.7.1 Getting the commercial framework right
(see also 13.3.6 and 13.3.7.)

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.

CH1.7.2 Accelerating timely deployment at scale of CCS and CCU technologies
(see also 13.1, 13.2, 13.3.4, 13.3.5)

- 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 & intensification (e.g. AI-driven process control, machine learning for catalyst development)

CH1.7.3 Driving costs down – through R&I, learning by doing and economies of scale
(see also 13.3.1, 13.3.2)

- 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

CH1.7.4 Enabling rapid scale-up to deliver on the climate goals
(see also 13.3)

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

CH1.7.5 Enabling EU citizens to make informed choices regarding the benefits that CCS and CCU bring
(see also 13.3.7)

- 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.

CH1.7.6 Production, optimisation and integration of blue hydrogen with CCUS

Europe's goal of a hydrogen economy can be met cost-effectively when considering technology research and innovation for synergistic production, optimization, and integration of green and blue hydrogen into the energy system. Blue hydrogen provides a path for upscaling Europe's hydrogen infrastructure and thus helps to overcome challenges for the large-scale uptake of a green hydrogen value chain in Europe.

- Explore the transition and synergies between green and blue hydrogen production (natural- and biogas reforming, capture technologies)
- Hydrogen as energy carrier to enable the decarbonisation of the heating/cooling of the building stock, transport sector, power sector and other industrial processes and facilities
- Integrate hydrogen and CO2 capture facilities in industrial sites and clusters
- Condition liquid hydrogen for safe transport and storage, and exploit synergies with CO2 transport and storage

Challenge 1.8 Ocean Energy

The following Challenge Areas represent a set of R&I fields that the ocean energy sector has identified as most worthy of investment during the next period of 4-5 years. Design and validation of ocean energy devices have the highest priority.

Identified challenges

CH1.8.1 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.

CH1.8.2 Foundations, 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

CH1.8.3 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.

CH1.8.4 Integration 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?

Challenge 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 wind and solar power plants, and store excess energy when variable renewables generate more than needed.
- 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.

Challenges identified

CH1.9.1 Increased flexibility from Hydropower plants:

- This includes research on; fatigue and lifetime on 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, CAES etc.

CH1.9.2 Utilization and expansion of European hydropower's storage capacity:

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

CH1.9.3 Markets and services for hydropower's capabilities:

- Ability to use and expand hydropower's capabilities in the energy transition requires research on develop models of 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.

CH1.9.4 Sustainable 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.

CH1.9.5 Sediment handling:

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

Relation to cross-cutting issues:

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.

Cross sectional: Hydropower can mitigate climate change and must be seen together 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.

Challenge 1.10 Solar thermal heating & cooling

The European Solar Thermal Technology Panel (ESTTP), part of the European Renewable Heating and Cooling Technology and Innovation Platform (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 GW_{th}.and thermal energy storage capacity equivalent to 180 GWh_{th}.

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.

This will be possible thanks to:

- 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.

Identified Challenges

CH1.10.1 Solar District Heating (SDH)

District heating and cooling is a powerful vector to integrate renewable and excess heat/cold and use it to supply homes, offices and even industries. The potential of solar thermal in district heating (DH) is clearly being demonstrated in some 200 SDH systems across Europe. The demand on district heat that can be covered by solar heat combined with seasonal storage is by far the biggest untouched potential for use of solar heat.

Large storages can store thermal energy from summer to winter. With the installation of seasonal storage pit solar thermal can provide the base load heat for many of the 6000 heat networks in Europe – from Helsinki to Leipzig and Madrid. Drake Landing in Canada is an example on how communities can have 100% of their heating from solar thermal using seasonal storage.

District cooling is currently at a low level of distribution only at rather few cities but with a great potential for expansion. Cooling is emerging massively by climate effects and increasing comfort demands. While today most district cooling systems are powered by waste heat or environmental heat combined with electric driven heat pumps, solar heat is today only used on campus level in cold water grids.

CH1.10.2 Solar Heat for Industrial Processes (SHIP)

According to IRENA, 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).

Solar heat for industrial processes (SHIP) is at an early stage of development but is considered to have huge potential for solar thermal applications. Currently, concentrating solar heat systems (CSH) reach temperatures of 400°C and even above. They may directly supply steam systems by injection. 635 operating solar thermal systems for process heat are reported in operation worldwide. The total gross area of the 301 documented systems which are larger than 50 m² is 905,000 m² gross and the thermal capacity is 441 MW_{th}.

Continuous process management, which can be achieved through innovative process technology and which makes the use of renewable energies at low temperature level possible, would lead to further significant reduction of the energy input and can be defined as a future long-term goal. In Europe, the size of SHIP (solar heat for industrial process) installations, is growing every year. Until 2018, the largest SHIP plant in Europe was 2MW, since then new plants became operative and reached 12MW.

The reasons for the low growth rates are mainly commercial and market related issues, namely the need for demonstration of the technology in diverse industrial heat processes, as a way to gain confidence from industrial clients and demonstrate the performance and reliability of such solutions.

In addition, alternatives for the future carbon neutral industrial heat supply, such as hydrogen or power-2-heat, are substantially more expansive. While the named solutions are of utmost importance for total decarbonization SHIP has lower costs for specific decarbonization for suitable solar shares.

CH1.10.3 Solar thermal use in buildings

In EU households, heating, and hot water alone account for 79% of total final energy use. 84% of heating and cooling is still generated from fossil fuels while only 16% is generated from renewable energy sources. Around 70% of the EU population lives in privately owned residential buildings.

Solar thermal are a 100% renewable energy (RE) solutions both in existing and in new individually heated & cooled buildings (residential and others) that are not possible to connect to district heating and cooling (DHC) grids due to limited existence (e.g. some southern European countries) or are difficult to connect to DHC grids, e.g. due to either its remoteness (in rural areas), or due to its low energy demand (new, low-energy buildings or passive houses).

Solar thermal systems used at building level, either residential or commercial, cover space, water heating, and solar cooling applications. These are the most common solar thermal systems, ranging from thermosyphon solar water heaters of 1.4 kW_{th} very common in Greece, or more efficient compact and forced solar water heaters in South Europe, to combi-systems for space and water heating between 7 and 14 kW_{th} in single family houses, popular in central Europe to larger systems (up to 500 kW_{th}) in multifamily houses or even bigger ones for commercial uses. The integration into buildings and nZEB/Passive-house 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.

CH1.10.4 Financing/business models for solar thermal

Solar thermal applications need a substantial scale up in size, to make a clear impact in the upcoming renewable energy mix. Applications such as large scale (1-100MW) Solar District Heating (SDH) and Industrial Process Heat (SHIP) can replicate the successes of Solar PV utility scale, provided they can profit of advanced project financing tools and methods, much the same way they have been deployed in large scale PV. This technology is expected to provide a substantial contribution in the future energy mix as showed in the graph below, but additional financing tools and new business models are needed to achieve this goal.

3.2 100% climate-neutral heating and cooling

100% climate-neutral heating and cooling in 2050 will be supported by development of the following sub-challenges:

Challenge 2.1 Towards 100% renewable heating and cooling of individual buildings

- 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.

- 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 district (see 2.1.2).
- A third aspect is the more **seamless integration of renewable energy technologies** in the urban environment, such as building integrated PV, 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.

Challenge 2.2 Heating/cooling in climate-neutral Energy Districts

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.

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

- **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.
- 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.
- 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 (cfr. 2.1.1).
- Organise **experimental facilities** such as regulatory sandboxes, testbeds, and living labs to develop, text, implement and monitor innovative solutions faster. Low-regulation zones can be an important enabler to test new tariff schemes, social acceptance and market design.

Challenge 2.3 Next generation of District heating and cooling systems

District heating 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:

- 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.
- 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.
- **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).

- 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.

Challenge 2.4 Towards 100% renewable industrial heating

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

The challenge for research and innovation 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. The road towards climate-neutral industrial heating and cooling requires innovations and demonstrations in the different topics:

- 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.
- 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 energy efficiency.
- 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.
- 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.

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 research and innovation 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.

3.3 System Integration[2]

The European target to reach, by the year 2050, a low-carbon, secure, reliable, resilient, accessible, cost-efficient, and market-based pan-European integrated energy system supplying all of society and paving the way for a fully carbon-neutral circular economy[3] can be achieved through a progressive moving away from fossil sources. Renewable energy sources, starting from 13% of the total energy consumption in 2015, will need to reach 25% in 2030, and exceed 60% in 2050. The electrification of Europe's energy systems (residential, tertiary, industry, agriculture and transport sectors) will be the backbone of its societies and markets, embodying full digitalization and flexible electricity interconnections.

The integration of such high shares of variable renewables will require significant energy system optimization, relying on strong flexibility options and better balancing capacities, such as interconnections at all grid levels, storage capacity, demand response, low-carbon flexible generation units (e.g. geothermal, biomass) and effective

[2] The structure of the challenges are taken from Section 3 (instead of Section 2) from the respective Input Paper
[3] ETIP SNET Vision 2050

energy conversion (PtX) options and integration of different energy vectors (electricity, gas, heating/cooling, water etc.).

The path towards the achievement of the functionalities of a fully decarbonized energy system requires a vast range of RD&I activities, to cope with multiple challenges across technology, markets, adoption/transition, legislative, regulatory and societal frameworks[4]. Among all possible views, the challenges for the development of the integrated energy system are discussed in the following according to the approach adopted in the Set Plan IWG4.

Challenge 3.1: Develop an optimised integrated European energy infrastructure

Develop the **European integrated energy infrastructure**, where electricity distribution and transmission grids are seen as the "backbone" of the future low-carbon energy systems with a high level of integration among all energy carrier networks, by coupling electricity networks with gas, heating and cooling networks, supported by energy storage and power conversion processes[5]. Such energy systems will be fully-digitalised, with a high level of automation. They will enable the appropriate level of reliability, resilience and economic efficiency, while integrating variable renewables, such as wind and solar generation by providing increased flexibility thanks to innovative technologies enhancing customer participation, integrating better storage, making the best use of connections with other networks (e.g. heat and cold, transport) and optimising the use of flexible sustainable combined power and heat generation.

A system approach is needed to guide research and innovation activities in view of designing and developing the adequate portfolio of solutions. The optimised energy system must enable a greater flexibility and effective capacity of the electricity system which, in turn, allows connecting effectively and efficiently an ever-increasing share of variable renewables (wind and solar) and coping with new consumption profiles coming, for instance, from electric vehicles. Conversely, system flexibility can be reached in several ways: upgrading of the entire electricity value chain (generation, transmission, distribution and customers, and energy storage), reinforcing / creating new links with other energy networks, via for example power to heat/cold, power to gas / liquid and connections with the electrical components of the transport network and increasing the capabilities of RES through the improvement of their predictability and mechanism development for the future systems network services.

Leveraging the indications of the ETIP SNET Roadmap 2020-2030 and the Set Plan IWG4 Implementation plan (revision), the RD&I activities needed to address this challenge are organised into the following clusters:

- **System planning: developing the seamlessly integrated energy system of the future[6]**: design and planning of the Integrated Energy System overcoming the silos among energy vectors. Necessary approaches and tools to plan and analyse the Integrated Energy System under all perspectives: from scenario setting based on reliable and transparent hypothesis, parameters and relations down to integrated and complete planning tools, addressing holistically an energy system where all vectors interact and foster one another.
- **System flexibility: robust and clean energy transition pathways[7]**: needs, solutions, and tools to ensure the adequate level of flexibility to cope with all the uncertainties and variabilities of the progressively Integrated Energy System. The flexibility issues addressed in this research area embrace the entire energy system: generation (conventional and renewable), energy storage (electricity, gas, heating/cooling, water), networks (e.g. applications of FACTS in the electricity networks, enhancement of electric networks transfer capacities or gas pressure dynamics, including the contribution of energy storage in all forms (e.g. electrochemical, pumped and reservoir hydro, compressed air etc.), the interaction with non-

[4] The research journey identified for the period 2020-2030 by the ETIP SNET, addressed in its Roadmap 2020-2030, and adopted in the Set Plan IWG4 Implementation Plan (revision), will enable the implementation of the system functionalities needed along the path towards the full decabonisation of the energy system by 2050. The approach is deemed valid also in the context of the "system integration" chapter of the CETP SRIA.

[5] This is a rephrasing of the definition of Flagship n.1 - SET Plan Action 4 Implementation Plan, 2018

[6] Research Area RA4 of the ETIP SNET Roadmap 2020-2030 – Planning – holistic architectures and assets

[7] Research Area RA5 of the ETIP SNET Roadmap 2020-2030 – flexibility enablers and system flexibility

electrical energy vectors (gas, heating, cooling, water, hydrogen, carbon neutral fuels) and conversion (P-t-X);

- **System operation: operational integration of integrated energy systems**[8]: Tools and systems for the development of the overall energy system control architecture (central and decentralized) and optimal operation of the integrated energy system under progressively increasing variabilities, constraints and uncertainties, also linked with extreme events and climate changes. Tools and devices for system observability, through advanced monitoring, control and protection, leveraging the advanced forecasting capabilities in all sectors
- **Economics: market design and regulation for an integrated energy system**[9]: business models, market design, governance and operation linked with the energy system, its opportunities and constraints. Market design for an integrated energy system taking a holistic approach (as opposed to defining optimal market design for separate energy vectors) and taking into account the specifics of different energy vectors so that cost-effective decarbonisation of the EU economy can be achieved.

Challenge 3.2: Develop Integrated Local and Regional Energy Systems

Develop integrated **regional**[10] **and local energy systems,** composed of locally and regionally available energy sources, built infrastructure, specific production and consumption characteristics as well as user and consumer structures from different sectors, including e.g. the transportation system. Such systems shall make it possible to efficiently provide, host and utilise high shares of renewables, up to and beyond 100% in the local or regional supply by 2030. They shall provide tailor-made solutions that meet the local and regional requirements and demand for solutions, including highly ambitious clean energy goals of specific communities and regions. At the same time, they shall link to a secure and resilient European energy system, enabling the participation in inter-regional exchange of energy as well as in sharing responsibility to maintain the overall system, considering a sustainable use of local and global resources. In this framework, complementing the approach developed in the first dimension, focus is given to technologies and solutions for decentralised energy systems, boosting digitalisation and associated business models as well as current societal trends. In that respect, regional and local innovation ecosystems and value chains play a very important role ."[11].

Regional and local energy systems and networks are composed of locally and regionally available energy sources, built infrastructure, specific production and consumption characteristics as well as user and consumer structures from different sectors, including the transportation system. Particular attention is driven to the living environment of citizens, including, in some cases, highly ambitious clean energy goals of specific communities and regions. In its "Clean Energy for All Europeans" legislative proposals, the EC particularly highlights specific drivers and elements of regional and local energy systems. Regional and local energy systems will have to cope with a fundamental transformation, responding to actual drivers such as the increasing uptake of new and improved technologies for decentralised energy systems, the boosting digitalisation and associated business models as well as current societal trends.

Leveraging the indications of the ETIP SNET Roadmap 2020-2030 and the Set Plan IWG4 Implementation plan (revision), the RD&I activities needed to address this challenge are organised into the following clusters:

- **Consumer, prosumer and energy communities**[12]**:** the complex relation of the consumer and prosumer (be it an individual, a community, a commercial user, an industry) with the energy system; is 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.
- **Economics, market design and regulation**: The business models for the different actors, products and services applicable to the local energy system (electricity, gas, heating/cooling, carbon neutral fuels, water, etc.) along its value chain: i.e. generation, transport, data analytics/mining conversion, storage,

[8] Research Area RA6 of the ETIP SNET Roadmap 2020-2030 – System operation
[9] Research Area RA2 of the ETIP SNET Roadmap 2020-2030 – System economics
[10] In this context „regional“ refers to subnational regions
[11] This is a rephrasing of the definition of Flagship n.2 - SET Plan Action 4 Implementation Plan, 2018
[12] Research Area RA1 of the ETIP SNET Roadmap 2020-2030 – Consume, prosumer and citizen energy communities

metering, delivery, prosumers, energy conservation and use etc. , the development of market services, allowing for participation in the development of local and regional value chains leveraging synergies by building on digital platforms accounting for security, privacy requirements and trade-offs; design of local energy markets considering neighbourhood, aggregated, retail, peer-to-peer market of energy products and services (flexibility, ancillary services, electricity, gas and heating/cooling, water etc.);

- **System planning;** planning, considering jointly the development of different types of networks and vectors (electricity, heating & cooling, gas, water, transport), considering synergies and mutual efficiency enhancements, cost-effective flexibility means along the value chain also in view of maximum RES integration at regional and local levels;
- System flexibility. needs, solutions, and tools to ensure the adequate level of flexibility to cope with all the uncertainties and variabilities of the progressively Integrated Energy System as seen from a local perspective. With special reference to DHC networks: flexibility can be obtained through technologies, systems and solutions able to minimise the mismatch between the load and supply profiles of alternative heat sources (incl. power-to-heat), reducing the use of fossil fuels in peak load and winter times and avoiding supply competition in summer times. These solutions may increase the short (hours to days) and long (weeks to months) term flexibility of district heating networks, improve the costs–benefit ratio of storage options and/ or improve the customer side integration in case of building side flexibility options.

Challenge 3.3: System modelling as a fundamental tool for the integrated energy system development

The energy sector is so complex, the factors shaping the transition so divers, the risks and possibilities so vast, that computer models are an inevitable tool for understanding many of the decisions that are to be made. At the same time, the current modelling toolbox is outdated. Currently the modelling results at national level do not yet provide sufficiently detailed energy transition models pathways which tailor to the regional/national needs: it is hard for national modelling exercises to replicate and complement the Clean Planet for All outcomes in a bottom-up exercise using more specialized grid or market models or increased detail in building stock or industrial process data. There is a strong need for an instrument for connecting bottom-up national modelling exercises to the consistent European model results, and explore the consistency and feasibility of different national strategies. Modelling these national/trans-national pathways consistently with the EU vision is an important challenge which can provide a basis for a futureproof industrial investment strategy, infrastructure investment strategy for utilities, and a robust set of national policies.

Advanced modelling tools need to be developed which are tailor made to the national/transnational needs. An important aspect of the innovative model development is the inclusion of cross-border energy flows, selection of consistent transnational scenarios and a very extensive data collection exercise. If the energy system modelling capability is structurally improved, benefits will be:

- Accurate estimates of investment requirements and infrastructure needs for the energy transition;
- Better consistency between national regulations with respect to carbon pricing and the ETS system;
- Reduced investment uncertainty in industries and utilities;
- Enhanced dialogue and exchange of expertise between industrial partners, policy makers, research centres, and utilities;
- Enhanced exchange of modelling expertise between different member states.

3.4 Storage and Fuels

Overview of identified challenges

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 using 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 (LCA)). Relevant drivers to determine the need and benefit of energy storage and fuel technologies are 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

The thematic priority focuses on the development of cost-effective, integrated storage and fuel systems and will support 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. This leads to the following energy vector clusters taking into account mentioned requirement dimensions in section 2 into Heating and cooling, Electric grids, biomass and fuels, cross-sectoral and hybrid solutions. Without doubts, a holistic system perspective is required to find optimal solutions and combinations of different energy storage and fuel technologies covering the different vectors. Topics such as system integration (Cluster 4) as well as cross-cutting issues (Cluster 6), such as environmental impacts, circular economy and digitalization are summarized in chapter 2.1 and are highlighted for those challenges where they are of high importance.

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

The development of thermal energy storage (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.

The challenge is broken down in the following Sub Challenges (SC):

- SC1 - Development of large-scale underground TES
- SC2 - Development of cost-effective large-scale TES in man-made constructions (tank- and pit thermal storages etc.)
- SC3 - Development of low temperature, mid- to long-term small TES
- SC4 - Large-scale day-to-month TES at temperatures > 120°C

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

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.

The challenge is broken down in the following Sub Challenges (SC):

- SC1 - Development of reliable and cost effective electrochemical technologies for long term electricity storage
- SC2 - Increase the European hydro-power potential for energy storage
- SC 3 Support of conventional power generators through storage technologies

Challenge 4.3 Renewable Fuels

Renewable 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.

The challenge is broken down in the following Sub Challenges (SC):

- SC1 - Production of advanced biofuels/bioenergy from sustainable biomass
- SC2 - Integrated bio-fuels and bioenergy production solutions with Power to Gas (e.g. biogas upgrading) and CCUS

- SC3 - Thermochemical Solar Fuels
- SC4 - Electrochemical Solar Fuels (sunlight direct conversion)

Challenge 4.4 Development of Cross-sectoral and hybrid energy storage solutions

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. Challenge 4 aims to obtain carbon-free, breakthrough technologies for integrated hybrid solutions[KT35] covering multiple time scales and sectors allowing an optimal exploitation of renewable energy sources.

The challenge is broken down in the following Sub Challenges (SC):

- SC1 - Development of Hybrid energy storage solutions
- SC2 -Development of reliable and cost effective P2X technologies for fuels and gas
- SC3 -Development of integrated decentralized energy storage solutions

Challenge 4.5 System integration and cross-cutting issues for energy storage

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 (see Cluster 4 Input Papers).

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 (see Cluster 6 Input Paper) 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.

The challenge is broken down in the following Sub Challenges (SC):

- SC1 - Assessment of the potential solutions for energy storage and fuels in a holistic approach for a CET
- SC2 - Optimized lifespan of storage systems and the failure modes, including stochastic cycling profiles, CAPEX, OPEX, efficiency and environmental impact

3.5 Cross-Cutting challenges

(This part takes input from cluster input papers 1, 2, 4 and 6)

Overview of identified challenges

A number of cross-cutting issues are central in the energy transition. This is natural, as the energy system plays a key role in the transition of other sectors in society like transport, the built environment and industry. The integration of a number of renewable, storage and low emission technologies into a distributed but still reliable and resilient energy system where consumers play a central role requires multidisciplinary approaches including research that is technological, techno-economic, socio-technical and environmental. The energy transition will take place in the facets between these dimensions. That is reflected in the cross cutting challenges described here focusing on challenges that aims to enable and speed up the transition towards a net zero society:

- Identifying robust pathways as alternative strategies towards a net zero society
- How to accelerate the transition through innovation ecosystems
- The regulation and market design to support optimal resource allocation and value creation both in the short term and long term.
- Policy and actions in support of fair, just and democration transition
- Encouraging digitalization of the energy transition processes
- Encouraging transition based on resource efficiency and circularity principles

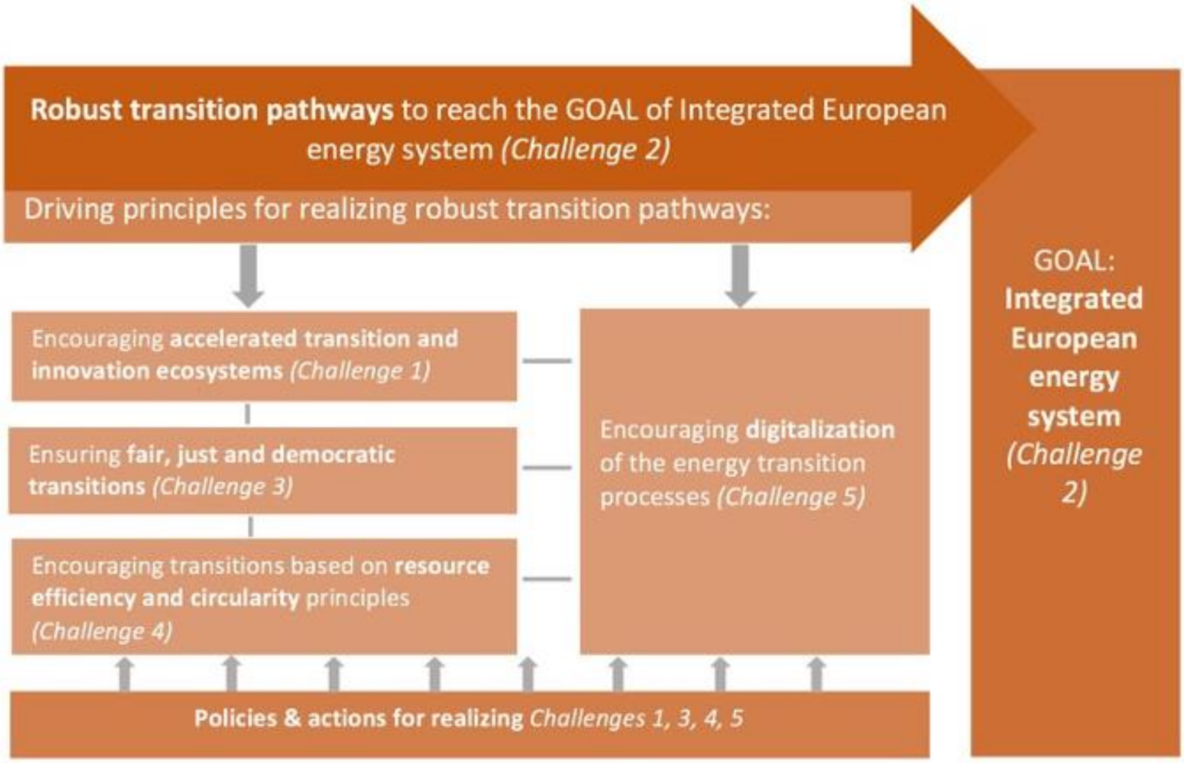

Figure 2: Connection between different cross-cutting energy transition challenges

Challenge 5.1 Robust transition pathways for an integrated European energy system

(compiled from input papers of cluster 4 and 6)

This challenge concerns methodology and analysis in support of the energy transition by focusing on transition pathways. 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. This in turn requires the integration of energy infrastructures across borders between energy vectors and from European to local level.

From a methodological perspective this requires the capacity to address pathways with sufficient detail of the energy system both in terms of geographical resolution, the integration of energy vectors and the role of humans and new ways of life. It also requires the ability to aggregate this to consistently aggregated and map this to the European level. Pathway analysis combines quantitative model scenarios and qualitative storylines based on social sciences, aimed at establishing consistent and holistic pathways including technology choice, sector coupling, timing of investments, policy measures, environmental aspects and socio-technical issues. The CETP may become an ideal instrument for connecting bottom-up national modelling exercises to the consistent European model results, and explore the consistency and feasibility of different national strategies. Pathways should provide a basis for a futureproof industrial investment strategy, infrastructure investment strategy for utilities, and a robust set of national policies.

CH5.1.1 Presenting pathways to support the energy transition for Member states and at the EU policy level. These analyses provide support at all relevant policy levels from EU to local, processing questions related to; *European leadership in the transition*; *Robust and feasible strategies*. *Utilizing and respecting regional differences*: *Recognize how technology acceptance and energy citizenship should shape policy creation and implementation; Fair and inclusive transition ; Macro-economic aspects and competitiveness*; *Environment and health* and the *impact of enabling technologies* .

CH5.1.2 Developing the models and methodologies to support the energy transition, combining modelling and social sciences. This scientific challenge is not only 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.

CH5.1.3 Managing uncertainty in the long-term planning of the integrated energy system. Modelling and simulating complex integrated energy systems with sufficient operational detail and links between technologies and between the system and people.

CH5.1.4 Establishing open platforms for sharing data and models in support of the energy transition.

Impact 1: Identification of robust strategies for arriving at the net zero society in 2050, while respecting intermediate socio-economic and environmental objectives.

Impact 2: Frameworks for analysing the transition in a holistic and consistent way, respecting both technological feasibility, socio-economic aspects like welfare, fairness, justice democracy and environmental targets.

Impact 3: Research based knowledge supporting both private and public decision makers in the energy transition.

Challenge 5.2 Accelerated transition and innovation ecosystems

(compiled from the cluster 6 input paper)

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 as 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 and (ii) full integration of local sustainable energy resources. 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. (iii) An integrated view on industrial policy, climate policy and energy policy

The overall challenge is aligning transition and industrial goals to mobilize businesses and legitimize transition policies, while at the same time de-legitimizing unsustainable practices.

CH5.2.1 Identifying included and excluded actors driving and hampering the energy transition, developing cooperation models. The energy transition shifts power structures between the existing actors, and creates new roles (i.e. prosumers, energy cooperatives).

CH5.2.2 Co-create and reinforce local and regional stakeholder innovation ecosystems, supporting their integration with global value chains. Diverse groups of stakeholders from local communities, industry and public sector need to be involved in this action.

CH5.2.3 Developing Societal Readiness Levels (SRL) assessment framework and corresponding funding structures. Social reality needs to be better connected to the technological development to ensure timely transition policy implementation. SRL assessment methods need to be developed and connected to TRL leading to TRL-SRL assessment framework.

CH5.2.4 Setting-up policy, regulatory and standardization frameworks for accelerated innovation using experimental regulatory mechanisms. This action focuses on creating the mechanism to address the bottlenecks preventing boosting socio-economic impacts of the energy transition (e.g. regulation for businesses integrating several energy vectors, permits of energy supply and production, fiscal incentives and tariffs, health, safety and security regulation).

CH5.2.5 Building capacity for Interdisciplinary education and cross-sectoral training. This action includes 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.

CH5.2.6 Creating networks of energy transition demonstration sites and activities to achieve synergies between innovation activities in the different member states and regions.

Impacts

- Boosting the potential for European leadership in value and welfare creation from the energy transition.
- Creating regulatory and standardisation frameworks capable of being the backbone of the energy transition
- Empowering and supporting key energy transition actors

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

(compiled from input papers for clusters 1, 2, 4 and 6)

The ultimate goal of market design and regulation for an integrated energy system is to achieve the necessary coordination between all energy vectors to achieve the most 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. Both the investment and the operational decisions of market parties, consumers and network operators are to a large extent guided by financial incentives, regulation and legal constraints.

Infrastructure development and operation are guided by national, sectoral regulation. The mono-sectoral, national focus needs to be integrated in order to develop the European energy infrastructure of the future. Market design for an integrated energy system needs to take a holistic approach (as opposed to defining optimal market design for separate energy vectors) 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.

CH 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? 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.

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

CH 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?

CH 5.3.4 Design and operate the digital market infra-structure supporting empowerment for citizens, the industry, and the public sector.

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

CH 5.3.6 Innovative pilots and demonstrators. New market instruments can best be tested in pilots. 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.

Impact: Support for creating policy, governance structures, regulation and markets consistent with the net zero society and the objectives in the Green Deal.

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

(compiled from input paper for cluster 6)

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 are beneficiaries and losers of particular transition strategies, (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.

CH 5.4.1 Defining justice and fairness applied for clean energy transitions policies. Stating more clearly justice and fairness dimensions based on existing knowledge (e.g. energy justice pillars: distributive, generational, procedural, recognition justice).

CH 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.

CH 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).

Impact 1. Transforming the role of energy consumers/prosumers/energy citizens in designing and implementing clean energy transition solutions.

Impact 2. Supporting local economies and fair jobs creation while transitioning to a carbon-neutral energy system in the EU.

Impact 3. Securing technological leadership in Europe without compromising ethical, social and environmental justice performance.

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

(compiled from input paper for cluster 6)

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, increased component/device lifetime, 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.

CH 5.5.1 Sustainable materials choice and extraction

- Make technologies work with acceptable raw materials.
- Develop environmentally friendly and circular extraction technologies
- Produce life cycle datasets on innovative materials, secondary raw materials and technologies, based on primary data representative of the European context

The third point is a cross-cutting challenge that is crucial for an informed evaluation of the actual life cycle and its impact for all technologies.

CH 5.5.2 Redesign installations/components/devices for energy generation/storage/conversion/distribution aiming to reuse and recycle parts and materials

- Develop advanced/innovative materials solutions and fabrication processes to increase lifetime/efficiency and facilitate reuse/recycling.
- Develop advanced recyclable materials/sustainable processes of use for groups of energy technologies, e.g. high temperature & corrosion resistant structural materials.
- Develop common tools and methodologies to accelerate materials development.
- Develop common standards for materials testing and characterisation.

Except the first point, which is technology-specific and in fact referred to in the corresponding technology sections, the others are truly cross-cutting challenges, at least for clusters of technologies, which are best addressed through demonstration actions.

CH 5.5.3 Monitoring and optimisation of installations, components and devices for energy value chains and systems

- Development and optimisation of NDE techniques.
- Development of data-driven and/or physical models of materials degradation.

These are also largely cross-cutting issues, also best addressed through demonstration actions.

CH 5.5.4 Energy flow optimisation based on pilots and demonstrators or feasibility studies studying:

- Energy cascading
- Waste heat recuperation
- Intelligent hybrid systems

This challenge connects 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 also heat.

CH 5.5.5 End-of-life considerations. Sustainable dismantling and disposal of installations/components/devices for energy generation/storage/conversion/distribution

- Enable or optimise recycling of a wider spectrum of materials.
- Identify possibilities of reuse/recycle through different technologies.
- Regulate safe disposal for parts/materials that cannot be recycled.
- Design appropriate legal and regulatory frameworks that incentivise reuse and recycling and circularity in general.
- Develop life cycle datasets of end-of-life processes.

The last point is crucial for an informed and correct evaluation of the actual impact on CO_2 emissions and environment in general of the life cycle of the different technologies, including a proper economic evaluation. It links to the third point in subchallenge 1.

Impacts:

- Outputs generated and planned: 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.
- Impact with respect to Clean Energy Transition: ensure 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.

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

(compiled from input paper for cluster 6)

Digitalization is affecting all types of economic sectors. For the CETP SRIA purpose, it is quite important to understand the Digital Transformation can play a fundamental role to support and accelerate the Energy Transition. 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.

The following research activities have been identified:

CH5.6.1 Energy-relevant data collection, interpretation, diffusion for achieving reliable, complete, and transparent (open access) information for decision and policy making and enabling citizen decisions (citizen empowerment).

CH5.6.2 Intelligent (artificial intelligence driven) generation, distribution and storage of energy (renewable electricity, carbon-free gas, heating/cooling). For optimal use of resources, cost minimization, possibility of citizens to decide from where to take energy, new business model for interaction with citizens, better market integration in Europe; help to better design relevant legal frameworks, energy systems robustness, or avoidance of failures.

CH5.6.3 (Online) monitoring (through sensors) of materials and components, digital twins for the simulation of their behaviour. 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)

CH5.6.4 Digitalization as enabler of industry 4.0, advanced and automated materials and component manufacturing and processing

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.

CH5.6.6 New business models, new human interaction. For avoiding disruption of the transition and achieving citizen empowerment (prosumers).

Impact. 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.