European Commission

ETIP SNET

R&I Roadmap 2022 – 2031

ETIP SNET

European Technology and Innovation Platform

Smart Networks for Energy Transition

ETIP SNET R&I Roadmap
2022-2031

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Acronyms

Active Demand	(see Demand Side Response)
Advanced Meter Management (AMM)	software that performs long-term data storage and management for the vast quantities of data delivered by smart metering systems.
Advanced Metering Infrastructure (AMI)	is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between utilities and customers.
Aggregator	Data Responsible who aggregates according to a defined set of market rules, e.g. of power generating modules, demand units and/or reserve providing units.
Alternating current (AC)	an electric current which periodically reverses direction.
Ancillary services	a service necessary for the operation of an electricity transmission or distribution system to support the electric power from seller to purchaser given the obligations of control areas and to maintain reliable operations of the interconnected electricity system.
Application Program Interface (API)	is a set of routines, protocols, and tools for building software applications. Basically, an API specifies how software components should interact. Additionally, APIs are used when programming Graphical User Interface (GUI) components.
Artificial Intelligence (AI)	Algorithms emulating the intelligence of human brain
Asset	an asset is something valuable or useful. Tangible assets are fixed such as buildings, equipment etc.; an asset is part of a TSO operator control area or located in a distribution system.
Balance Responsible Party (BRP)	means a market participant or its chosen representative responsible for its imbalances in the electricity market.
Balancing Service Providers (BSP)	in the European Union Internal Electricity Market, this is a market participant providing balancing services to its Connecting TSO, or in case of the TSO-BSP Model, to its Contracting TSO.
Blockchain	a system in which a record of transactions made in bitcoin, or another cryptocurrency are maintained across several computers that are linked in a peer-to-peer network.
Carbon-neutral	situations where the energy system consumes as much CO2 as it emits; the CO2 balance is equal to zero.
Capital Expenditures (CAPEX)	budget spent to buy or upgrade fixed assets
Citizen	use for people who value the development of smart grids as an opportunity to realise “We-centred” needs or motivations, e.g. affiliation, self-acceptance or community. Citizens want to help ensure the quality of supply and support environmental preservation and the community.
Cogeneration	simultaneous production of electricity and useful heat. In a regular power plant, the heat produced in the generation of electricity is lost, often through the chimneys. But in a cogeneration plant it is recovered for use in homes, businesses, and industry. A tri-generation plant, or Combined Cooling, Heat and Power (CCHP), produces cooling (air conditioning) as well as heat and electricity.
Combined Heat and Power (CHP)	is an energy efficient technology that generates electricity and captures the heat that would otherwise be wasted to provide useful thermal energy—such as steam or hot water—that can be used for space heating, cooling, domestic hot water and industrial processes.
Common information model (CIM)	is an open standard that defines how managed elements in an IT environment are represented as a common set of objects and relationships between them.

Consumer	Role of the energy user for electricity, heat and chemical energy (e.g. gas) classified in industrial consumers, consumers providing transport systems, consumers for a commercial entity or commercial building and residential consumers.
Contingency	an event (such as an emergency) that may but is not certain to occur. In power systems, a contingency is when an element such as a transmission line or a generator, or the electric grid fails.
Conversion technology (-ies)	any system that converts energy from one form to another (e.g. electricity, heat, work, and motion).
Customer / End-user	an end-user of energy.
Cybersecurity	Cybersecurity all mechanisms and processes for guaranteeing the integrity of the operation of computer systems in the event of attacks and malfunctioning.
Demand side flexibility	The capacity to change electricity usage by end-use customers (including residential) from their normal or current consumption patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in organised electricity markets or for internal portfolio optimisation.
Demand Side Response (DSR) / Active Demand	is a change in the power consumption of an electric utility customer to better match the demand for power with the supply. It is the capacity to change electricity usage by end-use customers (including residential) from their normal or current consumption patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in organised electricity markets or for internal portfolio optimisation
Digital twin	refers to a digital replica of physical assets, processes and systems that can be used for various purposes e.g. simulation and modelling. The digital representation provides both the elements and the dynamics of how an Industrial Internet of Things device operates and lives throughout its life cycle including continuous digital predictions through machine learning and artificial intelligence.
Direct current (DC)	is the unidirectional flow of electric charge.
Distributed system	systems that are installed at or near the location where the electricity is used, as opposed to central systems that supply electricity to grids. A residential photovoltaic system is a distributed system.
Distribution/ Transmission System Operators (DSO/TSO)	role for operating distribution/ transmission grids of electricity supply, who plans, builds and maintains distribution/transmission infrastructure responsible for grid access and integration of renewables, grid stability, load balancing and connections to grid users (generators and consumers) at distribution/ transmission grid level. Furthermore, a DSO/TSO is responsible for its interconnections with other systems and to ensure the long-term ability of the system to meet reasonable demands for the distribution/ transmission of electricity or gas.
Electric Vehicle (EV)	A vehicle equipped with electric motor for propulsion.
Electromagnetic Fields (EMF)	An electromagnetic field is created by moving electric charges
End-user	(see Consumer)

Energy Community / Citizen energy community / Local Energy Community (LEC)	a legal entity where citizens, SMEs and local authorities come together, as final users of energy, to cooperate in the generation, consumption distribution, storage (such as batteries, hot water, (CO2-neutral or free) gases), supply, aggregation of energy from renewable sources, or offer energy efficiency/ demand side management services.
Energy Management Systems (EMS)	A modular system that manages power stations and the network
Energy storage	system domain for appliances and assets storing energy within the group energy consuming units
Energy systems	electricity, gas, heating and cooling, liquid fuel systems, and other energy carriers (any system or substance that contains energy for conversion as usable energy later) are all considered “energy systems”.
Flexible AC Transmission / Distribution Systems (FACTS/FACDS)	is a system composed of static equipment used for the AC transmission / distribution of electrical energy. It is meant to enhance controllability and increase power transfer / distribution capability of the network. It is generally a power electronics-based system.
Gas to Heat (GtH)	combustion of gases to generate heat.
Gas to Power (GtP)	combustion of gas to generate electricity.
Gas to Power and Heat (GtP&H)	combustion of gases to generate at the same time and with high efficiency electricity and heat.
General Data Protection Regulation GDPR	(EU) 2016/679 (GDPR) is a regulation in EU law on data protection and privacy in the European Union (EU) and the European Economic Area (EEA). It also addresses the transfer of personal data outside the EU and EEA areas.
Green gas	is gas derived from the processing of organic waste or is hydrogen produced by renewable electricity from water.
Geographic Information system (GIS)	framework for the management and analysis spatial and geographic data
Grid to vehicle (G2V)	smart charging of s (see Smart Charging).
Hierarchical control	is a form of control system in which a set of devices and governing software is arranged in a hierarchical tree.
High Level Use Case (HLUC)	A HLUC represents the practical realisation-related dimension to achieve the integrated energy system needs of the year 2031
High voltage (HV)	usually considered any AC voltage over approximately 35,000 volts.
Holistic Architecture	Holistic energy system architectures facilitate all processes which are necessary for a reliable, economic and environmentally- friendly operation of integrated smart energy systems with multiple energy carriers, having electricity grids as its backbone.
Information technology (IT)	is the use of computers to store, retrieve, transmit, and manipulate data or information.

Institute of Electrical and Electronic Engineers (IEEE)	here intended as standardisation body.
International Electrotechnical Commission (IEC)	here intended as standardisation body.
Internet of Things (IoT)	is a system of interrelated computing devices, mechanical and digital machines provided with Unique Identifiers (UIDs) and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
Interoperability	the ability of two or more networks, systems, devices, applications, or components to interwork, to exchange and use information in order to perform required functions.
Levelised Cost Of Electricity (LCOE)	is a measure of a power source that allows comparison of different methods of electricity generation on a consistent basis. The LCOE can also be regarded as the minimum constant price at which electricity must be sold in order to break even over the lifetime of the project.
Liquid to Power (LtP)	Combustion of liquid fuel to generate power.
Load Frequency Control (LFC)	is used to allow an area to first meet its own load demands, then to assist in returning the steady-state frequency of the system to the nominal value.
Load shifting	shifting large electrical loads from high-demand peak times to times where generation and shifted load match better.
Low-carbon	situation where the CO2 balance (i.e. emissions vs sinks) is almost zero.
Low voltage (LV)	usually refers to AC voltages from 50 volts to below 1,000 volts.
Machine to Machine (M2M)	is direct communication between devices; it can include industrial instrumentation, enabling a sensor or meter to communicate the information it records to application software that can use it.
Machine Learning (ML)	the scientific study of algorithms and statistical models that computer systems use to perform a specific task.
Medium voltage (MV)	usually refers to AC voltages between 1,000 volts to 35,000 volts.
Multi-access Edge Computing (MEC)	a network architecture concept that enables cloud computing capabilities and an IT service environment at the edge of the cellular network and, more in general at the edge of any network.
Near Zero Energy Building (NZEB)	a building with zero net energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site or in other definitions by renewable energy sources offsite.
Net Transfer Capacity (NTC)	the maximum total exchange program between two adjacent control areas compatible with security standards applicable in all control areas of the synchronous area and taking into account the technical uncertainties on future network conditions.
On load tap changer (OLTC)	is a tap changer in applications where a supply interruption during a tap change is unacceptable.
Operational Expenditures (OPEX)	OPEX is the cost for operating a product, business, or system

Organic Rankine Cycle (ORC)	is a type of power plant using, instead of conventional (water/steam) an organic, high molecular mass fluid with a liquid-vapor phase change, or boiling point, occurring at a lower temperature than the water-steam phase change.
Overhead Transmission (OT)	Electric power transmission through overhead power lines
Phasor Measurement Unit (PMU)	is a device used to estimate the magnitude and phase angle of an electrical phasor quantity (such as voltage or current) in the electricity grid using a common time source for synchronisation
Phase Shifting Transformer (PST)	is a specialised form of transformer used to control the flow of active power on three-phase electric transmission lines.
Point of Common Coupling (PCC)	the point at which the interconnection between the public utility's system and the interconnection customer's equipment interface occurs.
Power Electronics (PE)	is the application of solid-state electronics to the control and conversion of electric power.
Power Quality (PQ)	involves voltage, frequency, and waveform. Good power quality can be defined as a steady supply voltage that stays within the prescribed range, steady AC frequency close to the rated value, and smooth voltage curve waveform (resembles a sine wave).
Power system stability	is the ability of an electric power system, for a given initial operating condition, to regain a state of operating equilibrium after being subjected to a physical disturbance, with most system variables bounded so that practically the entire system remains intact.
Power to Gas (PtG)	conversion of electrical power to a gas fuel. As an example of such conversion, electricity is used to split water into hydrogen and oxygen using the electrolysis principle, where hydrogen can then be converted to methane with CO2 as input.
Power to Heat (PtH)	conversion of electrical power into heat/cooling. The conversion can be done for example by using conventional electric heaters or heat pump systems.
Power to Gas and Heat (PtG&H)	conversion of electrical power to both gas and heat/cooling at the same time.
Power to Liquid (PtL)	process consisting in generating a synthetic liquid fuel by using renewable electricity, carbon dioxide from the atmosphere or other sources, and water.
Power to Water (PtW)	use of electrical power to pump water into higher-up hydro reservoirs and hydro dams for energy storage.
Priority Project Concept (PPC)	Projects covering all integration features of the Future Energy Systems with concrete goals and time schedule.
Prosumers	consumers of all types (households, tertiary, industry, transport and agriculture sectors) who also produce energy. Prosumers can be active market participants by engaging in the real-time control of their energy-consuming and producing devices.
Reliability	all the measures of the ability of the system, generally given as numerical indices, to deliver electricity to all points of utilisation within acceptable standards and in the amounts desired.
Renewable Energy Sources (RES)	energy derived from natural processes that are replenished constantly. In its various forms, it derives directly from the sun, or from heat generated deep within the earth. Included in the definition are electricity and heat generated from solar, wind, ocean, hydropower, biomass, geothermal resources, and biofuels and hydrogen derived from renewable resources.

Resilience	ability of the system with generating sources, transmission and distribution, conversion – to withstand high-impact, low-frequency events. This includes events that are natural, such as hurricanes or ice storms, as well as man-made, such as cyber or physical attacks on e.g. grid infrastructure.
Scalability	capability of being easily expanded as larger service or more powerful product, e.g. to include more participants, a higher load or more RES
Security of Supply	the capability of a power system at a given moment in time to perform its supply function in the case of a fault
Small And Medium size Enterprise (SME)	Enterprises with less than 50 employees and less than 50M€ turnover.
Smart Charging	charging system where electric vehicles, charging stations and charging operators share data connections. Through smart charging, the charging stations may monitor, manage, and restrict the use of charging devices to optimise energy consumption.
Smart Grid	an electricity network that can intelligently integrate the actions of all actors connected to it – operators of storage capacity (such as of batteries, (CO2-neutral or free) gases and liquids), generators and consumers – in order to efficiently deliver sustainable, economic and secure electricity supplies (European Technology Platform SmartGrids, 2010).
Smart Metering	the technology of recording usage in real time from metering devices and providing a two-way communication and/or control path extending from energy network to customer appliances
Smart Transformer / Solid State Transformer / Intelligent Transformer	a power transformer which transfers power between power networks at two voltage levels (usually corresponding to MV and LV levels) by using power electronics ("solid state") and an internal power transformer operating at high frequency; it has usually also internal DC busbars, possible extensions of electrical energy storage and has local control which allows a flexible and smart power exchange between the two power grids. Smart Transformers are considered as an enabling technology in the future distribution grids.
State of Health (SoH)	is a figure of merit of the condition of an asset, e.g. a battery (or a cell, or a battery pack), compared to its ideal conditions
Subsidiarity	The subsidiarity principle means that energy systems are operated in such a way that actions are optimised locally (at the most immediate level). Actions that cannot be handled locally are handled at the next level.
System architecture	a set of conventions, rules, and standards employed in a computer system's technical framework, plus customer requirements and specifications, that the system's manufacturer (or a system integrator) follows in designing (or integrating) the system's various components (such as hardware, software and networks).
Ten Years Network Development Plan (TYNDP)	provides an overview of the European electricity transmission infrastructure and its future developments and maps the integrated network according to a range of development scenarios.
TOTal EXpenditures (TOTEX)	CAPEX (Capital Expenditures) + OPEX (Operational Expenditures)
Transmission System Operators (TSO)	see DSO / TSO
V2G	feeding power and energy from the vehicle battery to the grid at the connection point.

Virtual power plant (VPP)	is a cloud-based distributed power plant that aggregates the capacities of heterogeneous distributed energy resources (DER) for the purposes of enhancing power generation, as well as trading or selling power on the electricity market.
Vulnerability	the openness to attack or damage.
Water to Power (WtP)	is power derived from the energy of falling or fast-running water; in the future also from waves.
Web of cells (energy cell)	compound comprehensive smart energy systems with subsidiary structures on the basis of decentralised generation and storage as well as decentralised, automated energy management in autonomously steered energy systems, which are able to run temporarily autarkic, e. g. in the case of failures.
Wide Area Measurement System (WAMS)	is technology to improve situational awareness and visibility within power system of today and future grids. It uses real time synchro phasor data to measure the state of grid that enables improvement in stability and reliability of power grid.

Executive Summary

Context

By 2050, the extensive electrification in (nearly) all sectors of the energy system, combined with significant energy efficiency improvements and CO2 reductions in all sectors, will led to a carbon-neutral energy system. It is widely understood that this will rely on:

- The massive use of renewables for electricity, transport and heating & cooling generation;
- Smart Grids technologies (Digitalisation and Smart control of flexible generation and demand, sustainable buildings);
- The combination of the above with sector coupling of all energy carriers via storage (such as batteries, by use of liquids (e.g., hydro pumping), CO2-neutral or CO2-free gases) and conversion technologies (for extensive use of carbon-neutral gases and green fuels and possibly hydrogen in industry, transport and buildings);
- A widely adopted circular approach to energy systems with high recycling rates.

To support Europe's energy transition by guiding and identifying research and innovation R&I priorities addressing the innovation challenges for the energy system, ETIP SNET publishes and updates three types of documents that consolidate the views of more than 350 stakeholders:

- The **ETIP SNET VISION 2050** (published in 2018) which provides a detailed description of this future with a set of goals to reach by 2050,
- The **ETIP SNET R&I Roadmap (RM)** which describes the 10-year path towards this future and is regularly revised. The current version covers the 2022-2031 time horizon.
- The **ETIP SNET R&I Implementation Plan (IP)**, which describes in more detail the most urgent R&I needs for the next 3-4 years and is currently revised every 2 years. The current version, published in 2021, covers the 2022-2025 time horizon.

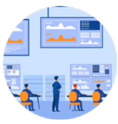
These paths are not linear for every energy system and integration goals identified for 2050. Some of the tasks and associated R&I projects will need to be deployed and implemented before others (prerequisites). Others - still- will only need to be prepared or demonstrated later, towards 2030, so that their deployment can be done between 2030 and 2040, for sure before 2050.

Approach for building the ETIP SNET R&I Roadmap 2022-2031

The ETIP SNET has introduced the concept of High-Level Use Cases (HLUC) and the associated Priority Project Concepts (PPCs) to better communicate to its key audiences, i.e., the European Commission (EC), national governments, associations and R&I community, institutes of technologies, universities, research centres and labs, etc. Indeed, by using and defining HLUCs, the ETIP SNET intends to underline the urgency of realising the transformation of today's energy system through concrete R&I projects into the needed widely renewable energy system of 2031 and the fully CO2-neutral energy system of 2050 as the ultimate goal. This is connected with concrete outcomes and scopes for real-world demonstrations.

The R&I Priority Projects Concepts (PPCs) for each of HLUC cover key integration features of the Future European Energy Systems with concrete goals and time schedule. Nine HLUCs – each valid for the next 10 years (until 2031) - are used to structure in this ETIP SNET R&I Roadmap 2022-2031 the needed R&I Priority Project Concepts.

Table 1: HIGH LEVEL USE CASES to be realised for the Integrated European Energy System by 2031

	**HLUC 1: Optimal Cross sector Integration and Grid Scale Storage**	identifies the value and realises the integration of monitoring and control, regulatory frameworks, cross-sector resilience, infrastructure design of integrated storages of all kinds with multi-energy systems (including hydrogen- and CO2-neutral gases based) and their assets.
	**HLUC 2: Market-driven TSO–DSO–System User interactions**	identifies the market models and architectures, the governance and realises them as business cases so that an integrated, full-system control and operation for both TSOs and DSOs results. HLUC2 also develops corresponding platforms with TSO and DSO planning tools.
	**HLUC 3: Pan European Wholesale Markets, Regional and Local Markets**	identifies and validates the fundamental market designs and regulatory frameworks, develops IT systems for real-time balancing and the cross-border trading.
	**HLUC 4: Massive RES Penetration into the transmission and distribution grid**	identifies technical barriers and develops measures for handling massive RES with their control and operation and related infrastructure and their functioning with RES-based markets, policies and governance. HLUC4 also develops planning tools with the goal of high system resiliency.
	**HLUC 5: One stop shop and Digital Technologies for market participation of consumers (citizens) at the center**	identifies the value of consumer/customer engagement and develops easy to use, standardised, communicating and (cyber-) secure-by-design solutions for them. HLUC5 contributes to consensus creation beyond electricity-related consumer solutions going into heating, cooling and EV sectorial uses.
	**HLUC 6: Secure operation of widespread use of power electronics at all systems levels**	identifies, simulates with digital twins and then realises control solutions for PV integrated with batteries and their inverters thereby considering transition path to hybrid AC/DC electricity grids, adapted distribution substations, HVDC multi-terminal configurations and their standardisation.
	**HLUC 7: Enhance System Supervision and Control including Cyber Security**	identifies and realises adapted TSO and DSO Control Room needs including new monitoring, control, protection and measurement technologies, their interfaces also to the grid operators and their standardisation. From that, HLUC7 develops the adapted requirements for grid operators and grid fields workforces.
	**HLUC 8: Transportation Integration & Storage**	identifies implications of the transport sector decarbonisation, how electromobility supports resilient energy system operation together with policy adaptations. HLUC8 also identifies market adaptations for seamless merging of transport and energy sectors including their integrated planning.
	**HLUC 9: Flexibility provision by Building, Districts and Industrial Processes**	identifies the value of buildings, of smart communities for control and operation of a RES-based energy system, including their integrated planning, market and governance adaptation needs.

Budget of the ETIP SNET R&I Roadmap 2022-2031

The budget proposal for the ETIP SNET R&I Roadmap 2022-2031 is presented in Figure 1. ETIP SNET assumes that a similar relative budget distribution is justified for the R&I Roadmap 2022-2031 as in the ETIP SNET R&I IP 2022-2025. Taking into account that the ETIP SNET R&I Roadmap 2022-2031 concerns four or more IPs, it is justified to take a factor of slightly more than 4 times the IP 2022-2025 budget for the 10-year time frame budget yielding total R&I budget needs of 4500 million EUR for the 10-year period.

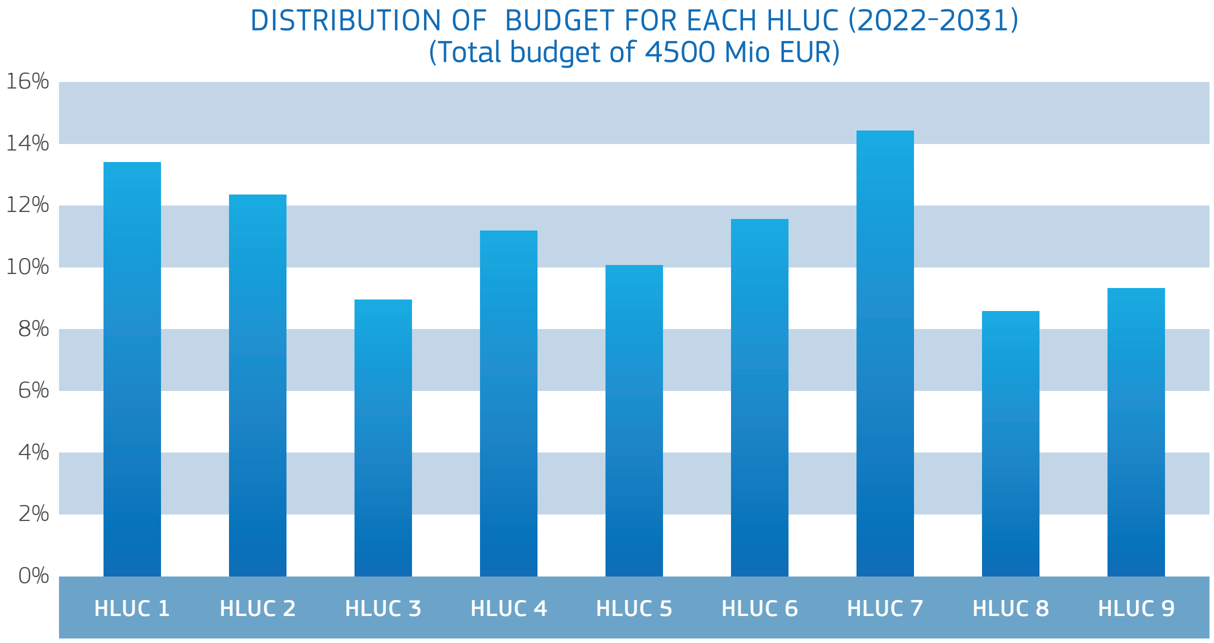


Figure 1: Distribution of budget for R&I projects of each HLUC in the 10-year time frame 2022-2031

1
Introduction

The ETIP SNET R&I Roadmap 2022-2031, together with several detailed Implementation Plans (the already published "2022-2025", the "2025+" that will be issued in in 2023 and the forthcoming "2026+"), outlines the framework in which the European energy system shall be developed along the path toward the goal of full decarbonisation by 2050. In particular, it focuses on achieving the intermediate goals of 2031, identifying the PPCs that need to be structured and funded during the next decade and preparing for the further steps towards 2040 and 2050. It has been agreed by extensive consultations among the more than 350 ETIP SNET experts representing the EU energy stakeholders.

The ETIP SNET's goal is the definition and the creation of incentives for publicly co-funded research and demonstration of the integration related to all pieces of an up to 100% Variable Renewable Energy System by 2031, which maintains cost-efficiency, security and resiliency.

This ETIP SNET R&I Roadmap shall also support the EC and national authorities in the process of building national and regional R&I Roadmaps aligned with the EU priorities and the definition of deployment instruments..

The ETIP SNET R&I Roadmap is further detailed in the periodic R&I Implementation Plans (IPs), that focus on the most urgent R&I needs for the next 3 to 4 years and are regularly revised every 2 years. These documents should be used as accompanying documents to this Roadmap. The most recently published IP covers the period 2022-2025.

This publication is structured as follows. After the introduction of Chapter 1, Chapter 2 describes the evolution of the European energy system towards 2031. This part overviews the EU Climate and Energy policies published since the previous ETIP SNET R&I Roadmap 2020-2030, which yield impacts on the future integrated energy system. These impacts are used to identify 9 High-Level Use Cases (HLUC) of the integrated energy system by the year 2031.

Chapter 3 describes the methodology followed to derive the High-Level Use cases (HLUCs) and the Priority Project Concepts (PPCs) that form the structure of the ETIP SNET R&I Roadmap and Implementation Plans. It also provides the main sources we have used to update these documents.

Chapter 4 describes in detail the 9 HLUCs, including the involved actors, the energy sectors covered, the high-level goals, the main technical challenges, the current status and the expected outcomes at the end of the current ETIP SNET R&I Roadmap timeframe. It also provides an overview of the relevant PPCs, that are further analysed in the current and future ETIP SNET R&I Implementation Plans.

Chapter 5 provides an estimation of the 10-year budget required for the ETIP SNET R&I Roadmap divided among the various HLUCs and years. This estimation takes into account the increased weight of the demonstration activities required for project outcomes that have reached a high TRL level.

Annex I summarises the Research Areas that have been used to structure the previous Roadmap 2020-2030: They were used as starting points for the new structures of HLUCs (High Level Use Cases) and PPCs (Priority Project Concepts) in this ETIP SNET R&I Roadmap 2022-2031.

2

Evolution of European Policies towards the Integrated Energy System 2050

The European Union has committed, in compliance with the engagements undersigned within the Paris agreement, to undertake action to keep global warming of the planet well below 2°C above preindustrial levels. According to Intergovernmental Panel on Climate Change (IPCC), reaching this goal is still possible if action is taken urgently, so that net zero global greenhouse gases (GHG) emissions are reached by 2070, and negative emissions characterize the rest of the century. In order to avoid temperature overshoot above the objective and to minimize the amounts of net negative emissions[10] necessary by the end of the century, net zero GHG emissions must be globally reached already by 2050, i.e well before 2070. Through the communication "European 2050 Low Carbon Economy Roadmap"[11] the European Commission demonstrated that the target is achievable and affordable, in the appropriate context, to reduce domestic EU GHG emissions by 80% by 2050 compared to 1990, with an intermediate milestone of reducing by 40% by 2031. The energy system has a major role to play in this context, not only for its potential to rapidly lower its own emissions, but also to compensate residual GHG emissions from other sectors, less prone to a full decarbonisation and to correct for possible temperature overshoots.

In line with this approach, the ETIP SNET has issued a Vision 2050 which considers "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 by the year 2050, while maintaining and extending global industrial leadership in energy systems during the energy transition".

Europe has, since long, been a global leader in this context, confirming through real policy and action, its strong attention towards the global picture when setting its own climate action targets. The EU climate and energy policies contributed significantly to global action and awareness on climate change, adopting proactive measures and demonstrating how to address the challenge. Between 1990 and 2017, data indicate a total emission decrease of 22%, while the EU's combined GDP grew by 58%[13,] which implies an actual decoupling between economic.

2.1 EU policies on the way to the Paris objectives

The first energy and climate policy package that explicitly addressed the urgency for emissions reduction is the 2020 Climate and Energy package[1] which in 2007 has set a three-level target – 20% reduction in GHG emissions (from 1990 levels), 20 % of EU energy from renewables and 20 % improvement in energy efficiency. These targets were in 2009 enacted in legislation together with a set of legal acts to ensure the EU meets its climate and energy targets for the year 2020. Furthermore, Renewable Energy Directive[2] and the Energy Efficiency Directive[3] have set national binding targets for renewable energy and energy efficiency measures. Since then Europe has been put on a transition towards a low-carbon economy, which in the last decade has been asking for increased digitalisation and electrification of the energy system. The energy sector has, in fact, been an early adopter of digital technologies, using them to facilitate grid management. The third Energy Package, adopted in 2009, put forward smart meters – a building block for the digitalisation of the electricity grid – as enabling technologies for more efficient and sustainable use of energy. At the same time, there has been increasing awareness that digital technology deployment entails active participation of consumers, though this should be accompanied by an assessment of the associated societal implications to guarantee early identification of the challenges and opportunities that the use of digital technologies could present for EU consumers' living conditions[4,5,6,7,8] .

Strategic roadmaps, based on a consistent analytical framework, have been developed and were instrumental in setting the EU on track with the United Nations agenda, setting 2030 targets and exploring the long-term perspective. Since the publication of the 2017-2026 ETIP SNET R&I Roadmap, a series of outstanding documents reshaping the European legislative framework has been published, such as the "2030 Climate and Energy Framework", updated in 2020 and the first European Climate Law – a framework for achieving climate neutrality by 2050.

1 https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2020-climate-energy-package_en
2 Directive (EU) 2018/ 2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
3 Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency
4 European Commission. 2015b. "Commission communication — Delivering a New Deal for Energy Consumers (COM/2015/339)", Brussels
5 European Commission. 2019. "Commission communication — The European Green Deal (COM/2019/640)", Brussels
6 European Commission. 2020a. "Commission communication — Shaping Europe's digital future (COM/2020/67)", Brussels
7 European Commission. 2020b. "Commission communication — Powering a climate-neutral economy: An EU Strategy for Energy System Integration (COM/2020/299)", Brussels
8 European Commission. 2020c. "Commission communication — Europe's moment: Repair and Prepare for the Next Generation (COM/2020/456)", Brussels

2.2 Clean energy for all Europeans

The Clean Energy for all European package proposal, which was published in 2016, consists of a set of legal acts underlying the 5 dimensions of the Energy Union – security, solidarity and trust, a fully integrated internal energy market, energy efficiency, climate action decarbonising the economy and research, innovation, and competitiveness. It is composed primarily of the following legal acts:

- Energy efficiency first principle[9] – Energy Efficiency Directive (EU) 2018/2002
- Making EU buildings more efficient – Energy Performance of Buildings Directive (EU 2018/844)[10]
- Global leadership on renewables[11] – Renewable Energy Directive (2018/2001/EU)
- A robust governance system for the Energy Union[12] – Regulation on the Governance of the Energy Union and Climate Action (EU) 2018/1999
- Electricity market design – with 4 new elements: Electricity Regulation (EU) 2019/943[13]; Electricity Directive (EU) 2019/944[14]; Regulation (EU) 2019/941 on risk preparedness and Regulation (EU) 2019/942[15] on outlining stronger role for Agency for the Cooperation of Energy Regulators (ACER)[16].

All these legal acts have set the path towards larger-scale integration of renewable energy into the system, more active and empowered customers and more cost-efficient operation and planning of the electricity system. They also validate the need for additional network hosting capacity to accommodate growing capacity of renewable power sources, but also deployment of smart grid infrastructure to monitor and control associated distribution grid imbalances and to enable demand-side flexibility. More specifically, to be able to cost-effectively integrate renewable energy into the electricity system, additional investments in various sources of flexibility (e.g. demand response and flexible generation) are needed[17] . Furthermore, energy efficiency needs to be considered in the energy system planning and energy efficiency and demand-side response can and should compete on equal terms with generation capacity. [Directive (EU) 2018/2002 on energy efficiency].

Also, the Renewable Energy Directive further strengthens the role of renewables self-consumers and renewable energy communities. Renewables self-consumers are empowered to generate, consume, store, and sell electricity without facing disproportionate burdens, including without liability for any double charge, including network charges, for stored electricity remaining within their premises. Also, final customers (such as households), are entitled to participate in a renewable energy community, while maintaining their rights or obligations as final customers.

On a similar note, the Electricity Directive (EU) 2019/944, as part of the Clean Energy for all European package, empowers the role of active energy customer by recognising certain categories of citizen energy initiatives at the Union level as citizen energy communities. This way it offers an inclusive option for all consumers to have a direct stake in producing, consuming, or sharing energy within an enabling framework allowing for a level playing field and fair treatment.

All the above calls for a more active DSO, including a closer cooperation between DSOs and TSOs and definition of products and services to be procured by both system operators. In view of this, the Electricity Directive sets the path towards a more active DSO, by defining a set of additional tasks for the DSO, among which the one of 'a neutral market facilitator in procuring the energy it uses to cover energy losses in its system in accordance with transparent, non-discriminatory, and market-based procedures' [Electricity Directive (EU) 2019/942]. Furthermore, the DSOs is encouraged to procure non-frequency ancillary services for its system needs using market-based approaches. To be able to do so and facilitate innovation, in general, adequate regulatory frameworks, including regulatory experimentation (e.g. regulatory sandboxes) need to be put in place.

To strengthen the transition towards a more active DSO, the Electricity Regulation (EU) 2019/943 endorses the establishment of the EU DSO entity (established in 2021) with one of its tasks to 'facilitate demand-side flexibility and distribution grid users' access to markets' and 'to facilitate the integration of renewable energy resources, distributed generation and other resources embedded in the distribution network such as energy storage.' The EU DSO Entity represents the DSOs regarding the development of network codes and guidelines.

9 Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency
10 Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings
11 Directive (EU) 2018/ 2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources
12 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R1999&from=EN
13 Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity (recast)
14 Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU (recast)
15 Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC
16 Regulation (EU) 2019/942 of the European Parliament and of the Council of 5 June 2019 establishing a European Union Agency for the Cooperation of Energy Regulators (recast)
17 Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency

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

This legislative package leverages the work of the EU Commission reported in the Communication COM (2018) 773 "A clean Planet for all – A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy"[18] and the "In depth analysis in support to the Communication"[19], both issued in November 2018. This package presented the EU Commission long-term strategy on how Europe can lead the way to climate neutrality, by investing into realistic technological solutions, empowering citizens and aligning action in key areas, such as industrial policy, finance and research, while ensuring social fairness for a just transition.

In the frame of a comprehensive sectoral and economy-wide analysis of the low-carbon and energy transformation pathways, the Energy supply is one of its central pillars. More specifically, the Carbon Capture and Use options, the electricity and heat sectors and the new energy carriers and storage technologies are elements of "sector coupling", i.e. the linking of the energy (electricity, gas and heat), transport and industrial infrastructures. They show –together with storage - the potential to make the energy transition faster and more cost-effective.

This integration will build on the interdependency of the energy transformation sectors (power, heating, new fuels production) with industry, mobility, buildings and the energy-using activities. It will allow the effective integration of the variable, non-programmable RES, that will be the predominant energy sources after 2031 – where digitalisation and development of a regulatory framework fit-for-purpose are identified as key factors for its success.

The EU Communication document "A clean Planet for all" analyses transition "enablers": The technology development (both new carbon-neutral fuels and energy efficiency) is the main enabler for the transition, while the costs and the large-scale technology deployment constraints are the main challenge. The most important single driver for the transition to a de-carbonized energy system is the growing role of electricity, both in the supply of alternative fuels and in the final uses. This will imply, however, a paradigm shift, from electricity production following demand to a largely meteorologically driven generation. Storage will be also a key enabler, both at a central level and distributed for flexible consumers. The significant increase in power generation capacity and the development of energy-related infrastructures will make the spatial planning –and the necessary citizen and local authorities' engagement- another key element of the transition.

2.4 Delivering the European Green Deal

In December 2019, the European Commission adopted the European Green Deal – an ambitious plan setting up the pathway for EU climate neutrality by 2050, including an intermediate target of 'at least 55 % net reduction in greenhouse gas emissions by 2030'. It is seen by the European Commission as overarching strategy but also a growth strategy towards decarbonising the European economy, create growth and jobs with less resources, including energy and thus, make a sustainable future for the coming generations.

Actions for decarbonisation of the energy sector to deliver the EU Green Deal include large-scale integration of RES and electrification of the industry, transport, and the building sector. Most of this electrification and growing integration of RES will take place in the distribution grids. To further support this, in 2020, EU adopted the policy document 'shaping Europe's digital future[20] as part of the EU Digital strategy, which highlights the importance of the twin challenge of green and digital transformation to support the implementation of the EU Green Deal. To this end, the European Commission has adopted an EU action plan on the digitalisation of the energy sector to ramp up investments in digitalising the EU's electricity infrastructure, with a flagship proposal to create a "digital twin" of the electricity grid by 2023.

The EU action plan on digitalising the energy system[21] will contribute to end the EU's dependence on Russian fossil fuels and tackle the climate crisis. Digitalisation of the energy sector my modernising access to markets, established of competitive, transparent and easy choices for consumers and by that innovative pricing and tariffs is key to help consumers save on their bills. Smart buildings, smart meters and electric vehicles, Internet of Things devices provide key information that allows the monitoring of energy consumption, increase renewables integration into existing energy systems. Innovative data services, apps, and energy management systems together with adequate policy support measures create a large potential for energy users. It will bring benefits to consumers by developing new data-driven services to allow them inter alia to better manage their energy consumption, share electricity they generate with their neighbours or sell it back to the market. However, it comes with an increased risk of cyberattacks. To this end, enhancing cybersecurity is one of the five focus areas indicated in the proposal of the European Commission's action plan on the digitalisation of the energy sector.

18 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773&from=EN
19 https://knowledge4policy.ec.europa.eu/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en
20 https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/shaping-europe-digital-future_en
21 https://ec.europa.eu/commission/presscorner/api/files/document/print/en/qanda_22_6229/QANDA_22_6229_EN.pdf

In parallel, coordinated planning and operation of the energy system 'as a whole', across multiple energy carriers, infrastructures, and consumption sectors – an EU strategy called energy system integration, adopted in 2020[22] – paves the way towards an effective, cost-efficient, and affordable decarbonisation of the European economy.

The most recent EU Fit for 55 package[23] embraces revision of Europe's climate, energy and transport-related legislation' in order to align current laws with the 2030 and 2050 ambitions. As part of this package, and for Europe to be able to deliver the EU Green Deal[24], the EU Emission Trading System (ETS) Directive[25], the Renewable Energy Directive[26] and the Energy Efficiency Directive[27] have been proposed for a second revision to align with the EU's increased climate ambition. A revision of the EU ETS Directive was proposed by the European Commission in view of achieving climate neutrality in the EU by 2050, including the intermediate target of an at least 55% net reduction in greenhouse gas emissions by 2030. In addition, the EU Climate Law (EU Regulation 2021/1119[28]) establishes the framework for achieving climate neutrality by 2050.

Both proposals, for a revision of the Renewable Energy Directive, and for a revision of the Energy Efficiency Directive reiterate the importance and value of demand-side flexibility and stress the role of national regulatory frameworks to enable and incentivise market-based approaches to procurement of flexibility and balancing, including participation of households and electric vehicles, both directly or through aggregation.

In view of the electrification of the transport sector and as part of the Fit for 55 package, the proposal for Regulation for the Deployment of Alternative Fuels Infrastructure[29] recognizes value of electric vehicles in providing flexibility to the energy system. As a result, it sets mandatory infrastructure targets for the electric vehicle fleet which will be primarily connected at distribution level, but also it empowers National Regulatory Authorities to assess the 'contribution of EVs to the flexibility of the energy system'. On the other hand, DSOs are responsible to assess the flexibility needs in preparation of their network development plans, while consulting all interested parties.

2.5 REPowerEU: A plan to rapidly reduce dependence on fossil fuels and accelerate the green transition

The European Commission's plan REPowerEU takes a stance on the recent geopolitical and energy market realities and calls on EU Member States to accelerate the clean energy transition and increase Europe's energy independence. Supported by a set of financial and legal measures, it aims to accelerate the twin green and digital transition and make sure that people are at the heart of the recovery. The plan rests on three pillars – accelerated roll-out of renewable energy, energy savings and diversification of supplies.

SAVING ENERGY

Energy savings can be the quickest and cheapest way to address the current energy crisis and reduce energy bills. The Commission proposes to enhance long-term energy efficiency measures, including an increase from 9% to 13% of the binding Energy Efficiency Target under the 'Fit for 55' package of European Green Deal legislation. To this end, the 'EU Save Energy Communication'[30] details short-term behavioural changes which could cut gas and oil demand by 5% building on 1) immediate energy savings through voluntary choices and 2) accelerating and strengthening structural, mid- to long-term energy efficiency measures. The REPower plan also provides a series of incentives for energy saving, such as reduced VAT rates on energy efficient heating systems, building insulation, appliances, and products.

DIVERSIFYING ENERGY SUPPLIES ALSO BY SUPPORTING EUROPE'S INTERNATIONAL PARTNERS

To achieve this, the EU has created the EU Energy Platform[31], supported by regional task forces to enable voluntary common purchases of gas, LNG and hydrogen by pooling demand, optimising infrastructure use and fostering new strategic partnerships, as outlined in the EU external energy engagement strategy.

22 European Commission. 2020b. "Commission communication — Powering a climate-neutral economy: An EU Strategy for Energy System Integration (COM/2020/299)", Brussels
23 https://www.consilium.europa.eu/en/policies/green-deal/fit-for-55-the-eu-plan-for-a-green-transition/
24 https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_en
25 https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets_en
26 https://energy.ec.europa.eu/topics/renewable-energy/renewable-energy-directive-targets-and-rules/renewable-energy-directive_en
27 https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en
28 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32021R1119&from=EN
29 https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A52021PC0559
30 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A240%3AFIN
31 https://energy.ec.europa.eu/topics/energy-security/eu-energy-platform_en

ACCELERATING THE ROLLOUT OF RENEWABLES

Renewable energy in power generation, industry, buildings, and transport would need to significantly scale-up to accelerate Europe's energy independence, give a boost to the green transition, and reduce prices over time. To this end, the Commission proposes to increase the 2030 target for renewables from 40% to 45% under the Fit for 55 package. To achieve this, the REPowerEU plan aims to double the deployment rate of heat pumps and solar rooftop panels, the latter facilitated by the recent EU solar strategy. Furthermore, REPowerEU has set out specific measures to tackle permitting issues – one of the greatest bottlenecks for fast deployment of renewables. To help in decarbonising the industry, the focus will be on developing green hydrogen.

2.6 The energy system transition towards 2050 – electricity as a dominant energy carrier

The Covid-19 pandemic resulted in a major disturbance of the world economy, leading to an unprecedented 5.8% decline in CO2 emissions in 2020. However, this figure started to climb again by the end of 2020, in parallel with renewed economic growth, at least in the near term[32].

Achieving climate neutrality by 2050 requires a wide range of policy approaches and technologies. Energy efficiency, behavioural change, electrification, massive deployment of renewables, hydrogen and hydrogen-based fuels, bioenergy and carbon capture, utilisation, and storage are seen as key pillars to decarbonize the global energy system[33].

Additionally, the current geopolitical crisis has pushed energy security to the forefront of the EU Governments concerns and reaffirmed the urgency of reconciling EU energy security and climate policy to accelerate the delivery of the EU Green deal. This is at the heart of the most recent EU policy document, the REPowerEU – a plan to ensure energy independence and fast forward the green transition. It reaffirms EU commitments to climate neutrality by 2050 and propose measures to accelerate the implementation rate of actions to respond to this ambition. This has been embedded in the EU 2050 long-term strategy[34] and the European Climate Law[35], adopted last year. The first European Climate Law provides a legal framework to ensure that all legislation and financial flows are consistent with the climate-neutral pathway and sets the intermediate target of reducing net greenhouse gas emissions by at least 55% by 2030, compared to 1990 levels.

The recently released European Commission's report State of the Energy Union 2022[36] take stock of the current geopolitical and energy crisis and reports the progress made at Union level towards meeting the climate and energy objectives of the Energy Union, among which the following:

- The EU energy efficiency and renewable energy targets set for 2020 were surpassed, while Final energy consumption and primary energy consumption were 5.4% and 5.8% lower than the 2020 targets, respectively. The EU share of renewable energy in gross final energy consumption, reached 22.1%, thus exceeding the 20% target set under the 2009 Renewable Energy Directive37. EU generated a record 12% of its electricity from solar from May to August 2022 and 13% from wind. Nevertheless, drought-related low water levels in rivers and reservoirs led to a decrease of hydroelectricity production from 14% to 11% in summer 2022 compared to previous years.
- The share of renewables in the electricity mix is expected to continue growing from 37% in 2021 to 69% in 2030. However, permitting procedures, grid integration issues and difficulties in the supply chains remain one of the greatest bottlenecks to accelerate the integration of RES.

In 2020, nuclear power plants generated around 24.6%[37] of the total electricity produced in the EU. Nevertheless, EU nuclear output is expected to temporarily decline until the end of the decade[38] due to nuclear fleet is ageing and until new investments take place.

Solar PV shows to be the leading renewable technology – early indications suggest that 2022 will be a record year for the European solar PV market with annual deployment growth in the largest EU Member State markets between 17-26%.

All new buildings will be able to optimise their solar energy generation potential in view of the ongoing revision of the Energy Performance of Buildings Directive (EPBD), with the aim to fully decarbonise the European building stock by 2050. Intermediary measures include setting of a minimum energy performance standards to trigger energy efficient renovation of buildings increasing the rate of renovations by 2030, phasing-out fossil fuel-based heating, and maximising the potential for solar energy in buildings.

32 Global Energy Review: CO2 Emissions in 2020, Understanding the impacts of Covid-19 on global CO2 emissions, https://www.iea.org/articles/global-energy-review-co2-emissions-in-2020
33 https://www.iea.org/reports/net-zero-by-2050
34 https://climate.ec.europa.eu/eu-action/climate-strategies-targets/2050-long-term-strategy_en
35 https://climate.ec.europa.eu/eu-action/european-green-deal/european-climate-law_en
36 https://energy.ec.europa.eu/report-state-energy-union-2022_en
37 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Nuclear_energy_statistics#Nuclear_heat_and_gross_electricity_production
38 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Nuclear_energy_statistics#Nuclear_heat_and_gross_electricity_production

Similarly, the IEA Roadmap[39] indicates reduction of the total energy supply by 7% between 2020 and 2030 in the Net Zero Emissions scenario and remains at around this level to 2050. Solar PV and wind become the leading electricity generation technology globally before 2030 and together they account to nearly 70% of global generation in 2050[40].

In view of the above, the supply for all energy system needs is nearly decarbonised by 2050 – with electricity being the main and most efficient energy carrier and it will need to be coupled with other energy sectors. To this end, the power system of the future will be based on three key elements – all contributing to a sustainable, resilient and affordable power system[41]:

- The power (electricity) generation will be mainly based on carbon neutral energy sources, mostly weather-dependent.
- System flexibility resources, to efficiently complement the variability of generation and consumption, and to address the increase in overall system complexity.
- Resilient and flexible power (electricity) grids, connecting generators, consumers and flexibility resources across Europe, and enabling a fully integrated European Energy Market.

For this to happen, Europe will need to:

- Mobilise significant smart grids investment, including building of new interconnectors at all grid levels, to unlock and the potential of large offshore wind farms (e.g. in the North Sea) and solar energy (e.g. in South Europe) [ref. revised TEN-E]
- Deploy increased energy conversion and storage capacity and capabilities, helping to match demand and supply for the needed energy carriers more locally and over multiple time frames;
- Integrate demand-side flexibility, particularly from the residential sector;
- Integrate low carbon flexible electricity generation units (e.g. geothermal, biomass);
- Deploy smart energy integration beyond electricity for heating and cooling, for industrial processes and for the mobility and directly linked, the right sector coupling including conversion between the various energy carriers and their storage means.

In view of the above, the building blocks paving the way towards decarbonisation – also aligned with the ETIP SNET Vision 2050 – can be summarised as follows:

ENERGY EFFICIENCY FIRST PRINCIPLE

Energy efficiency is treated as a sustainable and viable alternative to energy production and thus, it is seen as one of the major driving forces for the achievement of the GHG emission reduction. In 2050 the reduction of final energy demand by up to around 50% with respect to 2005[42] builds on all technology solutions but also couples them with consumer choice that further reduces energy demand. Such significant reductions of the final demand and highly energy efficient solutions that also contribute to the energy efficiency from the supply side, such as cogeneration, or electrification of heat and transport, confirm the large potential for energy demand moderation and opportunities for the development of dedicated industries and services.

In view of the latest geopolitical realities, the Commission proposed a set of initiatives starting with the EU 'Save Energy' plan to guide Member States to design the best tailored measures to cut energy consumption, to be factored into their National Emergency Plans due at the end of October 2022. Additionally, a European Gas Demand Reduction Plan was proposed in July 2022 with the aim to reduce gas use in Europe by 15% by next spring, as part of the Save Gas for a Safe Winter package[43] for which the Regulation was adopted in August 2022. Additionally, the Commission proposed an increased EU 2030 energy efficiency target of 13% to raise private financing for energy efficiency.

RENEWABLES

In the global net zero pathway, global energy demand in 2050 is around 8% smaller than today, but it serves an economy more than twice as big and a population with 2 billion more people[44]. More efficient use of energy, resource efficiency and behavioural changes combine to offset increases in demand for energy services as the world economy grows and access to energy is extended to all. Instead of fossil fuels, the energy sector is based largely on renewable energy. Two-thirds of total energy supply in 2050 is from wind, solar, bioenergy, geothermal and hydro energy. Solar becomes the largest source, accounting for one-fifth of energy supplies. Solar PV capacity increases 20-fold between now and 2050, and wind power 11-fold[45]. Net zero means a huge decline in the use of fossil fuels – falling from almost four-fifths of total

39 https://www.iea.org/reports/net-zero-by-2050
40 Ibid.
41 https://vision.entsoe.eu/
42 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52018DC0773
43 https://ec.europa.eu/commission/presscorner/detail/en/ip_22_4608
44 https://www.iea.org/reports/net-zero-by-2050
45 Ibid.

energy supply today to slightly over one-fifth by 2050. Electricity accounts for almost 50% of total energy consumption in 2050. It plays a key role across all sectors – from transport and buildings to industry – and is essential to produce low-emissions fuels such as hydrogen. To achieve this, total electricity generation increases over two-and-a-half-times between today and 2050. At the same time, the least efficient coal plants are expected to be phased out by 2030, and the remaining coal plants still in use by 2040 are retrofitted. By 2050, almost 90% of electricity generation comes from renewable sources, with wind and solar PV together accounting for nearly 70% and the remainder is mostly coming from nuclear[46].

Despite claims to the contrary, wind and solar power have delivered even throughout the electricity price crisis, which began in the second half of 2021 – with outputs being the highest on record for most of the months in the second half of 2021. The electricity price crisis led to a paradigm shift as new renewables replaced costly gas instead of a more carbon intensive coal. As for the other type of renewable sources, a modest change has been observed for biomass (4% between 2019 and 2021) and the output of hydro was broadly stable with slight increase (9%) in comparison to 2019[47]. Nuclear power output remains in a long-term decline despite a slight increase (7%) in 2021 in comparison to 2020. Without new power plants and further lifetime extensions of the ones already in operation, nuclear power output in advanced economies will decline by two-thirds over the next two decades[48]. On the other hand, owing to recent EU policies to accelerate deployment of renewables, 2022 is expected to be a record year for the European solar photovoltaic market with annual deployment growth in the largest EU Member State markets between 17% and 26%[49].

Such massive take up of renewables requires significant investment in the electricity sector – three- times higher on average than in recent years [IEA Roadmap] and up to USD 750 billion per year to 2030 in the IEA Net Zero Energy (NZE) Scenario of the most recent World Energy Outlook[50]. Around 70 % of this investment goes to distribution grids – mainly attributed to expanding, strengthening and digitalising of the network. This calls for increased flexibility needs of the electricity system – fourfold by 2050 (IEA NZE scenario), largely met by demand-side flexibility, flexible low-emission generation sources and battery storage. Moreover, as we move on from the energy crisis, EU must look beyond what appears to be the quickest fix to the energy needs and prevent new dependencies in materials and infrastructure that could delay energy transitions or make them more costly. Demand for critical minerals for clean energy technologies is set to rise sharply, with copper seeing the largest increase in terms of absolute volumes, but also silicon and silver for solar PV, rare earth elements for wind turbine motors and lithium for batteries[51].

INCREASED ELECTRIFICATION OF OTHER END-USE SECTORS

The direct use of low-emissions electricity in place of fossil fuels is one of the most important drivers of emissions reductions, accounting for around 20% of the total reduction achieved by 2050 [IEA, roadmap]. A common characteristic of each scenario in the 2022 IEA World Energy Outlook is the rising share of electricity in the global final energy consumption[52] Global electricity demand is expected to more than double between 2020 and 2050, reaching more than 50% by mid-century in the IEA NZEScenario. In transport, the share of electricity increases from less than 2% in 2020 to around 45% in 2050, with more than 60% of total passenger car sales globally being EVs by 2030 (compared with 5% of sales in 2020), and almost fully electrified car fleer worldwide by 2050. This necessitates growth in battery production and associated demand for critical minerals – demand for lithium for battery use grows 30-fold to 2030 and is more than 100-times higher in 2050 than in 2020[53]. In buildings, electricity demand is expected to have a moderate growth, largely pushed by increased efficiency of home appliances, cooling, lighting and building envelopes. Nevertheless, large increase in activity, together with widespread electrification of heating using heat pumps, contributes to a steady rise of electricity demand in buildings over the period and reaching 66% of total energy consumption in 2050[54]. In addition to the increase of a direct use of electricity in end-use sectors, significant increase of electricity use for hydrogen production is expected. However, emissions from generation are likely to fall to net-zero in advanced economies by 2035 and globally by 2040, mainly due to increase in renewables – up from 29% of generation in 2020 to 60% in 2030 and nearly 90% in 2050

46 Ibid.
47 Ibid.
48 https://www.iea.org/reports/world-energy-outlook-2019
49 https://www.solarpowereurope.org/insights/market-outlooks/global-market-outlook-for-solar-power-2022
50 https://www.iea.org/reports/world-energy-outlook-2022
51 IEA World Energy Outlook, 2022 https://www.iea.org/reports/world-energy-outlook-2022
52 Ibid.
53 https://www.iea.org/reports/net-zero-by-2050
54 Ibid.

EVOLUTION OF DISTRIBUTED HEATING AND COOLING

The evolution of distributed heating and cooling in the period towards 2050 mainly owes to improvements in the building envelope and in the heating and cooling technology. Homes heated by natural gas is expected to fall from nearly 30% of the total today to less than 0.5% in 2050, while homes using heat pumps rise from nearly 20% of the total today to 35% in 2030 and about 55% in 2050[55]. This makes high efficiency electric heat pumps becoming the primary technology choice for space heating. Additionally, other technologies, such as bioenergy boilers, solar thermal, district heat, low-carbon gases in gas networks and hydrogen fuel cells play a role in making the global building stock zero-carbon-ready by 2050. No new coal and oil boilers will be sold globally from 2025[56], whereas sales of gas boilers fall by more than 40% from current levels by 2030 and by 90% by 2050[57]. The share of low-carbon gases (hydrogen, biomethane, synthetic methane) in gas distributed to buildings rises from almost zero to 10% by 2030 to above 75% by 2050[58]. Space cooling represented only 5% of total buildings energy consumption worldwide in 2020, but demand for cooling is likely to grow strongly in the coming decades with rising incomes and a hotter climate. High-performance building envelopes, including bioclimatic designs and insulation, can reduce the demand for space cooling by 30-50%, while providing greater resilience during extreme heat events.

ENERGY CARRIERS BESIDES ELECTRICITY

In addition to electricity, new carriers are being considered in energy and industrial applications where it is difficult to replace fossil fuels (because of the chemical and physical properties sought). Hydrogen (H2) and its carbon derivatives obtained by reaction with CO2 like carbon-neutral gas (carbon neutral-CH4) and carbon neutral liquids are considered as possible options for decarbonisation of transport, buildings, industry and in power generation. These new carriers will have to rely in particular on availability of carbon-free electricity. Low-emissions fuels today account for just 1% of global final energy demand, a share likely to increase to 20% in 2050 [IEA Roadmap]. Liquid biofuels meet 14% of global transport energy demand in 2050, up from 4% in 2020; hydrogen-based fuels meet a further 28% of transport energy needs by 2050 [IEA Roadmap]. Low-carbon gases (biomethane, synthetic methane and hydrogen) account for 35% of global demand for gas supplied through networks in 2050, up from almost zero today [IEA Roadmap].

Green Hydrogen (and other carbon- neutral gases and liquids) can gradually take the role of an energy vector beyond its potential role as a chemical storage of electricity and could be used in flexible power plants when the short-term demand is higher than the non-stored, variable renewables-based electricity supply. In a power system largely based on variable renewable sources, hydrogen could be produced at times of low electricity demand providing additional flexibility, which makes the electricity sector an important driver of hydrogen demand.

SECTOR COUPLING AND ENERGY SYSTEM INTEGRATION

Many of the energy technologies, infrastructures and sectoral systems (electricity, gas, heat and transport) can further optimise their contribution to decarbonization when being coupled or integrated among sectors allowing the best possible use of the available resources, the avoidance of stranded assets, and the best information base for decisions on investments. Energy system integration[59] refers to, for instance, linking the energy, transport and industrial infrastructures with a view to increase the penetration of renewable energy sources and decarbonise the economy. Sectoral integration and coupling of electricity, gas, heat and cooling impacts the energy system at several levels: physical and cyber-physical layer (i.e. new technologies and ICT solutions), functions and services (e.g. for business, for consumers), market (regulation, transactions). Sectoral integration also means that action in one sector is heavily dependent on other sector(s). For instance, decarbonisation of heating via electrification will not happen unless power (electricity) generation decarbonises. This integration will build on the interdependency of energy transformation sectors (power/electricity, heating, production of new fuels) with industry, mobility, buildings sector, and other energy using activities. Finally, sector coupling can be seen as a leveller to provide the enhanced flexibility that urban energy systems and cities need towards a net zero future, while encompassing increased flexibility and interconnectedness of energy systems[60].

55 Ibid.
56 https://www.iea.org/reports/world-energy-outlook-2022
57 https://www.iea.org/reports/net-zero-by-2050
58 Ibid.
59 https://energy.ec.europa.eu/topics/energy-systems-integration/eu-strategy-energy-system-integration_en
60 IRENA World Energy Transitions Outlook, 2022, https://irena.org/publications/2022/mar/world-energy-transitions-outlook-2022

REGULATION FIT-FOR-PURPOSE

The "Clean energy for all Europeans" package adopted by the EU Council on 22 May 2019 addresses the major changes required in the energy market structure and operation. More work will be needed if challenges will emerge during the evolution of the new energy system, especially when the penetration of renewables will be so high that centralised measures for stabilising and balancing the system alone will not be feasible anymore. With the increasing presence of DERs on the distribution network, the definition of new roles, regulatory frameworks and market design for the provision of grid services have to be the result of a coordinated action among all the stakeholders: customers, DSOs and TSOs. This is essential to further enhance cooperation among TSOs, DSOs and market participants (including consumers) all along the value chain of procurement of balancing, congestion management and ancillary services. To this end, European Regulators have started to use regulatory experimentation, mainly in form of regulatory sandboxes[61] to foster and support innovation in the energy sector. More specifically, national regulatory authorities have been using regulatory sandboxes, as part of their toolkit to provide incentives to the distribution system operators in procuring market-based flexibility services as an alternative to traditional network investments[62].

DIGITALISATION OF THE ENERGY SYSTEM

To be able to effectively tackle the climate and energy crisis, the EU energy system needs to undergo a significant digital and sustainable transformation. For example, installation of solar PV panels on the roofs of all commercial and public buildings by 2027 and on all new residential buildings by 2029[63], installation of 10 million heat pumps over the next 5 years[64] and replacement of 30 million cars with zero-emission vehicles on the road by 2030[65] are few of the short-term measures to be realised by 2030 as a response to the on-going crisis. Furthermore, reducing greenhouse gas emissions by 55% and reaching a share of 45% renewables in 2030 can only occur if the energy system is ready for it. This requires increased level of interaction and smart monitoring and control capabilities to facilitate consumers embrace the benefits of the green transition. For the twin digital and green transition to happen, significant investment in the range of EUR 584 billion[66] will need to take place in the electricity grid between 2020 and 2030, and mostly in the distribution network. A study performed by EURELECTRIC indicates around EUR 170 billion investment in digitalisation out of total of around EUR 400 billion[67].

The energy sector has been an early adopter of digital technologies, using them to facilitate grid management and operation and adoption of digital technologies in the coming decades will enable more connected, intelligent, efficient, reliable and sustainable energy systems (IEA 2017). The number of IoT devices in the world is expected to surpass 25.4 billion in 2030[68] and 51% of all households and SMEs in the EU will be equipped with smart electricity meters[69].

In the view of the above, the recently adopted EU action plan for digitalising the energy system [ref. COM(2022)552/2] proposes concrete actions, among which the following:

- promote connectivity, interoperability and seamless exchange of data between different actors while respecting privacy and data protection
- stimulate more and better coordinated investments in the electricity grid and a EU-wide coordinated plan for accelerated deployment of the necessary digital solutions
- empower consumers, including the most vulnerable or with low digital skills, to benefit from new ways to engage in the energy transition or from better services based on digital innovations, whilst being protected against high energy prices. In the same realm, facilitate the development of energy communities and local energy initiatives.
- enhance cyber-security and resilience of the energy system – which requires a continuous effort and investment
- address energy consumption of digital technologies (e.g. through environmental labelling scheme for data centres, energy label for computers, etc.) and promote greater efficiency and circularity
- design an effective governance, through structural and joint planning by public authorities in cooperation with the private sector, as well as continuous support for R&I.

61 in the financial sector, 'a regulatory sandbox is a 'safe space' in which businesses can test innovative products, services, business models and delivery mechanisms without immediately incurring all the normal regulatory consequences of engaging in the activity in question' [ref. UK Financial Conduct Authority, Regulatory Sandboxes", Nov. 2015, PUB REF: 005147 www.fca.org.uk/publication/research/regulatory-sandbox.pdf]
62 https://www.ceer.eu/documents/104400/-/-/72eab87d-9220-e227-1d26-557a63409c6b
63 EU Solar Energy Strategy COM(2022)221
64 REPowerEU Communication COM(2022)230 final
65 Sustainable and Smart Mobility Strategy COM(2020)789 final
66 https://energy.ec.europa.eu/communication-digitalising-energy-system-eu-action-plan-com20225522_en
67 (Figure EU+UK) https://www.eurelectric.org/connecting-the-dots/
68 https://www.cbi.eu/market-information/outsourcing-itobpo/industrial-internet-things/market-potential
69 Smart Metering Benchmarking Report (March 2020), European Commission, Directorate- General for Energy, Alaton, C., Tounquet, F., Benchmarking smart metering deployment in the EU-28 : final report, Publications Office, https://data.europa.eu/doi/10.2833/492070

2.7 Power system flexibility is key to electricity security

Flexibility needs are driven primarily by the rising share of variable wind and solar PV in electricity generation and changes in electricity demand profiles. Rising shares of non-dispatchable wind and solar PV increase the variability of the net load (the load that remains after removing wind and solar production from electricity demand), while the electrification of additional end-uses, e.g. electric heating, road transport or industrial processes, raises peaks and increases the hourly, daily and seasonal variability of electricity demand. According to the IEA Global Outlook 2022[70], in the STEPS (Stated Policies Scenarios) hour-to-hour flexibility needs more than triple by 2050 on a global level. In the APS (Announced Pledges Scenario), the needs double on a global level by 2030 and increase more than 3.5-times by 2050, while they more than quadruple between today and 2050 in the NZE scenario.

Power system flexibility is treated in several R&I activities developed in this Roadmap, as presented at the end of Chapter 4.

2.8 Relation with the Digitalisation of the Energy System Action Plan

European Union recently published the Digitalisation Digitalisation of the Energy System Action Plan[71] (DAP) to build an energy system that is much smarter and more interactive than it is today, where some key goals have been identified. More specifically the DAP proposes:

- promote connectivity, interoperability and seamless exchange of data between different actors while respecting privacy and data protection; foster more and better coordinated investments in the electricity grid as the enabler for a smarter and more resilient energy system and a EU-wide coordinated plan for the accelerated deployment of the necessary digital solutions;
- empower consumers, including the most vulnerable or with low digital skills, to benefit from new ways to engage in the energy transition or from better services based on digital innovations, whilst being protected against high energy prices online as they are currently off-line;
- enhance cyber-security – which requires a continuous effort and investment;

These points are related to several R&I activities developed in this Roadmap, as presented at the end of Chapter 4.

70 https://www.iea.org/reports/world-energy-outlook-2022
71 Digitalisation of the energy system (europa.eu)

3

Methodology: High Level Use Cases (HLUCs) and Priority Project Concepts (PPCs)

The ETIP SNET R&I Roadmap 2022-2031 describes the required R&I goals to be achieved by 2031. It reuses the concepts defined in the previous R&I Roadmaps and R&I Implementation plans72, briefly described in Annex I, capitalising the assessment of running European projects, both Horizon and nationally funded, the Roadmaps of stakeholder associations73, like ENTSO-E, and international Visions74 and R&I Roadmaps. It is based on the key concept of High-Level Use Cases (HLUCs) with associated sets of Priority Project Concepts (PPCs) to specify more precisely the practical, including demonstration-related outcome of R&I families of projects.

To be sure that integrated energy systems with high shares of Variable Renewable Energy (VRE) can guarantee security of operation, nine High-level Use Cases composed of more than 50 Priority Project concepts are needed, enabling all involved stakeholders in Europe and its countries to contribute together to technical, market and regulatory solutions best fitting to their own geography, energy system and national strategies

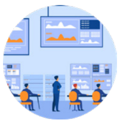
In this Roadmap agreed upon among several hundred stakeholders and describing the most urgent High-level Uses Cases and their Priority Project Concepts, ETIP SNET identifies the innovation priorities that need to be tackled urgently through research and large demonstrators combined with knowledge sharing, capacity building and dissemination activities.

The concept of HLUCs and the associated Priority Project Concepts (PPCs) were selected to communicate to the key audiences of this ETIP SNET R&I Roadmap, i.e. the European Commission, the national governments, the associations and the R&I community at Institutes of Technologies and in the manufacturing industry, Universities, Research Centres and Labs, etc. By using and defining HLUCs, the ETIP SNET intends to underline the urgency of realising the transformation of today's energy system through concrete R&I projects into the strongly renewable energy system of 2031 and the fully CO2-neutral energy system of 2050 as the ultimate goal. This is strongly connected with concrete outcomes and scopes for real-world demonstrations to be done in R&I projects.

The Priority Projects Concepts (PPCs) for each HLUC should cover all not yet fully mature integration features of the Future Energy Systems with concrete goals and time schedules. Nine HLUCs – each valid for the next 10 years (until 2031) - are used to structure in this ETIP SNET R&I Implementation Plan 2022-2025 the needed R&I Priority Project Concepts.

The following table gives the titles of the 9 High-Level Use Cases (HLUCs).

Table 2: HIGH LEVEL USE CASES to be realized by 2031 for the Integrated European Energy System 2031

	**HLUC 1: Optimal Cross sector Integration and Grid Scale Storage**	identifies the value and realises the integration of monitoring and control, regulatory frameworks, cross-sector resilience, infrastructure design of integrated storages of all kinds with multi-energy systems (including hydrogen- and CO2-neutral gases based) and their assets. **Total 10-year Budget: 620M€**
	**HLUC 2: Market-driven TSO–DSO–System User interactions**	identifies the market models and architectures, the governance and realises them as business cases so that an integrated, full-system control and operation for both TSOs and DSOs results. HLUC2 also develops corresponding platforms with TSO and DSO planning tools. **Total 10-year Budget: 530M€**
	**HLUC 3: Pan European Wholesale Markets, Regional and Local Markets**	identifies and validates the fundamental market designs and regulatory frameworks, develops IT systems for real-time balancing and the cross-border trading. **Total 10-year Budget: 410M€**
	**HLUC 4: Massive RES Penetration into the transmission and distribution grid**	identifies technical barriers and develops measures for handling massive RES with their control and operation and related infrastructure and their functioning with RES-based markets, policies and governance. HLUC4 also develops planning tools with the goal of high system resiliency. **Total 10-year Budget: 500M€**
	**HLUC 5: One stop shop and Digital Technologies for market participation of consumers (citizens) at the center**	identifies the value of consumer/customer engagement and develops easy to use, standardised, communicating and (cyber-) secure-by-design solutions for them. HLUC5 contributes to consensus creation beyond electricity-related consumer solutions going into heating, cooling and EV sectorial uses. **Total 10-year Budget: 420M€**
	**HLUC 6: Secure operation of widespread use of power electronics at all systems levels**	identifies, simulates with digital twins and then realises control solutions for PV integrated with batteries and their inverters thereby considering transition path to hybrid AC/DC electricity grids, adapted distribution substations, HVDC multi-terminal configurations and their standardisation. **Total 10-year Budget: 530M€**
	**HLUC 7: Enhance System Supervision and Control including Cyber Security**	identifies and realises adapted TSO and DSO Control Room needs including new monitoring, control, protection and measurement technologies, their interfaces also to the grid operators and their standardisation. From that, HLUC7 develops the adapted requirements for grid operators and grid fields workforces. **Total 10-year Budget: 660M€**
	**HLUC 8: Transportation Integration & Storage**	identifies implications of the transport sector decarbonisation, how electromobility supports resilient energy system operation together with policy adaptations. HLUC8 also identifies market adaptations for seamless merging of transport and energy sectors including their integrated planning. **Total 10-year Budget: 400M€**
	**HLUC 9: Flexibility provision by Building, Districts and Industrial Processes**	identifies the value of buildings, of smart communities for control and operation of a RES-based energy system, including their integrated planning, market and governance adaptation needs. **Total 10-year Budget: 410M€**

Each HLUC is to be realized by several PPCs, and each PPC is to be realised during defined time frames within the next 10 years until 2031. PPCs have time dependencies among each other, meaning that the output of one PPC may serve as input to later PPCs. This is defined by the IP-Period during which each PPC shall begin.

The proposed PPCs serve as a conceptual basis for one or more (publicly co-funded) R&I projects to be launched in an Implementation Plan period. Each such 4-year period has been and will be described in an ETIP SNET R&I Implementation plan, the latest being for this ETIP SNET R&I RM 2022-2031 the ETIP SNET IP 2022-2025, the next one being ETIP SNET IP 2025+ (to be published in 2023), etc. By associating in each ETIP SNET R&I Implementation Plan the Research TASKS and knowing that these TASKS contribute to a defined subset of PPCs, upcoming R&I projects will be able to consider both the practical demonstration aspects through defined, desired project outcomes and the fundamental and applied research needed as defined in the Research TASKS in a timely manner and the right order and priority.

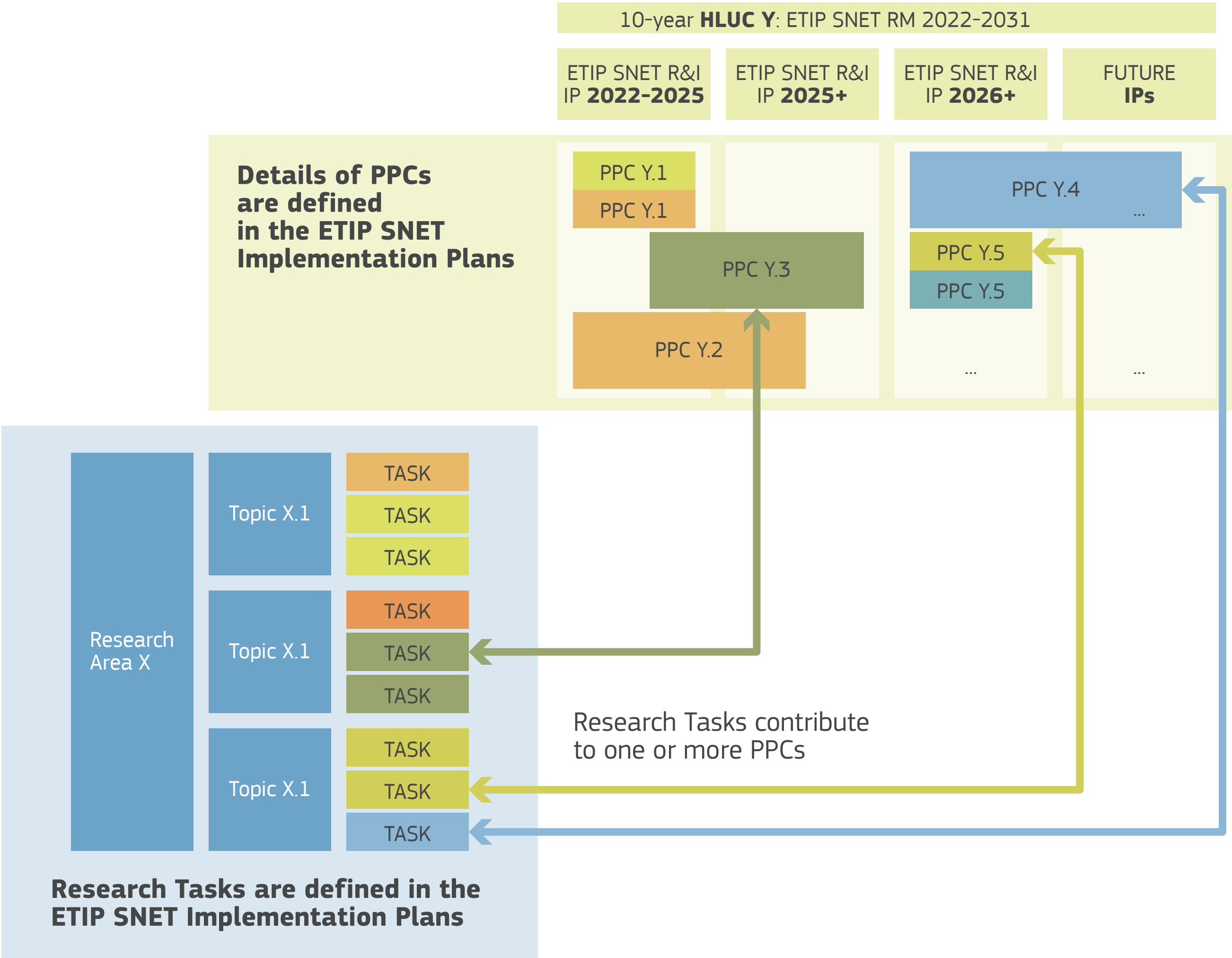


Figure 2: The conceptual link between HLUCs and their PPCs (upper part); and: Research Areas, TOPICS and TASKS with PPCs (lower part)

The PPCs and their associated HLUCs are intended to serve as inputs not only to "Horizon Europe" for work programs and calls for co-funded projects at European level, but also to the transnational, national and regional funding programs (with national roadmaps, R&I Implementation Plans, work programmes and calls) with their R&I projects among and within European countries.

The PPCs are to be defined in the ETIP SNET R&I Implementation Plans, foreseen to be published and updated every two years. They outline the practical actions to address the identified PPCs. The implementation of the PPCS must go together with the European Commission, European national governments, private sector companies, organizations being active beyond Europe and the R&I community to collaborate: Gained knowledge must be shared among R&I projects as done in the BRIDGE initiative of the European Commission and as planned in the TRI1 and TRI 5 initiatives (both together share many concepts with those published in this ETIP SNET R&I Roadmap) of the CETP. While other initiatives and action plans concentrate more on collaborating pillars such as the integration of Variable Renewables, system flexibility, market design and digitalization, ETIP SNET adds to those layers (they are described as Research Areas with Research Topics and Tasks in the ETIP SNET R&I Implementation Plans), this Roadmap highlights the practical integration needs and their demonstrations by validating innovative solutions by means of upscaled and repetitively - implemented demonstrations to effectively foster their deployment. At the same time, it is clearly recognised that affordable and reliable VRE integration, system flexibility and smart digitalization are key as well as technology, business and market aspect:

Each PPC is designed to be called for in a "Call for R&I project" by the EC and/or national governments and is to be realized after that call year within typically 4 or more project years. On the other side (lower part in the previous figure), it has a defined set of associated Research TASKS (defined in the ETIP SNET R&I Implementation Plan). The ETIP SNET recognises that in order to reach deployment75, research and innovation in these tasks and, above all, demonstrations are needed not only locally, but also at country, cross-country and pan-European levels. It is well recognised that some of the tasks are local and national:

- due to fundamentally different characteristics of weather (temperature, clouds, sunshine, wind, rain, etc.) during each day and •season of the year;
- due to different energy potentials;
- due to different consumer and prosumer mixes and needs, etc.
- due to different national legislation.

As a consequence, different aspects of tasks need to be researched and demonstrated in different types of environments, such as large, medium and small size cities, communities, rural areas, mountain areas, islands, etc. Some of the tasks can be demonstrated in cross-border, regional or even pan-European R&I projects such as:

- the (EU-) internal electricity market;
- Harmonisation and standardisation of the IT;
- flexibility markets;
- sector coupling initiatives;
- industrial applications.

Challenges, such as balancing of variable RES, differ from one environment (e.g. north of Europe with more off-shore wind capacity) to another (e.g. south of Europe with higher PV yield). Across all solutions, however, are principles such as interoperability, Grid-Operator cooperation, system flexibility solutions, smart charging, hierarchical control etc, that urgently require common solutions and knowledge sharing across Europe.

These aspects need to be balanced when selecting and funding R&I projects in the years to come.

In the following table, each of the 9 HLUCs is described thereby highlighting the:

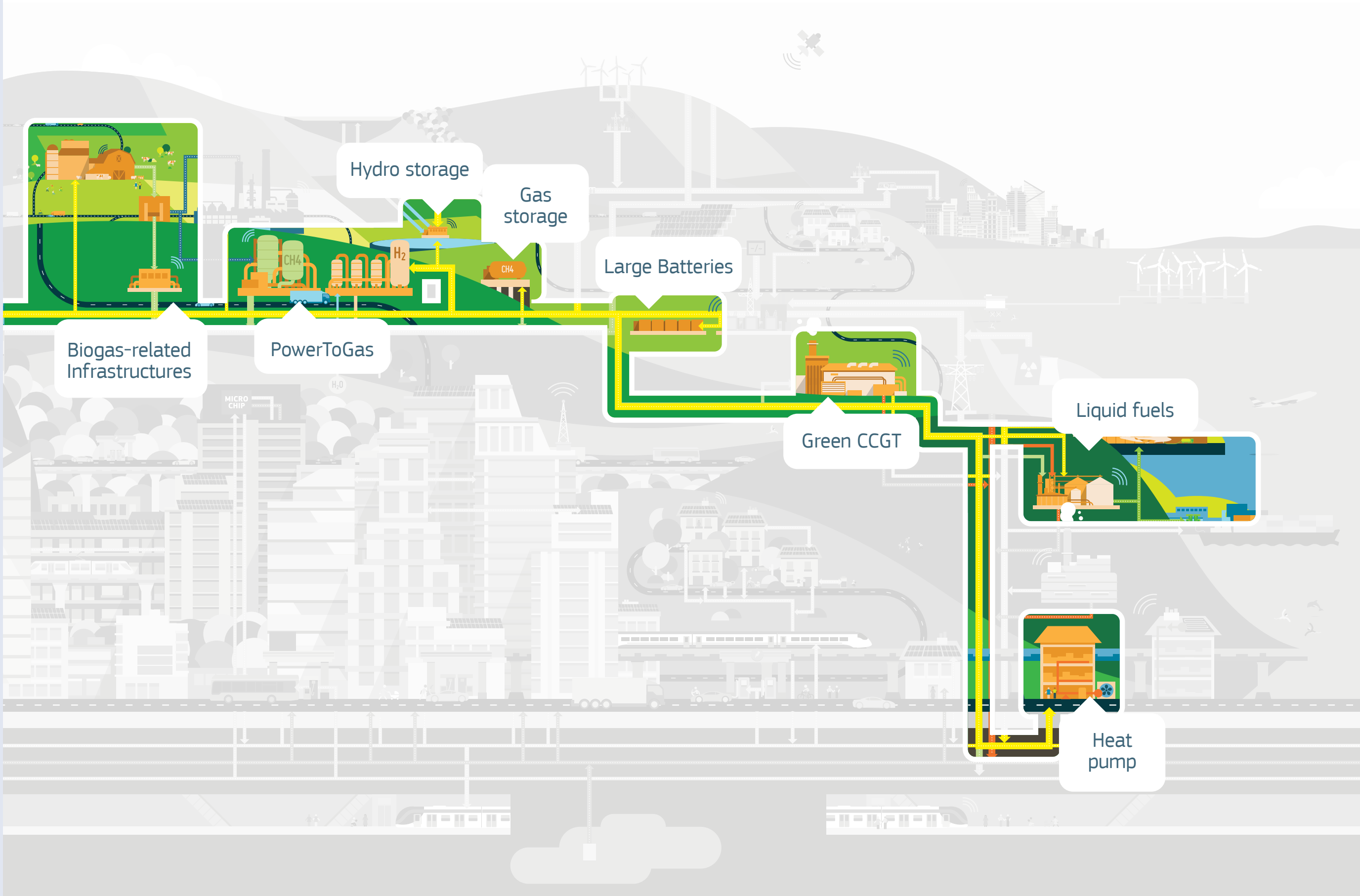
- **Scope**
- **Actors involved**
- **Sectors covered**
- **High Level Goals**
- **Main technical challenges**
- **Current (implementation) status**
- **Expected outcome 2031**
- **And the associated PPCs,** each with an ideal year in which the PPC shall be called for in EC or National Calls for R&I Projects.

	ETIP SNET IP **2022-2025**	ETIP SNET IP **2025+**	ETIP SNET IP **2026+**	**LATER** ETIP SNET **IPs**
HLUC 1: Optimal Cross sector Integration and Grid Scale Storage	PPC 1.1: Value of cross sector integration and storage PPC 1.2: Control and operation tools for multi-energy systems PPC 1.3: Smart asset management for a circular economy	PPC 1.4: Integrating hydrogen and CO2-neutral gases PPC 1.5: Regulatory framework for cross sector integration	PPC 1.6: Cross sector resilience PPC 1.7: Future cross-vector infrastructure design PPC 1.8: Validation/Demonstration	
HLUC 2: Market-driven TSO–DSO–System User interactions	PPC 2.1: Market models and architecture PPC 2.2: Control and operation PPC 2.3: Platform Development PPC 2.4: Planning tools	PPC 2.5: Develop a Digital Twin of the European Electricity Grid PPC 2.6: Viable business cases through market mechanisms and incentives PPC 2.7: Governance for TSO, DSO and System Users		
HLUC 3: Pan European Wholesale Markets, Regional and Local Markets	PPC 3.1: Fundamental market design PPC 3.2: Regulatory framework and strategic investments PPC 3.3: IT systems for cross-border trading	PPC 3.4: Validation of new market concepts	PPC 3.5: IT systems for TSO/DSO control to support real time balancing	
HLUC 4: Massive RES Penetration into the Transmission and Distribution Grid	PPC 4.1: Technical barriers and technical measures PPC 4.2: Control and operation tools PPC 4.3: Infrastructure requirements and network technologies PPC 4.4: Planning for a resilient system	PPC 4.5: Well-functioning markets for a RES based energy system PPC 4.6: Policies and governance for a RES based energy system		
HLUC 5: One-Stop Shop and Digital Technologies for Market Participation of Consumers (citizens) at the Centre	PPC 5.1 Value of Consumer/Customer acceptance and engagement PPC 5.2: Plug and play devices and IoT PPC 5.3: Utilisation of Communication Networks including cyber security PPC 5.4: Cross-sectorial flexibility use cases	PPC 5.5: Data Spaces PPC 5.6: Building skills needed for developers and users of the energy system to accelerate its transition through its digitalization PPC 5.7: Service management and operations PPC 5.8: Sharing IT infrastructure investments	PPC 5.9: Large Scale Demonstration activities PPC 5.10: Creating consensus on consumer solutions	
HLUC 6: Secure operation of widespread use of power electronics at all systems levels	PPC 6.1: Control solutions for next generation inverters PPC 6.2: Hybrid transmission/distribution and hybrid distribution AC/DC grids PPC 6.3: Next Gen. distribution substation PPC 6.4: Simulation methods and digital twins		PPC 6.5: HVDC interoperability, multi-terminal configurations, meshed grids PPC 6.6: Large Scale Demonstration activities PPC 6.7: Standardisation activities	
HLUC 7: Enhance System Supervision and Control including Cyber Security	PPC 7.1: Next Gen. of TSO control room PPC 7.2: Next Gen. of DMS PPC 7.3: Next Gen. of measurements and GIS for distribution grids PPC 7.4: Wide area monitoring, control and protections	PPC 7.5: Grid operator of the future PPC 7.6: Grid field workforce of the future PPC 7.7: Human machine interface (HMI) PPC 7.8: Cybersecurity of Energy Networks	PPC 7.9: Large scale demonstration activities PPC 7.10: Standardisation activities	
HLUC 8: Transportation Integration & Storage	PPC 8.1: Technical and economic implication of decarbonisation of transport sector PPC 8.2: Enhancing effectiveness of energy system operation and resilience with electromobility PPC 8.3: Integrated planning of energy and transport sectors	PPC 8.4: Adapting policy and market for seamless cost-effective merging of transport and energy sectors	PPC 8.5: Demonstration activities	
HLUC 9: Flexibility provision by Building, Districts and Industrial Processes	PPC 9.1: Value assessment of the integration of buildings PPC 9.2: Control and operation tools for the integration of buildings PPC 9.3: Planning for reliable integration of buildings	PPC 9.4: Governance for an effective integration of buildings and smart energy communities	PPC 9.5: Evolved markets for enabling buildings and energy community facilities	
	ETIP SNET IP **2022-2025**	ETIP SNET IP **2025+**	ETIP SNET IP **2026+**	**LATER IPs**

4

List of HIGH LEVEL USE CASES (HLUC) 2022-2031 and their Priority Project Concepts (PPC)

HLUC1 Optimal Cross sector Integration and Grid Scale Storage



SCOPE

The traditional energy system silos for electricity generation and end-use, for gas transport, for heating & cooling needs and for mobility / transport must be coupled and optimised as one overall, Integrated Energy System considering P2X, X2P and large-scale energy storage technologies in order to achieve the carbon targets at lowest costs. The coupling of such complex systems needs new services based on higher degrees of automated management and control of flexible energy network resources including the conversion between them.

Energy storage technologies need to improve their integration with the grid and meet the challenges of a decarbonised energy system. Several technologies are available, and their state of the art showed different level of development and maturity. Some of these are established technologies, while others have yet to demonstrate their potential at scale. Nevertheless, all of them faces challenges that require R&I efforts to be adequate and cost-effective in a carbon-neutral energy system.

Decarbonisation of industrial sector, transport and end use energy demand at the building level, shall be supported by smart coordinated control of the interaction between energy sectors. This should also inform the role and value of alternative technologies related to energy production, transport, storage and demand sectors, from the whole-multi-vector energy system perspective / requirements, in supporting decarbonisation objectives. For an effective decarbonization of the cross-energy sectors, sustainable environmental and social circular economy objectives should be promoted and thus foster technological and business model innovation.

It will be important to develop appropriate technical and commercial frameworks in order to coordinate sector-coupling (electricity, gas, heat, transport, etc.), the usage of all flexibility sources, and maximise the benefits of coordinated operating synergy, deployment and conflict mitigation. The ability of cross-sector coupling flexibility to enhance energy system reliability and resilience cost effectively, is an important aspect of whole-system approach to energy sector planning and operation that should be investigated. The topics above can be applied into different regional scales from buildings to microgrids or local distribution systems to national and Pan European systems.

ACTORS INVOLVED

Energy companies (trading electricity, gas, hydrogen, heat etc.), Network operators TSO/DSO (electricity), TSO/DSO (gas), Heating/Cooling network operators, EV chargers/Aggregators, Water distribution network managers, Industrial and R&D sector and end users, local and national authorities / urban planning.

SECTORS COVERED

electricity, gas, heating & cooling, water hydrogen, mobility, industry.

HIGH LEVEL GOALS

Optimise the operation and planning of the integrated energy systems in order to facilitate cost effective transition to zero carbon energy future. Provide evidence related to the importance of cross-energy vectors coupling that would facilitate integration of large amount of RES and decarbonisation of heat / cooling, transport, industrial sectors. Develop a new market, regulatory and policy frameworks for delivering low-emission, low cost, secure, reliable and resilient whole-energy system also relying on circular economy strategies. Facilitate the development of the appropriate energy storage and conversion technologies and related infrastructure.

MAIN TECHNICAL CHALLENGES

- Improvement of critical integration to the grid aspects of energy storage and conversion technologies and demonstrate their technical and economic feasibility in an integrated energy system
- Development of advanced whole-system based models and tools for co-optimisation of operation and planning of future low carbon multi-energy systems under different decarbonisation pathways, while considering uncertainties in future cost and performance of different energy production, transport, demand and storage technologies.
- Development and demonstration of advanced technologies and control concepts /platform tools for multi-energy systems based on appropriate data exchange between different energy sectors in local, national and pan EU regions.
- Development of reliability and resilience standards for operation and planning of future multi-energy infrastructures. Develop models for optimisation of the operation and planning of the integrated energy systems, in order to facilitate cost effective transition to zero carbon energy future.
- Provide evidence related to the importance of cross-energy vectors coupling that would facilitate integration of large amount of RES and decarbonisation of heat / cooling, transport, industrial sectors.
- Demonstrate the ability of providing real time balancing and management of flexibility by cross-energy vector coordination including various P2X, X2P, grid scale energy storage technologies.
- Development of control concepts /platform tools for multi-energy systems based on appropriate data exchange between different energy sectors in local, national and pan EU regions.
- Production of green hydrogen by offshore wind and transport on shore by existing gas infrastructure, considering different electrolyser technologies
- Coordinate the planning of on shore electrolysers location, typology and operational modes between their industrial operators and the system operators, for capturing their flexibility potential as both short and long term storage.
- Coordinate the planning and realisation of hydrogen logistic system (pipeline either new or re conditioned, shipping facilities, operational storage on site and caverns for long term storage) to match the corresponding power system developments.
- Assessment of the benefits of sector coupling flexibility to support cost effective sys-tem planning under uncertainties
- Develop new design standards that would enable cost effective transition to secure, reliable and resilient integrated cross-sector energy system
- Develop new market, regulatory and policy frameworks for delivering low-emission, low cost whole-energy systems.

CURRENT STATUS

SHARQ (Cross-sectoral data exchange at European level); X-Flex (PtG and Electricity), Grids (Swiss Federal Office of Energy- Development of technologies for sector coupling), NEW4.0(Germany-Sectoral Coupling energy concepts, industrial flexibility)

EXPECTED OUTCOMES 2031

Tools for operation and planning of multi-energy systems, Development of platform for cross-sector real time control, Development of new security and resilience standards for operation and planning of future multi-energy infrastructure, Development of regulatory, policy and market frameworks to facilitate cross-sector integration, including Data exchange Standards; business model innovation also based on circular economy practices;develop and deploy a governance model ensuring the satisfaction of each coupled sector at the same time optimising the overall performances of the “System of Systems”. Ensure the integration of reliable and cost-effective energy storage and conversion technologies, including related infrastructure, to ensure efficient and resilient cross-sector integration.

The following figure puts the proposed PPCs of HLUC 1 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

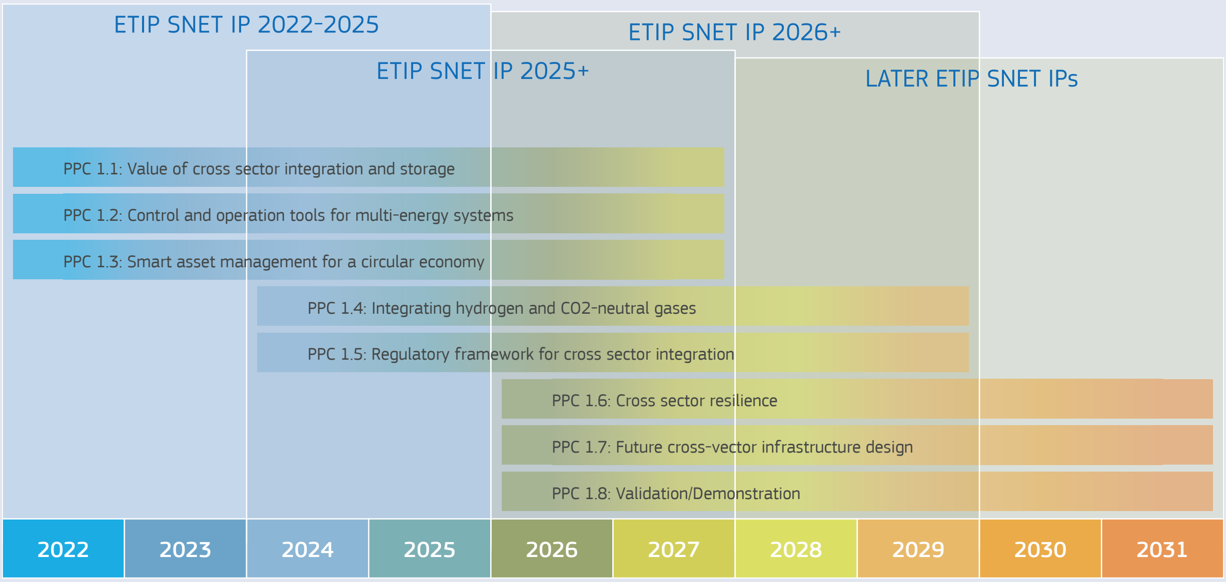


Figure 3: HLUC 1 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 1.1: Value of cross sector integration and storage (IP 2022--2025)
Scope of PPC: Role and value of cross sector Integration and energy storage under different future decarbonisation pathways, assessing the impact on operation and planning of energy infrastructure costs. Assessment of cost and benefits of local versus national and international approach to cross-sector integration. Role of large-scale energy storage (electricity, thermal, synthetic liquids, hydrogen, etc) in supporting cost effective decarbonisation.

PPC 1.2: Control and operation tools for multi-energy systems (IP 2022-2025)
Scope of PPC: Development and demonstration of advanced technologies and control concepts /platform tools for multi- energy systems based on appropriate data exchange between different energy sectors in local, national and international regions.

PPC 1.3: Smart asset management for a circular economy (IP 2022-2025)
Scope of PPC: Advanced management of assets in the energy system along their entire lifecycle, deployment of IoT sensors, communication, data management & analysis and feedback to control systems. Maximise the use of existing infrastructures, compatibly with the transition speed, avoiding stranded assets.

PPC 1.4: Integrating hydrogen and CO2-neutral gases (IP 2025+)[72]
Scope of PPC: Development and demonstration sectoral integration of hydrogen and CO2-neutral gases with electricity system and renewables.

PPC 1.5: Regulatory framework for cross sector integration (IP 2025+)
Scope of PPC: Design of new market and regulatory frameworks that would provide business cases for cross-sector coupling in low carbon energy future, considering local, regional and international areas.

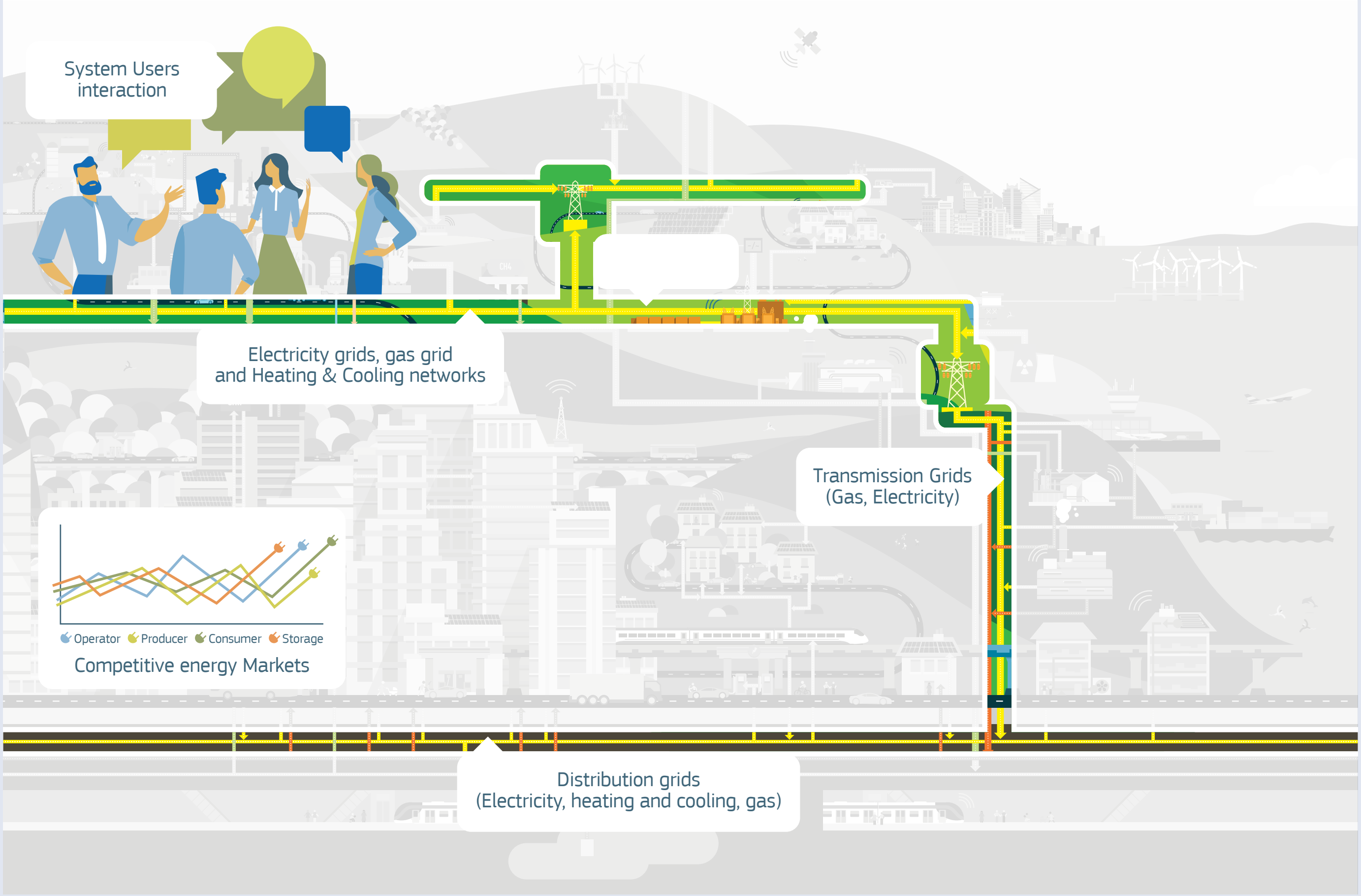
PPC 1.6: Cross sector resilience (IP 2026+)[73]
Scope of PPC: Enhancing Security & Resilience of the energy system through optimal cross sector Integration and long duration energy storage. Enhancing resilience of interconnected regions in EU.

PPC 1.7: Future cross-vector infrastructure design (IP 2026+)
Scope of PPC: Development of the new design standards that would enable cross-sector integration and energy storage to be compared with traditional energy infrastructure design approach, while achieving appropriate security and resilience requirements.

PPC 1.8: Validation/Demonstration (IP 2026+)
Scope of PPC: Large scale demonstration projects focused on coordinated operation of cross-sector coupled energy systems, while managing synergies and conflicts between consumers and actors of the different sectors.

72 IP 2025+ (ETIP SNET R&I Implementation Plan 2025+) refers to the naming of the expected upcoming Horizon Europe Work Programme 2025.
73 IP 2026+ (ETIP SNET R&I Implementation Plan 2026+) refers to the naming of the expected upcoming Horizon Europe Work Programme 2026-2027.

HLUC2 Market-driven TSO–DSO–System User interactions



SCOPE

The electricity grid needs to interact with many actors or devices based on a detailed level of observability, and hence availability of data, to enable flexibility, smart charging and smart buildings. The EU's electricity network has become increasingly digitalized in the last decade, and there is a need for coordination and cooperation among operators and system users to be able to face increasing operational challenges. The recent clean energy legislation requires that electricity system operators must cooperate in planning and operating their networks. This requirement originates from different angles. On one side, there are efficiency gains in planning if information is shared, thus avoiding unnecessary investments or complexities. On the other side, both efficiency gains and increased reliability (risk reduction) can be achieved in the operation process. This cooperation aims in particular at exchange of coordinated balancing and congestion handling services (coming from DER, conventional Power Plants or controlled loads located in their grids). Additionally, sharing of forecasting information benefits a more efficient and secure energy system. All these drivers for system operators' cooperation contribute to the integration of massively increased renewable energy sources in the system, since the cooperation allows an effective, efficient and secure management of renewable sources. Increasing cross-border cooperation shall also be considered.

The cooperation between System Operators and the use of services provided to each other shall be efficient, effective and transparent. Market mechanisms should be used for this purpose. This provides for a level playing field where different types of assets and system users can compete and provide the more effective and efficient solutions for the system challenges. System Operators need, therefore, to reinforce competitive energy markets.

Furthermore, the recent policies and legislation stress the need to involve the consumer (individual, community or organization) in the energy system, making the prosumer-related processes central in the energy system design and operation. This requires the development of adequate mechanisms for the prosumer to interact with the system operators, to contribute to the energy system operation and to participate in the energy markets. An appropriate design shall achieve both a valuable outcome for the prosumer (either financially, convenience or other) and for the operators, benefiting the energy system as a whole. Innovative tools and solutions shall be developed and tested in order to enable user-friendly interactions (e.g., by use of Social Sciences and Humanities (SSH) approaches) among and between prosumers and system operators.

This integration and cooperation between actors require adequate platforms that consider the available data, respect the defined governance and allow for seamless, transparent, non-discriminatory and cost-effective interactions.

The cooperations and interactions shall be market-driven and applicable in heterogeneous geographical, social environments and under various economic conditions. Planning and operational coordination, and flexibility mechanisms shall be primarily market-based, with appropriate market signals and incentives. Regulatory, administrative and governance design shall facilitate these market-driven interactions. Design, development and test of adequate incentives shall be performed to maximize the welfare of the energy transition. The operational and planning arrangements between TSOs and DSOs need to be revised and developed further in order to support a market framework that unlocks the potential of prosumers. Resources should be enabled to value their potential in the most efficient way.

Throughout the market-driven interactions, data will need to be managed in an efficient and transparent way, while respecting competition laws, confidentiality laws and the privacy of prosumers, and allowing adequate access to ensure that prosumers are active in the market.

Finally, the market-driven interactions shall be designed, developed and tested having in mind a cross-sectorial approach in order to facilitate an effective and efficient integrated energy system.

ACTORS INVOLVED

Network operators TSO and DSO from multiple sectors, Aggregators, Prosumers, Communities

SECTORS COVERED

electricity, gas(es), H&C, mobility, industry

HIGH LEVEL GOALS

In line with the Green Deal and the Fit for 55 policy documents, key objectives of this HLUC are:

- Increase RES Penetration (according to RED II) in view of a wide penetration of distribution grids by Distributed Energy Resources and the need to exploit their flexibility for the operation of the power system with high share of Renewable Generation
- Increased participation of consumers and local communities (with RED II specific targets for transport, heating and cooling, buildings and industry, and for savings in the EED)
- Integrate distributed storage assets, such as domestic batteries and batteries of electric vehicles that have the potential to offer considerable flexibility and balancing services to the grid through aggregation
- Ensure that the 30 million electric vehicles expected in the Union by 2031 can fully contribute to the system integration of renewable electricity
- Ensure adequate real time balancing and management of flexibility
- Ensure that the flexibility and balancing services from the aggregation of distributed storage assets are developed in a competitive manner
- Create a predictable business environment for industry and investors.
- Optimize the operation and planning of the electricity system.
- Optimize provision of Ancillary Services from distributed resources in the distribution network.
- Develop efficient long-term planning and corresponding tools and simulation capabilities.
- Define suitable market models for the interaction of TSOs and DSOs including interactions between central and local markets. Identify technical, market and business barriers to the smooth cooperation and interaction between TSOs, DSO and consumers.
- Provide evidence related to the benefits of market-driven options and solutions.
- Provide recommendations to TSOs and DSOs for improvement paths in system operation to enable the integration of new services and products in system operation.
- Stimulate Demand Side participation, consumer involvement and Local Energy Communities.
- Ensure resilience contributions from DER (including black start). Develop and improve digital technologies (e.g., protocols, devices) to support customers and distributed energy resources to participate in the operation and market.
- Leverage the use of standards for data exchange of data (CGMES, CIM, etc).
- Define appropriate data models that can represent properly all the TSO-DSO-Prosumer interactions.
- Understand alternative and cumulative business models and business cases.
- Explore opportunities and benefits of security data sharing. Use advanced analytics and big data management for decision-making.

MAIN TECHNICAL CHALLENGES

Create a digital twin of the European electricity grid to enhance the efficiency and smartness of the grid as a way to make not only the networks, but the energy system as a whole, more intelligent. Increase observability in the power system and allow data exchange between the DSOs and TSOs. Identify what data and how it is exchanged between the system operators; Specify appropriate technical characteristics and time-frames to participate in the markets. Unlock markets of flexibility at every level to address the needs of the SOs. What are appropriate market models and in which situations? Standardize balancing market data exchange vertically (across the electricity value chain) and horizontally (across vectors/sectors). Design and test efficient optimization algorithms for near real-time TSO-DSO-Consumer coordination considering grid constraints. What are the real-time control strategies needed? Expand TSO-DSO cooperation towards the network planning longer time-frame. How are planning tasks to be coordinated? Create incentives and mechanisms for non-electric sector participants in an integrated energy system. Understand what is the level of cooperation between different system operators of multiple energy carriers (including organizational issues). Evaluate the adequate degree of integrated transmission and distribution planning considering Demand Flexibility. Ensure and test overall dynamic stability, understanding also what is the measurement infrastructure needed. Develop models for robust net load forecasting and robust forecasting of available flexibility. Develop and demonstrate effective and efficient platforms for market-driven interactions between multiple players that are interoperable and that fit the market requirements and have flexible interfaces. Improve/deploy and demonstrate IoT and EMS at prosumer premises to optimize (self) consumption and market participation according to grid needs and/or market signals (intelligent agents). Manage (big) data collected from multiple sources and apply them to decision-making at operational and planning level.

CURRENT STATUS

Platforms for TSO/DSO and consumer collaboration under development and testing in BRIDGE projects (e.g., INTERRFACE, OneNET, Coordinet, TDX_ASSIST, OSMOSE, EU-SysFlex, Integrid); definition, activation and provision of services started in demonstration and pilot projects; cross-sector integration still limited; existing standards, guidelines and data exchanges still insufficient; network planning cooperation less developed than operational short-term cooperation. There is an ongoing Horizon call to create the Digital Twin of the European Electricity System and as a first step, the EU DSO Entity and ENTSO-E signed on December 20 an official Declaration of Intent to develop jointly the Digital Twin of the EU electricity grid, and a number of BRIDGE projects initiated in recent months are working towards this goal…

EXPECTED OUTCOMES 2031

A sophisticated virtual model of the European electricity grid (Digital Twin of the European System covering dynamic monitoring, (smart) grid planning, secure operation, forecasting and scenario analysis)[74]. Seamless and efficient coordination between SOs; Increased DER integration and increased DER participation in Standards definition for data exchange between TSO and DSO and consumer; Demonstrated functioning of Market Models in a cross-sector environment; Understanding the needed and desired level of cooperation between different system operators of multiple energy carriers (including organizational issues). Demonstrated viable Business models; Reliable and robust demand-side aggregation; Reliable and robust forecasting of consumption, load, flexibility needs, as well as of available flexibility; High penetration of smart meters and IoT+EMS devices; Demonstrated functioning of common or coherent market design for Europe; Implemented interoperability platforms and defined common IT Architecture and common IT Interfaces.

The organising figure puts the proposed PPCs of HLUC 2 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

74 Supporting the development of a digital twin to improve management, operations and resilience of the EU Electricity System in support to REPowerEU.

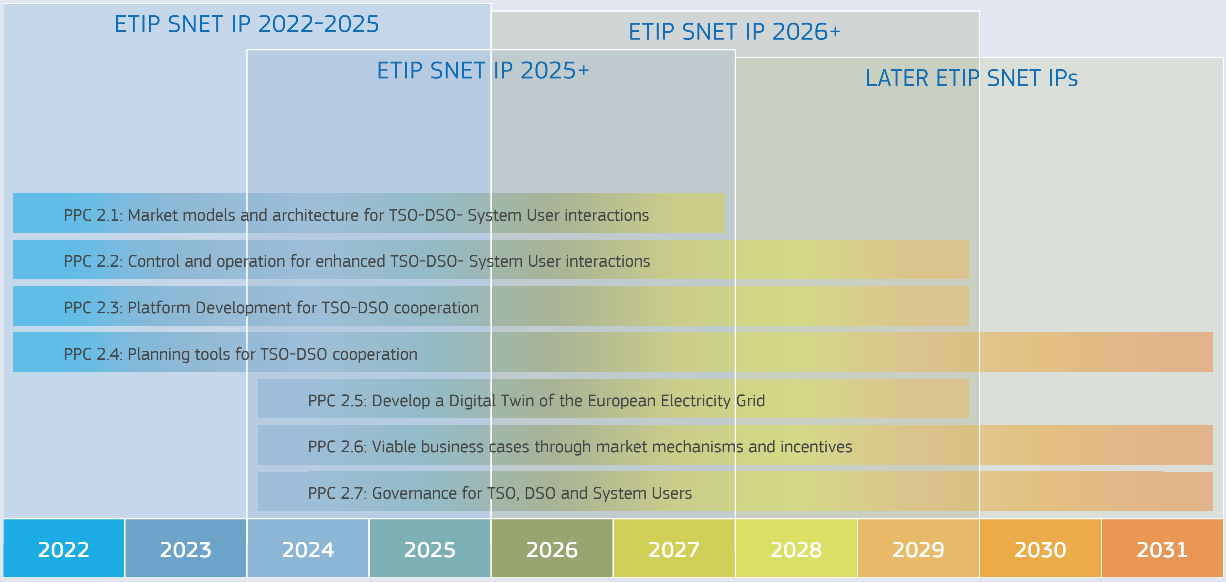


Figure 4: HLUC 2 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 2.1: Market models and architecture for TSO-DSO- System User interactions (IP 2022-2025)
Scope of PPC: Definition of suitable market models for the interaction of TSOs and DSOs, to central and local markets and their users and across different time frames. Identification of technical, market and business barriers to the smooth cooperation and interaction between TSOs, DSO and prosumers. Provide evidence related to the benefits of market-driven options and solutions. Interfaces definition and specification between different actors.

PPC 2.2: Control and operation for enhanced TSO-DSO- System User interactions (IP 2022-2025)
Scope of PPC: Design, development and demonstration of effective control mechanisms and technologies for prosumers participation in the market. Optimisation of the operation of the energy system and the provision of Ancillary Services from distributed resources, ensuring resilience contributions from DER. Real time balancing and management of flexibility.

PPC 2.3: Platform Development for TSO-DSO cooperation (IP 2022-2025)
Scope of PPC: Design and development of platforms for an effective secure and governed information sharing, allowing access and cooperation from multiple energy system players and an efficient organization of the energy system. Identify what data and how it is exchanged between the system operators, for each service (e.g., balancing, controlled islanding, congestion management and voltage control, reactive power, dynamic voltage control, etc).

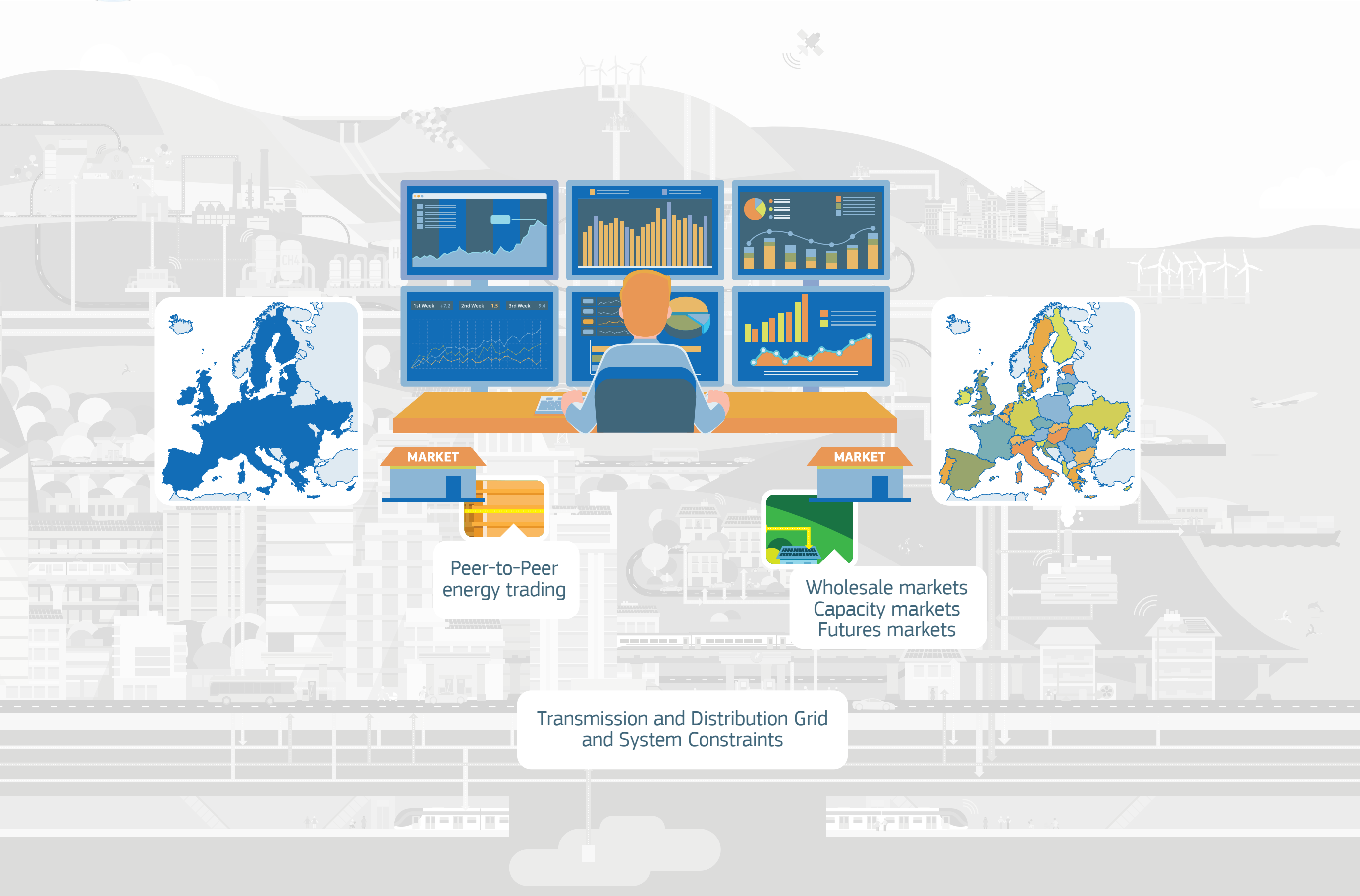
PPC 2.4: Planning tools for TSO-DSO cooperation (IP 2022-2025)
Scope of PPC: Optimisation of the energy system planning and its implications on capital investments. Expand the more developed TSO-DSO cooperation at operational level and time-frame towards the network planning longer time-frame. Clarify how the planning tasks are coordinated, in order to contribute to an efficient digitalization of the entire electricity grid.

PPC 2.5: Develop a Digital Twin of the European Electricity Grid (IP 2025+)
The creation of a digital twin will build on initial pilot innovation projects already started or being prepared for in 2023 and be achieved through coordinated investments in five areas: (i) observability and controllability; (ii) efficient infrastructure and network planning; (iii) operations and simulations for a more resilient grid and improved security of supply; (iv) active system management and forecasting to support flexibility and demand response; and (v) data exchange between TSOs and DSOs.

PPC 2.6: Viable business cases through market mechanisms and incentives (IP 2025+)
Scope of PPC: Design, test and demonstrate market mechanisms and incentives for an open participation of (aggregated) prosumers (system users) and effective cooperation of system operators ensuring viable business cases and positive cost benefit analysis in a sector coupling context. Perform cost-benefit analysis of different options for coordination schemes.

PPC 2.7: Governance for TSO, DSO and System Users (IP 2025+)
Scope of PPC: Enhancing the regulatory and administrative framework for an effective and efficient Energy System Governance. Develop and demonstrate enhanced and robust standards for cooperation and coordination among energy system players. Leverage the use of standards for data exchange of data. Definition of appropriate data models that can represent properly all the TSO-DSO-System User interactions.

HLUC3 Pan European Wholesale Markets, Regional and Local Markets



SCOPE

There is a clear need to design a radically new multi-energy market that would include cross-energy sector coupling, covering all temporal scales (from seconds, minutes, hours, days, months and years) and spatial granularity (from local district to regional and international areas), which will be critical for cost effective transition to a low carbon energy future, with energy supply based on increasing amount of renewable generation and decarbonisation of demand sectors (transport, heating, cooling, industry)

In this context, emerging flexibility technologies and advanced control systems in all energy sectors (electricity, heating and cooling, Gas, transport, hydrogen, etc), would deliver major cost savings, that the new market design needs to address, including:

- savings in system operating costs by the avoided curtailment of zero-carbon renewable generation and providing significantly more cost-efficient provision of the required balancing services across all energy sectors (energy trading and balancing services market)
- savings in capital expenses associated with reinforcing distribution, transmission network assets (gas/hydrogen and electricity) driven by reduced peak demand levels and the cost-effective management of network constraints (market for network congestion management)
- savings in capital expenses associated with investments in conventional generation, driven by reduced peak demands and support by interconnection (capacity market)
- savings in capital expenses associated with investments in low-carbon generation while meeting the carbon targets, driven by the much more efficient utilisation of lower-cost variable renewable generation (low carbon generation market)
- In this context the new legislation asks for enhanced roles of DSOs, particularly in procurement of ancillary services, flexibility, data management, effective integration of heat and transport sectors. Markets must encourage development of flexible technologies and control systems and Member States must eliminate obstacles to market-based pricing. Bidding zones must be reviewed by TSOs, and possible alternative concepts should be proposed. DSOs should align network access and congestion tariffs and charges. Member States should enable scarcity pricing, interconnection, DSR and storage to contribute to capacity market.

ACTORS INVOLVED

NEMOs, Energy companies (trading electricity, gas, hydrogen, heat etc.), RES aggregators, Network operators TSO/DSO (electricity, gas, heat), Retailers, Prosumers (Industrial, commercial, domestic).

SECTORS COVERED

electricity, gas, heating & cooling, water, hydrogen, mobility.

HIGH LEVEL GOALS

There is a clear need to design a radically new multi-energy market and policy framework that would include cross-energy sector coupling, covering all temporal scales (from seconds, minutes, hours, days, months and years) and spatial granularity (from local district to regional and international areas), which will be critical for cost effective transition to low carbon energy future.

Specifically, high level goals are:

- Develop fundamentally new multi-energy market with appropriate temporal and special spatial granularity to facilitate cost effective transition to low carbon energy future.
- Develop cost effective market mechanism for allocation of costs related to the provision of balancing services, network charging, investment in conventional and low carbon generation.
- Demonstrate that the new market will enable flexibility technologies and advanced system control concepts to access revenues associated with all benefits delivered.
- Develop fully decentralized energy markets including pear-to-pear trading of energy and balancing services, while maximizing service quality delivered to end consumers
- Assess the value of flexible distributed energy resources, such as demand side response, domestic batteries and batteries in electric vehicles, thermal energy storage etc., in offering flexibility and balancing services to the grid through aggregation
- Enhance renewable power purchase agreements
- Guarantees of origin are a key tool for consumer information as well as for the further uptake of renewable power purchase agreements.
- Provide capacity market renumeration to traditional and emerging small and large scale technologies, enable development of EU wide capacity market supported by interconnections
- Develop market design / regulatory framework for supporting cost effective delivery of resilience of supply from local to national / international level
- Develop market design that would recognize option value of flexibility technologies dealing with uncertainties in future deployment of low carbon technologies in local, regional and EU wide areas.
- Development and demonstration of advanced technologies and control concepts /platform tools for (a) supporting multi-energy systems market based on appropriate data exchange between different energy sectors in local, national and international regions (b) management of uncertainties in the provision of alternative balancing / ancillary services by different technologies (establishing level playing field for competition in provision of system services by different technologies / concepts)

MAIN TECHNICAL CHALLENGES

- Cross sector/multi energy market design that would be based real-time monitoring and appropriate data exchange
- Coordination between energy trading and real time balancing markets
- Development of a fully decentralised energy market
- Regional Market and cross-border trading /collaboration
- Flexibility monitoring and control

CURRENT STATUS

Several EU funded projects dealing with local and regional markets (CLUE, EU-SysFlex, HONOR, PARITY, SMARTNET, TDX ASSIST, CROSSBOW, TRINITY, CoordiNET). Enera (Germany-Integration of grids and markets, flexibility market in EPEX)

EXPECTED OUTCOMES 2031

dynamic market-time intervals, dynamic price zones and grid-constraints. Integration PtX and XtP; Market design considering integrated energy system, Strategic Investment

The following figure puts the proposed PPCs of HLUC 3 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

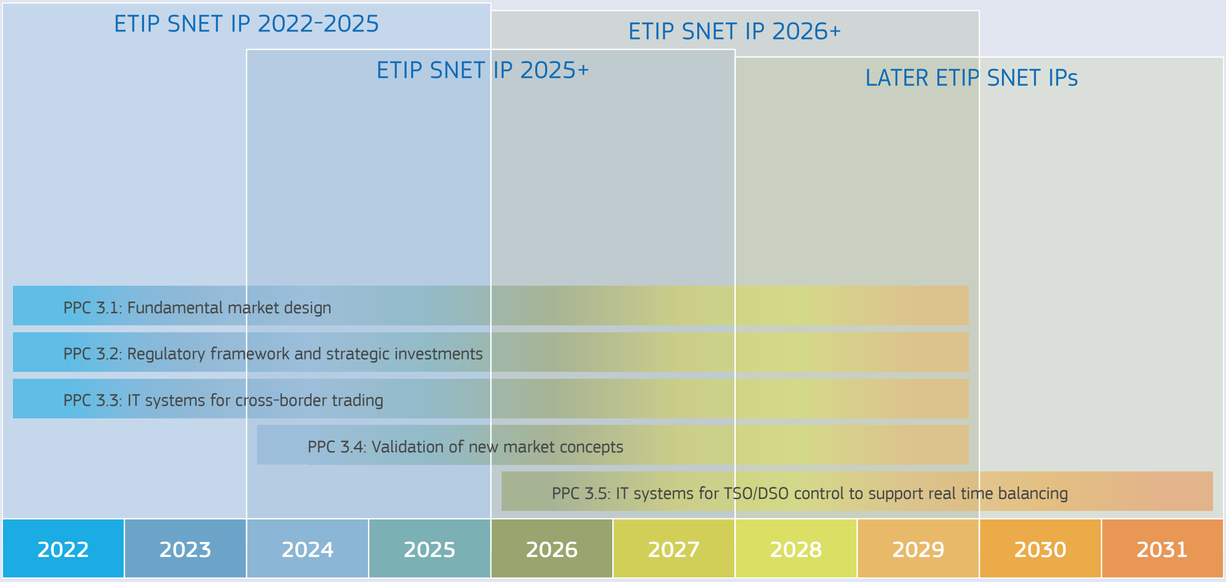


Figure 5: HLUC 3 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 3.1: Fundamental market design (IP 2022-2025)
Scope of PPC: Development of fundamentally new, multi-energy market with appropriate temporal and spatial granularity to facilitate cost effective transition to low carbon energy future, considering energy balancing, network congestion management services, EU wide capacity market, renewable power purchase agreement. Development of cost effective market mechanism for allocation of costs related to the provision of balancing services, network charging, investment in conventional and low carbon generation and would recognise option value of flexibility technologies dealing with uncertainties in future deployment of low carbon technologies.

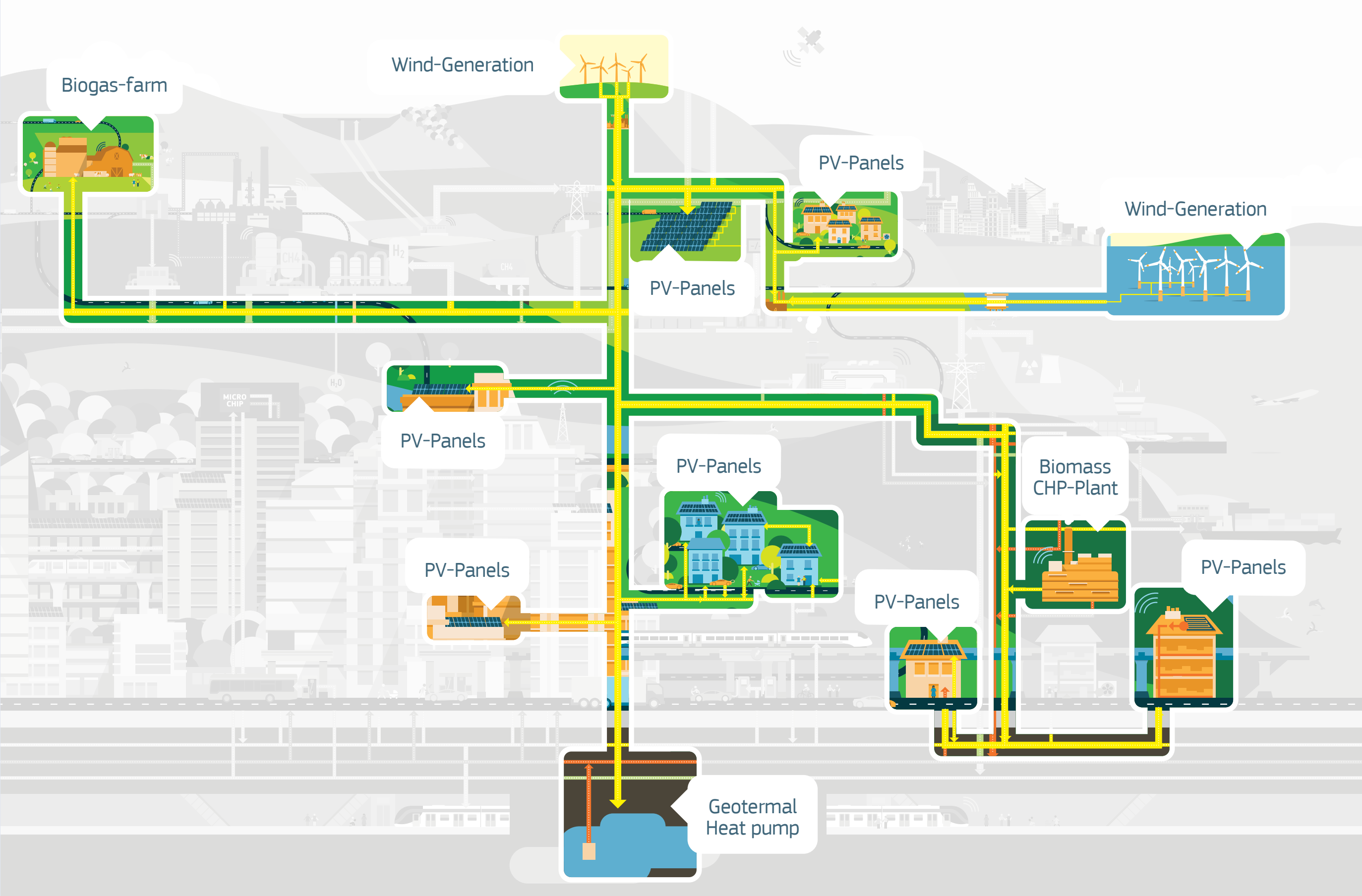
PPC 3.2: Regulatory framework and strategic investments (IP 2022-2025)
Scope of PPC: Development of new regulatory frameworks that would enable development of new security of supply standards, for supporting cost effective delivery of security and resilience of supply from local to national / international level (dealing with high-impact low probability events) and that would support strategic investment in energy infrastructure when/where appropriate

PPC 3.3: IT systems for cross-border trading (IP 2022- 2025)
Scope of PPC: Demonstration of platforms /IT systems for market-based trading of energy, balancing services across interconnectors and supporting EU wide capacity market and for enhancing security and resilience of supply of multi-energy systems

PPC 3.4: Validation of new market concepts (IP 2025+)
Scope of PPC: Development and demonstration of advanced technologies and control concepts /platform tools forsupporting multi-energy systems market based on appropriate data exchange between different energy sectors in local, national and international regions and supporting decentralised, peer-to-peer trading, (enabling end consumers to trade energy and ancillary services in real time), while supporting market driven system control (e.g. congestion management) and assess the impact on end consumers services quality.

PPC 3.5: IT systems for TSO/DSO control to support real time balancing (IP 2026+)
Scope of PPC: Demonstration of platforms /IT systems for market driven coordination of trading of energy, balancing services and network congestion management. Demonstration of advanced platforms for coordination of trading of energy, balancing services and network congestion management considering local, national and international level.

HLUC4 Massive RES Penetration into the Transmission and Distribution Grid



SCOPE

The EC has set very ambitious targets for RES penetration in the European Energy System. This is a key element of both the EU Green Deal package and the Fit for 55 proposals. Furthermore, it is also part of the REPowerEU ambition to reduce the European dependency on imported energy. In order for this ambition to be successful, significant developments are required of both large, centralised RES installations at Transmission level and distributed RES at both Transmission and Distribution levels. The massive penetration of RES stresses the power grids at multiple levels.

On one side, the operation with less mechanical inertia and with increased imbalances between generation and load, reinforcing the importance of improved forecast, where sophisticated analytics can play a key role. Still on the technical side, adequate protection mechanisms and controls for grid stability must be in place. Furthermore, adequate global monitoring systems need to be installed to anticipate and correct system stresses.

The integration of higher levels of RES must also be considered in the context of more DC connections from UHV level (embedded interconnections) downwards to Power Electronics connected devices (see also HLUC 6), raising the need of extensive grid-forming capabilities and evoluted control of such devices.

On the other side, market dynamics and new market designs must ensure participation and guarantee a well-functioning market also in the future situation of predominant zero-variable-costs generation. Furthermore, as also reinforced in the recent REPowerEU communication by the European Commission, reduced risk exposure for vulnerable consumers must be taken into account in such designs.

Energy System resilience shall be assured in the context of a massive RES penetration, counting with the contribution of storage and flexibility solutions. Indeed, with the expected increase of sectors integration and maturity of a multi-energy vectors system of systems, with the corresponding storage and flexibility capabilities, the scenarios, the ability to integrate higher levels of renewables and whole system behaviour need to be revisited to ensure an effective and efficient functioning.

An important part of the increased penetration of RES would be utility-scale wind and solar PV projects for which completion dates could be brought forward by tackling delays with permitting. This includes clarifying and simplifying responsibilities among various permitting bodies, building up administrative capacity, setting clear deadlines for the permitting process, and digitalising applications.

ACTORS INVOLVED

TSOs, DSOs, RES plants developers and operators (including off-shore wind), aggregators, Regulators, permitting authorities, prosumers, local energy communities, manufacturers and technology providers., storage operators.

SECTORS COVERED

electricity generation, transmission and distribution, sectors coupled (transport, heating & cooling, synthetic gases) for flexibility provision digital applications.

HIGH LEVEL GOALS

Key objectives of the European Commission communications, namely the EU Green Deal package, the Fit for 55 proposals and the REPowerEU initiative, include increased energy efficiency, increase RES penetration, accurate calculation of RES share, Off-Shore Wind and Ocean energy development, integration of RES from H&C, buildings, industry, transport, energy communities and multinational interconnection design to support offshore wind

The corresponding High Level Goals are the following:

- Ensure a cost effective, secure and reliable energy system with a further increasing level of renewables. Increase RES hosting capacity and penetration in transmission and distribution levels (reduction of curtailment, improved forecasting); improved modelling and simulation capabilities;
- participation of cross-sector RES;
- reduce system risks associated with increased fluctuating generation;
- de-risk and long term price signals for RES investments;
- User-friendly market access for RES participation (short-term bids, aggregation for ancillary services);
- Development of advanced, efficient and effective network technologies, such as FACTS, WAMS; Ensure efficient and effective DER control and Hybrid Power Systems.

MAIN TECHNICAL CHALLENGES

Transmission Network: Increase RES hosting capacity of Transmission System: expansion of the offshore grid; integration with increased DC grid presence; address infrastructure bottlenecks, grid integration of flexible grid technologies; mastering stability and dynamic behaviour .

Distribution Network: Increase RES hosting capacity, technologies for distribution Grid operation exploiting Flexibility and Storage management and corresponding coordination with Transmission System Operators; Optimisation of energy flows across the electricity networks and across interfaces towards othr sectors; appropriate forecast (load, generation, transits); Protections and Control; lack of inertia; ensure stability; accommodate increased grid forming capabilities in the system; Analysis of re-dispatch process and efficient market solutions; (Big) Data management for decision making; Coordination with other energy carriers and vectors, in particular hydrogen.

CURRENT STATUS

Several BRIDGE projects (OSMOSE, EU-SysFlex, CROSSBOW, FLEXITRANSTORE) address the integration of renewables in the energy system; despite developments on contribution of RES to primary voltage and frequency control, on advanced RES forecasting and stability analysis, several areas need further analysis: shortage of research on Investment planning in RES at EU level; need for further Probabilistic planning taking into account the DER stochasticity; need for further research on Synthetic inertia provided by power electronic Converters; need for further analysis of converter driven stability; need for integrating hydropower forecasting; research and understanding of large scale inter-area oscillations resulting from massive penetration of renewables.

EXPECTED OUTCOMES 2031

Reliable and cost-effective energy system management with a RES participation according to the latest RED III directive, with minimization of curtailment; integration and secure operation of massive off-shore wind energy via HVDC connections; Planning and Operating methods that aim at increased RES participation; resilience assessment and targets internalised in the grid planning process; seamless integration of renewable sources from heating & cooling networks, from buildings and industry; seamless participation of distributed renewable sources from different energy vectors into the energy market; seamless integration of renewable generation with storage systems in the electrical network and with other energy vectors.

The following figure puts the proposed PPCs of HLUC 4 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

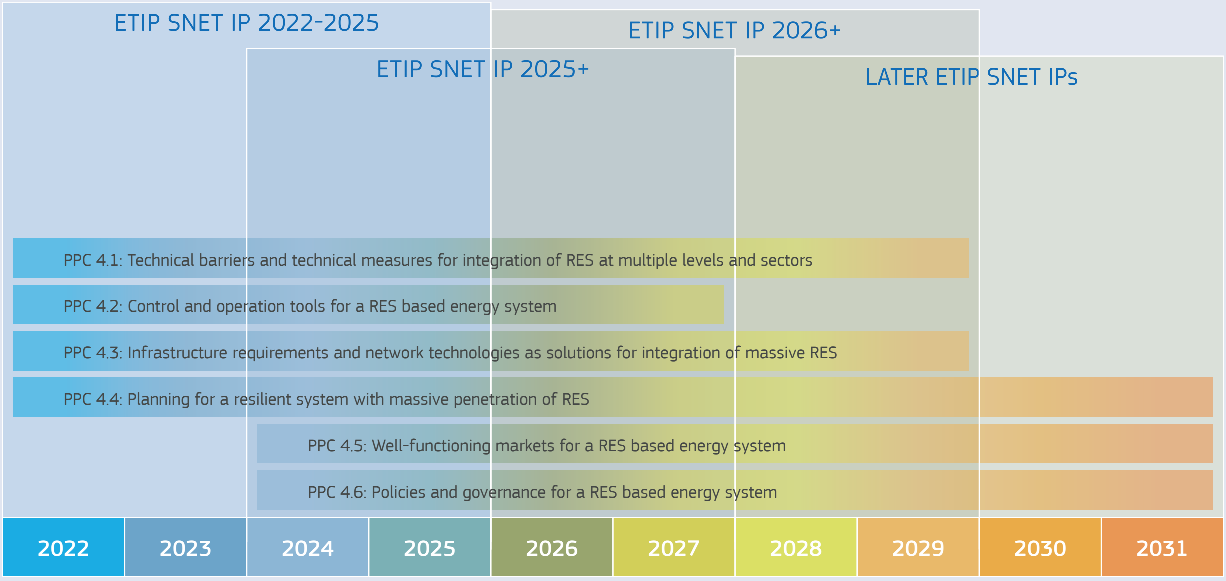


Figure 6: HLUC 4 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 4.1: Technical barriers and technical measures for integration of RES at multiple levels and sectors (IP 2022-2025)
Scope of PPC: Creating the conditions for the effective participation of industrial, residential actors and energy communities and for deploying corresponding grids leading to an increased share of RES in the energy system; ensure the digital capabilities for enabling more players being able to be present in the energy system and in the energy markets

PPC 4.2: Control and operation tools for a RES based energy system (IP 2022-2025)
Scope of PPC: Design and test advanced technologies and control mechanisms for integrating massive volumes of RES at distribution and transmission level, handling network constraints and providing flexibility needs, ensuring coordination across voltage levels and energy sectors. Design and test of Virtual Power Plant (VPP) solutions and hybrid power stations, design solutions for renewable energy generation technology to be able to contribute to system flexibility, stability and congestion management, investigate implications in protection and control.

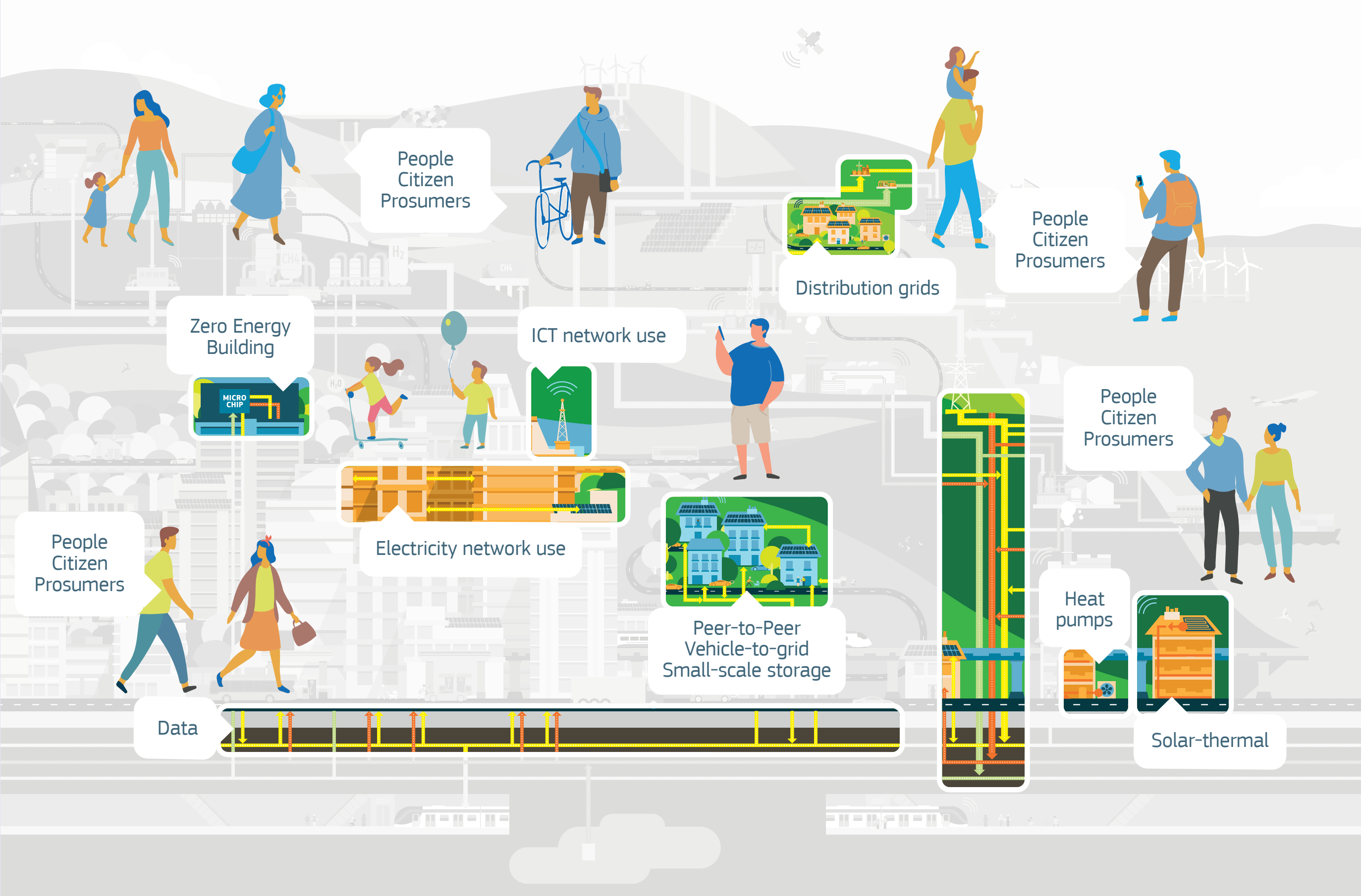
PPC 4.3: Infrastructure requirements and network technologies as solutions for integration of massive RES (IP 2022-2025)
Scope of PPC: Ensure the integration of massive RES at multiple voltage levels through advanced grid solutions (e.g., HVDC, FACTS) and increasing flexibility capabilities from RES. Ensure the efficient and reliable grid-connection and system-integration of large RES generation (e.g., large offshore grids) and multiple microgrids connected to the distribution grid. Resilience and cybersecurity risks in the renewable energy and grid supply chain, including offshore wind.

PPC 4.4: Planning for a resilient system with massive penetration of RES (IP 2022-2025)
Scope of PPC: Enhance system resilience in the presence of increased RES penetration at all levels, via situational awareness, advanced forecasting methods, restoration mechanisms, adaptive network reconfiguration including microgrids and smart load shedding ensuring stability of the system and robustness to extreme events; Planning should take into consideration the integration of other energy carriers (e.g. hydrogen) and sectors (e.g. mobility).

PPC 4.5: Well-functioning markets for a RES based energy system (IP 2025+)
Scope of PPC: Ensure appropriate mechanisms for market participation from RES at multiple levels, from local to global scale, and from heterogeneous energy sectors, ensuring viable business cases and backed by supporting regulations; Ensure reduced risk for vulnerable consumers under a market design with massive penetration of renewables; ensure market mechanisms are transparent and non-discriminatory.

PPC 4.6: Policies and governance for a RES based energy system (IP 2025+)
Scope of PPC: Develop tools and mechanisms to ensure the governance of top-down RES targets with bottom-up private investments in RES, storage and flexibility means; ensure temporal match in the evolution trajectories of RES plants, grids developments, and sector coupling and ensure adequacy at various time frames (season, year, multiple years) through most appropriate mechanism (capacity market, variable capacity subscription, non-wire solutions)

HLUC5 One-Stop Shop and Digital Technologies for Market Participation of Consumers (citizens) at the Centre



SCOPE

Consumers - also in the role of prosumers – and citizens have a critical proactive role to play to accelerate the adoptions of new energy services and technologies in their environment as well as for deciding the most suitable options for them to reach the decarbonisation objectives set through the high-level policies. The pace of consumer adoptions will significantly impact the design of Cross sectorial Energy System infrastructures with the acceleration of electrification – particularly to accommodate new heat pumps and electrical vehicle home charging as well as the introduction of new decarbonised heat network and Green Hydrogen in specific sectors. Education and training is a fundamental aspect of this HLUC as consumers buy energy for their daily and seasonal needs (having light in their homes, E-Vehicles for moving around, heating pumps to have warm homes, ovens for cooking, batteries for computers, smart phones which need to be loaded, etc). Integrated Energy System Complexity is and will be hidden and citizens must not be requested to become all engineers. Their needs will, however, change. Consumer needs will also evolve with different renewable energy carriers (such as hydrogen). System adoptions for the cross sectorial efficient integration require an energy system evolution beyond electricity over time. While local solutions may differ country by country, it is necessary that the differences are transparent to the consumers and citizens. IT solutions are needed that facilitate consumer/citizen inclusions and that are independent or abstract from the contingencies of a specific market.

Furthermore, it is necessary to integrate the energy system in the wider picture of the data economy so that consumer/citizen inclusion means also to facilitate use cases that go beyond energy and cross-link to completely new domains.

This HLUC will develop the necessary research and innovation to facilitate one stop shop consumer/citizen participation in the energy system and, correspondingly, inclusion of the energy system in the concept of data economy. This implies several aspects: standard interfaces, communication solutions and better secure communication solutions.

The transformation to the distributed, renewable energy future demands the paradigm shift from supply side response to demand side response. Consumer behavior has an impact on the EU decarbonization targets. They can contribute to system flexibility and renewable consumption. Not by manual intervention but with the help of digital enabled energy management of microgrids in customer premises.

ACTORS INVOLVED

DSO (gas, electricity and others like green hydrogen), Consumer/ Prosumer, RES aggregators, Mobility providers, ICT providers, Training providers, energy retailer, heat contractor, landlord/ housing association

SECTORS COVERED

electricity and gas, local heating and cooling network, other sectors that could be linked to energy such as transportation, building, ICT and health.

HIGH LEVEL GOALS

Provide access to the consumer to energy data and advanced services (including DR) going beyond the electricity sector to fully integrate energy in the data economy so to open new opportunities and business cases that will facilitate the decarbonization of the energy system. This will contribute to achieve the objectives of the following Fit for 55 indicators: electricity to become the dominant energy carrier and widely replace fossil based energy needs, increasing consumer flexibility of the energy system; increasing electricity transport share, increasing residential and industrial electricity use, households (citizens) becoming active energy consumers providing flexibility, and massive integration of distributed energy renewables. Massive digital involvement of consumers in the energy system including strategies to engage consumers in the design and use of accessible and affordable digital tools and to identify indicators to assess engagement over time. Increase RES penetration at consumer sites, connected to the distribution grids. Optimal and continuous provision and use of system flexibility. Increased EV-based transport and massive use of electric heat pumps enabled by minimum-cost, smart energy system enhancements. Finally the is a need for an open, transparent and secure digital ecosystem, where data and services can be made available, collated and shared in an environment of trust

MAIN TECHNICAL CHALLENGES

The main challenges are twofold: On one side, to create the conditions for a real plug&play situation for consumer assets and related data exchange needs and on the other side, to define the technical requirements for the platforms to be used by consumers / citizens as the entry to a one-stop shop which must be adaptable as the consumer needs will change and evolve. Right now, there is too much dependency on interfaces that are proprietary and then closed and not ready for quick adaptation to new conditions. This is endangering the adoption of digital technology and slowing down the process. It is fundamental to operate under much more open conditions so that customers not only can easily join but also rapidly change service providers in a competitive scenario. Digitalization should be the main tool to hide the complexity of the future energy system while opening completely new scenarios of services to the customers. Services that are data-driven and go beyond the energy sector for an integrated data economy.

The overall challenge is to create a common European energy data space, comprising an appropriate data sharing framework for energy that could facilitate the participation on the wholesale markets and the participation of EVs smart charging, virtual power plants, energy communities, smart buildings and smart heating that make full use of digital solutions by 2050. In particular, it should be ensured that the consumers and citizens have a way to get access to the one-stop shop platform as well as enabling in a simple way, whenever required, access to other existing platforms for system-enhancing data exchange and Local Energy Markets. It is important to make this access simple not only from the technical point of view but also in the sense that the service offers should speak a language customers can understand.

Interoperability for non-discriminatory and transparent procedures for access to data required for demand response and customer switching needs, as well as for access to metering and consumption data (as provided for by the Electricity Directive, Article 24) needs to be ensured. Promoting a code of conduct for energy-smart appliances to enable interoperability and boost their participation in demand response schemes..

This can be obtained particularly if we extend the horizon beyond electricity and make sure that data are shared among domain so to create new opportunities.

CURRENT STATUS

Many R&I for platforms in Distribution Grid, lack of solutions for cross sectors application, limits in the way data can be used for advanced use cases. Furthermore, too many solutions are built as proprietary so that many significant data silos are present and the situation is not facilitating the customer participation. Furthermore 5 ongoing projects focusing on Energy Data Spaces.

As result it is difficult for consumers to have a broad sense of possibilities to be involved in a variety of market and services. The only practical way is the design and deployment of a platform fully serving the needs of the consumer. It is also important that the offers to the customers address clear needs of the customers and not technical needs of the infrastructure (e.g. flexibility)

To speed up the energy transition is critical that also the energy system becomes service driven and this will be also the quickest way to get customer involved.

At the same time this can happen only if digitalization hides the complexity: this means that plug&play concept in the wider sense from data connection to service provision should be pursued.

This scenario makes sense only if it can be achieved while guaranteeing privacy and security. Every approach should be based on security-by-design and privacy-by-design avoiding to add security on top of already developed solutions.

Finally, there is a need for common standards to avoid vendor/provider lock-in; scalable engagement ICT infrastructures

EXPECTED OUTCOMES 2031

- The energy sector (using all types of energy carriers and sources in an optimal, system-integrated way) is fully linked with the data economy
- Significant new business cases have emerged across different sectors.
- Market platforms for local market and consumer participations are available, based on open access, plug&play situations avoiding restrictions from proprietary solutions.
- A common European Data Space.
- Solutions are built according to security and privacy-by-design so that customers can safely join the new opportunities.
- Interoperability
- Different communication media are integrated to facilitate the data exchange.
- Achieved EU target CO2 reduction goals supported by citizen participation.

The following figure puts the proposed PPCs of HLUC 5 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

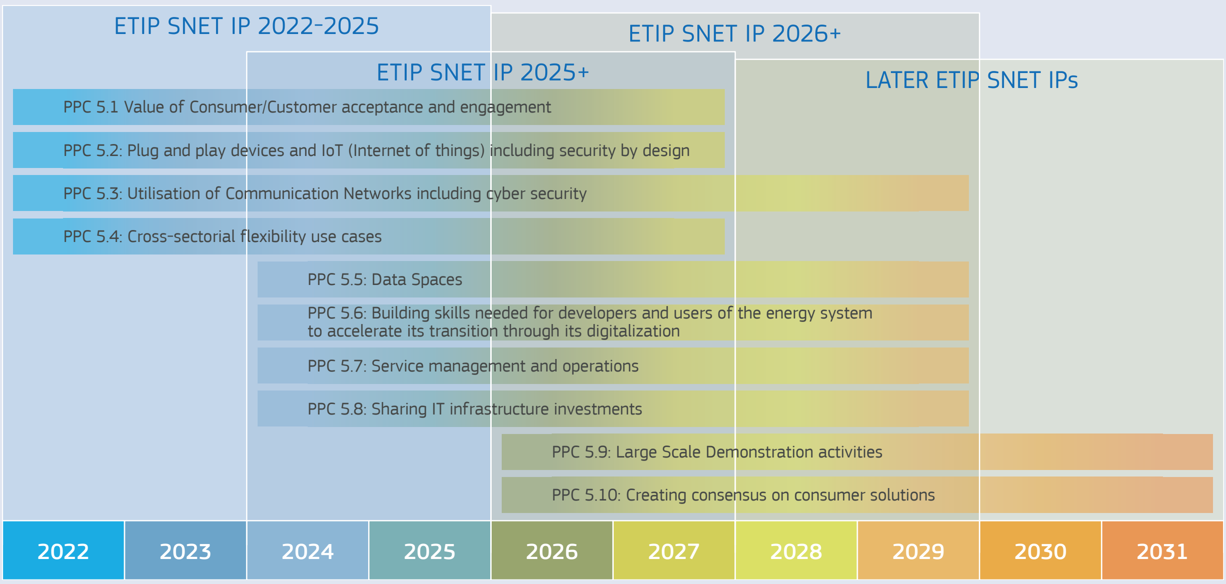


Figure 7: HLUC 5 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 5.1 Value of Consumer/Customer acceptance and engagement (IP 2022-2025)
Scope of PPC: Analysis of the platform requirements in order to accelerate the adoption of new energy services and technologies. The access to data and energy services will allow the consumer/customer to go beyond the electricity sector into a fully integrated energy system. Educational aspects and training needs for consumers must be considered within the analysis so to ensure the widest access to the platform.

PPC 5.2: Plug and play devices and IoT (Internet of things) including security by design (IP 2022-2025)
Scope of PPC: One of the obstacles for consumers to have a more active role in the energy system is the lack of solutions that really support plug and play. Purpose of this PPC is to remove this barrier and develop solutions that facilitate joining any kind of energy market across Europe. Particular emphasis will be placed in promoting interoperability for energy-smart appliances to their participation in demand response schemes. Also special care must be taken to enhance smart meters connectivity trending to the real time domain as this will be more and more requested by flexibility opportunities.

PPC 5.3: Utilisation of Communication Networks including cyber security (IP 2022-2025)
Scope of PPC: Smart solutions will use a variety of connection solutions. It is critical to facilitate connection while preserving security. This PPC will investigate how security by design can support use of communication networks, including private ones, in energy applications.

PPC 5.4: Cross-sectorial flexibility use cases (IP 2022-2025)
Scope of PPC: Redefine access to flexibility by means of use cases that do not target directly energy flexibility but bring flexibility as consequence, in order to attract citizens. Examples can be given by the idea of selling comfort instead of heating, other ideas can emerge from other business sectors such as security or health.

PPC 5.5: Data Spaces (IP 2025+)
Scope of PPC: Considering current developments in the Energy Data Space field, promote the development and validation of de-centralized and federated data spaces, addressing on the one hand the data management needs of each of the stakeholder involved in the energy system value chain and on the other hand, safeguarding data security and sovereignty. Focus on the development of federated data sharing mechanisms (utilizing suitable and "green" Distributed Ledger Technologies) and associated business models that facilitate both economic and non-economic transactions between data owners/ providers and data consumers, while exploring objective data valuation models to avoid deterministic and non-realistic fee requests for shareable data assets..

PPC 5.6: Building skills needed for developers and users of the energy system to accelerate its transition through its digitalization (IP 2025+)
Scope of PPC: Develop and Preparation of guidelines for the development of digital skills in energy as needed by the industry and users. An analysis of digital skills gaps, between what is demanded and what is offered, has to be done and continousaly updated Educational frameworks will target program not only for Universities but also practicing for engineers, technicians and installers in the whole energy domain. Also, users of the energy system has to be a target for training and skilling. Focus on modern smart grid technologies. . There is project funded by ERASMUS+, EDDIE, targeting a blue print to address this subject.

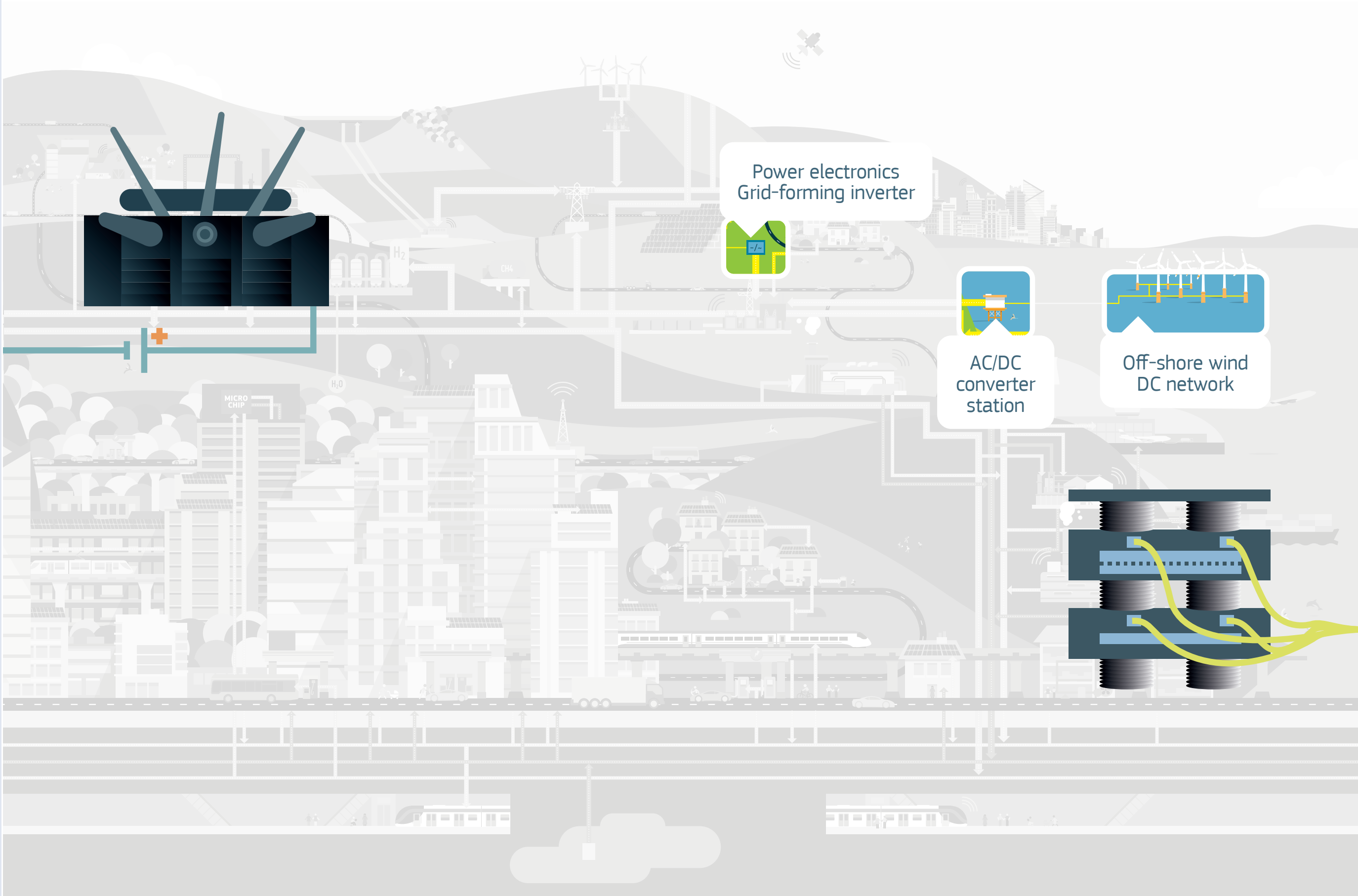
PPC 5.7: Service management and operations (IP 2025+)
Scope of PPC: Design of adequate Service Management. Digitalise the energy system and processes based on new business models, new revenue streams and value producing opportunities: Setup appropriate service management processes, systems and organizations that meet demand for superior customer service and deals with strong competition. These projects are at a Innovation Action (IA) level.

PPC 5.8: Sharing IT infrastructure investments (IP 2025+)
Scope of PPC: Use IT infrastructure actively by more than one actors in the energy domain. Develop new business models and processes by digitalization the energy system. Develop new business models, new revenue streams and values producing opportunities. Create the right incentives to develop advanced communication infrastructures: Identify such infrastructure and propose a fair funding scheme for the involved actors. These projects are at a Coordination, Support Action (CSA) level.

PPC 5.9: Large Scale Demonstration activities (IP 2026+)
Scope of PPC: This PPC should take the results of the PPCs 5.1-5.8 and bring them to a new scale by large demonstrators. For example, develop an experimentation platform to test and simulate energy communities in combination with innovative activities such as blockchain-based energy trading.

PPC 5.10: Creating consensus on consumer solutions (IP 2026+)
Scope of PPC: Transfer the results of all the PPCs from innovation to real life by preparing the conditions for new standards in particular at the level of software API's and in terms of service definitions.

HLUC6 Secure operation of widespread use of power electronics at all systems levels



SCOPE

Power electronics driven components are becoming a key asset for modern power grids, but there is not yet a clear understanding of how these devices will shape system operation. The more the share of power electronics devices grows, the more there is a need to involve these devices with an active role. This is true at different levels for the grid. Projects considering the transmission system shall consider the evolution of HVDC towards multi-terminal multi-vendors meshed DC grids. These are appearing first of all for off-shore RES applications, but are expected to spread also in on-shore solutions and to move from HV also to MV applications. In particular, the definition of the roles of grid-forming converters is still mostly at research level and a flexible transition between different modes of operation shall be further investigated, including how substations with traditional transformers can be enhanced by power-electronics and how the penetration of smart power routing devices such as FACTS and Solid-State Transformers can be applied.

This HLUC will explore the role of the power electronic devices at every level from the transmission to the LV distribution and prepare the condition for a system level operation that is fully capable of using the control capability of power electronics. The overarching goal is to facilitate a power electronics dominated grid.

ACTORS INVOLVED

Equipment and software developers, TSOs and DSOs, Research and Academia

SECTORS COVERED

electricity

HIGH LEVEL GOALS

Advanced simulation tools, new power electronics controls, evolution of the concept of substation. Enabling high penetration of renewables. Smooth integration of storage at every level. Increased security of operation thanks to increased flexibility in the grid operation

MAIN TECHNICAL CHALLENGES

Energy Systems are characterized by widespread penetration of power electronic converter interfaced technologies, due to their efficient conversion capabilities and their controllability. Among these new technologies are wind and photovoltaic generation, various storage technologies, flexible ac transmission systems (FACTS), High Voltage Direct Current (HVDC), lines, and power electronic interfaced loads. With significant integration of converter interfaced generation technologies (CIGs), loads, and transmission devices, the dynamic response of power systems has progressively become more dependent on (complex) fast-response power electronic devices, thus, altering the power system dynamic behavior. The increasing share of CIGs in power generation mix affects all types of system stability, frequency, voltage and rotor-angle stability and leads to new types of power system instability problems, like converter driven or harmonic instability. These problems arise due to the different dynamic behavior of CIGs compared to that of the conventional generators. The stability issues arise due to interactions between CIG controls, reduction in total power system inertia, and limited contribution to short circuit currents from CIG during faults. New tools are needed to model and simulate all these types of fast and slower stability phenomena. Further challenges include the need of analysis tools to map all uncertainties – both power electronics and power systems, the need of new testing methods to analyze thousands of power converters operating at the same time and how to aggregate 1000's of them in complex systems and to develop reliability assessment methods of complex systems. In the future we can expect meshed DC grids at all voltage levels, hybrid transmission and hybrid distribution AC/DC grids. These topologies will require new control concepts for system integration so to guarantee a safe operation of the grid.

From the grid operation perspective, a new generation of substation with high adoption of power electronics is emerging. This means the possibility to substitute old transformers with the so called smart-transformers, but also to integrate DC buses in the substation or other advanced power electronic solutions such as FACTS. Goal is to transform the substation in an intelligent node able to guarantee a high level of reliability in the region of operation

At the lower level we will have a growing role of industrial grids and prosumer driven energy communities. As result, also at LV level we will experience new dynamics but also new possibility to flexibly manage the power flow.

CURRENT STATUS

Power electronics driven components are becoming a key asset for modern power grid but there is not yet an overarching concept of how these devices will shape system operation. The more the share of power electronics devices grows, the more there is a need to involve these devices with an active role. This is true at different levels for the grid. Starting from the transmission system we have the evolution of HVDC towards multi-terminal multi-vendors meshed DC grids. These are appearing first of all for off-shore applications but are expected to spread also in off-shore solutions and to move from HV also to MV applications. In particular, grid-forming inverters need to be developed, mainly to support weak grids and a flexible transition between different mode of operation is also a not completely explored. ity. Substations are still fully based on traditional transformers and the penetration of smart power routing devices such as FACTS is rather limited.

EXPECTED OUTCOMES 2031

- Clear understanding of the dynamics of a power grid with high penetration of power electronics.
- Simulation tools implementing the aforementioned concepts
- New generation of grid-connected inverter able to provide grid services in a flexible way and able to commute
- Grid operation principles for multi-terminal HVDC and MVDC networks
- Grid operation principles for hybrid AC/DC networks at MV and LV level
- Definition of a fully electronic substation able to provide active control of the power flow
- Process of standardization to support all the aforementioned principles

The following figure puts the proposed PPCs of HLUC 6 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

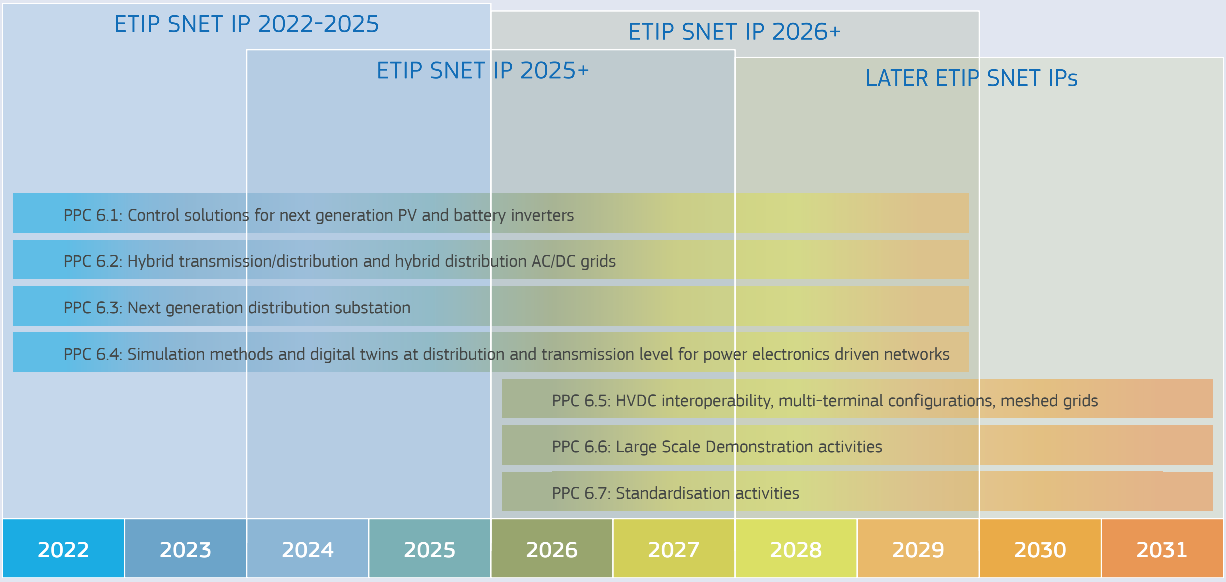


Figure 8: HLUC 6 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 6.1: Control solutions for next generation PV and battery inverters (IP 2022-2025)
Scope of PPC: This PPC will develop control solutions for components such as PV and Battery inverters that can be considered grid friendly, i.e. able to provide a variety of services that can be used at system level. The goal is the facilitation of digitalised plug & play solutions.

PPC 6.2: Hybrid transmission/distribution and hybrid distribution AC/DC grids (IP 2022-2025)
Scope of PPC: This PPC will develop the necessary control solution that support the development of hybrid AC/DC grids in HV and MV. Goal is not to focus on new topology but on the development of the proper concepts that support interoperability and cooperation between converters operating in the DC and in the AC section of the system.

PPC 6.3: Next generation distribution substation (IP 2022-2025)
Scope of PPC: This PPC will explore all the possible integration of power electronics in the substation or close to the substation to develop the concept of a flexible and programmable power grid in which the substation is a center of intelligence that facilitate the optimal power routing while ensuring power grid resilience.

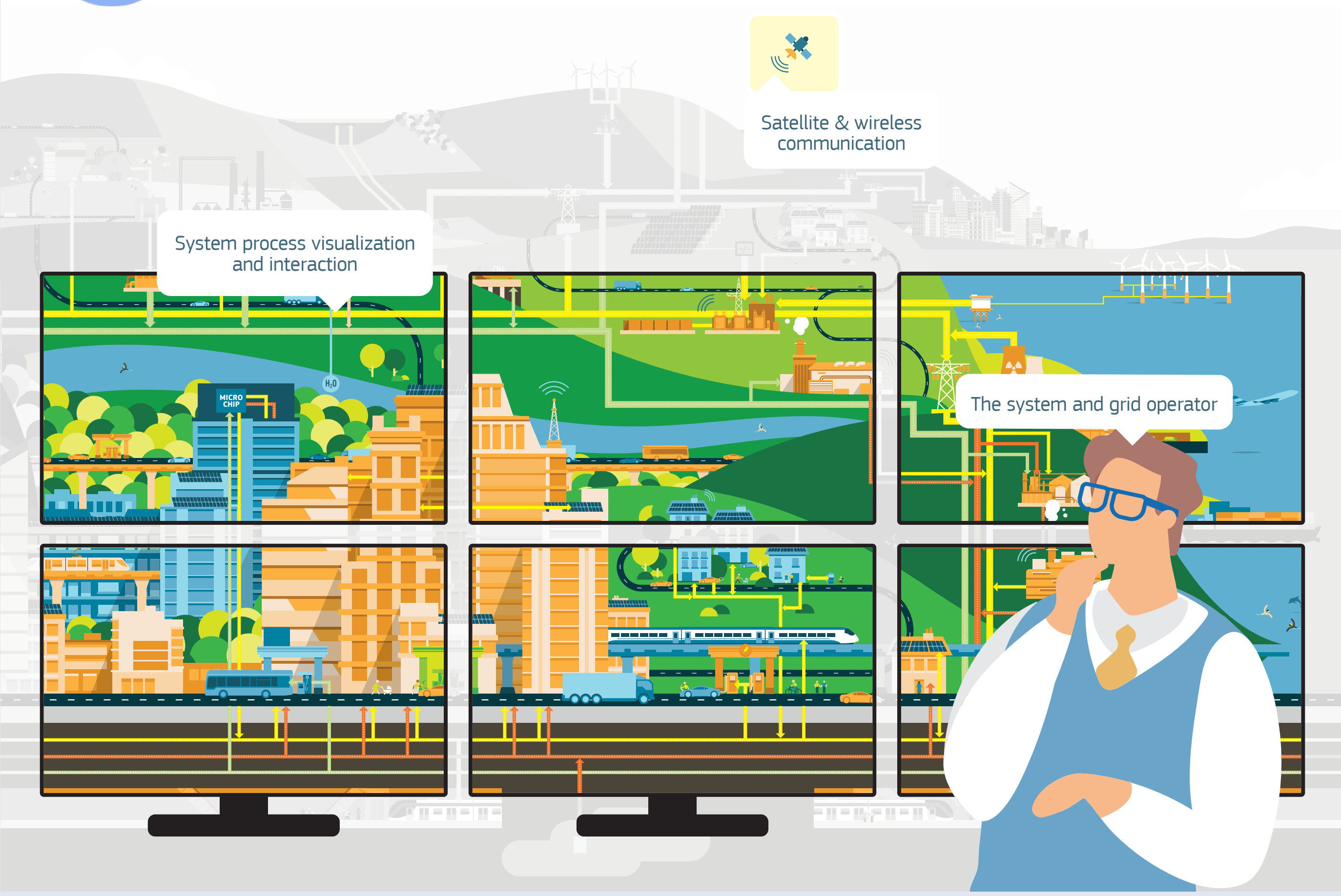
PPC 6.4: Simulation methods and digital twins at distribution and transmission level for power electronics driven networks (IP 2022-2025)
Scope of PPC: The growing presence of power electronics is radically modifying the dynamics of the power grids. This PPC will tackle the need of the new simulation tools that go beyond the classical separation between phasor simulation and electromagnetic transient analysis.

PPC 6.5: HVDC interoperability, multi-terminal configurations, meshed grids (IP 2026+)
Scope of PPC: As mentioned in the CIGRE Green Book, the goal of multi-terminal DC transmission systems is to keep the main advantages of point-to-point DC transmission networks and to maximise the utilisation of the assets. Multi-terminal configurations will improve the investment on assets and the environmental impact of the power system infrastructure. The goal of this PPC is the development of the necessary methodologies, tools and models for the analysis of the operation of such configurations.

PPC 6.6: Large Scale Demonstration activities (IP 2026+)
Scope of PPC: This PPC shall take the results of the PPCs 6.1-6.5 and bring them to a new scale by large demonstrators.

PPC 6.7: Standardisation activities (IP 2026+)
Scope of PPC: Transfer the results of all the PPCs of this HLUC from innovation to real life preparing the condition for new standards and grid codes compatible with the results of the projects. These projects are at a Coordination, Support Action (CSA) level.

HLUC7 Enhance System Supervision and Control including Cyber Security



SCOPE

The growing electrification and the more decentralised deployment of renewable power generation will require reinforced and smarter electricity networks, able to accommodate both centralised and decentralised elements and to make the best of RES allocation over the European territory. Pervasive network Digitalisation, supported by high-capacity cyber-secure communication networks, will ensure decentralised monitoring and control. Not only density of the network, but also interconnection capacities –with harmonised security, planning and operation standards- will be needed to match growing RES supply and electricity demand over larger areas, as well as transparency to market participants all over Europe. These changes are calling for a complete reconsideration of the concept of control room both at TSO and DSO level. The change will affect not only the definition of the appropriate HLUCs but also the fundamentals of the architectures. While we can still imagine the control room as a centralised place, the intelligence will be more distributed and, for the case of distribution grids, mostly at the edge.

As in most of the cases there are existing "legacy systems", where not only hardware and software but data base contrasted and updated are fundamental to keep the operation of the system, the transition to the new required architectures should be well planned, checked and implemented in a secure way. This will be referred from now on as the "transition from legacy systems".

At the same time with introducing significant changes in the concept of operation, there will be a significant impact on the workforce. This impact can be manifested in two directions: needs of new types of Human Machine Interface and need of training to prepare the workforce to operate under the modified conditions.

ACTORS INVOLVED

TSO, DSO, providers of SCADA and network supervision and control solutions (hardware and software), providers of cloud (computing and telecommunication) solutions, providers of operational telecommunication (OT) services.

SECTORS COVERED

electricity and gas

HIGH LEVEL GOALS

Electricity becomes the dominant energy carrier, through the increase of renewable share, while increasing networks efficiency, resiliency and reliability; providing Flexibility of energy systems, through the needed real time supervision and control (whereas appropriate) of the different DERs connected to electricity networks ; supporting the share of transport electricity, through the smart charging (both grid2EV and EV2grid); and supporting industrial electricity use shift to carbon neutral heat supply

MAIN TECHNICAL CHALLENGES

The grid is becoming a complex cyber-physical infrastructure characterized by a high number of intelligent devices many of them connected at the edge. This is a huge revolution that is transforming the originally strictly hierarchical architecture in a more distributed and bottom-up situation. As result control centers both at distribution and transmission level should evolve to better serve the new conditions.

The massive distribution of smart devices is bringing more and more the need to distribute the intelligence. This does not mean that we will not need a control room in the future but it means that the relation between functions and locations will change.

Control functions can be distributed, but an overarching concept of supervision is still needed.

This view defines the concept of control room of the future and the situation is basically the same at transmission or distribution level where only specific functions may differ depending on the responsibility of TSOs and DSOs.

First of all a higher level of observability is needed that is not limited at the transmission level and covers all the voltage levels reaching also the LV infrastructure. The monitoring needs to cover new types of dynamics and, in particular, faster dynamics. This results in higher telecommunications requirements supporting real time (small latency) monitoring/supervision and control.

As the number of distributed renewable generation is increasing and this type of generation is very much dependent of the weather conditions, the accuracy of predictions and follow up of weather will become a fundamental auxiliary of the future control rooms.

The complexity of the operation is such that the manual action of the human operator will be reduced but not removed. Many actions specially in the distributed domain should be done automatically, of course allowing the concourse of the human operator as needed for the safety of persons, environment and assets. This means that creating awareness for the operator is actually an even more complex task than in the past.

Besides that, the maintenance of software, being sure that the appropriate versions in the (normally remote) intelligent devices have fully embedded cybersecurity provisions, will be fundamental in the future systems and will become an important part of the activities within the control rooms.

Also the interconnection with systems which are considered IT, like Geographical Information (GIS) and asset management (covering the cycle of planning, design, implementation (including CAPEX), will be more integrated for efficient operations (OPEX). Automatic updating and debugging of data bases using MML and AI techniques, supported by the use of workforce mobility devices will become a basis of continuous improvement.

Such a significant change is only possible also if there are adequate plans in parallel for the long-term education of the work force to make sure that the personnel is always fully aware of the potential of the new infrastructure.

The increasingly digitalization of the energy system raises a number of cybersecurity threats. Cybersecurity plays a key role for the energy system to remain secure and robust against cyber incidents and major attacks, from production and transmission to distribution and the consumer, including all the digital interfaces along this path. It is essential to identify the specific ICT services, systems or products that might be subjected to cybersecurity risks and assess the technical and non-technical risk factors.

CURRENT STATUS

The discussion about the role of TSO and DSO in the future is still on going. At the same time also the automation architectures are still based on classical solutions and, even if projects have shown new and more advanced approaches, their adoption is still rather limited. For the moment, we are mostly trying to embed the new situation in the old system.

Correspondingly, also the workforce in service has limited knowledge about the upcoming solutions and on the implications of digitalization and the consequences for grid operation coming from power electronic devices.

EXPECTED OUTCOMES 2031

- Next generation control room for TSO ready as product
- Next generation control room for DSO ready as product
- Integrated planning and operation (including control and maintenance) in a fully digitalized grid operation
- New control concepts and data management are integrated in the control room of the future
- The network code for cybersecurity aspects of cross-border electricity flows, including rules on common minimum requirements, planning, monitoring, reporting crisis management.
- Adaptation of gas and hydrogen networks to risks, such as cyber-attacks.

The following figure puts the proposed PPCs of HLUC 7 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

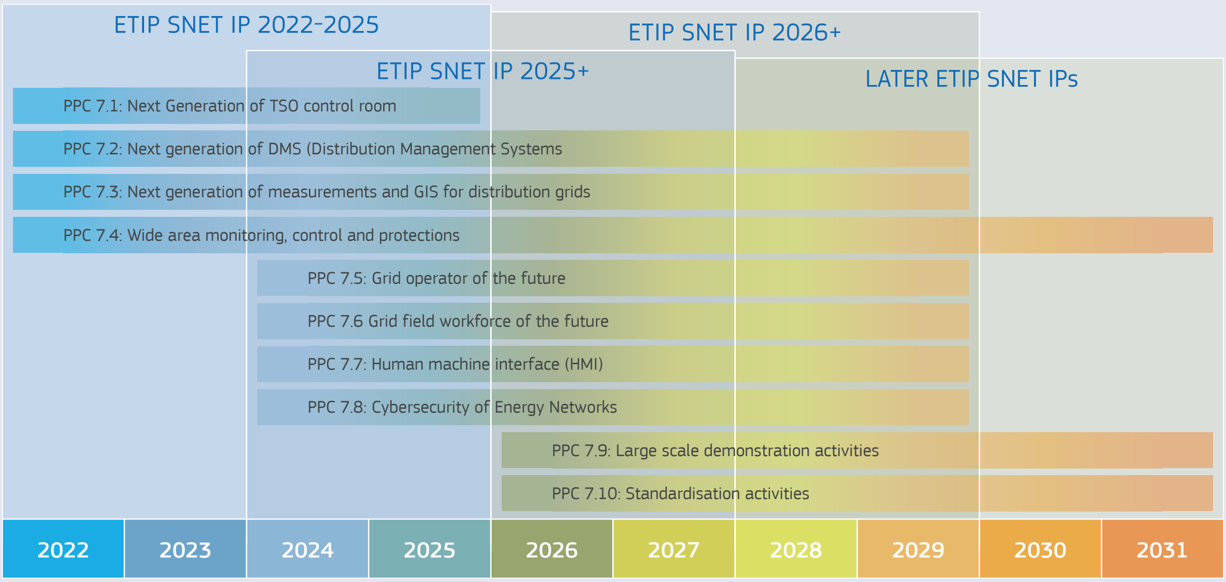


Figure 9: HLUC 7 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPT

PPC 7.1: Next Generation of TSO control room (IP 2022-2025)
Scope of PPC: System level automation to cope with the distributed characteristics of the generation and the active role of the loads. Define new architecture and solutions for the control room of the future. Coordinate work with PPC 7.2 for a coherent TSO-DSO cooperation.

PPC 7.2: Next generation of DMS (Distribution Management Systems (IP 2022-2025)
Scope of PPC: Design new architecture of the Advanced DMS to consider new DER integration services and interfaces with both IT and OT solutions. Investigate new architectures and services for the DSO. Coordinate work with PPC 7.1 for a coherent TSO-DSO cooperation.

PPC 7.3: Next generation of measurements and GIS for distribution grids (IP 2022-2025)
Scope of PPC: Investigate data fusion, as one of the key topics in the process of digitalisation of power grids. Investigate new types of data associated to new measurement devices and other sources of information, such as GIS (Geographic Information System) to improve planning and operation of distribution grids. Also special care must be taken to enhance smart meters connectivity trending to the real time domain as this will be more and more requested by flexibility opportunities.

PPC 7.4: Wide area monitoring, control and protections (IP 2022-2025)
Scope of PPC: Investigate in depth the potential of Phasor Measurement Units as a key measurement tool both at transmission and distribution level, the application in monitoring, control and protection that fully exploit the capability of the Wide Area approach.

PPC 7.5: Grid operator of the future (IP 2025+)
Scope of PPC: Prepare the next generation of control room operators to deal with changing solutions and tools for grid operation. Cybersecurity challenges and countermeasures are fundamental. Define educational needs and solutions for the personnel that will work in the control room of the future in cooperation with 7.1-3.

PPC 7.6 Grid field workforce of the future (IP 2025+)
Scope of PPC: Prepare the field workforce to handle many more electronic devices (hardware and software), each with cybersecurity challenges and countermeasures, where needed. Distribution grids with a high number of DERs (different ownership than the network operator) and an increasing intervention of distributed control (i.e. cloud computing) require special attention.

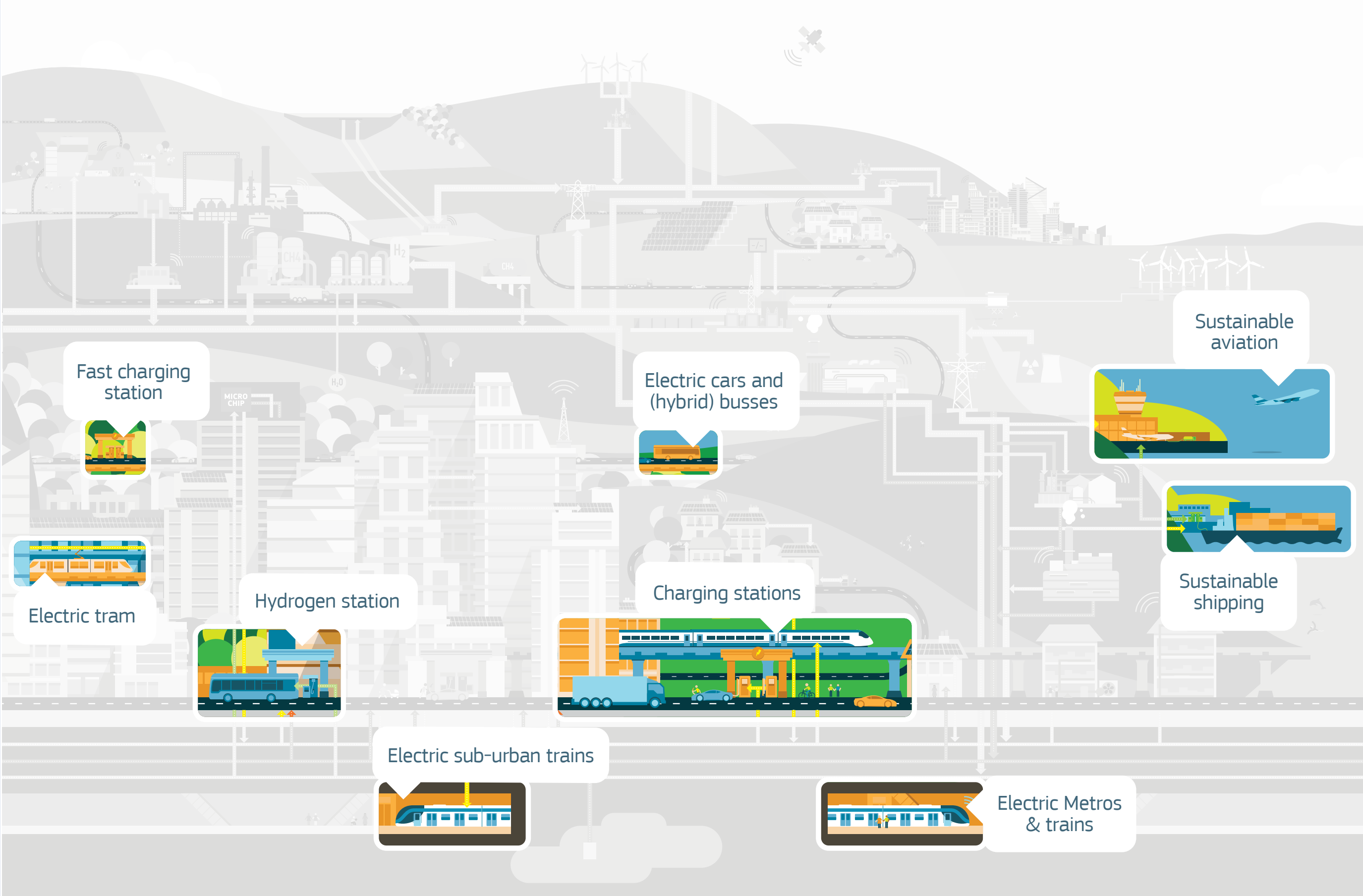
PPC 7.7: Human machine interface (HMI) (IP 2025+)
Scope of PPC: Design effective ways to present data to the operator and the way the HMI drives the possibility of interaction of the operator, as the automation level grows and more data becomes available. There will be a clear trend to distribute control allowing automatic actions in the network that must be well supervised and controlled in a coordinated way by the control room operator(s).

PPC 7.8: Cybersecurity of Energy Networks (IP 2025+)
Scope of the PPC: Identify the specific ICT services, systems or products that might be subjected to coordinated risk assessments with priority, including risks in the renewable energy, e.g. offshore wind and grid supply chain. Both the electricity and gas and hydrogen networks will be considered. The outcomes of the PPC should consider the current and the future Directives on cyber security.

PPC 7.9: Large scale demonstration activities (IP 2026+)
Scope of PPC: This PPC shall take the results of the PPCs 7.1-7.8 and bring them to a new scale for higher impacts by large demonstrators.

PPC 7.10: Standardisation activities (IP 2026+)
Scope of PPC: Transfer the results of all the PPCs 7.1-7.8 from innovation to real life preparing the condition for new standards and architectures compatible with the results of the projects.

HLUC8 Sustainable transport Integration



SCOPE

The 2016 EU "Low-emissions mobility strategy" and the 2020 "Sustainable and Smart Mobility Strategy" have shown that an integrated system approach is required to put the transport sector on a sustainable path. Central elements of such an approach include actions on overall vehicle efficiency, promoting low- and zero emission vehicles and the long-term evolution to low- and zero-carbon electricity system. This entails alternative and net-zero- carbon fuels for transport, together with multi- modal integration that shifts towards more sustainable transport modes of holistic operation. Conditions must ensure the effective deployment of publicly accessible and private recharging points for all types of electric vehicles and the smart efficient integration of vehicle charging infrastructure into the electricity system.

With the focus on system implications, different transport sectors will be considered, including:

- Road transport: including (a) micro mobility (e-bikes, e-scooters), (b) private vehicles, (c) taxies and fleet vehicles, (d) buses (e) lorries
- Railway transport: Trains
- Waterborne transport: River and sea boats
- Airborne transport: commercial and passenger airplanes

In the context of fuel/energy used, low carbon sources could be electricity and lower carbon fuels (biofuels, hydrogen, ammonia) including a combination of electricity and fuels (hybrid technologies).

The challenge of EV charging in its broader perspective is to be an active component of the integrated grid utilising the fundamental characteristics of the on-board battery for achieving optimal solutions for the benefit of the end users and improving the carbon footprint of e-mobility. Inevitably, such an approach will require charging modes that meet the needs of the user on the one hand but are aligned with the interconnected system capabilities calling for smart charging solutions (as opposed to direct and immediate charging from the moment the vehicle is plugged in to the charging point).

This need is primarily dictated by the user's needs, leading to low system cost solutions that will enhance the advantages of BEVs as opposed to other forms of transport. R&I needs in this field are of high priority and timely, since optimal operation of the interconnected systems requires the active contribution of the connected EVs following modes that do not violate the comfort needs of end users and, at the same time, achieve low-cost solutions that will guarantee an affordable mobility, contributing to enhance BEV penetration and to support the energy transition objectives.

Adopting smart charging solutions can lead to dynamic load management which is a pivotal concept to create customer benefits from the intelligent recharging of EVs. Smart charging has the ability to automatically distribute the available power between the charging points and the electric vehicles that are being charged simultaneously. In consequence, through such advanced systems, energy flows can be effectively managed in order to have a positive effect in the use of local resources. This will lead to an integrated grid capable of smoothing peaks and maximising the use of the developed smart infrastructure serving all connected users through optimal energy prices for the benefit of the end users.

Hence, as opposed to traditional blind charging, smart charging allows to exchange information, allowing monitoring and management of the energy consumption. As a result, smart charging strategies can lead to the following advantages:

- improved utilization factor of low or high-power charging infrastructures,
- decrease the need for investments for grid reinforcement by a factor of two compared to a situation with no smart charging and, hence, increasing the number of BEVs charged from the same infrastructure,
- generate tradeable flexibility to the grid, offering tangible benefits to the users (in terms of cost reductions and ease of charging) since they are the providers of the flexibility,
- reduce the prospective peak load for the generation plant and grid by up to 25%, which can lead to improved utilisation rates of the electricity distribution infrastructure and additionally improve the stability of the integrated grid.
- The assessment of the role and value of alternative approaches for the transport sector decarbonisation should be the focus of this work, considering the impact on the future energy system operation and design and benefits of achieving cost effective transition to zero carbon energy future, as the interface between transport and energy sectors is the crucial element for ensuring the successful development for both.

ACTORS INVOLVED

Transport sector manufacturers, owners of EV /railway/ boats/ aviation devices, IT industry, transportation network managers, TSOs, DSOs, Energy Communities, local administrations, urban planners, energy regulators, policy makers.

SECTORS COVERED

EV, light railway, DSO, Energy Communities, Aggregators, EV Aggregators, electricity, gas, hydrogen, battery, mobility.

HIGH LEVEL GOALS

- Assess the whole-system value of alternative decarbonisation strategies for transport sector, including on road and ground transport, river/sea-boats, and aviation
- Develop new policy and market frameworks that support the cost-effective decarbonisation and integration of transport energy sectors
- Assess the role and value of electric vehicles in providing energy control services at the local and national level (smart charging, V2G) through coordinated DSO/TSO control
- Assess the impact of rapid-charging infrastructure on the energy system
- Assess the differences in system value of smart electro mobility, based on full electric vehicles, plug-in hybrids and hydrogen fuel-cell based vehicles
- Develop affordable, user-friendly charging infrastructure concepts, considering the costs and benefits related to provision of system services through smart EV charging and V2G
- Explore the viability of developing offshore charging facilities for sea boats/vessels supplied by offshore wind, considering the energy system impacts.
- Assess the ability of V2X based concept and fast-charging stations to enhance the security and resilience of energy supply, including major outage events in national infrastructure
- Develop appropriate ICT infrastructure to enable information exchange between energy system and charging point operators and support market driven management of charging stations.

- Establish full interoperability between energy and transport sectors through development of common standards, protocols and digital services including connection of EVs to IoT.
- Enhance electricity network design standards to include security contribution of smart operation of transport sector
- Assess the option value of smart charging and V2G in energy system planning under uncertainties
- Consider the benefits of second life of the EV batteries in supporting energy system operation, while efficiently recycling them

MAIN TECHNICAL CHALLENGES

- Charging management, network energy system planning and operation with high penetration of low carbon transport sectors, including development of advanced control concepts.
- Key features of V2G and communication technologies, considering the speed of delivery of V2G services, in order to support grid frequency and stability control.
- Large scale deployment of V2G concept incorporating smart charging principles to support operation and stability of future RES dominated low energy system and maximizing the embedded benefits of the flexibility resource so generated.
- Harmonisation of rapid-charging infrastructure considering the role of large-scale electricity storage and hydrogen-based resources for electricity production, in supporting cost effective operation and development of the future energy system.
- Optimise production of hydrogen from available RES production or otherwise for river boats and large road transport vehicles.
- Development of cold ironing and offshore charging facilities for sea boats
- Decarbonisation of aviation sector considering full electrification for smaller aircrafts and hybrid electric solutions for larger aircrafts, and the implications on electricity system
- Application of the concept of V2X (Grid, Home and/or Business) and energy storage technologies for enhancing security and resilience of energy system
- Development of full interoperability between energy and transport sectors through establishment of common standards, protocols and digitalised systems and solutions.

CURRENT STATUS

The “Fitfor55 package” released by the EU in July 2021 states that average emissions of new cars must be reduced by 55% from 2031 and 100% from 2035 compared to 2021 levels and therefore all new cars on the European market must be zero-emission vehicles from 2035. It is recognised that batteries and green hydrogen will be the two main technologies for decarbonisation of transport sectors.

It has been demonstrated that an integrated system approach is required to put the transport sector on a sustainable path. There has been significant innovation work on assessing the challenges related to impact of the electrification of transport sector on the electricity system, including the potential benefits of V2G concept.

EXPECTED OUTCOMES 2031

Develop strategies for full decarbonisation of transport sector, including changes in policy and market frameworks for cost-effective integration of the transport sector with the whole-energy system, benefiting on the way with the high flexibility nature of the transport sector for effective utilization of RES systems on the road to the decarbonized economy that strategically Europe is leading to.

Demonstrate the impact of alternative advanced charging technologies and control systems in urban and rural areas, motorways, airports, cold ironing, etc., on the local and national energy infrastructure, and develop most effective strategies for decarbonisation of all transport sectors. This will not be an end in itself but seamlessly linking with the decarbonization strategies of the energy sector with EVs playing a critical role on the way.

The following figure puts the proposed PPCs of HLUC 8 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

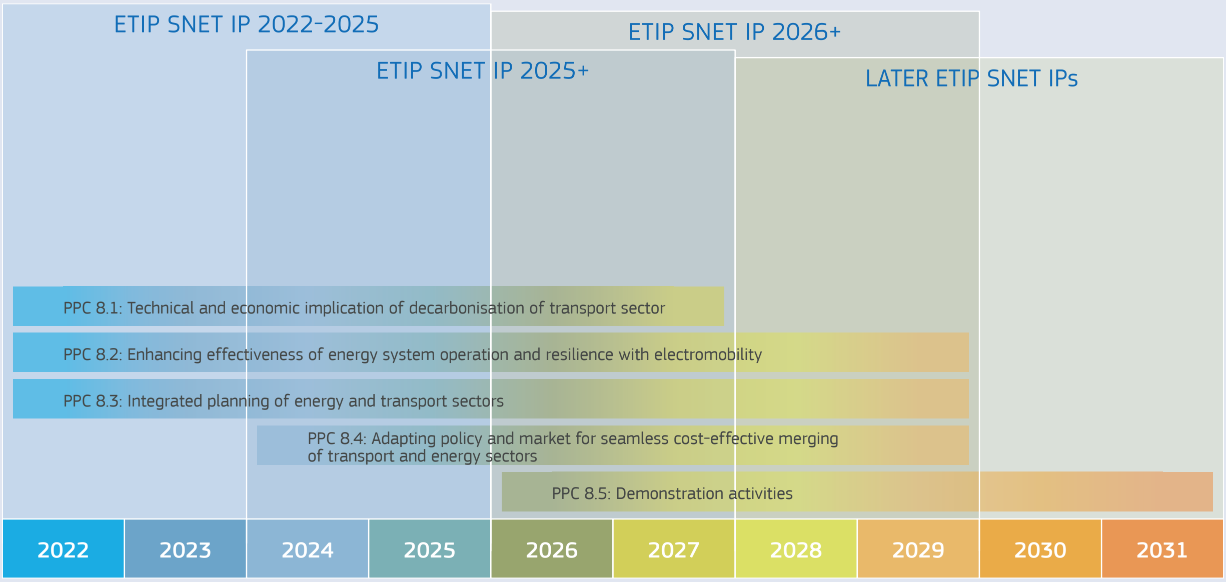


Figure 10: HLUC 8 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 8.1: Technical and economic implication of decarbonisation of transport sector (IP 2022-2025)
Scope of PPC: Development of alternative decarbonisation strategies for transport sectors (electricity and hydrogen based) for (a) micro-mobility, public, fleet and private vehicles, (b) long-on the ground transport (c) riverboats, sea-boats, (d) aviation. Assess alternative funding policy strategies for decarbonisation of different transport sectors. Assess the the impact on investment cost of conventional and low carbon generation, network infrastructure reinforcement and system operating costs and the system value of smart electro mobility in providing control services.

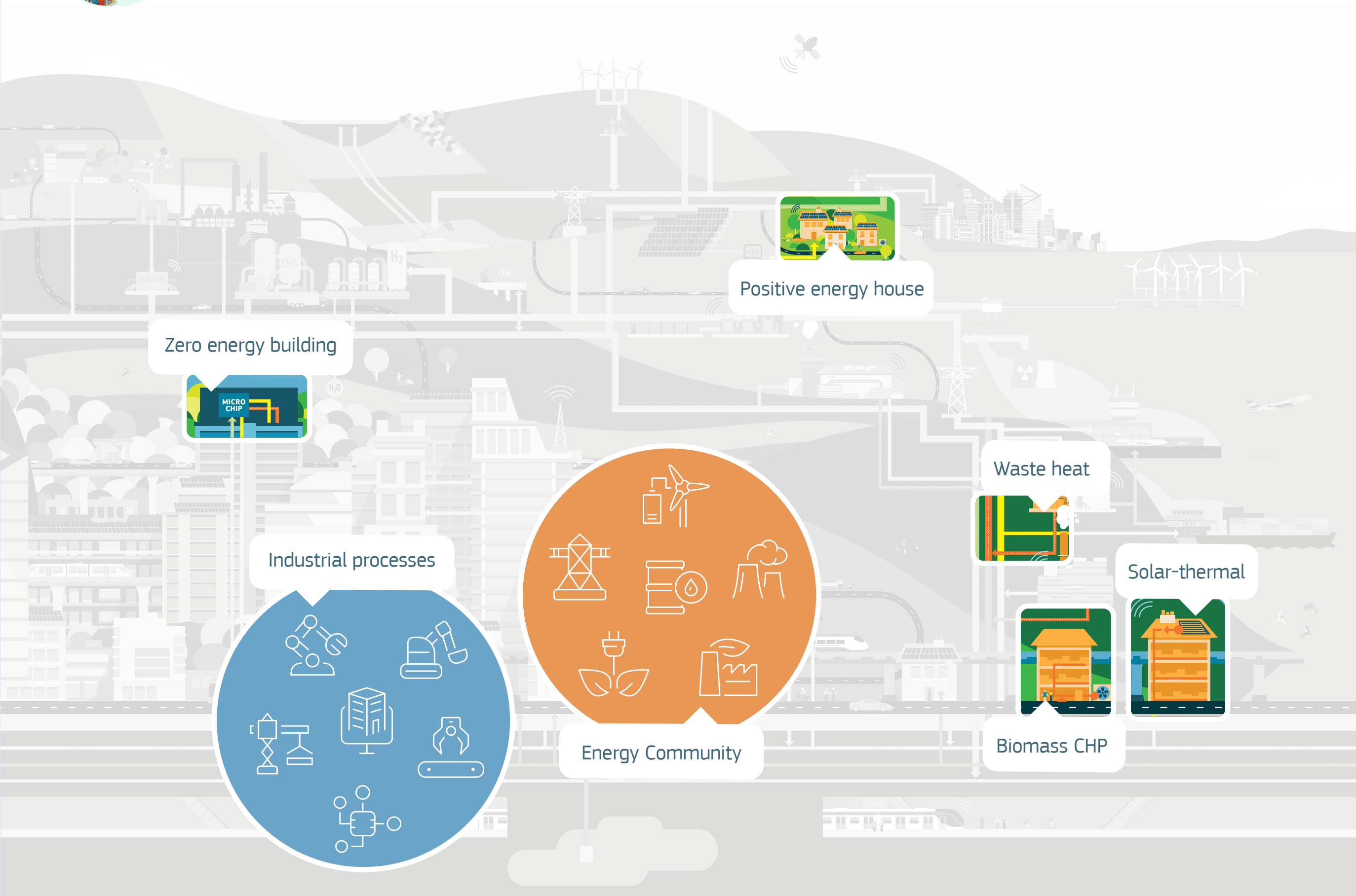
PPC 8.2: Enhancing effectiveness of energy system operation and resilience with electromobility (IP 2022- 2025)
Scope of PPC: Assessment of the benefits of smart control of different charging infrastructures in providing various system services through connecting EVs to IoT concept. Incorporation of uncertainties related to the provision of services by transport sector, specifically considering V2G from private, fleet and public vehicles. Assessment of the V2X based enhancement of resilience of supply and the benefits of fast-charging stations in providing security services.

PPC 8.3: Integrated planning of energy and transport sectors (IP 2022-2025)
Scope of PPC: Development of probabilistic system planning strategies incorporating the impact of large- scale deployment of different transport sector and energy storage technologies. Develop common standards, protocols and digital services for full interoperability between energy and transport sectors, allowing seamless connectivity of EVs to IoT. Development of electricity system design codes to include the secure contribution of smart charging of EVs and V2G, practices, considering solutions for slow and rapid charging infrastructures. Planning for Battery efficient recycling and health preservation.

PPC 8.4: Adapting policy and market for seamless cost-effective merging of transport and energy sectors (IP 2025+)
Scope of PPC: Development of appropriate market design to enable smart connectivity and use of the energy system through responsive charging infrastructure. Modify regulatory framework to enhance TSO–DSO interaction in supporting cost effective solutions for the transport sector. Provide evidence for the required changes in the design of the energy market to provide appropriate costs/ revenues related to the operation of the charging infrastructure (e.g. establishment of electro-mobility market for system services).

PPC 8.5: Demonstration activities (IP 2026+)
Scope of PPC: Development of appropriate IT infrastructure for common management of charging stations supported by appropriate market design to enable information exchange between energy system and charging point operators. Demonstrate V2G operability in terms of the speed of discharging and measurements /signals needed for provision of frequency regulation and grid stability services.

HLUC9 Flexibility provision by Building, Districts and Industrial Processes



SCOPE

The recent Clean Energy legislation requires that renewable heating and cooling must contribute to the progressive increase of the share of renewable energy and contribute substantially to the efficient use of available resources. Provisions are expected to be included, at national, regional and local level, for the integration and deployment of renewable energy, including for renewables self-consumption with the parallel growth of renewable energy communities. The effective use of unavoidable waste heat and cold when planning, including early spatial planning, designing, building and renovating urban infrastructure, industrial, commercial or residential areas. Additionally, effective use should be made of the renovation and development of energy infrastructure, including electricity, district heating and cooling, natural gas and alternative fuel networks.

Furthermore, extrapolating from the building level to a wider neighborhood, campuses and community level (and even smart city level), provisions should be included to allow an efficient and effective integration of smart communities in the energy system, addressing smart grid connectivity issues, market participation issues, advance control mechanisms capable of preserving and enriching resilience.

Finally, the integration of the heating and cooling sector with the integrated grid is still limited. Rules for effective participation in the market are incipient. Initial control mechanisms and technologies for allowing such sector-coupling integration exist but need further development. Understanding of behaviour and impact of buildings, infrastructure and communities in the grids and markets need further analysis and demonstration. Data management and cybersecurity issues still need further development to enhance smartness, responsiveness, security and resilience of all interconnected active resources in the integrated grid.

ACTORS INVOLVED

Aggregators, ESCOs, DSOs, Energy Communities, consumers/prosumers, TSO, other sector operators

SECTORS COVERED

electricity, gas, H&C, industry

HIGH LEVEL GOALS

Efficient carbon-neutral buildings; integration of building flexibility in distribution network operation; Integration of Energy Communities and Smart Cities in the wider grid; Microgrid efficiencies integrated in the developed solutions; Resilience support to the grid and system (e.g., extreme events); Develop flexibility mechanisms (support to System Operators) from building level to Community and Smart City level; Integration of VPP/VPS operational capabilities for aggregating local resources (logic aggregation of demand/prosumers); integration of aggregated demand in the wholesale energy market and in the ancillary services market; Improved flexibility assessment and forecast; Use AI and digital twins for demand flexibility assets; Peer-2-peer mechanisms; Effective Home Energy Management System (HEMS) for improving monitoring and control.

MAIN TECHNICAL CHALLENGES

Efficient heating and cooling for buildings and industries; RES integration; Waste heat recovery solutions; ICT related aspects: connection of buildings to the power system, communication requirements; Integration of heterogeneous flexibility in one platform; Market participation related aspects: (pre-) qualification, communication, bid mechanisms; Improved forecasting (including behind-the-meter aspects); net load forecasting; Aggregated forecasting; market design; consumer/prosumer engagement; Improved DER control; Stabilization of weak grids and microgrids using valuable flexibility of local resources and load; (Intended) Islanding mode of operation; Black start capabilities; NZEB topics to be considered collectively in the integrated solutions; Development of more accurate user profiles for holistic management of buildings; Exchange of information with HEMS to achieve:

- device monitoring and control,
- seamless communication between devices,
- communications, demand response, data management, security and privacy,
- consumer interface,
- EV integration,
- centralized vs distributed management and control

Pursuing the above will lead to results that will meet the ambitions of FitFor55:

- decarbonisation of heating and cooling in this sector through an increased share in production and use of renewable energy
- increase the production and use of renewable energy in buildings
- Infrastructure development for district heating and cooling networks

CURRENT STATUS

Integration of heating and cooling sector and coupling with the electricity grid is still limited. Rules for effective participation in the market are incipient. Initial control mechanisms and technologies for allowing such sector-coupling integration exist but need further development. Understanding of behaviour and impact of buildings, infrastructure and communities in the grids and markets need further analysis and demonstration. Data management and cybersecurity issues in relation to these planned activities still need further development.

EXPECTED OUTCOMES 2031

Robust forecasting and aggregation techniques; inclusive market design; efficient sector integration; effective participation of multi-sector buildings, infrastructures and communities in the energy system.

The following figure puts the proposed PPCs of HLUC 9 into the 10-year-Roadmap time frame 2022-2031. The beginning of each PPC-bar indicates when projects within the PPC shall ideally begin. The length of the bar indicates the desired duration of upcoming R&I projects. Details of each PPC are given in the ETIP SNET R&I Implementation Plans IP 2022-2025, IP 2025+, IP 2026+ and later ETIP SNET IPs.

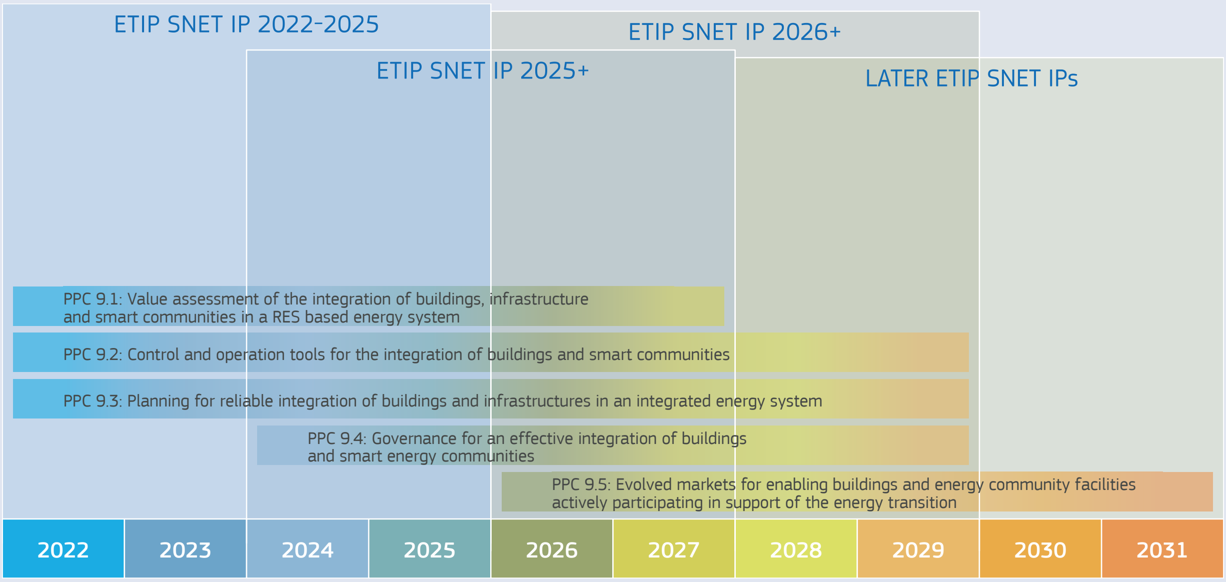


Figure 11: HLUC 9 Distribution of the PPCs during 2022-2031

PRIORITY PROJECT CONCEPTS

PPC 9.1: Value assessment of the integration of buildings, infrastructure and smart communities in a RES based energy system (IP 2022-2025)
Scope of PPC: Creating the conditions for the effective integration of renewable generation from multiple sectors in buildings and other individual or aggregated infrastructures leading to an increased share of RES in the energy system supported by digitalisation.

PPC 9.2: Control and operation tools for the integration of buildings and smart communities (IP 2022-2025)
Scope of PPC: Design and test advanced control methods and enabling technologies to integrate multi-sector generation, ensuring the needed flexibility from individual or aggregated heating and cooling devices, buildings, local communities, benefiting from energy system digitalisation. Demonstrate effective and efficient management (e.g., via HEMS and BMS) of connected and stand-alone buildings, living quarters, businesses and industries, communities supplied by RES.

PPC 9.3: Planning for reliable integration of buildings and infrastructures in an integrated energy system (IP 2022-2025)
Scope of PPC: Design and validate energy models connecting in a digitized electricity grid multi-vector systems supplying buildings, infrastructures and communities, through enhanced forecasting and multi-objective techniques to achieve optimal use of resources. Ensure secure and resilient integration of multiple infrastructures, forming microgrids, VPPs and VPSs, offering overall grid stability at the lowest cost.

PPC 9.4: Governance for an effective integration of buildings and smart energy communities (IP 2025+)
Scope of PPC: Development of solutions of designing, setting up and operating active energy buildings and communities that will offer optimal solutions to the tenants, users and the community as an entity. The deployed practices and systems will cover design and use of appropriate smart technologies and systems and develop appropriate codes, standards and regulations for coordination mechanisms with system operators and multiple energy stakeholders. Identify best practice governance options for buildings and energy communities.

PPC 9.5: Evolved markets for enabling buildings and energy community facilities actively participating in support of the energy transition (IP 2026+)
Scope of PPC: Ensure appropriate mechanisms for market participation of buildings and infrastructures with multi-vector RES sources (e.g., low carbon gas-fired, biomass CHP units), making use of digitally enabling smart technologies, to actively participate offering viable business cases that they are capable of, including the provision of ancillary services at different aggregation levels.

Relation with the Digitalisation of the Energy Action Plan

European Union recently published the Digitalisation of the Energy Action Plan[75] (DAP), where some key goals have been identified. Some of these goals are inline with the goals of ETIP SNET as described in this document. More specifically the DAP proposes:

TOWARDS AN EU FRAMEWORK FOR SHARING DATA TO SUPPORT INNOVATIVE ENERGY SERVICES

The first target to promote the data sharing is to support the creation of the common Data space with specific short and long term targets. Namely the DAP identifies the need to start the deployment of common data spaces by 2024 and facilitate the integration of 580GW of flexibility resources by 2050. Considering that there are already 4 ongoing projects in this area, the RM proposes new goals for further research as presented in PPC 5.5.

Furthermore, the DAP proposes several actions to promote connectivity, interoperability and seamless exchange, such as the creation of the creation Smart Energy Expert Group'/ Data for Energy' (D4E) working group. To this respect the RM and the next IP will support this WG, by introducing tasks that will support it.

PROMOTING INVESTMENTS IN DIGITAL ELECTRICITY INFRASTRUCTURE

The DAP proposes the support of coordination and cooperation in investments of digitalization that will help to ensure the best value for money and an efficient digitalization of the electricity grid. For this goal the RM proposed a PPC (PPC 5.8-CSA action) focusing on the identification of common infrastructure and proposals for a fair funding scheme for the involved actors. This PPC could also give feedback to ACER and NRAs.

Furthermore, the DAP proposes the creation of a digital twin of the European electricity grid. The recently published Horizon Europe Work programme 2023-2024, proposes a large program in this area and a PPC (2.4) is included in the RM as a follow-up project.

BENEFITS FOR CONSUMERS: NEW SERVICES, SKILLS AND EMPOWERMENT

The DAP proposed several actions to empower consumers, focusing on various aspects such as:

- A legal framework that empowers and protects consumers
- Digital tools designed for and with consumers
- Energy communities and local energy initiatives
- A skilled workforce to accelerate the digital transition.

Several PPCs are supporting these actions as presented in the next figure. These PPCs include the assessment of the value of the consumer engagement (PPC 5.1) and the creation of consensus on the various solutions (PPC 5.6) in order to support the corresponding legal framework. Several PPCs propose solution for the support of consumers and energy communities (PPC9.4, PPC????). Finally, some PPCs focus on training actions for the future workforce and users (PPC 5.6, PPC 7.6).

STRENGTHENING CYBERSECURITY AND RESILIENCE IN THE ENERGY SYSTEM

The DAP identified the need to strengthen the Cybersecurity and the resilience of the energy system. The new NIS 2 Directive is a systemic approach to strengthen the cybersecurity of energy networks. Thus, PPC 7.X considers that current and future directives should be considered as well other energy vectors such as gas. Furthermore, the resilience of the energy system is considered in several PPCs as presented in the next figure.

These points are related to several PPC and some of them are presented at the next chart. Digitalization is included in several other PPCs

75 Digitalisation of the energy system (europa.eu)

EU-DAP ENERGY SYSTEM FLEXIBILITY GOALS AND RELATED PPCS OF THE ETIP SNET R&I ROADMAP

Benefits for consumers

PPC 5.1 Value of Consumer/Customer acceptance and engagement
PPC 5.2: Plug and play devices and IoT (Internet of things) including security by design
PPC 5.6: Building skills needed for developers and users of the energy system to accelerate its transition through its digitalization
PPC 5.10: Creating consensus on consumer solutions
PPC 7.6 Grid field workforce of the future
PPC 8.4: Adapting policy and market for seamless cost-effective merging of transport and energy sectors
PPC 9.1: Value assessment of the integration of buildings, infrastructure and smart communities in a RES based energy system
PPC 9.4: Governance for an effective integration of buildings and smart energy communities
PPC 9.5: Evolved markets for enabling buildings and energy community facilities

Strengthening Cybersecurity and Resilience

PPC 1.6: Cross sector resilience
PPC 1.7: Future cross-vector infrastructure design
PPC 3.3: IT systems for cross-border trading
PPC 4.3: Infrastructure requirements and network technologies as solutions for integration of massive RES
PPC 4.4: Planning for a resilient system with massive penetration of RES
PPC 5.3: Utilization of Communication Networks including cyber security
PPC 7.4: Wide area monitoring, control and protections
PPC 7.5: Grid operator of the future
PPC 7.6 Grid field workforce of the future
PPC 7.8: Cybersecurity of Energy Networks

Interoperability

PPC 1.2: Control and operation tools for multi-energy systems
PPC 2.3: Platform Development for TSO-DSO cooperation
PPC 2.6: Viable business cases through market mechanisms and incentives
PPC 3.4: Validation of new market concepts
PPC 5.5: Data Spaces
PPC 5.7: Service management and operations
PPC 8.4: Adapting policy and market for seamless cost-effective merging of transport and energy sectors
PPC 6.7: Standardization activities
PPC 7.9: Large scale demonstration activities

Investment in Digital Electricity Infrastructure

PPC 1.3: Smart asset management for a circular economy
PPC 2.4: Planning tools for TSO-DSO cooperation
PPC 2.5: Develop a Digital Twin of the European Electricity Grid
PPC 3.3: IT systems for cross-border trading
PPC 5.8: Sharing IT infrastructure investments
PPC 6.4: Simulation methods and digital twins at distribution and transmission level for power electronics driven networks
PPC 7.7: Human machine interface (HMI)
PPC 8.5: Demonstration activities
PPC 9.2: Control and operation tools for the integration of buildings and smart communities
PPC 9.3: Planning for reliable integration of buildings and infrastructures in an integrated energy system

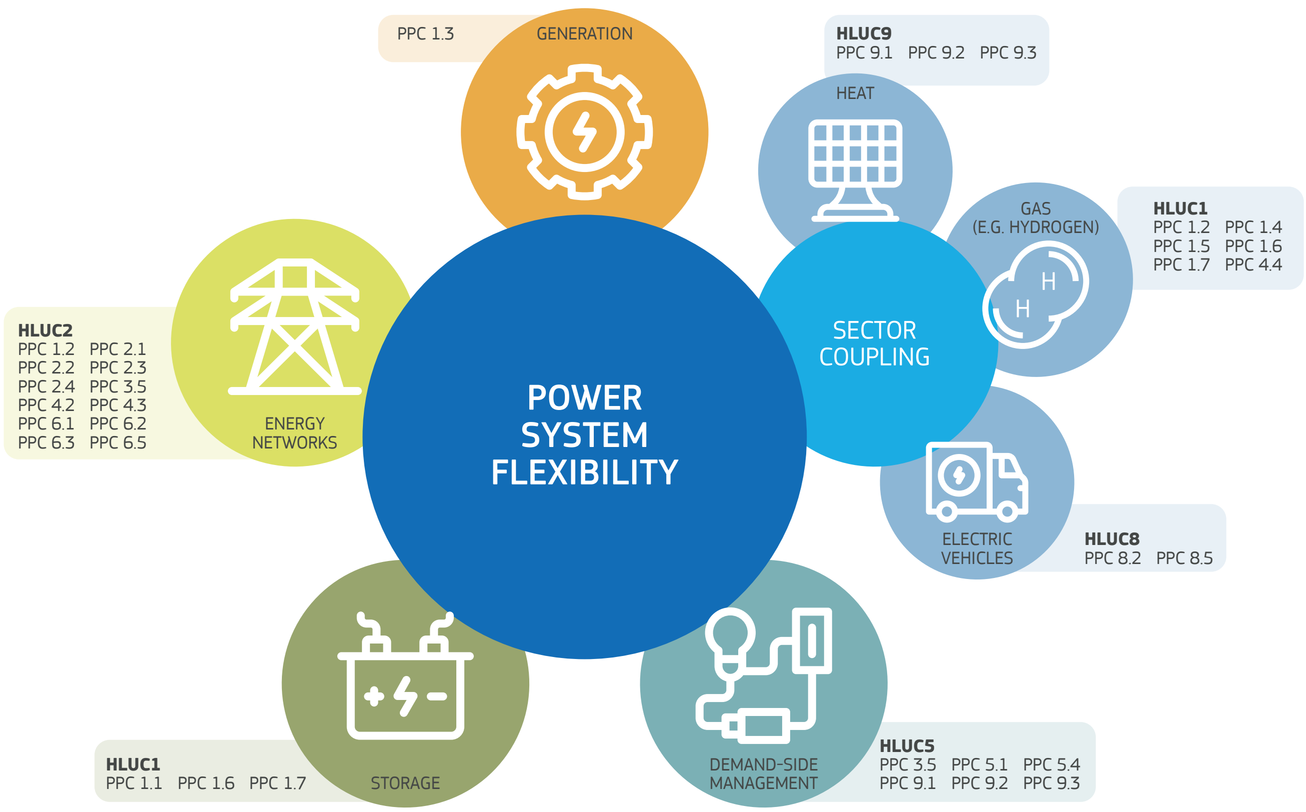


Figure 12: HLUCs and PPCs related to energy system flexibility

EU-DAP DIGITALIZATION PRIORITIES AND RELATED PPCS OF THE ETIP SNET R&I ROADMAP

Figure 13: PPCs related to Energy System Digitalization

Indicative scheduling

The following table puts all proposed PPCs into the 10-year-Roadmap time frame 2022-2031. Colored cells indicate that R&I projects of the PPC shall ideally be ongoing during that year. Details on the desired duration of upcoming R&I projects will be given in the ETIP SNET R&I Implementation Plans made ready for the publicly co-funded R&I project calls foreseen in the years 2021 to 2027 by the EC and national

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<tr><th></th><th>2022</th><th>2023</th><th>2024</th><th>2025</th><th>2026</th><th>2027</th><th>2028</th><th>2029</th><th>2030</th><th>2031</th></tr>
<tr><td rowspan="8"></td><td colspan="6">PPC 1.1: Value of cross sector integration and storage</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">PPC 1.2: Control and operation tools for multi-energy systems</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="6">PPC 1.3: Smart asset management for a circular economy</td><td></td><td></td><td></td><td></td></tr>
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<tr><td colspan="8">PPC 2.2: Control and operation for enhanced TSO-DSO- System User interactions</td><td></td><td></td></tr>
<tr><td colspan="8">PPC 2.3: Platform Development for TSO-DSO cooperation</td><td></td><td></td></tr>
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<tr><td rowspan="5"></td><td colspan="8">PPC 3.1: Fundamental market design</td><td></td><td></td></tr>
<tr><td colspan="8">PPC 3.2: Regulatory framework and strategic investments</td><td></td><td></td></tr>
<tr><td colspan="8">PPC 3.3: IT systems for cross-border trading</td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td colspan="6">PPC 3.5: IT systems for TSO/DSO control to support real time balancing</td></tr>
<tr><td rowspan="6"></td><td colspan="8">PPC 4.1: Technical barriers and technical measures for integration of RES at multiple levels and sectors</td><td></td><td></td></tr>
<tr><td colspan="6">PPC 4.2: Control and operation tools for a RES based energy system</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">PPC 4.3: Infrastructure requirements and network technologies as solutions for integration of massive RES</td><td></td><td></td></tr>
<tr><td colspan="10">PPC 4.4: Planning for a resilient system with massive penetration of RES</td></tr>
<tr><td></td><td></td><td colspan="8">PPC 4.5: Well-functioning markets for a RES based energy system</td></tr>
<tr><td></td><td></td><td colspan="8">PPC 4.6: Policies and governance for a RES based energy system</td></tr>
<tr><td rowspan="10"></td><td colspan="6">PPC 5.1 Value of Consumer/Customer acceptance and engagement</td><td></td><td></td><td></td><td></td></tr>
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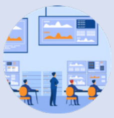
<tr><td rowspan="10"></td><td colspan="4">PPC 7.1: Next Generation of TSO control room</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">PPC 7.2: Next generation of DMS (Distribution Management Systems</td><td></td><td></td></tr>
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<tr><td rowspan="5"></td><td colspan="6">PPC 8.1: Technical and economic implication of decarbonisation of transport sector</td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">PPC 8.2: Enhancing effectiveness of energy system operation and resilience with electromobility</td><td></td><td></td></tr>
<tr><td colspan="8">PPC 8.3: Integrated planning of energy and transport sectors</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">PPC 8.4: Adapting policy and market for seamless cost-effective merging of transport and energy sectors</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td colspan="6">PPC 8.5: Demonstration activities</td></tr>
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<tr><td colspan="8">PPC 9.2: Control and operation tools for the integration of buildings and smart communities</td><td></td><td></td></tr>
<tr><td colspan="8">PPC 9.3: Planning for reliable integration of buildings and infrastructures in an integrated energy system</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="6">PPC 9.4: Governance for an effective integration of buildings and smart energy communities</td><td></td><td></td></tr>
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</table>

governments or their funding agencies in Europe.

Table 3: Indicative beginning and ending year (and indicative duration) for R&I projects of each PPC

5
Budget for ETIP SNET R&I Roadmap 2022-2031

The assumed durations for the R&I projects for each PPC lead to distribution of budgets over the 10 year period and at the same time to each of the associated HLUC. The results of this mapping are described in the following chapter.

The budget proposal for this 10-year ETIP SNET R&I Roadmap 2022-2031 takes into account the

- Budget proposal of the most recent ETIP SNET R&I Implementation Plan 2022-2025
- The needed PPCs with assumed approximate R&I project beginning and ending years and durations
- Validation to Budget Analysis of the Horizon Europe Work-Program 2021-2022.
- Demonstration acceleration needs due to the increased independence from Russian fossil fuels.

In this 10-year ETIP SNET R&I Roadmap, ETIP SNET defines PPCs for three IP-Periods beginning 2022, beginning 2025 and beginning 2026 corresponding to the European Commission work programmes expected for the 7-year Horizon Europe duration 2021-2027. The definition of details of PPCs and R&I project families to be called for at the latest in the years 2025, 2026 and later will be given in future ETIP SNET R&I Roadmaps and Implementation Plans (IP 2025+, IP 2026+, Later ETIP SNET IPs)

IP 2022-2025: This ETIP SNET R&I Roadmap 2022-2031 foresees R&I project families for the following PPCs to be called for in the years **2022 to 2024** (they are described in detail in the ETIP SNET R&I Implementation Plan 2022-2025).

HLUC 1: Optimal Cross sector Integration and Grid Scale Storage
PPC 1.1: Value of cross sector integration and storage
PPC 1.2: Control and operation tools for multi-energy systems
PPC 1.3: Smart asset management for a circular economy
HLUC 2: Market-driven TSO–DSO–System User interactions
PPC 2.1: Market models and architecture for TSO-DSO- System User interactions
PPC 2.2: Control and operation for enhanced TSO-DSO- System User interactions
PPC 2.3: Platform Development for TSO-DSO cooperation
PPC 2.4: Planning tools for TSO-DSO cooperation
HLUC 3: Pan European Wholesale Markets, Regional and Local Markets
PPC 3.1: Fundamental market design
PPC 3.2: Regulatory framework and strategic investments
PPC 3.3: IT systems for cross-border trading
HLUC4 Massive RES Penetration into the Transmission and Distribution Grid
PPC 4.1: Technical barriers and technical measures for integration of RES at multiple levels and sectors
PPC 4.2: Control and operation tools for a RES based energy system
PPC 4.3: Infrastructure requirements and network technologies as solutions for integration of massive RES
PPC 4.4: Planning for a resilient system with massive penetration of RES
HLUC 5: One-Stop Shop and Digital Technologies for Market Participation of Consumers (citizens) at the Centre
PPC 5.1 Value of Consumer/Customer acceptance and engagement
PPC 5.2: Plug and play devices and IoT (Internet of things) including security by design
PPC 5.3: Utilisation of Communication Networks including cyber security
PPC 5.4: Cross-sectorial flexibility use cases
HLUC6 Secure operation of widespread use of power electronics at all systems levels
PPC 6.1: Control solutions for next generation PV and battery inverters
PPC 6.2: Hybrid transmission/distribution and hybrid distribution AC/DC grids

PPC 6.3: Next generation distribution substation
PPC 6.4: Simulation methods and digital twins at distribution and transmission level for power electronics driven networks
HLUC 7: Enhance System Supervision and Control including Cyber Security
PPC 7.1: Next Generation of TSO control room
PPC 7.2: Next generation of DMS
PPC 7.3: Next generation of measurements and GIS for distribution grids
PPC 7.4: Wide area monitoring, control and protections
HLUC 8: Sustainable transport Integration
PPC 8.1: Technical and economic implication of decarbonisation of transport sector
PPC 8.2: Enhancing effectiveness of energy system operation and resilience with electromobility
HLUC 9: Flexibility provision by Building, Districts and Industrial Processes
PPC 9.1: Value assessment of the integration of buildings, infrastructure and smart communities in a RES based energy system
PPC 9.2: Control and operation tools for the integration of buildings and smart communities
PPC 9.3: Planning for reliable integration of buildings and infrastructures in an integrated energy system

IP 2025+: In addition this ETIP SNET R&I Roadmap 2022-2031 foresees future R&I families of projects related to the following **PPCs** to be called for at the latest **in the year 2025**.

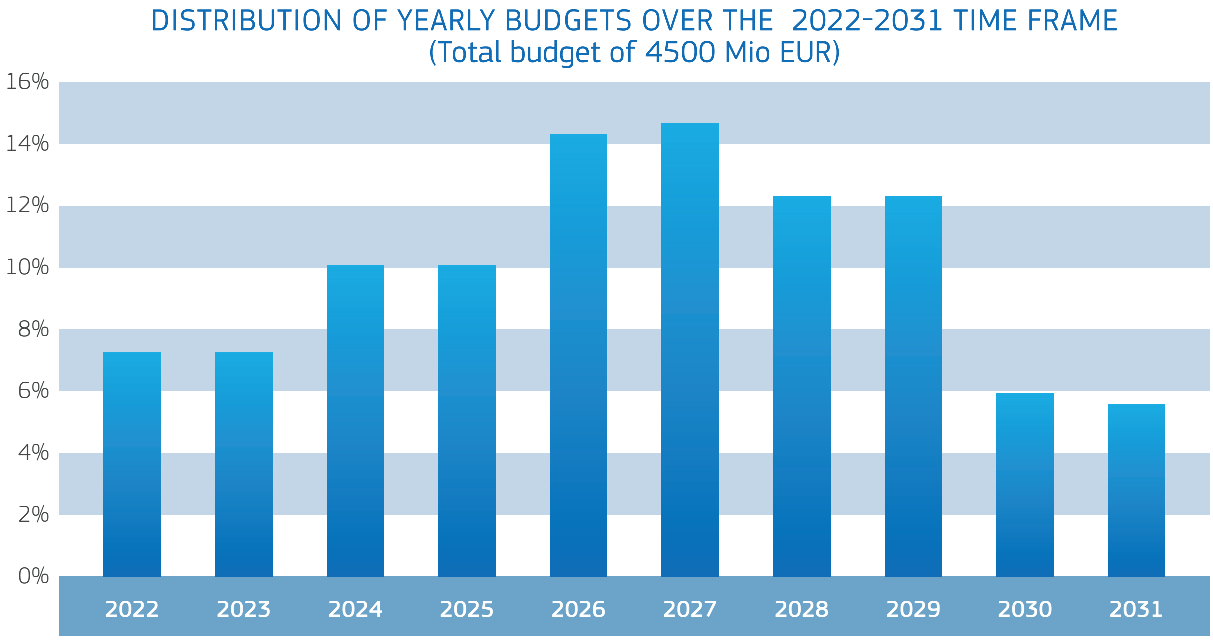
HLUC 1: Optimal Cross sector Integration and Grid Scale Storage
PPC 1.4: Integrating hydrogen and CO2-neutral gases
PPC 1.5: Regulatory framework for cross sector integration
HLUC 2: Market-driven TSO–DSO–System User interactions
PPC 2.5: Develop a Digital Twin of the European Electricity Grid
PPC 2.6: Viable business cases through market mechanisms and incentives
PPC 2.7: Governance for TSO, DSO and System Users
HLUC 3: Pan European Wholesale Markets, Regional and Local Markets
PPC 3.4: Validation of new market concepts
HLUC4 Massive RES Penetration into the Transmission and Distribution Grid
PPC 4.5: Well-functioning markets for a RES based energy system
PPC 4.6: Policies and governance for a RES based energy system
HLUC 5: One-Stop Shop and Digital Technologies for Market Participation of Consumers (citizens) at the Centre
PPC 5.5: Data Spaces
PPC 5.6: Building skills needed for developers and users of the energy system to accelerate its transition through its digitalization
PPC 5.7: Service management and operations
PPC 5.8: Sharing IT infrastructure investments
HLUC 7: Enhance System Supervision and Control including Cyber Security
PPC 7.5: Grid operator of the future
PPC 7.6 Grid field workforce of the future

PPC 7.7: Human machine interface (HMI)
PPC 7.8: Cybersecurity of Energy Networks
HLUC 8: Sustainable transport Integration
PPC 8.4: Adapting policy and market for seamless cost-effective merging of transport and energy sectors
PPC 8.5: Integrated planning of energy and transport sectors
HLUC 9: Flexibility provision by Building, Districts and Industrial Processes
PPC 9.4: Governance for an effective integration of buildings and smart energy communities

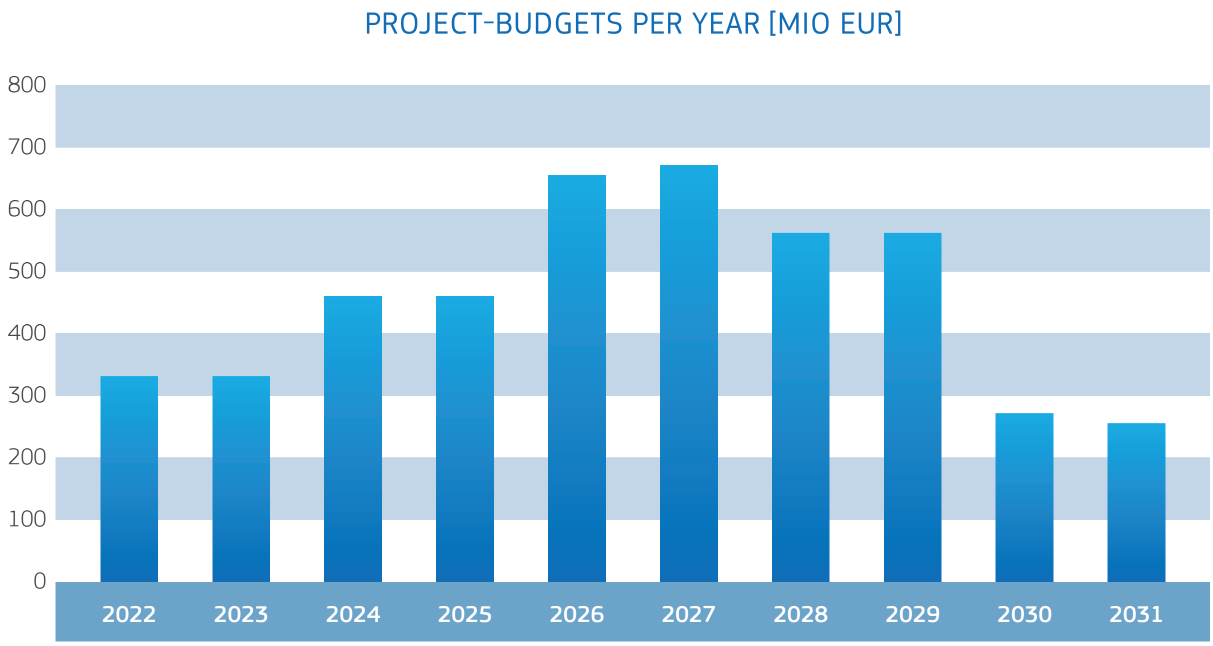
IP 2026+: Finally, this ETIP SNET R&I Roadmap 2022-2031 foresees also families of R&I projects for the following **PPCs** to be called for at the latest **in the years 2026 and 2027**:

HLUC 1: Optimal Cross sector Integration and Grid Scale Storage
PPC 1.6: Cross sector resilience
PPC 1.7: Future cross-vector infrastructure design
PPC 1.8: Validation/Demonstration
HLUC 3: Pan European Wholesale Markets, Regional and Local Markets
PPC 3.5: IT systems for TSO/DSO control to support real time balancing
HLUC 5: One-Stop Shop and Digital Technologies for Market Participation of Consumers (citizens) at the Centre
PPC 5.9: Large Scale Demonstration activities
PPC 5.10: Creating consensus on consumer solutions
HLUC6 Secure operation of widespread use of power electronics at all systems levels
PPC 6.5: HVDC interoperability, multi-terminal configurations, meshed grids
PPC 6.6: Large Scale Demonstration activities
PPC 6.7: Standardisation activities
HLUC 7: Enhance System Supervision and Control including Cyber Security
PPC 7.9: Large scale demonstration activities
PPC 7.10: Standardisation activities
HLUC 8: Sustainable transport Integration
PPC 8.5: Demonstration activities
HLUC 9: Flexibility provision by Building, Districts and Industrial Processes
PPC 9.5: Evolved markets for enabling buildings and energy community facilities

Using the timing of PPC-related R&I Calls and considering the duration of projects including their Demonstration intensity and related higher



project costs of all proposed PPCs, ETIP SNET derives the following budget needs for R&I projects beginning through R&I calls in 2022-2024,



2025, 2026 and 2027 and ongoing during the time frame of this Roadmap, i.e. 2022-2031.

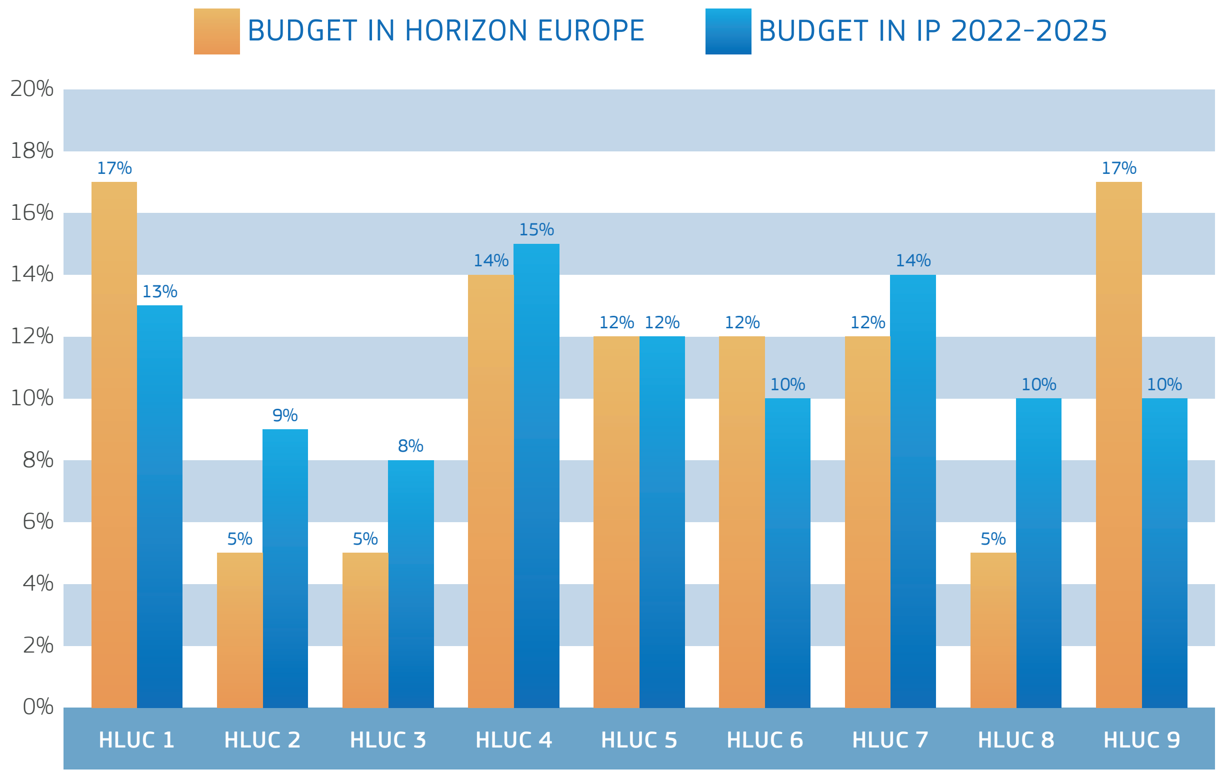
Figure 14: Yearly budgets during 2022-2031: Total of 4500 Mio EUR.
Figure 15: Distribution of Budget for each HLUC (2022-2031): Total of 4500 Mio EUR.

In order to further validate these budgets, they are compared to those defined with published calls of Horizon Europe (HE) Work Programme 2021-2022. HE runs for seven years (2021 to 2027) and the total budget is 95,500 million €. At the time of publication of this ETIP SNET RM 2022-2031, the calls of Cluster-5[76] and Cluster-4[77] of the Horizon Europe (HE) Work Program (WP) 2021-2022 were published by the EC. They fall within the ETIP SNET scope and were examined in the relevant analysis for the ETIP SNET R&I Implementation Plan 2022-2025. 26 calls were identified in HE-Cluster-5 which were linked with the ETIP SNET-proposed HLUCs and their PPCs, with a total budget of 428

76 https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-8-climate-energy-and-mobility_horizon-2021-2022_en.pdf

77 https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-7-digital-industry-and-space_horizon-2021-2022_en.pdf million € (out of a total budget of 1,216.3 million € for Cluster-5). Regarding HE-Cluster-4, one call was identified to be relevant to ETIP-SNET with a budget of 39 million € (out of a total budget of around 520 million € for Cluster-4).

In this analysis, each HE call was thematically linked with the relevant ETIP SNET High Level Use Case(s). In case a HE call is related to more



than one HLUC, percentages have been used to indicate how the HE call budget is assumed to be allocated to each linked HLUC. In general, each call of the WP 2021-2022 is linked to one or more HLUC(s)[78].

Figure 16: Budgets for HLUCs as a percentage of the HLUC-related Horizon Europe Calls 2021-2022 and as percentage of the total 4-year budget proposed in the already published ETIP SNET R&I Implementation Plan 2022-2025 ("IP")

Based on the budgets assigned to each call of Horizon Europe WP 2021-2022 and its relevance to each HLUC, Figure 16 depicts the distribution of the budget per HLUC as a percentage of the total proposed funding (467 million €) of all the calls in the Horizon Europe Work Program 2021-2022 which have a strong relevance to HLUCs. This is compared to the HLUC related distribution of the budgets proposed by the ETIP SNET in the R&I Implementation Plan 2022-2025, as percentage of the total suggested R&I budget of 1000 Million € for R&I projects ongoing between 2022-2025.

The analysis shows that Horizon Europe Call 2021-2022 allocates a significant budget for HLUC 1 (Optimal Cross sector Integration and Grid Scale Storage), with a smaller budget for HLUC 2 (Market-driven TSO–DSO–System User Interactions). On the other hand, the R&I Implementation Plan 2022-2025 suggests a more balanced distribution of research funds between these two HLUCs, still suggesting, however, that HLUC 1 should be more funded. This is done in recognition of the high importance of cross-sector coupling and storage by the ETIP SNET, but also because large projects have been already funded by previous calls in the TSO-DSO coordination area raising the TRL status of HLUC 2. Moreover, these two HLUCs are highly linked. Thus, if we compare the cumulative funding of HLUC 1 and HLUC 2 in the Horizon Europe and the R&I Implementation Plan 2022-2025, it is that they closely match.

The budget for HLUC 3 (Pan European Wholesale Markets, Regional and Local Markets) appears smaller in the Horizon Europe WP 2021-2022 than in the IP. However, it shall be noted that most calls touch upon market issues, yet not many identify HLUC 3 as the main topic of research. Thus, the budget allocated to HLUC 3 appears smaller in Horizon Europe calls.

78 The detailed analysis of the budget allocation of the Horizon Europe Calls (HE WP 2021-2022) for the nine ETIP SNET HLUCs can be found in [ETIP SNET IP 2022-2025]

The percentages of budget assigned to HLUCs 4, 5, 6 and 7 closely match in the R&I Implementation Plan 2022-2025 and the Horizon Europe WP 2021-2022.

HLUC 8 (Transportation Integration & Storage), appears less funded in the Horizon Europe, however the ETIP SNET highlights the need for additional funding of this area in future calls.

A difference is also noted in HLUC 9 (Flexibility provision by Building, Districts and Industrial Processes). However, it should be noted that some of the calls in Horizon Europe related to HLUC 9, include wider R&I needs, not directly related to the ETIP SNET. For instance, the call HORIZONCL5- 2022-D4-01-02 (Renewable-intensive, energy positive homes), although very relevant to the ETIP-SNET's scope, also concerns issues, like constructions and renovation of buildings, integrated design and construction concepts, etc.

Overall, the relative budget distribution proposed by the ETIP SNET R&I IP 2022-2025 is in satisfactory agreement with the funding allocated by Horizon Europe WP 2020-2021 with few notable differences in areas that have reached a high TRL level and areas where additional funding is recommended by the ETIP SNET.

As a consequence of this strong matching between ETIP SNET IP 2022-2025 and the then existing HE calls, ETIP SNET assumes that a similar budget reasoning is justified for the R&I Roadmap 2022-2031 as in the IP 2022-2025. Taking into account that the ETIP SNET R&I Roadmap 2022-31 concerns 4 IPs, taking a factor of slightly more than 4 for the 10-year time frame budget as compared to the budget for the IP 2022-2025 seems to be justified. This yields the total R&I project related budget needs of 4500 Mio EUR for this ETIP SNET R&I Roadmap. As noted in the reasoning above for the PPC-related budgets for the next two IP Periods in 2024 and 2026, however, demonstrations related PPCs requiring a multiple of the funding of purely Desktop-research related PPCs. The need for an increased amount of funding related to demonstration activities has already been identified in the ETIP SNET RM 2020-2030.

Moreover, an increased budget needs to be considered, taking into account the acceleration of R&I due to the European energy supply crisis since February 2022. Such an acceleration requires even more an increased number and intensity of demonstration activities.

6
Annex I: Research Areas

Annex I introduces the functionalities and research areas. These are elements of the previous Roadmap, now used for the current one.

Research Areas (RA)		Research TOPICs
1. CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY	1.1	Social campaigns and social studies (related to societal acceptance and environmental sustainability of energy infrastructures)
	1.2	Adaptive consumer/user behavior including energy communities (interaction, incentives by dynamic tariffs)
	1.3	Consumer and prosumer device control
2. SYSTEM ECONOMICS	2.1	Business models (including Aggregators)
	2.2	Market design and governance (Retail, Wholesale; Cross-border; Ancillary services; Flexibility markets)
3. DIGITALISATION	3.1	Protocols, standardisation and interoperability (IEC, CIM, Information models)
	3.2	Data Acquisition and Communication (ICT) (Data acquisition, Smart Meter, Sensors (monitoring), AMR, AMM, smart devices)
	3.3	Data and Information Management (Platforms, Big Data, Software, IoT)
	3.4	Cybersecurity (vulnerabilities, failures, risks) and privacy
	3.5	End-to-end architecture (integrating market, automation, control, data acquisition, digital twin, end-users)
4. PLANNING - HOLISTIC ARCHITECTURES and ASSETS	4.1	Integrated Energy System Architectures (design including new materials and hybrid AC/DC grids)
	4.2	Long-term planning (System development)
	4.3	Asset management and maintenance (maintenance operation, failure detection, asset lifecycles, lifespan and costs, ageing)
	4.4	System Stability analysis
5. FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY	5.1	Demand flexibility (household and industry related)
	5.2	Generation flexibility (flexible thermal, RES such as Hydro, PV and wind generators)
	5.3	Storage flexibility & Energy Conversion flexibility (PtG&H, PtG, GtP, PtL, LtP; PtW; WtP)
	5.4	Network flexibility (FACTS, FACDS, smart transformers and HVDC)
	5.5	Transport flexibility (V2G/EV; railway, trams, trolleybus)
6. SYSTEM OPERATION	6.1	Supervisory control and State estimation
	6.2	Short-term control (Primary, Voltage, Frequency)
	6.3	Medium- and long-term control (Forecasting (Load, RES), secondary & tertiary control: LFC, operational planning: scheduling/optimization of active/reactive power, voltage control)
	6.4	Preventive control/restoration (Contingencies, Topology (including Switching) optimisation, Protection, Resilience)
	6.5	Control Center technologies (EMS, platforms, Operator training, Coordination among Control Centers)

6.1 RA 1: CONSUMER, PROSUMER and CITIZEN ENERGY COMMUNITY

This research area addresses the complex relation of the consumer and prosumer (be it an individual, a community, a commercial user, an industry) with the energy system. It addresses:

- The NIMBY (i.e. "Not In My BackYard") effect related to the energy infrastructures: i.e the refusal of citizens to tolerate the existence of energy infrastructures (overhead lines, cell phone antennas, regasification plants etc.) in their surroundings and in the landscapes. This area addresses the necessity to complement the engineering studies related to the development of the energy system with societal studies and social campaigns to include the citizens in the decisions process since their very beginning;
- The societal changes characterised by a progressively increase of environmental consciousness that triggers behavioural and process changes (sustainable mobility choices, corporate responsibility and transparency, distributed renewables integration, demand response by the user, energy and water conservation measures, neighbourhood comparison and related rewards, etc.);
- The relationship of the consumer towards energy system technologies (leveraging early adopters and digital fanatics, looking at the user centeredness of technologies, smart appliances, prosumer device control, solutions, APPs, market tools etc.);
- The solutions in the hand of the consumer that en- able to be an actor in the energy system (roles and integration of consumer-owned DER, smart me- tering, storage, micro CHP, heat pumps, EV, smart appliances, incentives, dynamic tariffs, etc.);

6.2 RA 2: SYSTEM ECONOMICS

This research area addresses business models, market design, governance and operation linked with the energy system, its opportunities and constraints. It comprises:

- The business models for the different actors, products and services applicable to the energy system (electricity, gas, heating/cooling, carbon neutral fuels, water, etc.) along its value chain: generation (e.g. CHP), transport (flexibility), data analytics/mining conversion (efficiency, flexibility), storage, metering, delivery (forecasting, demand response, aggregation), prosumers (aggregation, peer-to-peer, energy communities) conservation (efficiency), use (demand response, flexible energy uses, mobility) etc;
- The design of energy markets at all geographical scales, addressing from the pan-European cross-border wholesale electricity and gas markets, products, services and businesses, down to local, neighbourhood, aggregated, retail, peer- to-peer market of energy products and services (flexibility, ancillary services, electricity, gas and heating/cooling, water etc.);
- The governance of the markets made of European and national acts, policy and regulation, grid rules (for ancillary services, capacity, etc.).

6.3 RA 3: DIGITALISATION

This research area addresses the digital layers integrated in the energy system. It addresses the issues linked with the energy system operation (i.e. the digital infrastructure which enables the operation and control of the physical energy system), as well as the tools and networks for data communication, exchange and analytics. It finally considers the digital applications enabling markets and user participation. It includes:

- The definition and application of communication protocols, rules and semantics, including all aspects of standardisation (e.g. IEC, CENELEC, CIM etc.): i.e protocols, data and information models, to ensure interoperability;
- The communication infrastructure (physical layer, infrastructure, services, business): the digitalisation of the measurable, controllable physical quantities of energy system (e.g. energy through smart meters, system functional parameters through smart sensors and devices, sensors for IoT etc.) and its processes, considered as a continuous evolution, thus enabling observability, controllability, integration, stability, protection (cybersecurity) and efficiency;
- The data and information management capabilities, such as the Big Data management platforms related to different data sources (i.e. meters, sensors, etc.), and the methods for an efficient data analytics, (e.g. AI, digital twins etc), and use in different frameworks (e.g. blockchain).
- Enabling interaction of the energy system sec- tor with other business sectors (Health, Mobility, Information) by solutions that support open APIs and open platforms, trust-raising technologies and adequate service management, education and adaptation of legislation for massive application of smart technologies;
- Providing adaptive, taylored, intuitive, multi- device and secure functionalities and tools for the different actors and stakeholders involved in the energy systems according to their role, using cyber-secure and service-oriented soft- ware infrastructures, considering the protection of the user (consumer rights, privacy, cyberprotection) and safeguarding the energy system by planning from cyber threats that have the potential to cause considerable damage both on structures and on operation;
- Application of cyber physical systems concepts, methods and tools to energy systems, with a focus on use of pre-integrated architectures and open source frameworks for data ex- change among the different energy systems ac- tors (e.g. TSO/DSO communication interfaces), including information models (e.g. 61850), also from other industrial sectors.

6.4 RA 4: PLANNING - HOLISTIC ARCHITECTURES and ASSETS

This research area addresses the design and planning of the Integrated Energy System overcoming the silos among energy vectors. It considers the 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. Holistic energy system architectures facilitate all processes which are necessary for a reliable, economic and environmentally friendly operation of smart electricity systems, including innovative asset and lifecycle management, related technologies, and asset maintenance. It includes:

- Integrating energy system modelling/simulation and design/planning architectures in highly un- certain environments (risk analysis, stochastic modelling, etc.); from long term planning of the system developments to the short term system stability analysis, considering vectors integration and digitalisation (co-simulation), environmental aspects (externalities, Life Cycle Analysis (LCA)), societal and economical evolutions (cost-bene- fits analysis, Life Cycle Cost (LCC) thinking etc.);
- System planning, considering jointly the development of different types of networks and vectors (electricity, heating&cooling, gas, water, transport), considering synergies and mutual efficiency enhancements; planning methods considering cost-effective flexibility means along the value chain (demand response, energy storage, generation, transmission, cross-carrier) as well as resilience under high uncertainties (variable generation) and against natural and human-related threats (single and multiple contingencies);
- Advanced management of existing assets: life- cycle estimation and failure mechanisms and models, advanced asset management techniques (based on risk approach, reliability etc.), diagnostics, monitoring, life extension, reliability and vulnerability evaluation, failure mechanisms and models, etc;
- Development and performance assessment of innovative technologies and solutions for the future energy system, based on the necessary integration of FUNCTIONALITIES, needs, and conditions of the evolving system; equipment and systems shall leverage the diffused digitalisation (cyber secure) and must be designed to leverage technical as well as environmental performances (sustainability, eco-design, circularity etc.)

6.5 RA 5: FLEXIBILITY ENABLERS and SYSTEM FLEXIBILITY

This research area addresses the 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, progressively across the different vectors considered. The area comprises:

- The evaluation of the needs for flexibility along the entire energy value chain, in consideration of the uncertainties, variabilities and risks;
- The flexibility potential of all types of generation (from the ancillary services from variable renewables to the thermal plants flexibility potential) thereby considering the wide heterogeneity in products and rules across countries (including retrofit of Power Plants; Governance-based incentives for Flexibility etc.);
- The contribution to flexibility of energy storage advanced management, embracing all vectors (electricity, gas, heating/cooling, water) to man- age variability and contributing to system efficiency and reliability;
- The intrinsic networks flexibility: leveraging the capabilities 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.) and their conversion (P-t-X, X-t-P etc.) to enhance network flexibility;
- The specific applications of FACTS in the electricity networks to ensure and enhance flexibility, such as for example the integration of AC, AC/ DC (hybrid) and DC microgrids; the interaction of networks and the appropriate grid connection and operation;
- The interaction with non-electrical energy vectors (gas, heating, cooling, water, hydrogen, car- bon neutral fuels) and conversion (P-t-X);
- The combined flexibility options enabling grid operators, as well as aggregators/balancing par- ties to make optimal use of the flexibility resources, for example, cells with all kinds, sizes and variability/controllability of networks elements, combined with energy generation, demand and conversion to and from non-electricity energy carriers (energy vector coupling);

6.6 RA 6: SYSTEM OPERATION

This research area addresses the tools and systems for the development of the overall control architecture (e.g. from hierarchical system control to coordinated collaborative concept, development of the roles of the actors in the system (TSO, DSO etc.)) from direct control to delegation with the subsequent optimal operation of the Integrated Energy System under progressively increasing variabilities, constraints and uncertainties, also linked with extreme events and climate changes. It spans across the tools and devices for system observability, through advanced monitoring, control and protection, leveraging the advanced forecasting capabilities in all sectors. It comprises:

- The tools for the system observability (from control architectures to sensors, data management and backup, enabling their filtering, aggregation, condensing and concentration);
- The solutions for system operation and control at all time spans (from primary frequency and control, to medium-long term secondary and tertiary control) designed or influenced by flexibility integration, under normal and constrained conditions (such as, under reverse flow conditions from local renewable generation excess, system events under limited inertia conditions, behaviour under extreme meteorological events, etc.);
- The operational planning of the energy systems, through scheduling and optimisation of active/ reactive power;
- The solutions for system operation that, based on market requests for ancillary services, can automatically provide complex control actions (grid couplings, activation of flexibility services and new market request for replacement of activated services) and advanced control room solutions supporting expanded levels of automation;
- The sciences of forecasting and risk analysis, in- cluding generation and load forecasting at different time scales and the consequences and mitigation for errors, the effects of climate changes and extreme events, thus triggering the resilience and remedy actions, comprising threats, vulnerabilities, contingencies, mitigation and restoration;
- Training tools at all level of the integrated sys- tem development, management and operation to ensure adequate and uniform level of skills and approaches.

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